SERVICE MANUAL

Due to a continuous program of research and development, some procedures, specifications and parts may be altered in a constant effort to update and improve our products.

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INTERNATIONAL® T 444E

DIESEL ENGINE

SERVICE MANUAL

MODEL YEARS LATE 1997-2003

SERIAL NUMBER 634234 AND UP

FORM EGES-205

Printed in the United States of America

SERVICE MANUAL

INTERNATIONAL® T 444E
DIESEL ENGINE

MODEL YEARS 1997-2003
EGES205, OCTOBER 2003

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Foreword

This publication provides general and specific service procedures and repair methods 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.

Departure from instructions in this publication or disregard of warnings and cautions can lead to injury or death, or both and damage to the engine or vehicle.

Read safety instructions below before doing service or test procedures in this publication for the engine or vehicle. See related engine manuals for more information.

Periodic revisions may be made to publications. When ordering publications, the latest revision will be supplied.

The following literature supporting International® Diesel Engines is available from:

International Truck and Engine Corporation
Printing & Distribution Center
61 Clark Road North
Battle Creek, Mich. 49015
(269) 968–4856

1171737R7 – *T 444E Diesel Engine Operation and Maintenance Manual*
EGES-120–1 – *T 444E Diesel Engine Service Manual 1994–1997, S/N 634233 And DOWN*
EGES-205 – *T 444E Diesel Engine Service Manual 1997–2003, S/N 634234 And UP*
EGES-190 – *T 444E Diesel Engine Diagnostic Manual*
EGED-140 – Supplemental Coolant Level Ref. Chart (for conventional GREEN coolant)
EGED-195 – Hard Start / No Start Performance Diagnostic Form
EGED-200 – Electronic Control System Diagnostic Form

Service Diagnosis

Service diagnosis is a systematic procedure of investigation to be followed in order to locate and correct an engine problem. The engine is first considered as a complete unit in its specific application and then the problem is localized to components or systems; intake, exhaust, cooling, lubrication or injection. Testing procedures will then help analyze the source of the problem.

PREREQUISITES FOR EFFECTIVE DIAGNOSIS:

- Knowledge of the principles of operation for both the engine and application systems
- Knowledge to perform and understand all procedures in the diagnostic and service publications
- Availability of and the ability to use gauges and diagnostic test equipment
- Availability of the most current information for the engine application

Although the cause of an engine failure may be apparent, very often the real cause is not found until a repeat failure occurs. This can be prevented if specific diagnostic action is taken before, during and after engine disassembly and during engine assembly.

It is also very important that specific diagnostic tests follow engine assembly before and after the engine is placed back into service.

Identification of the symptoms which lead to engine failure is the result of proper service diagnosis. Effective service diagnosis requires use of the following references:

- Engine Service Manual
- Hard Start and No Start Diagnostics
- Performance Diagnostics
- Electronic Control Systems Diagnostics
- Service Bulletins

NOTE: Metric values precede English values for test procedures and reference.

Examples: 96 kPa (14 psi), 20°C (68°F)

This publication is arranged in sections. Any photos and artwork are also numbered consecutively from the beginning of the publication. An index arranged according to sections is located at the beginning of the publication.

Safety Information

This manual provides general and specific service procedures and repair methods 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 can not be stated.

Departure from instructions in this manual or disregard of warnings and cautions can lead to injury or death, or both and damage to the engine or vehicle.

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

SAFETY TERMINOLOGY

Three terms are used in this manual to stress your safety and safe operation of the engine: **Warning**, **Caution**, and **Note**.

Warning: Signals conditions, hazards, and unsafe practices that can cause injury or death.

Caution: Signals conditions and practices that can cause damage to the engine or vehicle.

Note: Signals a key point or procedure that must be followed 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 (do not work in bare feet, sandals, or sneakers.)
- Wear correct work clothing.
- Do not wear rings, watches, or other jewelry.
- Restrain long hair.

Fire prevention

- Keep a charged fire extinguisher close by.

NOTE: Three kinds of fire extinguishers are required:

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.

- Avoid leaning over batteries.
- Protect your eyes.
- Do not expose batteries to open flames or sparks.
- Do not smoke.
- Always disconnect the ground cable before working on the electrical system.

Compressed air

- Limit shop air pressure for blow gun to 207 kPa (30 psi).
- Use approve equipment.
- Do not direct air at body or clothing.
- Wear safety glasses or goggles.
- 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.
- Keep the funnel or nozzle of the hose in solid contact with the metal of the fuel tank inlet. Solid contact will prevent electrical sparks.
- Do not refuel the tank when the engine is running.

Removal of tools, parts, and equipment

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

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Engine Identification

Serial Number Location

The engine serial number is permanently stamped on the crankcase pad on the lower rear left side of the engine.

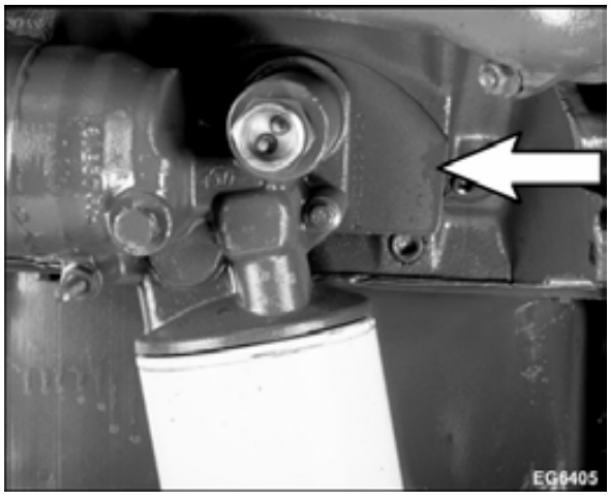

Figure 1 Engine Serial Number Location

Explanation of the Engine Serial Number

7.4 – Engine Identification Code
H – Type of Code: H=Diesel, turbocharged, air cooled and electronically controlled
M2 – End Use Code: M2=Truck, A2=Stripped and service
U – Country of Origin: U=U.S.A. or
N – Country of Origin: N=Brazil (IESA)
XXXXXX – Engine serial number sequence

Other nameplates on the turbocharger and auxiliary devices like the starter provide manufacturer specifications and inform the operator or maintenance personnel of the type of equipment that is on the engine and its range of operating conditions.

Emission Label

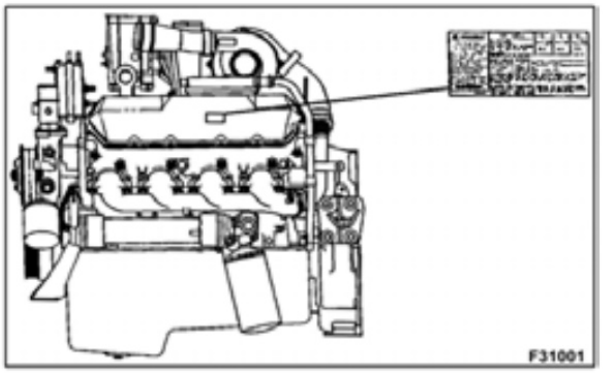

Figure 2 Emission Label Location

The emission label is located on the left valve cover.

The emission label identifies an engine's model code, the year it was manufactured, the year the engine was certified to meet government emission standards, and other relevant information. This label exists in multiple languages.

Engine Component Location

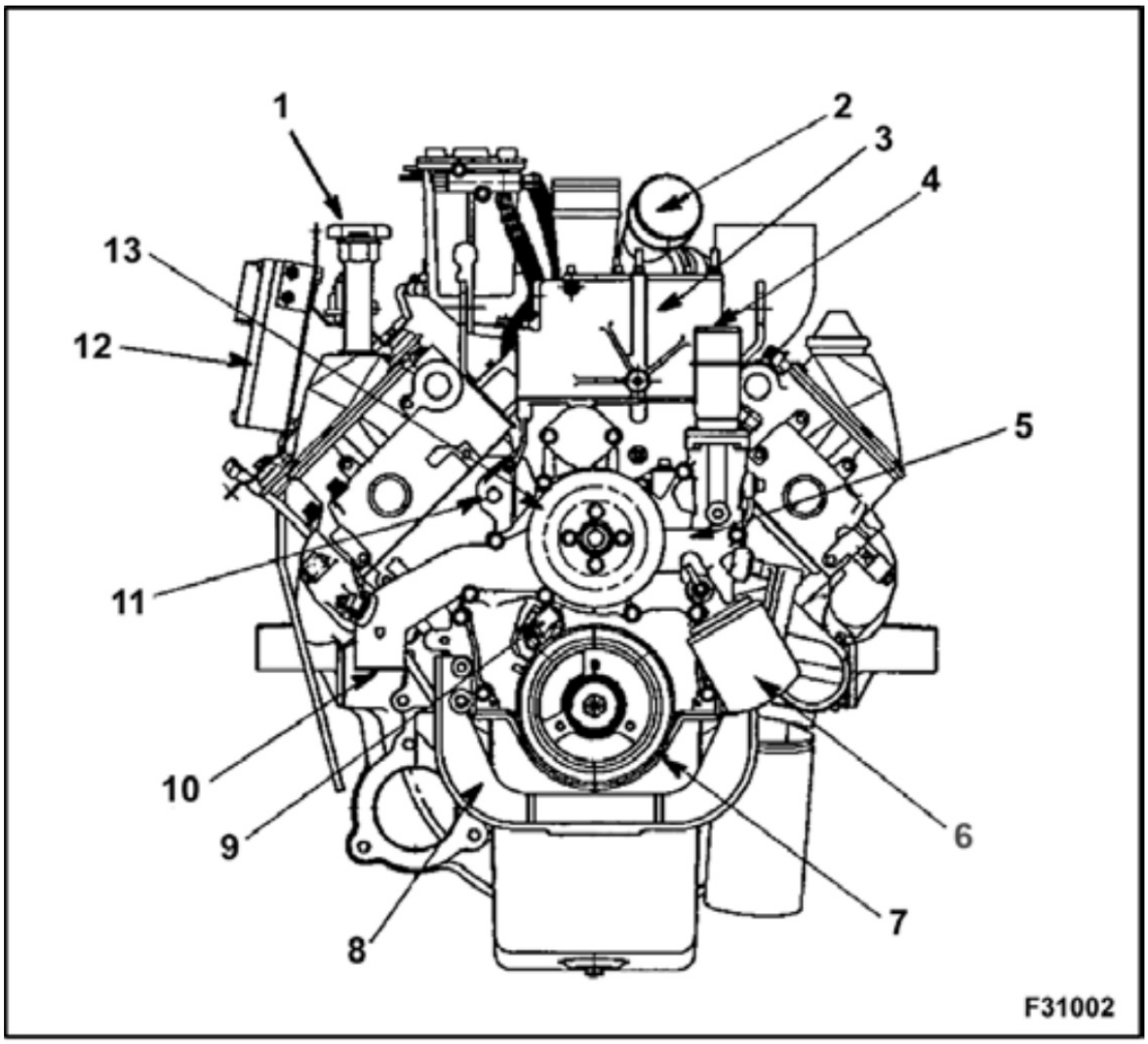

Figure 3 Component Location, (Front View)

1. Lube Oil Fill Tube
2. Turbocharger Air Outlet Tube (to CAC)
3. High-pressure Pump Oil Reservoir
4. Water Outlet and Thermostat Housing
5. Water Pump
6. Coolant Filter
7. Crankshaft Vibration Damper Pulley
8. Engine Front Mount Support
9. Camshaft Position Sensor
10. Water Pump Inlet
11. Coolant Temperature Sensor
12. ECM International Diamond Logic™
13. Water Pump Pulley

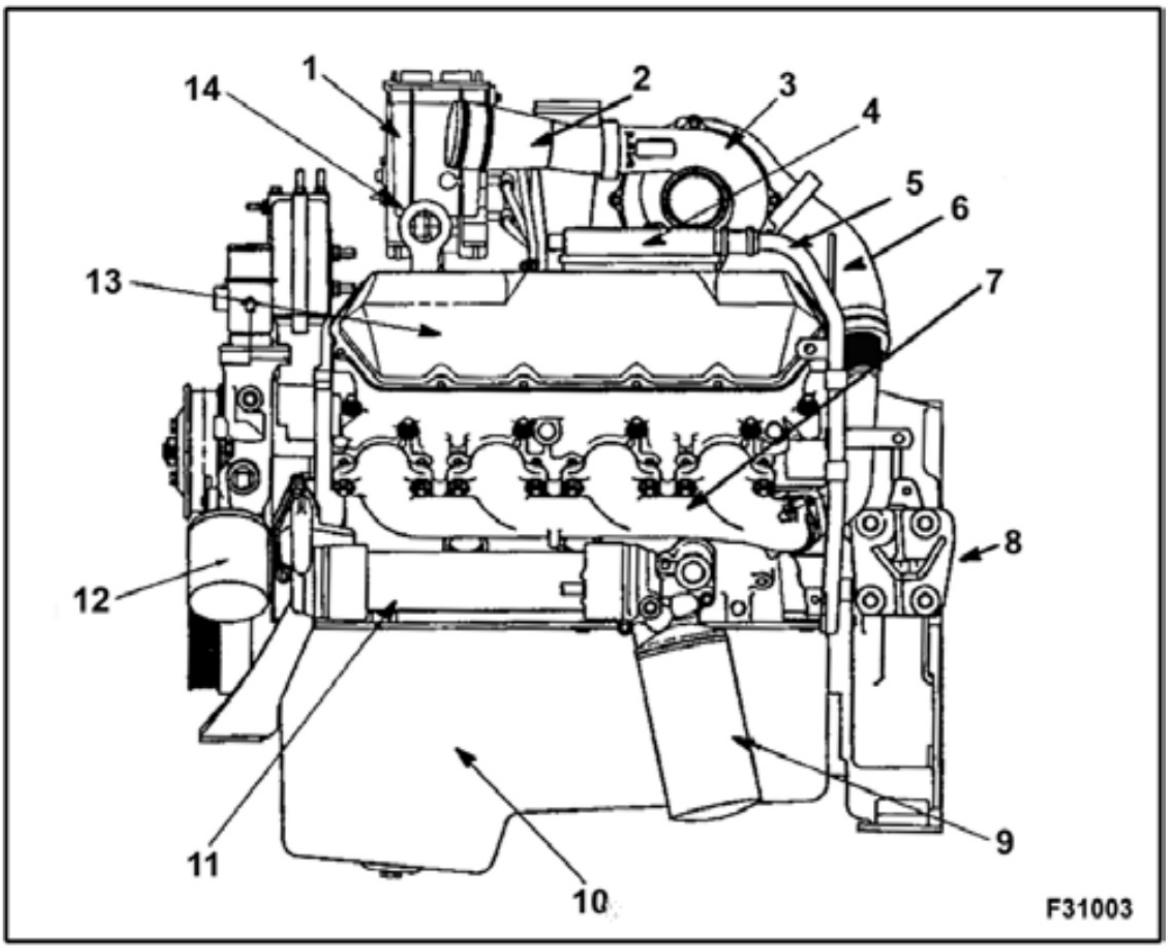

Figure 4 Component Location, (Left Side View)

1. Fuel Filter
2. Turbocharger Air Outlet Tube (to CAC)
3. Turbocharger
4. Crankcase Breather
5. Road Draft Tube
6. Rear Lifting Eye
7. Exhaust Manifold
8. Rear Engine Mounting Bracket
9. Lube Oil Filter
10. Oil Pan
11. Oil Cooler
12. Coolant Filter
13. Valve Cover
14. Front Lifting Eye

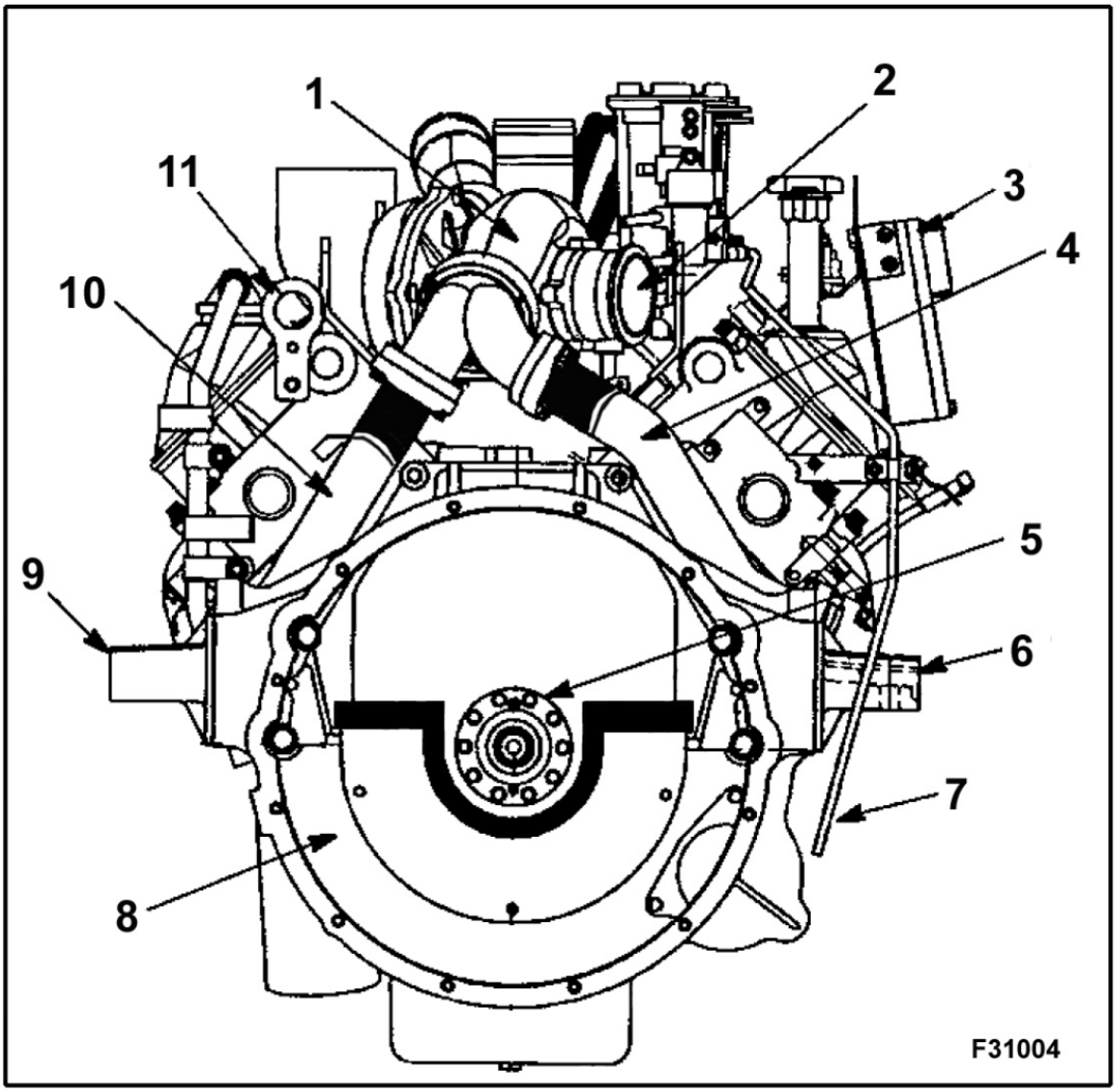

Figure 5 Component Location, (Rear View)

1. Turbocharger
2. Turbocharger Exhaust Outlet With Optional Exhaust Back Pressure Control Valve
3. ECM International Diamond Logic™
4. Right Side Exhaust Tube With Bellows
5. Crankshaft
6. Rear Engine Mounting Bracket, Right Side
7. Fuel Filter Water Drain Tube
8. Flywheel Housing
9. Rear Engine Mounting Bracket, Left Side
10. Left Side Exhaust Tube With Bellows
11. Rear Lifting Eye

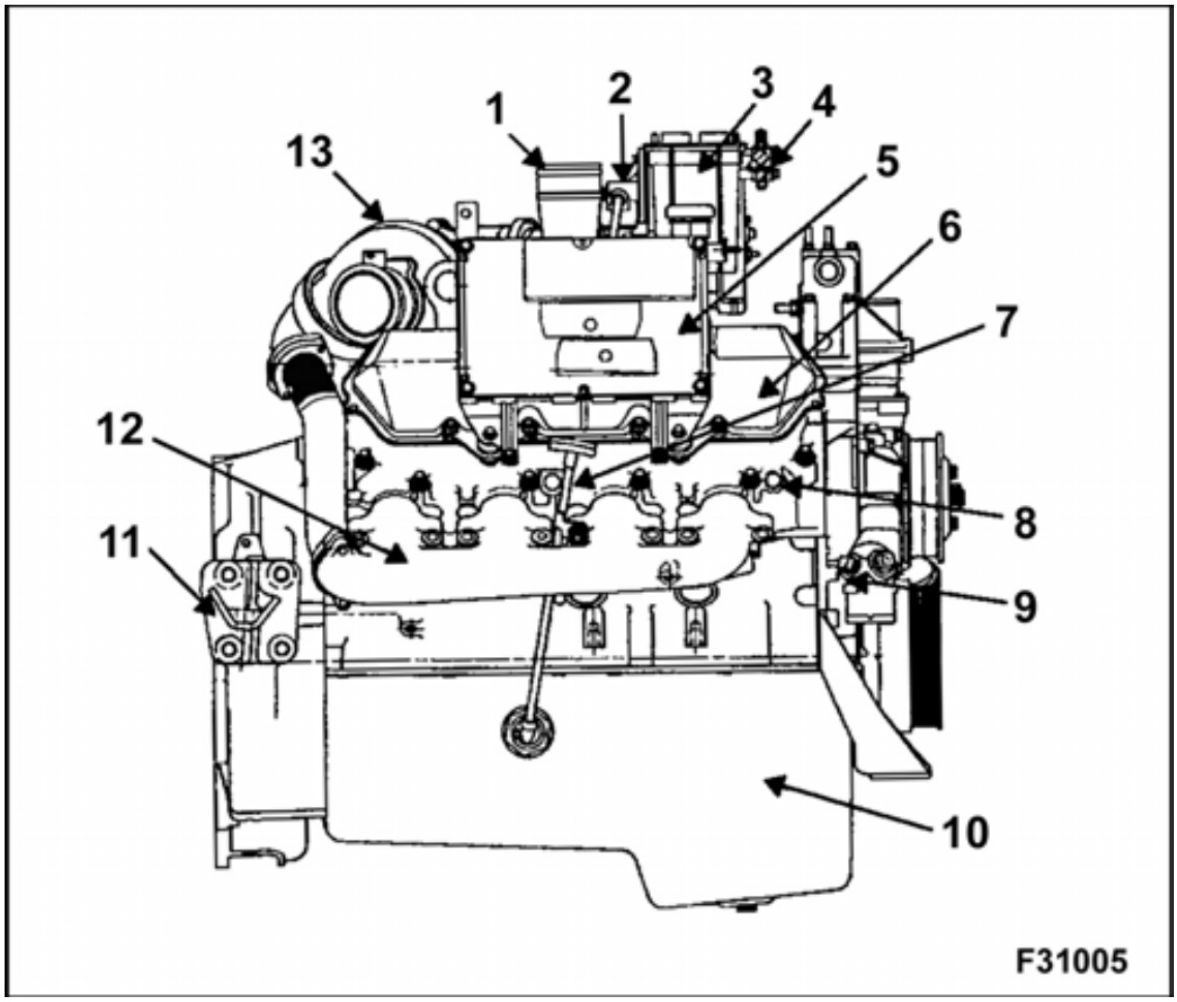

Figure 6 Component Location (Right Side View)

1. Air Outlet
2. Fuel Filter Pre-Strainer
3. Fuel Filter
4. Fuel Pressure Regulator
5. ECM International Diamond Logic™
6. Valve Cover
7. Oil Level Gauge
8. Coolant Heater Supply
9. Coolant Heater Return
10. Oil Pan
11. Rear Engine Mounting Bracket
12. Exhaust Manifold
13. Turbocharger

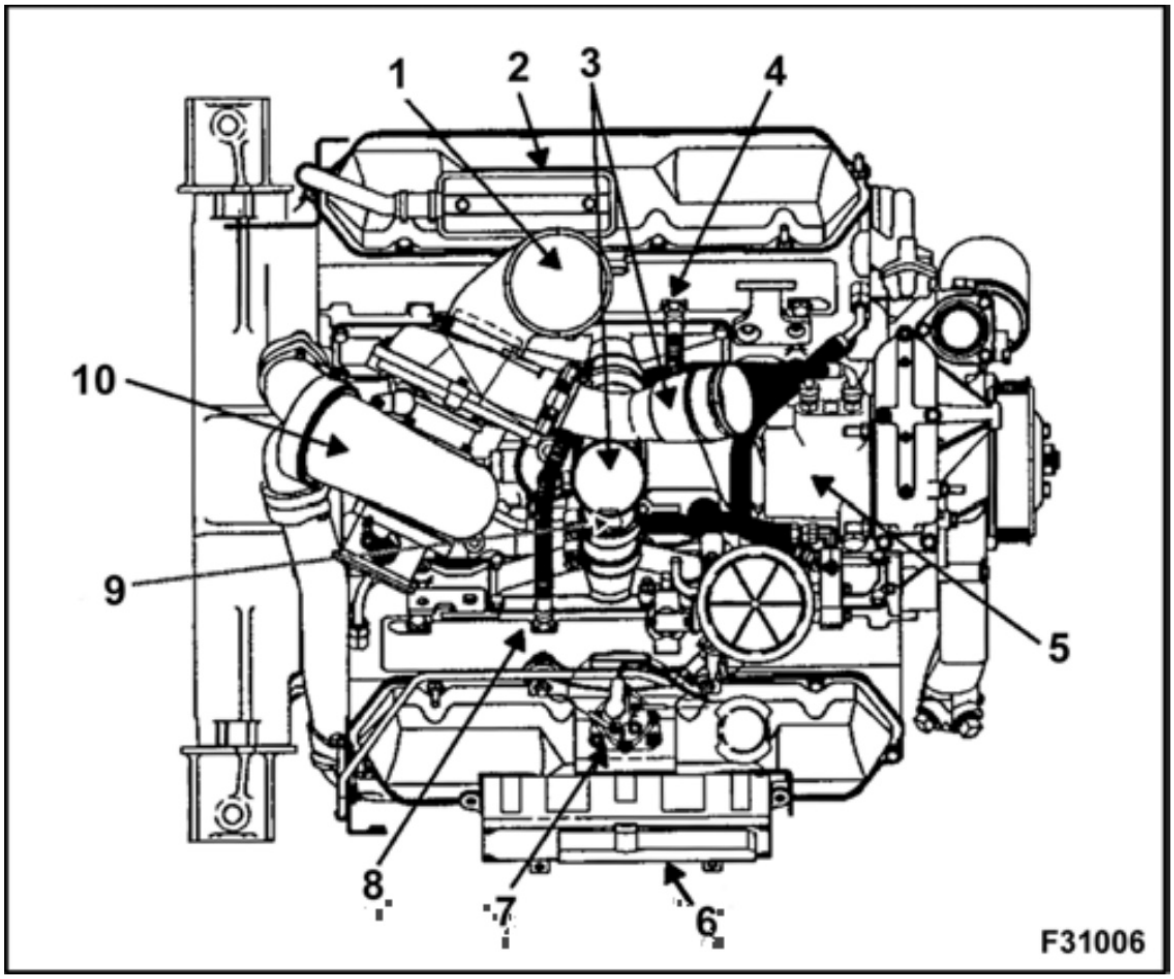

Figure 7 Component Location, (Top View)

1. Turbocharger Air Inlet Elbow
2. Crankcase Breather
3. Turbocharger Air Outlet Tubes (to and from CAC)
4. High-pressure Oil Supply Manifold, Left Hand Side (Integral part of cylinder head)
5. High-pressure Oil Pump
6. ECM – International Diamond Logic™
7. Glow Plug Controller
8. High-pressure Oil Supply Manifold, Right Hand Side (Integral part of cylinder head)
9. Manifold Absolute Pressure Sensor (MAP)
10. Turbocharger Assembly

Engine Description

General Features

The International® T 444E diesel is a four stroke V8 engine. It features overhead valves and is water-cooled and turbocharged. The engine is fueled by a direct injection fuel system with electronic sensors and Hydraulically actuated Electronically controlled Unit Injectors (HEUI). It has a displacement of 7.3 liters (444 cubic inches).

When viewing the engine from the rear (flywheel end), the right hand bank of cylinders are numbered 1, 3, 5, and 7. Cylinder number 1 is at the front. The left bank consists of cylinders 2, 4, 6, and 8. In this case, cylinder number 2 is at the front. The engines numerical firing sequence is 1–2–7–3–4–5–6–8.

The International Diamond Logic™ Electronic Control Module (ECM) monitors and controls engine performance to ensure optimal efficiency, and adherence to emissions standards. The ECM is also able to monitor and control vehicle features.

The crankcase has been especially designed to withstand the loads of diesel operation and utilizes a four bolt main bearing cap to assure a rigid support for the rotating parts. The crankcase also has piston oil cooling jets and their function is to direct oil to the underside of the piston to help dissipate heat to the lube oil.

The crankshaft is a five main bearing unit with fore and aft thrust controlled at the rear (Number 5) bearing.

Connecting rods are attached to the crankshaft. Two connecting rods share each crankpin journal. There were two types of connecting rods used on this engine for model years 1997 and above. The connecting rods are easily identified by the way the connecting rod cap is secured to the connecting rod.

- Forged steel connecting rods were used on engines with serial numbers ranging from 634234 to 1498318. The connecting rod caps are secured to the connecting rod with bolts and nuts.
- Powered metal forged steel connecting rods were used on engines with serial numbers ranging from 1498318 and up. The connecting rod caps for these later style connecting rods are secured with bolts that thread into the connecting rod (no nuts used).

The piston pin is a free floating type. It permits the pin to move or float freely in the piston and connecting rod. The piston pin is held in place with two piston pin retaining rings.

The camshaft is supported by five insert-type bearings pressed into the crankcase, and is gear driven from the crankshaft. The end thrust of the camshaft is controlled by a thrust flange located between the front camshaft journal and the cam gear.

The aluminum-alloy pistons are fitted with two compression rings and one oil ring. The top compression is a keystone configuration.

The hydraulic valve lifters minimize engine noise and maintain zero valve lash or tappet clearance. This eliminates the need for periodic adjustment of the valve lash. The hydraulic valve lifters have roller followers which provide excellent camshaft and lifter durability.

The one piece cylinder heads used on the engine are equipped with a positive valve rotating mechanism on both the intake and exhaust valves. This device is called a rotator and it is located at the top of each valve spring.

An electrically controlled glow plug system provides outstanding cold weather starting capability. An optional block heater is available to warm coolant at extremely cold ambient temperatures below -29°C (-20°F).

Some of the features incorporated in this series of engines include a gerotor lube oil pump (driven directly by the crankshaft at engine speed), cast water and oil passages in the crankcase and front cover, spin-on type lube oil filter, fuel filter/strainer assembly, and spin-on type coolant filter.

Chassis Mounted Charge Air Cooler

The T 444E diesel engine utilizes a charge air cooling (CAC) system. The cooler is chassis mounted adjacent to the radiator. Air from the turbocharger is pushed through a network of heat exchanging tubes before entering the intake manifold. Outside air flowing over the fins and tubes serves to cool the air charge. The resulting cooled intake air is denser than the compressed (warmed) air, allowing for improved fuel/air ratio in the cylinders during the combustion process. The results are improved emission control and increased power output.

Cooling System

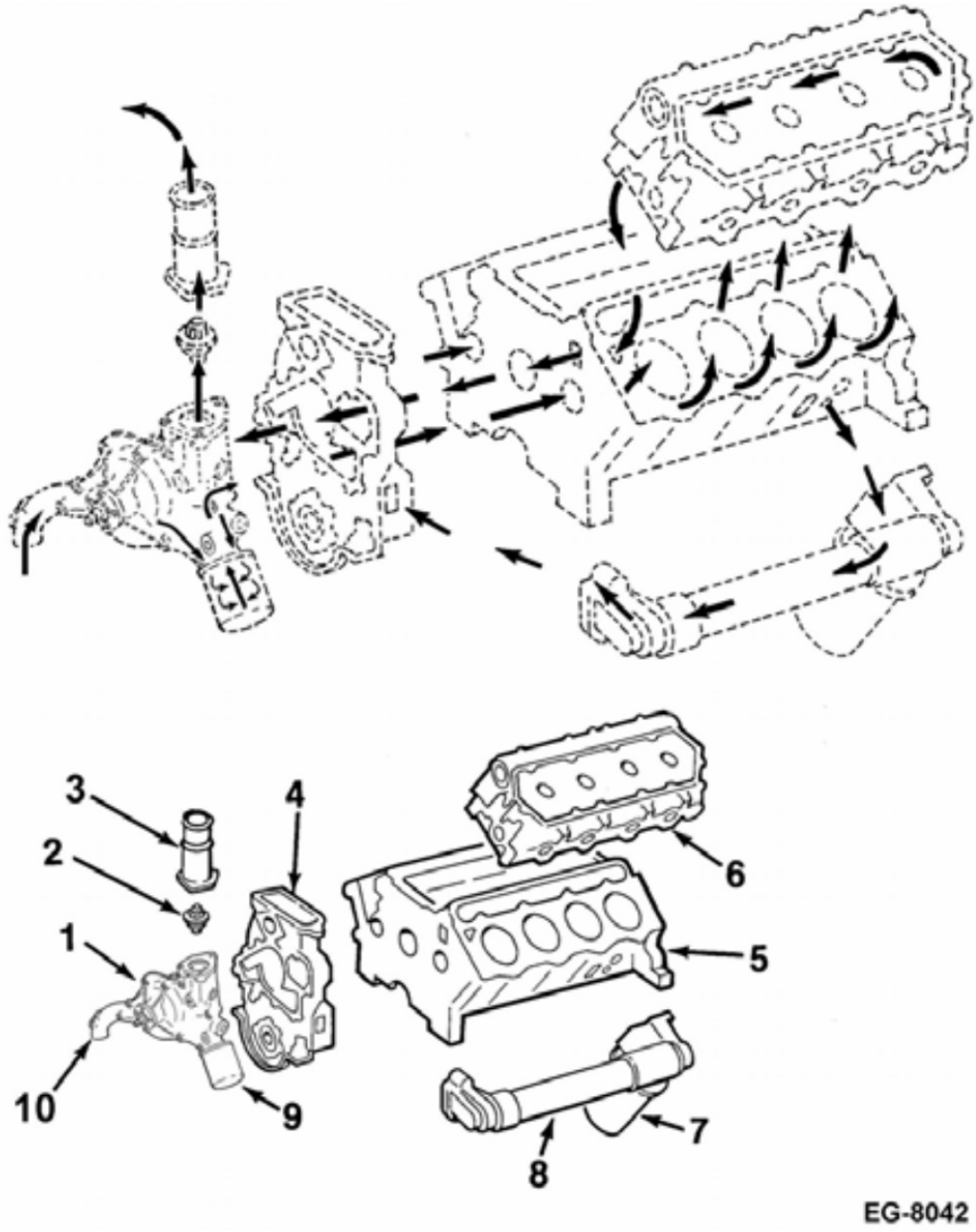

Figure 8 Engine Coolant Flow Diagram

1. Water Pump
2. Thermostat
3. Outlet Tube
4. Front Cover
5. Crankcase
6. Cylinder Head
7. Lubricating Oil Filter
8. Oil Cooler
9. Coolant Filter
10. Water Pump Inlet

Description

The function of the cooling system is to keep the engine within a designated temperature range. Major components of most cooling systems include a radiator and fan combination with a water pump, thermostat, oil cooler, and coolant filter. The water pump is a belt-driven centrifugal type, which is set into the front cover.

The front cover incorporates two separate passages. One passage channels coolant from the water pump to the crankcase. The other passage is a bypass that routes coolant back to the water pump when the thermostat is closed. The thermostat starts to open at 89°C (192°F) and is fully open at 104°C (219°F).

Coolant flows from the bottom of the radiator into the inlet tube of the water pump, and into the front cover. Coolant is pushed by the impeller in the water pump, through an internal passage in the front cover, and out into the crankcase. An internal passageway in the crankcase directs coolant from the front to the rear, evenly distributing coolant around the cylinders and into the cylinder heads.

Coolant leaves the cylinder head in the following two ways:

- The coolant is directed, via an internal passage in the crankcase, to the oil cooler header. Coolant flows through passages in the oil cooler and exists at the water pump, to be mixed with incoming coolant from the radiator.
- Coolant exists from the cylinder head, flows through an internal passage in the crankcase, and into the front cover. It is then directed to the water pump passage containing the thermostat.

Thermostat Operation

The thermostat incorporates two outlets that work independently to channel coolant to two different parts of the engine. One outlet carries coolant to the radiator, the other outlet directs coolant back to the water pump.

When the engine coolant temperature is below the specified thermostat opening temperature, the outlet to the radiator is thermally blocked. This blockage forces coolant to flow through the bypass passage back into the water pump. As the engine approaches its normal operating temperature, the thermostat opens, closing off the bypass passage and allowing coolant to flow towards the radiator.

Lubrication System

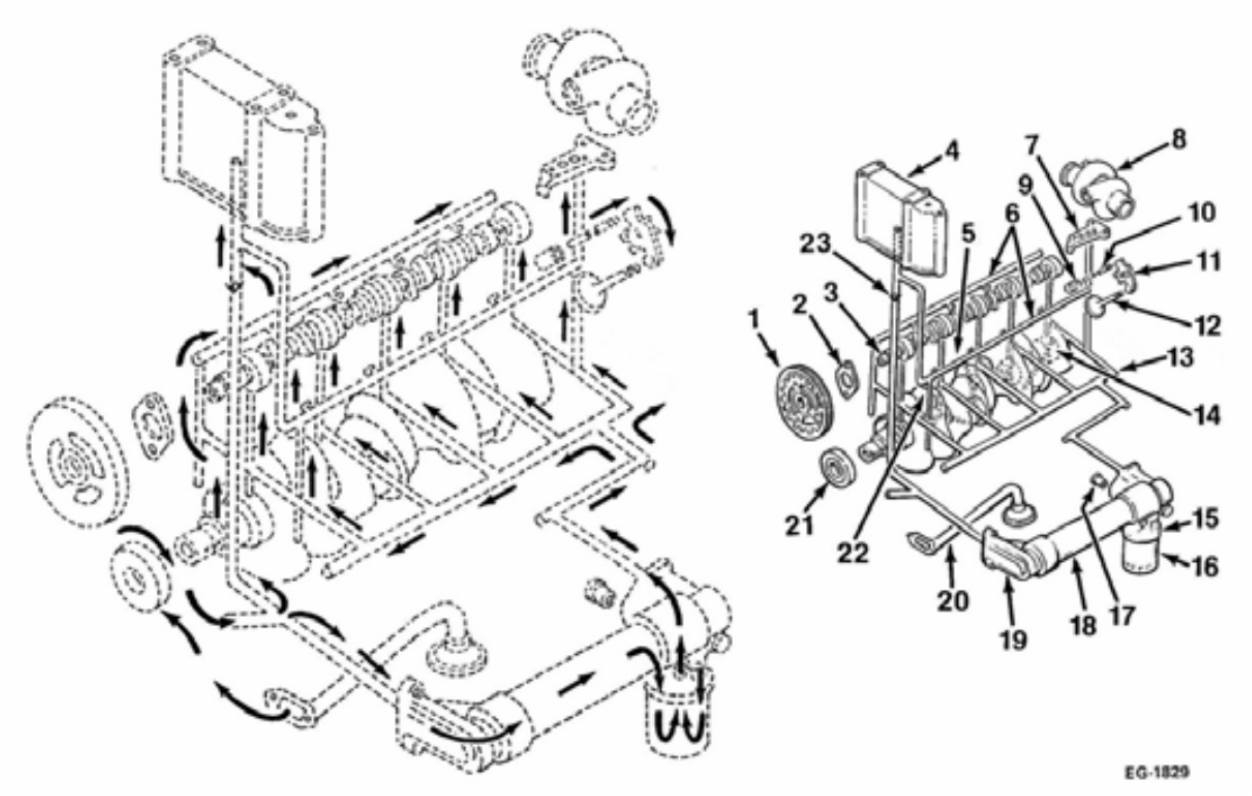

Figure 9 Lubrication System Diagram

1. Camshaft Gear
2. Camshaft Thrust Plate
3. Camshaft
4. High-pressure Pump Oil Reservoir
5. Piston Cooling Jets (8)
6. Hydraulic Valve Lifter Oil Gallery
7. Turbocharger Pedestal
8. Turbocharger Assembly (Typical)
9. Hydraulic Valve Lifter
10. Push Rod
11. Valve Lever Assembly
12. Intake/Exhaust Valve
13. Main Oil Gallery
14. Main Crankshaft Bearings
15. Oil Filter Bypass Valve
16. Oil Filter
17. Oil Pressure Regulating Valve
18. Oil Cooler
19. Oil Cooler Header
20. Oil Pick-Up Tube
21. Oil Pump
22. Connecting Rod Bearings
23. Check Valve

Description

The lubrication system is pressure regulated, cooled, and full flow filtered. In addition to providing engine lubrication, pressurized lube oil is used to control fuel delivery to the HEUI fuel injectors.

Oil Flow

Lube oil is drawn from the oil sump, through the pick up screen and tube, and into the oil pump. The oil pump is of the gerotor type with the inner rotor portion driven directly by the crankshaft. The pump housing, containing the inner and outer gerotor gears, is bolted onto the front cover. The pump inlet and outlet passages are ports in the front cover. Upon leaving the oil pump, unfiltered lube oil enters the front oil cooler header through a passage in the front cover.

At initial engine start up, a small portion of the oil is passed directly from the pump to the high pressure pump oil reservoir on top of the front cover. Oil flows from the oil cooler header around the oil cooler tubes into the oil filter assembly. The oil enters the oil filter through the outside of the filter element and flows through the filtering medium to the center. The filtered oil now passes through the oil gallery in the crankcase. The oil pressure regulator controls lube oil pressure via a spring loaded plunger which relays oil back to the sump once operating pressure is reached. The rear oil cooler header supports the oil filter, which also contains a bypass valve that allows oil to pass directly to the main oil gallery if the filter becomes excessively restricted.

The five crankshaft main bearings are oil fed through drilled passages in the crankcase directly from the main oil gallery. Connecting rod bearings receive pressurized oil from the main bearings through drilled passages within the crankshaft. The camshaft journals receive pressurized oil through passages drilled vertically through the main bearing webs.

Two tappet galleries, which are fed from the main oil gallery through the holes of main bearing bolt number 1, intersect each tappet bore to provide pressurized lube oil to the valve lifters and piston cooling jets. The valve lever assemblies and push rods are lubricated by oil passing from the lifter ball socket upward through the hollow push rods to valve lever arms. Oil drains back to the sump through holes located at each end of the cylinder head.

The oil reservoir, which is used to maintain a ready supply of oil to the high pressure pump, is filled via two passages. At initial start up, oil is directed from the oil pump discharge port through a passage in the front cover and crankcase, which also contains a cold startup bypass check valve. To ensure sufficient oil pressure to operate the injectors for quick starts, this reservoir oil supply quickly replenishes oil to the high pressure pump during cold cranking. The primary reservoir oil supply is continuously fed from the left bank tappet gallery through the front cover, and discharges oil near the top of the reservoir.

Pressurized lube oil reaches the turbocharger bearings from the main oil gallery (left bank) through a passage in the turbocharger pedestal (mounting pad). Oil drains from the turbocharger through another adjacent passage in the pedestal directly back to the sump. This oil supply and drain eliminate the need for external lube lines to the turbocharger.

Hydraulic oil pressure that is used to actuate the exhaust back pressure (EBP) warm-up control is received from the turbocharger lube supply port. This port is located in the turbocharger support pedestal.

Air Induction and Exhaust System

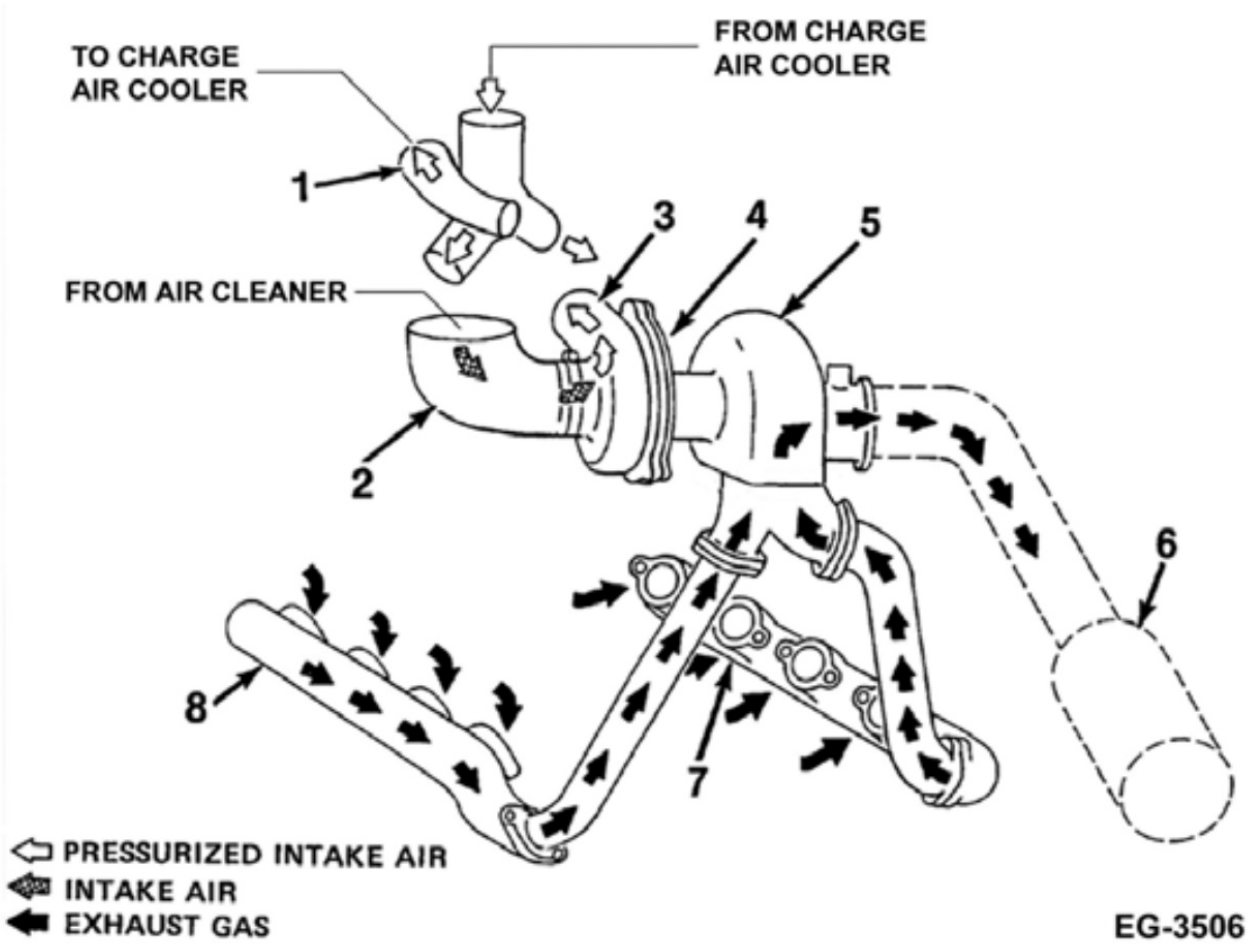

Figure 10 Air Induction/Exhaust System Diagram

1. Charge Air Cooling Tube
2. Turbocharger Air Inlet Assembly
3. Turbocharger Compressor Assembly
4. Turbocharger Center Housing
5. Turbocharger Turbine Housing
6. Muffler
7. Right Hand Exhaust Manifold
8. Left Hand Exhaust Manifold

Description

The intake and exhaust systems consist of those components that contain the flow of filtered air into the engine cylinders and exhaust gases to the atmosphere.

The turbocharger is used to increase engine power output by increasing the air supply to the engine, resulting in more uniform performance at various operating altitudes. The turbocharger incorporates an exhaust driven air compressor that allows filtered air to enter the center of the air compressor where it undergoes an increase in pressure from “atmospheric” to “boost” as it flows into the combustion chambers. After combustion, hot and expanding exhaust gases move out of the cylinders and into the turbine housing driving the turbine wheel. The turbine wheel drives the compressor wheel through a solid common shaft allowing the engine to respond directly to changing engine loads. During heavy loads, an increased flow of exhaust gas spins the turbine wheel faster causing the compressor impeller to spin in direct relation, supplying greater volumes of air (boost) into the intake manifold and cylinders. Conversely, with lighter engine loads, the flow of exhaust gas decreases as does the volume of air being compressed into the intake manifold and cylinders.

Some engines are equipped with an optional exhaust back pressure device to allow for a faster warm-up of the engine and passenger compartment when heat is needed. This device increases heat production. It uses a butterfly valve located in the exhaust side of the turbocharger housing. When the exhaust is restricted by the butterfly valve, exhaust back pressure increases, forcing the engine to work harder to expel the exhausted gases. When the valve is open, exhaust gases flow out freely.

The hot boost air from the compressor is cooled by a charge air cooler before entering the intake manifold. Air then flows into the combustion chamber where the required quantity of fuel is injected, igniting the combustion phase. Exhaust gases leave the cylinders through exhaust ports and the exhaust manifold. From the exhaust manifold, the expansion of exhaust gases on the exhaust turbine drive the turbocharger and are released through an exhaust pipe into the atmosphere.

The exhaust system includes exhaust valves, an exhaust manifold, exhaust piping and a muffler. The turbocharger turbine side is also an integral part of the exhaust system. The compressor side is a component of the induction or intake system.

Fuel System

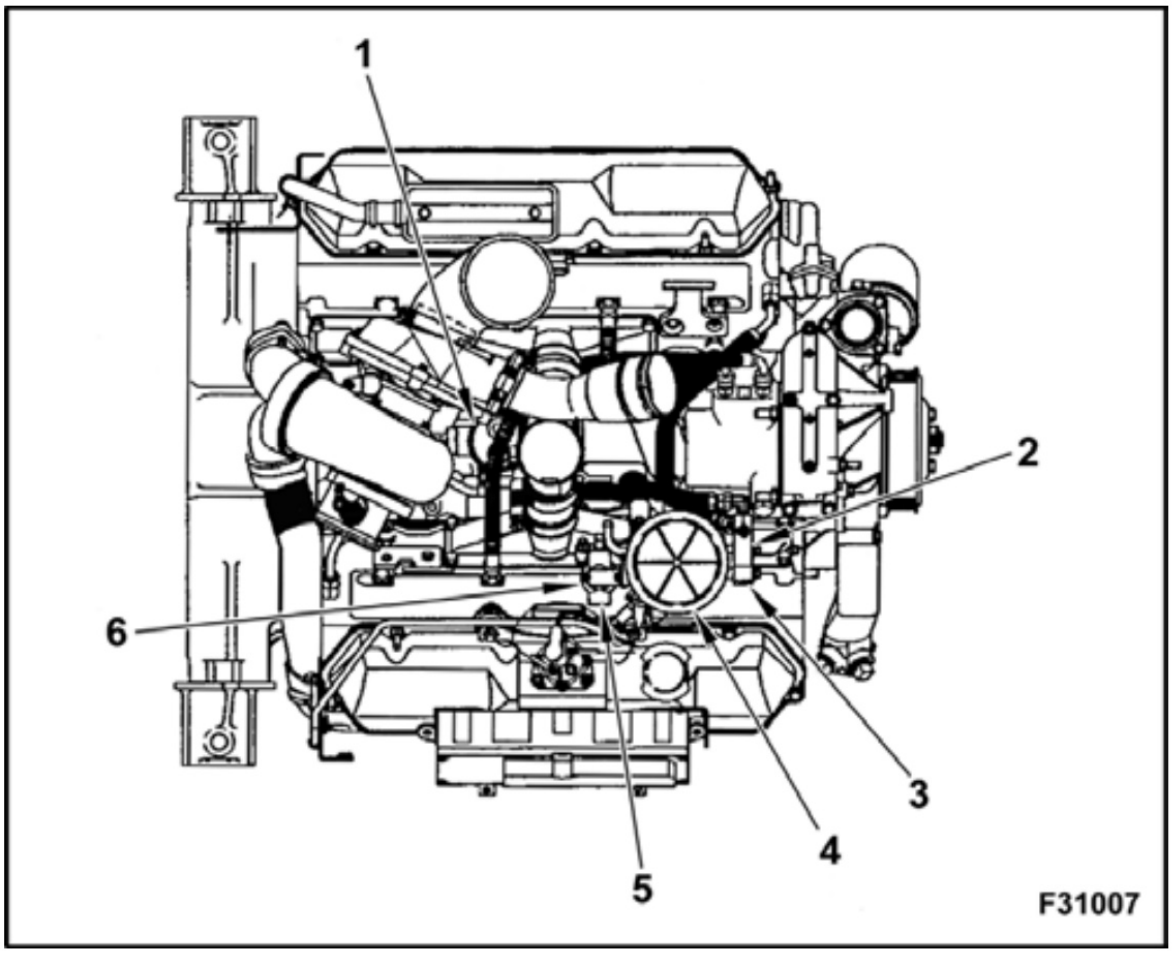

Figure 11 Major Fuel System Component Locations

1. Fuel Supply (Transfer) Pump
2. Fuel Pressure Regulating Valve
3. Fuel Return Port
4. Fuel Filter Canister
5. Fuel Inlet
6. Fuel Strainer

Description

The function of the fuel system is to deliver fuel from the fuel tank(s) through a filter to the fuel injectors at a regulated pressure. The fuel injectors use high pressure lube oil to pressurize the fuel and inject it into the combustion chambers.

The fuel system consists of the following components:

- Fuel tank(s)
- Fuel supply lines and return line
- Fuel filter
- Fuel passages that feed the fuel injectors
- Fuel pressure regulator
- Fuel supply (transfer) pump

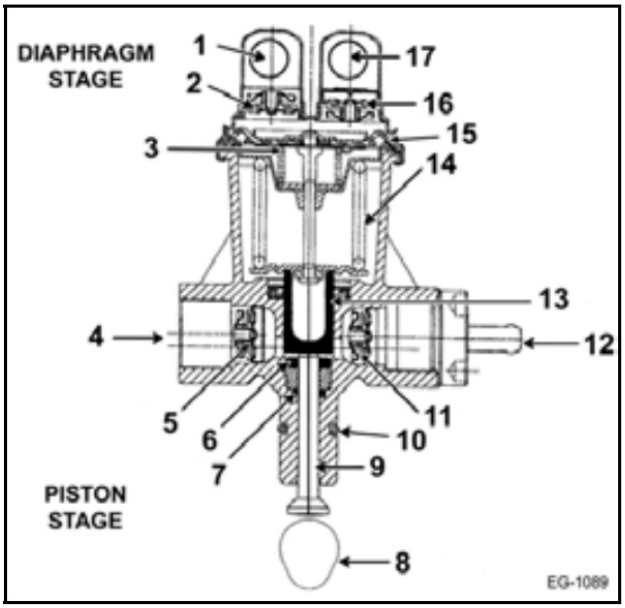

Figure 12 Fuel Supply (Transfer) Pump Diagram

1. Low Pressure Fuel Outlet
2. Outlet Check Valve
3. Spring
4. High-pressure Outlet
5. Outlet Check Valve
6. Fuel Seal
7. Oil Seal
8. Camshaft Lobe
9. Tappet
10. O-ring
11. Inlet Check Valve
12. Inlet
13. Piston
14. Spring
15. Diaphragm
16. Inlet Check Valve
17. Fuel Inlet

The fuel supply (transfer) pump is a camshaft driven, two stage diaphragm/piston pump. This pump is mounted in the engine "V."

Operation

The diaphragm stage of the tandem lift pump draws fuel from the tank through a fuel strainer located on the fuel filter housing. Fuel is then delivered to the fuel filter under low pressure of less than 67 kPa (10 psi). Air that is trapped in the filter is vented back to the tank through an opening (or hole) in the regulator block mounted on the filter housing. This opening is protected from plugging by a wire mesh screen located inside the filter housing.

Fuel in the filter housing passes through the filter element to a standpipe in the center of the filter assembly. Clean fuel then passes to the inlet side of the piston stage located on the tandem pump.

NOTE: The fuel filter element is attached to the threaded filter cover. When servicing, the element can be separated from the cover and replaced with a new element. Fuel flow will be interrupted without the fuel filter element in place. The standpipe in the center of the housing contains a shut off valve that is open only when the filter element is in place.

The piston stage of the tandem pump raises fuel pressure to ensure proper filling of the fuel injectors. Fuel from this stage is delivered to one end of each cylinder head. These lines supply fuel to a gallery drilled in each cylinder head. Fuel enters at the rear of the right cylinder head and the front of the left cylinder head. No fuel returns to the fuel tank from the cylinder heads.

On some engines, the base of the filter housing contains an electric heating element that is used to warm fuel. Heating helps prevent the fuel from waxing during cold weather. Also located in the base of the housing is a sensor to detect the presence of water in the fuel (optional). When sufficient water has collected in the bottom of the filter, the sensor will illuminate a 'water in the fuel' lamp located on the instrument panel.

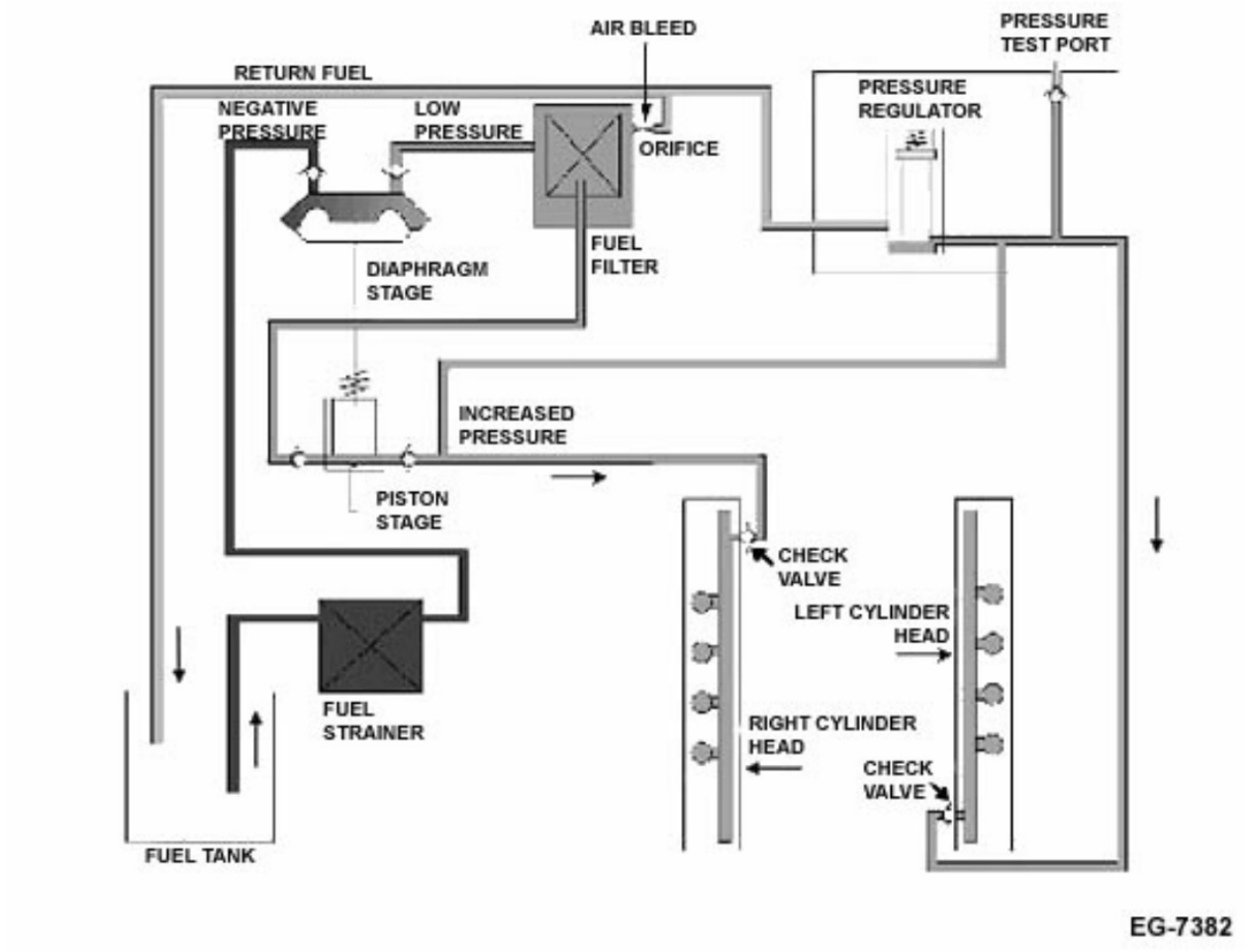

Figure 13 Split Shot Injector Fuel System Schematic

These engines are equipped with the split shot fuel injectors. A fuel inlet check valve is used in each cylinder head. The inlet check valve dampens the pulses in the fuel rail in the cylinder head. There are no return lines from the galleries on this system.

The pressure regulator contains a spring loaded valve to control pressure in the fuel galleries. Return fuel flows through the regulator and is routed back to the fuel tank(s). No fuel is returned to the fuel tank(s) from the cylinder heads with split shot fuel system flow.

Injection Control Pressure System

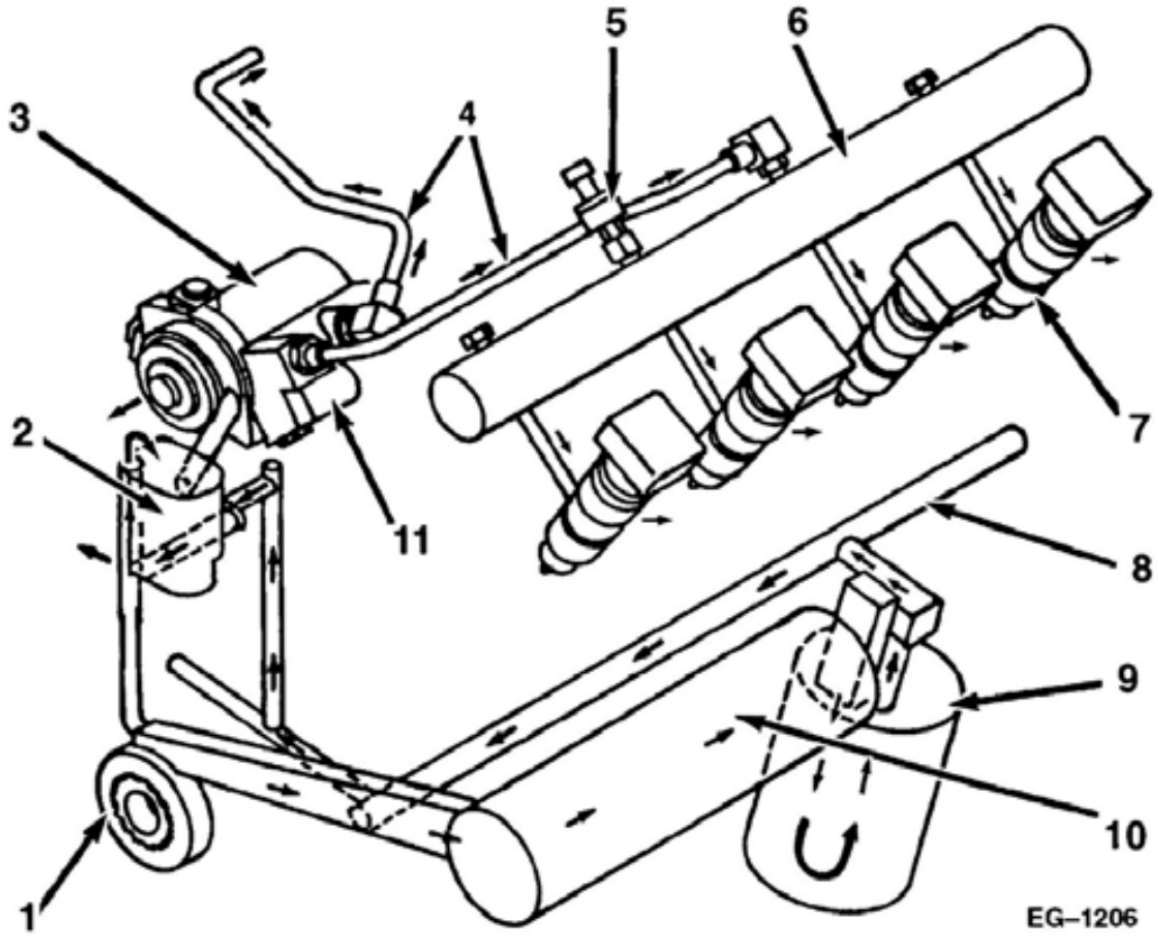

Figure 14 Injector Oil System Diagram (Left Side)

1. Lubricating Oil Pump
2. Reservoir (Located On Top of Front Cover)
3. High – pressure Pump
4. High – pressure Lines
5. Injection Control Pressure (ICP) Sensor
6. Cylinder Head High Pressure Oil Rail (2)
7. Fuel Injectors (8)
8. Crankcase Main Oil Gallery
9. Oil Filter
10. Oil Cooler
11. Injection Control Pressure Regulator

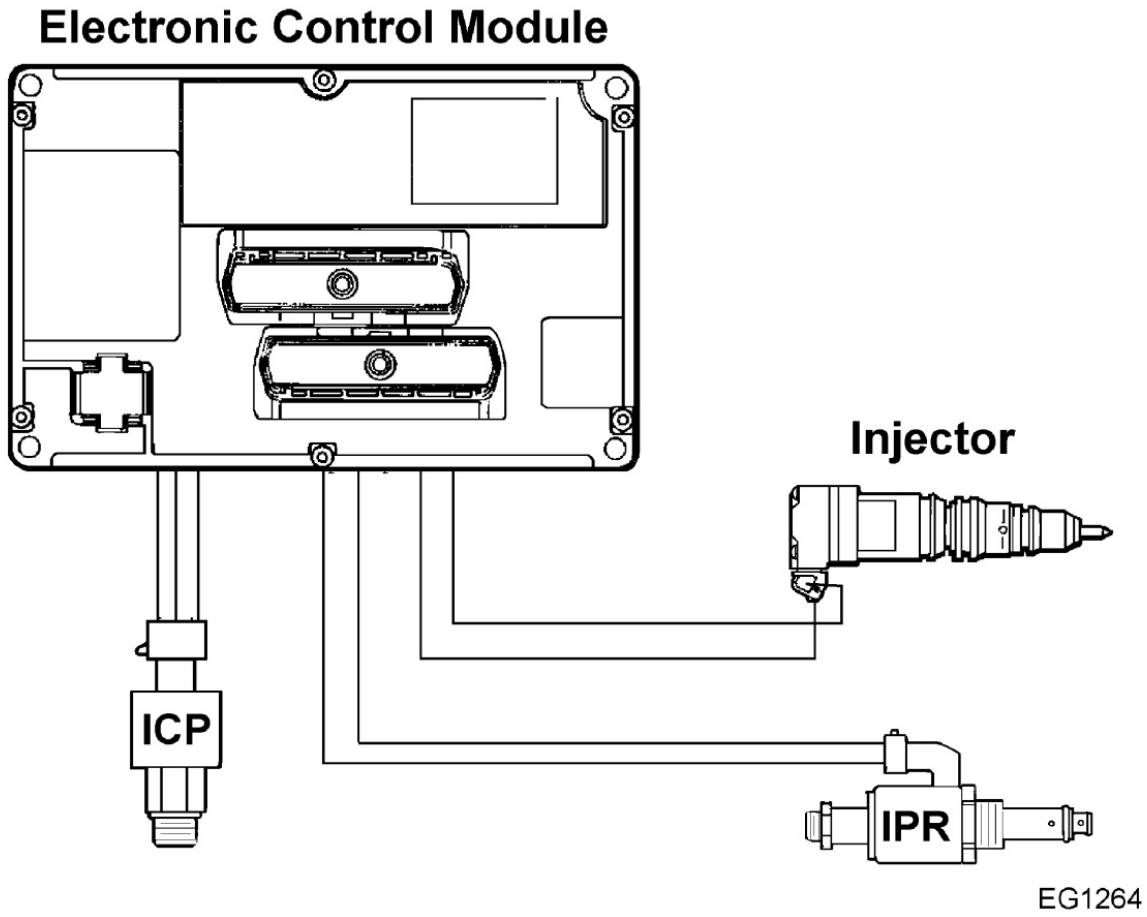

Figure 15 ECM And IPR Configuration

Operation

The injection control pressure system utilizes a hydraulically actuated injector to pressurize fuel inside the injector. The hydraulic fluid used to actuate the injector is engine oil.

Oil is drawn from the oil pan through the pick up tube by the engine oil pump. The engine oil pump is a gerotor type pump driven by the crankshaft. At start-up, oil is fed through passages in the front cover to an oil reservoir mounted on top of the front cover. Once the engine is running, oil is supplied through the left lifter oil gallery.

The reservoir makes available a constant supply of oil to a high pressure hydraulic pump mounted in the engine "V." The high-pressure pump is a gear driven seven plunger swash plate pump. High pressure oil is delivered by the high pressure pump, through high pressure oil lines, to oil galleries machined into the cylinder heads. Drilled intersecting passages supply high-pressure oil to the fuel injectors.

This high-pressure oil is utilized by the Hydraulically actuated Electronically controlled Unit Injectors (HEUI) when the solenoid is energized to pressurize and atomize the fuel into the combustion chamber. After injection is complete, the solenoid is de-energized and the oil inside the injector is vented through the top portion of the injector, splashed on the valve train and allowed to drain back into the oil pan.

The injection control pressure system is a closed loop operating system that consists of the electronic control module (ECM), injection control pressure (ICP) sensor and injection pressure regulator (IPR) valve.

The ECM is programmed with an injection pressure control strategy which determines the correct injection control pressure at all engine operating conditions. The ECM receives a 0 – 5 volt (DC) analog feedback signal from the ICP sensor located in the high pressure oil supply gallery on the left cylinder head that indicates injection control pressure. The ECM processes this signal and controls injection control pressure by controlling the ground to the IPR valve.

Injection Pressure Control

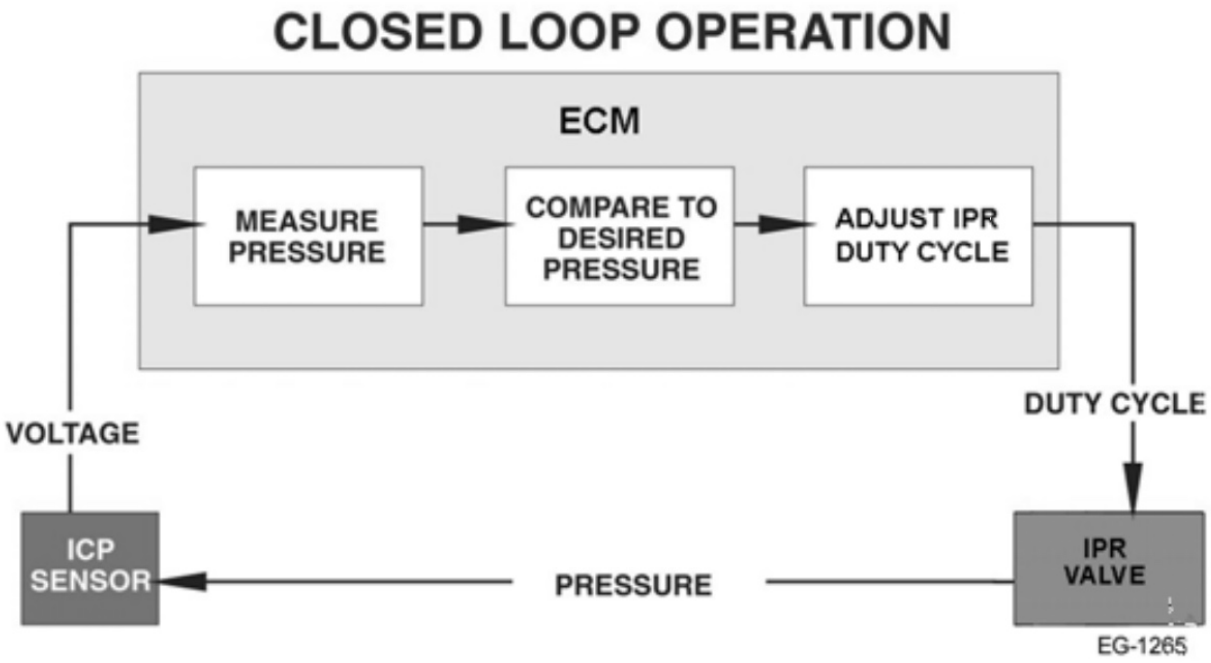

Figure 16 Closed Loop Operation Diagram

The ECM controls the injection control pressure by operating the IPR valve. The result of this control is continuously monitored by the ECM using the ICP sensor. The pressure signal obtained from the ICP allows the ECM to know the actual injection control pressure at all times of engine operation, even during cranking mode. This operation is known as "Closed Loop."

Diagnostic codes can be set by the ECM if the ICP electrical signal is out of range or if the ICP signal received corresponds to an out of range value for the injection control pressure at a given operating condition.

Should any of these occur, the ECM will ignore the ICP signal and control the IPR valve operation from previously programmed default values. This condition is known as an "Open Loop."

IPR Valve Operation

The IPR valve is a pulse width (duty cycle %) modulated valve operating at 400 Hz. The pulse width is modulated between 8 and 60% to control ICP pressure. The regulator is mounted in the high pressure pump. The regulator maintains the desired injection control pressure by dumping excess oil through an internal spool valve. The excess oil then travels, through an internal stand pipe, into the front cover and back to the oil pan.

As the demand for injection control pressure increases, the ECM increases the pulse width (duty cycle %) over the IPR solenoid. This action forces the poppet against the drain hole, thereby increasing the pressure behind the spool valve.

As oil pressure increases behind the spool valve, it moves forward and blocks the drain ports on the sides of the IPR valve.

When the demand for injection control pressure decreases, the ECM decreases the pulse width (duty cycle %) over the solenoid allowing oil to drain out of the drain hole. This is accomplished by relieving the pressure behind the spool valve. This reduction in pressure allows the spool valve to partially open the relief port, decreasing the injection control pressure.

The described operation allows the IPR to continuously adjust the injection control pressure commanded by the ECM.

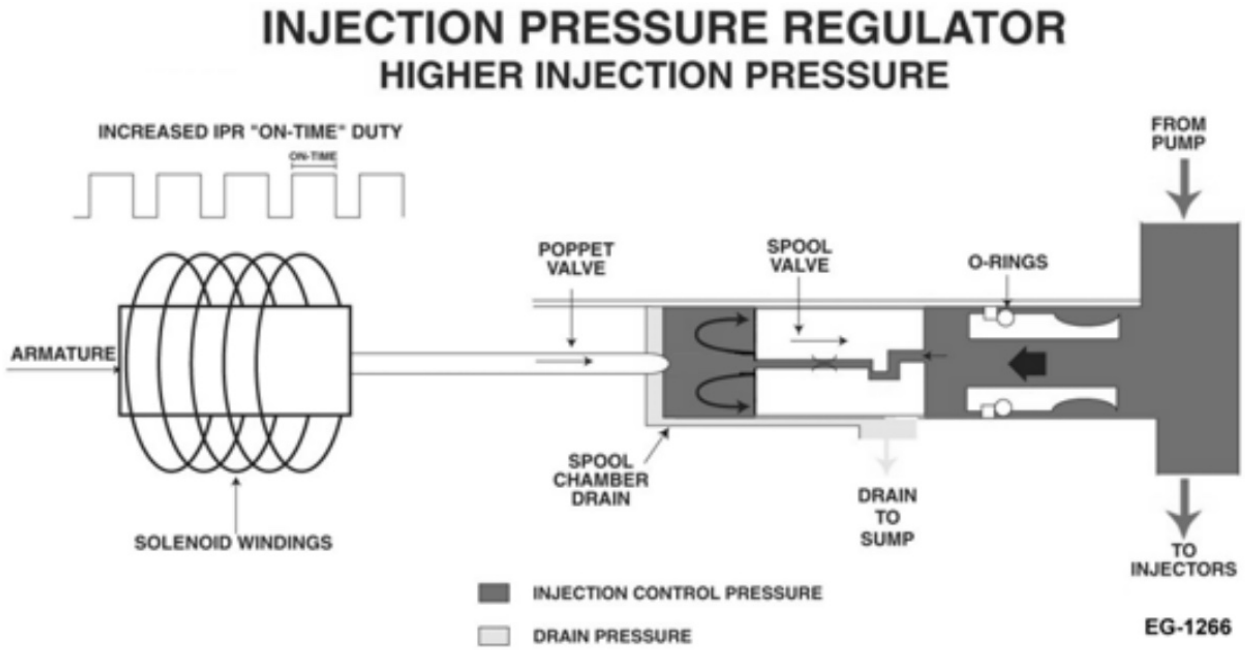

Figure 17 IPR Higher Injection Pressure Diagram

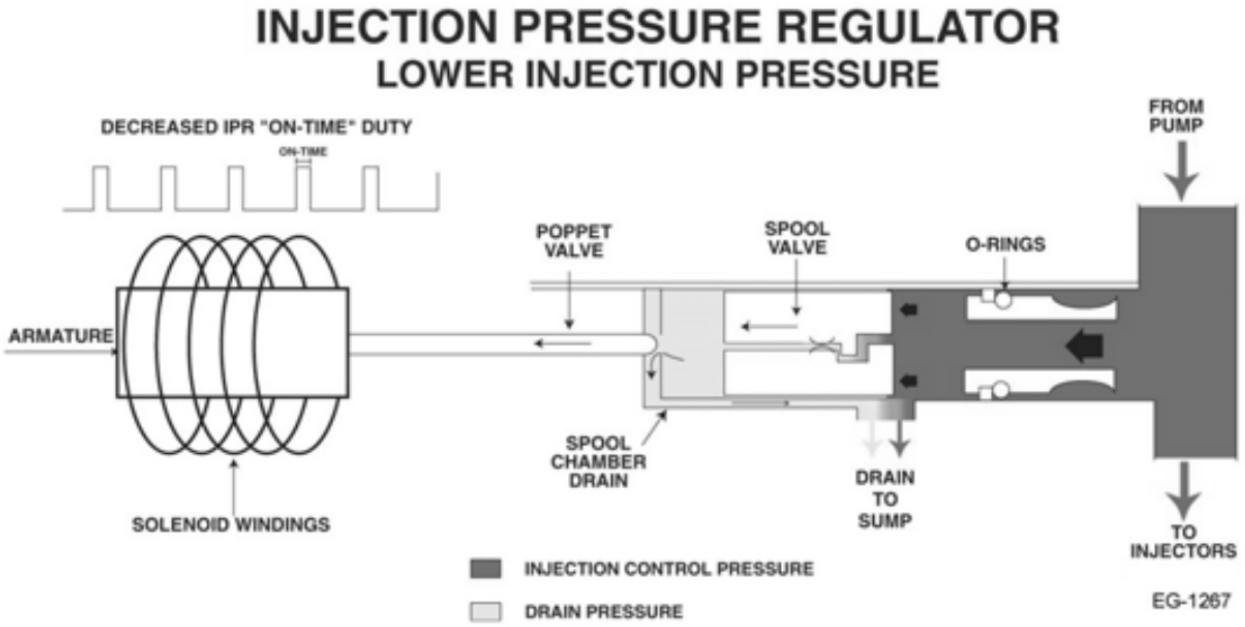

Figure 18 IPR Lower Injection Pressure Diagram

Fuel Injector

Description

The fuel injector is a unitized fuel injector that is hydraulically actuated and electronically controlled.

Hydraulic actuation is accomplished when the injector solenoid is energized, opening a poppet valve and allowing ICP pressure to flow on top of the amplifier accumulator.

Fuel is supplied to the injector by passages drilled through the cylinder head that intersect fill ports in the injector.

The area under the plunger is filled with fuel from pressure supplied by the transfer pump. As the plunger moves down, the increase in pressure closes the fuel inlet check ball. Pressure continues to rise until the nozzle valve pressure setting is overcome. Fuel is pressurized through the nozzle orifices and atomized into the combustion chamber. Injection is terminated when the solenoid is de-energized and ICP pressure is released.

Component Description

Solenoid

The solenoid is a very fast acting electromagnet that, when energized, pulls the poppet valve off its seat.

Poppet Valve

The poppet valve is held on its seat by a spring. In this closed position, high pressure inlet oil is blocked and the intensifier cavity is opened to drain.

When the solenoid is energized, the poppet is quickly lifted off its seat. The passage to the drain is closed and the inlet for high pressure oil is opened.

Intensifier Piston and Plunger

When the poppet valve opens the inlet port, high pressure oil enters the injector and acts on the top of the intensifier piston. Pressure builds on the intensifier, pushing it and the plunger down. The intensifier is seven times larger in surface area than the plunger. This difference allows for an equal multiplication of force. The downward movement of the plunger pressurizes the fuel in the plunger cavity, causing the nozzle to open.

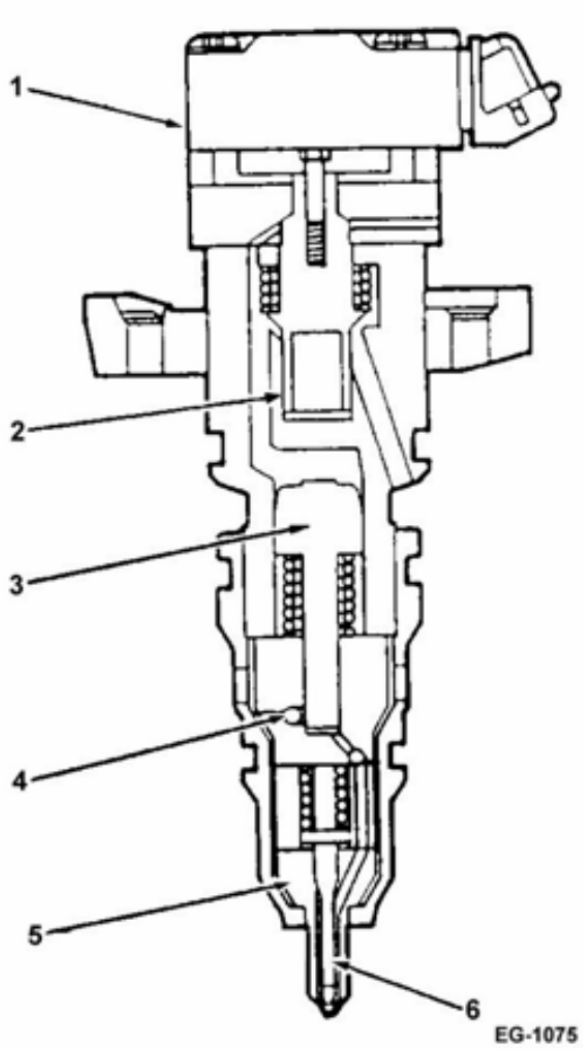

Figure 19 Fuel Injector Component Location

1. Solenoid
2. Poppet Valve
3. Intensifier Piston
4. Check Ball
5. Nozzle Assembly
6. Nozzle Valve

Operation

These engines are equipped with split shot fuel injectors. The injection operation is divided into two stages or cycles.

1. Pre-injection
2. Primary injection

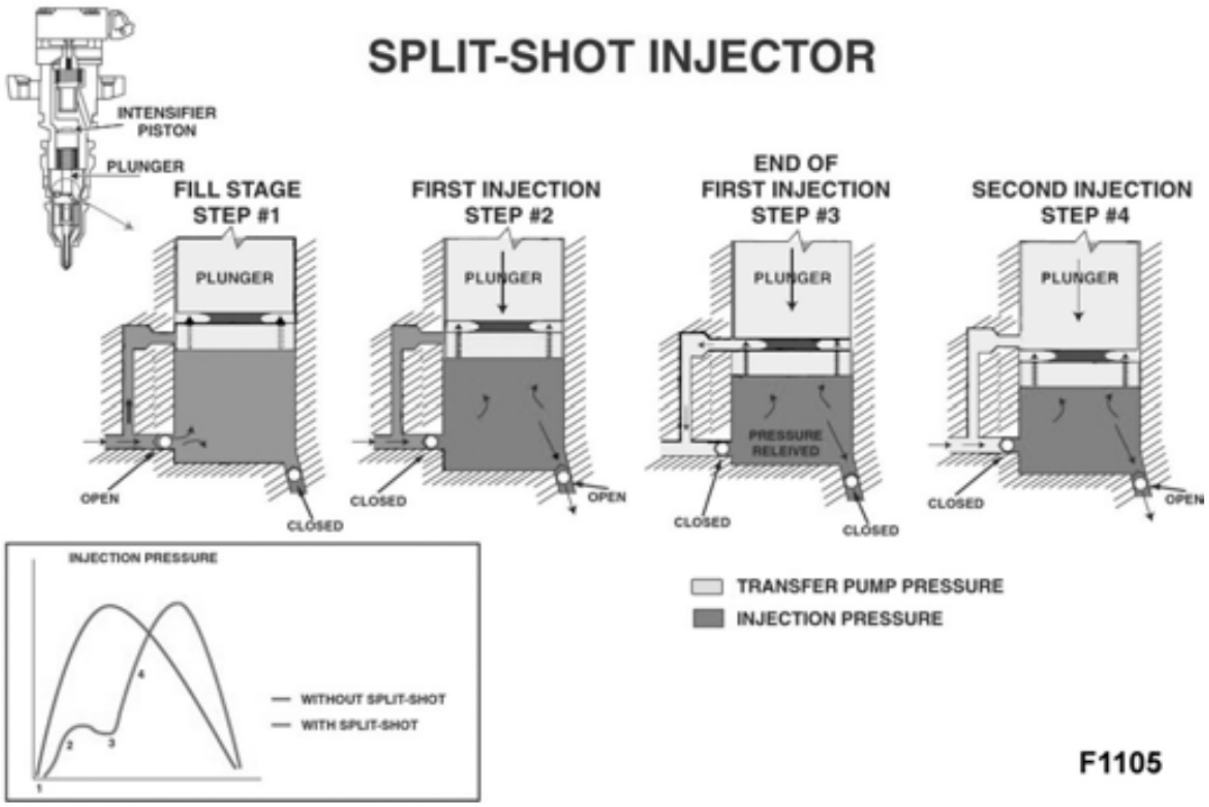

Figure 20 Stages of Injector Operation

The injection cycle is executed in two stages. Some fuel is pre-injected into the combustion chamber to initiate the combustion. Following combustion initiation, the primary injection takes place. This feature reduces emission levels during light load operations. It also reduces light load engine noise.

The barrel and plunger were redesigned and a spill port was incorporated. When injection is initiated, the first shot of fuel is pre-injected into the combustion chamber. Pre-injection is complete when the spill port of the plunger coincides with the slot on the barrel.

At this time, some fuel is allowed to return to the fuel supply port until the spill port slot is once again blocked by the plunger and the primary injection stroke takes place.

Glow Plug Controller System

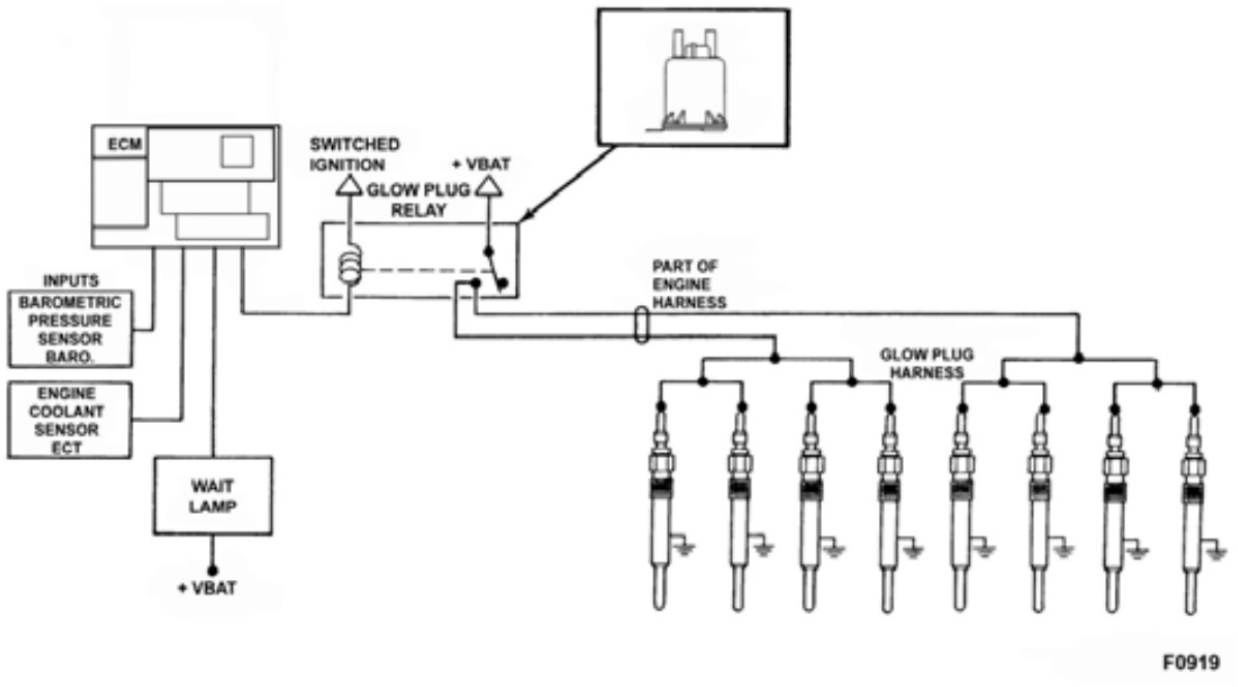

Figure 21 Glow Plug Controller System Diagram

The purpose of the glow plug system is to warm up the engine cylinders to improve cold engine starting and to reduce exhaust emissions during the engine warm-up period.

The ECM is programmed to turn on the "wait to start" light. The ECM also energizes the glow plugs via the glow plug relay each time the ignition switch is placed in the ON position before starting an engine.

The ECM monitors battery voltage and uses information from the Engine Coolant Temperature (ECT) and barometric (BARO) sensors to determine the amount of "wait to start" light time and glow plug activation time. The ECM controls the "wait to start" light ON time and the activation of the glow plugs separately.

The glow plugs are activated for a longer period of time if the engine is cold or the barometric pressure is low (high altitude). Battery voltage is monitored to extend glow plug life. If the battery voltage is high, power to the glow plugs is modulated by turning the glow plug relay ON or OFF at programmed intervals.

The engine is ready to start when the "wait to start" light is turned off by the ECM. To reduce exhaust emissions during engine warm up, the glow plugs may remain ON for up to 120 seconds while the engine is running.

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Mounting Engine On Stand

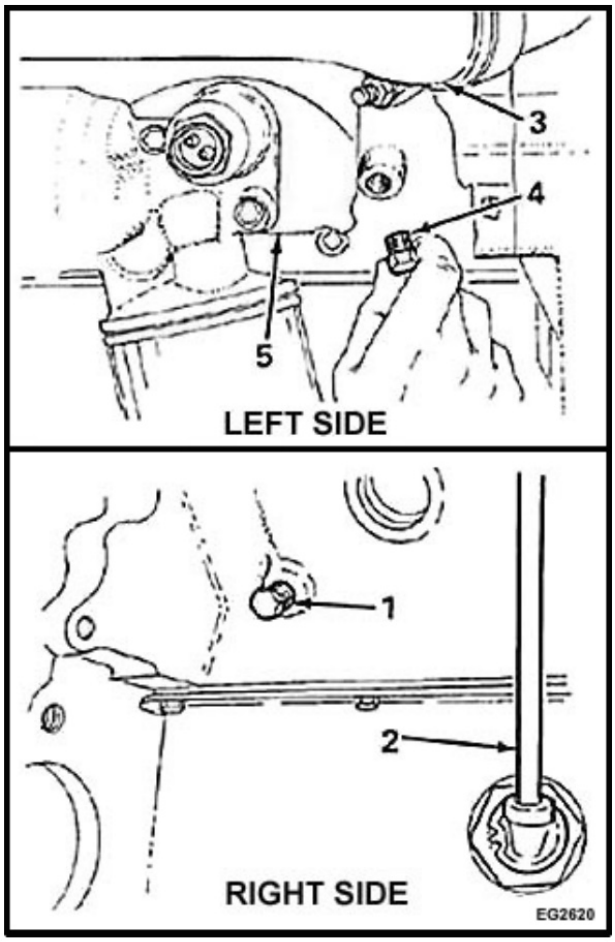

Figure 22 Location of Coolant Drain Plugs

1. Right Coolant Drain Plug
2. Oil Level Gauge
3. Left Exhaust Manifold
4. Left Coolant Drain Plug
5. Oil Cooler/Filter Header

1. Drain the coolant from the crankcase by removing two coolant drain plugs. The drain plugs are located at the rear of the crankcase, behind the exhaust manifolds on each side of the engine.
2. After the coolant has drained, install coolant drain plugs into crankcase and tighten.
3. Dispose of the coolant according to local regulations.

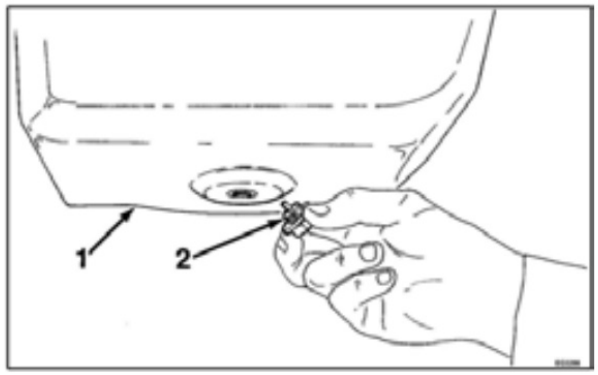

Figure 23 Location of Oil Drain Plug

1. Oil Pan
2. Oil Drain Plug

4. Remove the oil drain plug. Allow the oil to drain into a suitable container.
5. After oil has drained, install the oil pan drain plug and tighten to the special torque value.
6. Dispose of the oil according to local regulations.

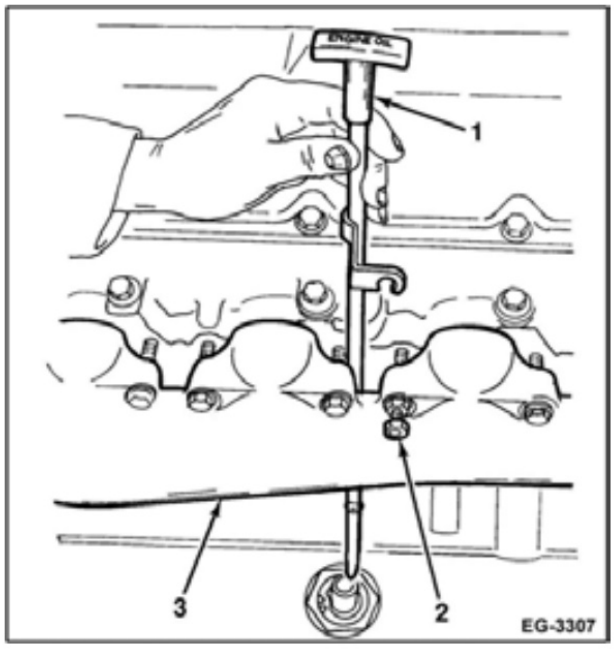

Figure 24 Removing Oil Level Gauge

1. Oil Level Gauge
2. Stud Nut
3. Right Exhaust Manifold

7. Loosen the stud nut that secures the slotted oil level gauge mounting bracket to the right exhaust manifold. Remove the oil level gauge.

WARNING: To avoid personal injury or possibly death, attach the hoist hook lifting bracket at the engine lifting eyes before lifting the engine. Failure to do so can cause the engine to lift on one end and swing out, injuring any personnel standing in the area.

8. Attach the hoist hook lifting bracket at the engine lifting eyes. Use a safety catch on the hoist hook when lifting the engine.

WARNING: To avoid personal injury or possibly death, or engine damage, use only grade 8 or greater metric bolts when mounting the engine to the stand. Other bolts may sheer, causing the engine to fall from the engine stand.

NOTE: For specific directions on the safe use of engine mounting stands and adapter plates, refer to the manufacturer's instructions included with these parts.

NOTE: Use the correct engine stand adapter plate when mounting the engine to the stand.

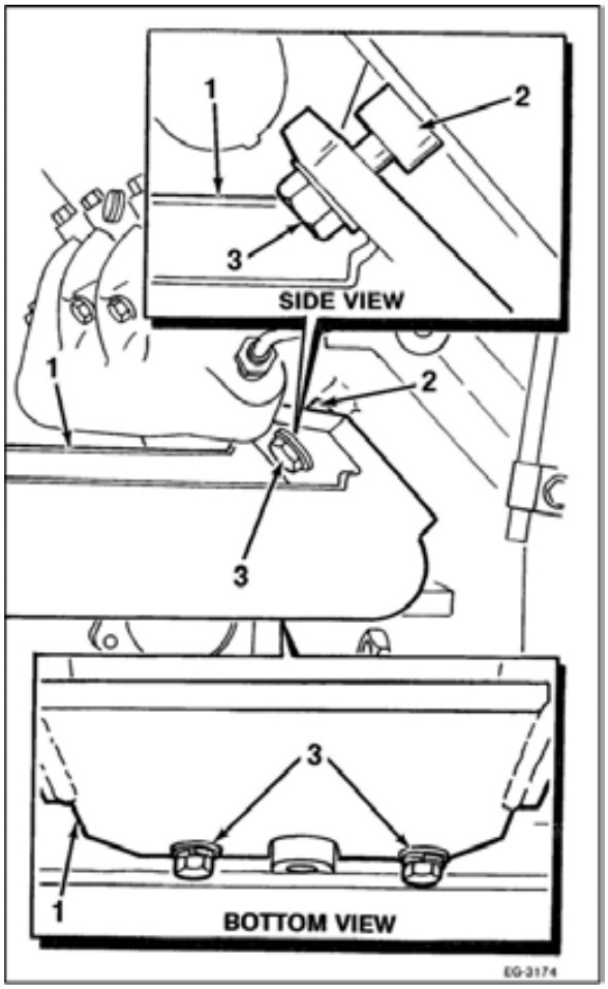

Figure 25 Installing Engine Stand Adapter Plate to Engine

1. Engine Mounting Adapter Plate
2. Spacer
3. Mounting Bolts (3)

9. Position and secure engine stand mounting adapter plate to right side of engine. Use three grade 8 bolts.
10. Mount engine to stand using the specified adapter plate and grade 8 or greater mounting bolts.

Special Torque

Table 1 Engine Mounting Special Torques

Oil Level Gauge Tube Adapter Nut	36 N·m (26 lbf·ft)
Oil Pan Drain Plug	41 N·m (30 lbf·ft)

SPECIAL SERVICE TOOLS

Table 2 Engine Mounting Special Service Tools

ZTSE4151A	Rear Mounted Engine Bracket (Keine Stand) (Not shown)
ZTSE4348	Side Mounted Engine Bracket (OTC Stand)
OEM4137	Engine Turn-Over Stand

Table of Contents

Description

The turbocharger is an exhaust driven centrifugal air compressor. It's purpose is to increase 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. The bearings are sleeve-type and are lubricated by engine oil. Oil is pumped directly from the crankcase and circulated in the turbocharger housing. Then the oil is returned to the sump through an oil drain in the turbocharger mounting pedestal.

NOTE: There are no external oil inlet or drain tubes for the turbocharger. Oil is exchanged via machined passages in the crankcase and the turbocharger mounting pedestal.

High velocity engine exhaust gases drive the turbine shaft assembly at rates up to 130,000 rpm. Filtered air entering the compressor side of the turbocharger is compressed and delivered to the engine intake manifold at a pressure greater than atmospheric pressure. Because more air is delivered to the intake manifold, the net result is more power, improved fuel efficiency, and the ability to maintain power at higher altitudes.

Some engines are equipped with an optional exhaust back pressure (EBP) device. This control device helps bring the engine up to its normal operating temperature at an increased rate. The device increases the engine's heat production by controlling a butterfly valve in the exhaust outlet housing. When the exhaust is restricted by the butterfly valve, exhaust backpressure increases, causing the engine to work harder in order to force out exhaust gases. The net result is that the engine warms up at a much faster rate. When the valve fully opens, the exhaust gas flows out unrestricted.

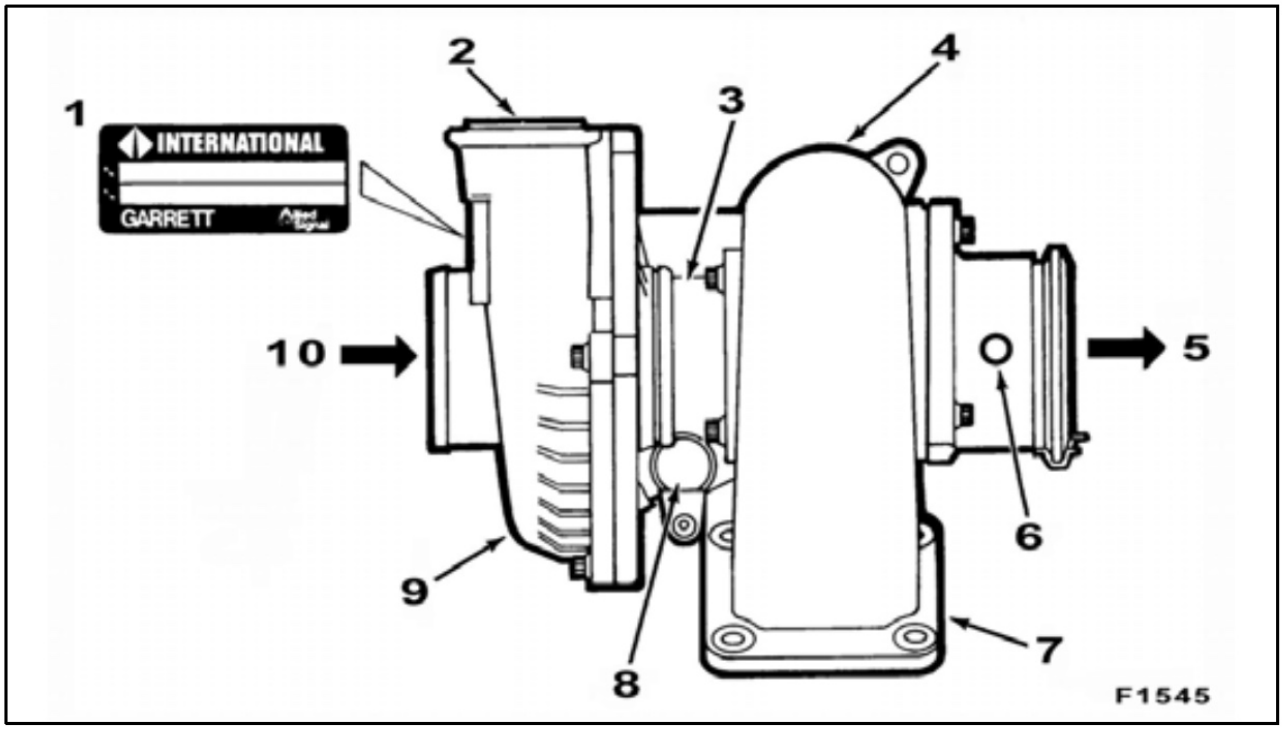

Figure 26 Standard Torque Non Wastegated Turbocharger, Late 1997 Model Year

1. Identification Tag
2. Compressor Air Outlet
3. Oil Cooled Center Housing
4. Turbine Housing
5. Exhaust Outlet
6. EBP Device
7. Turbine Inlet
8. EBP Regulator
9. Compressor Housing
10. Air Intake

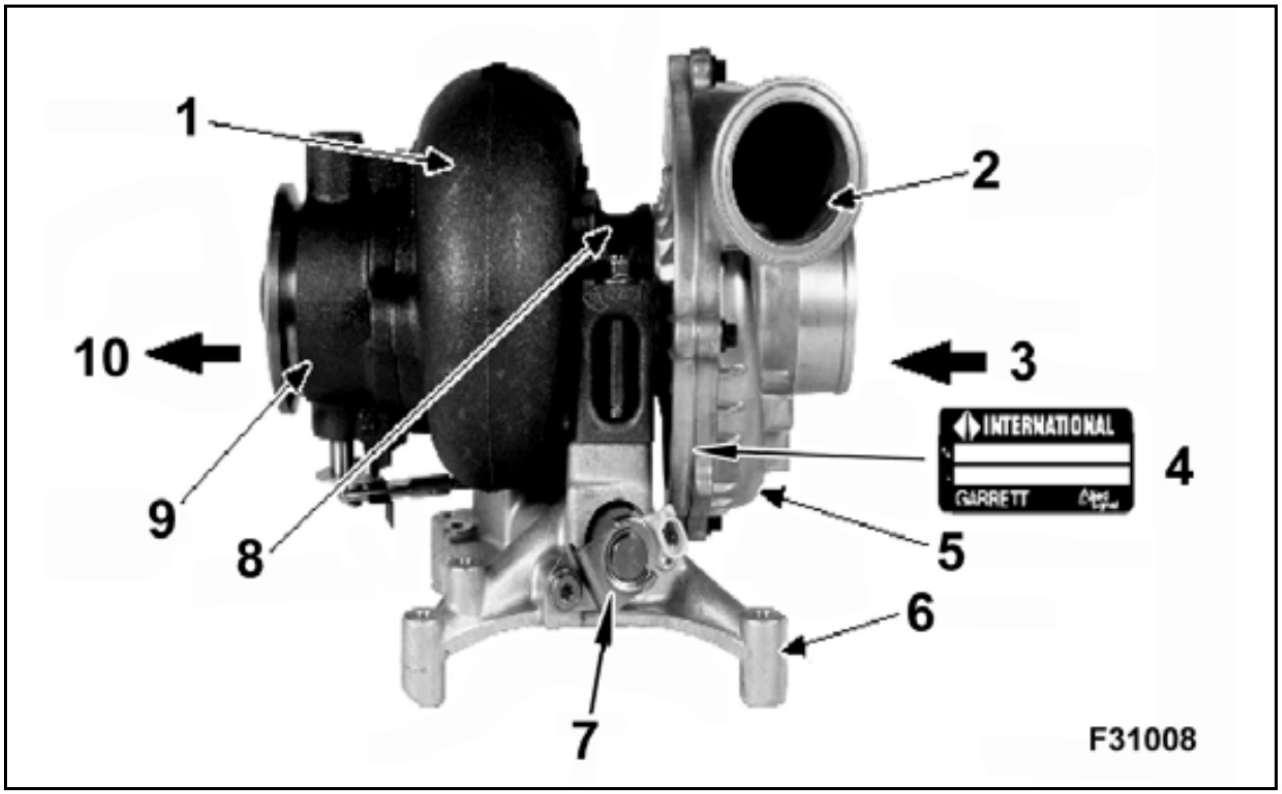

Figure 27 Standard Torque, Non Wastegated Turbocharger 1998 Through Early 2000 Model Years (GTP-38 Model Shown)

1. Turbine Housing
2. Compressed Air Outlet
3. Air Intake
4. Identification Tag
5. Compressor Housing
6. Turbocharger Pedestal
7. Exhaust Back Pressure Solenoid
8. Oil Cooled Center Housing
9. Optional Exhaust Back Pressure Valve
10. Exhaust Outlet

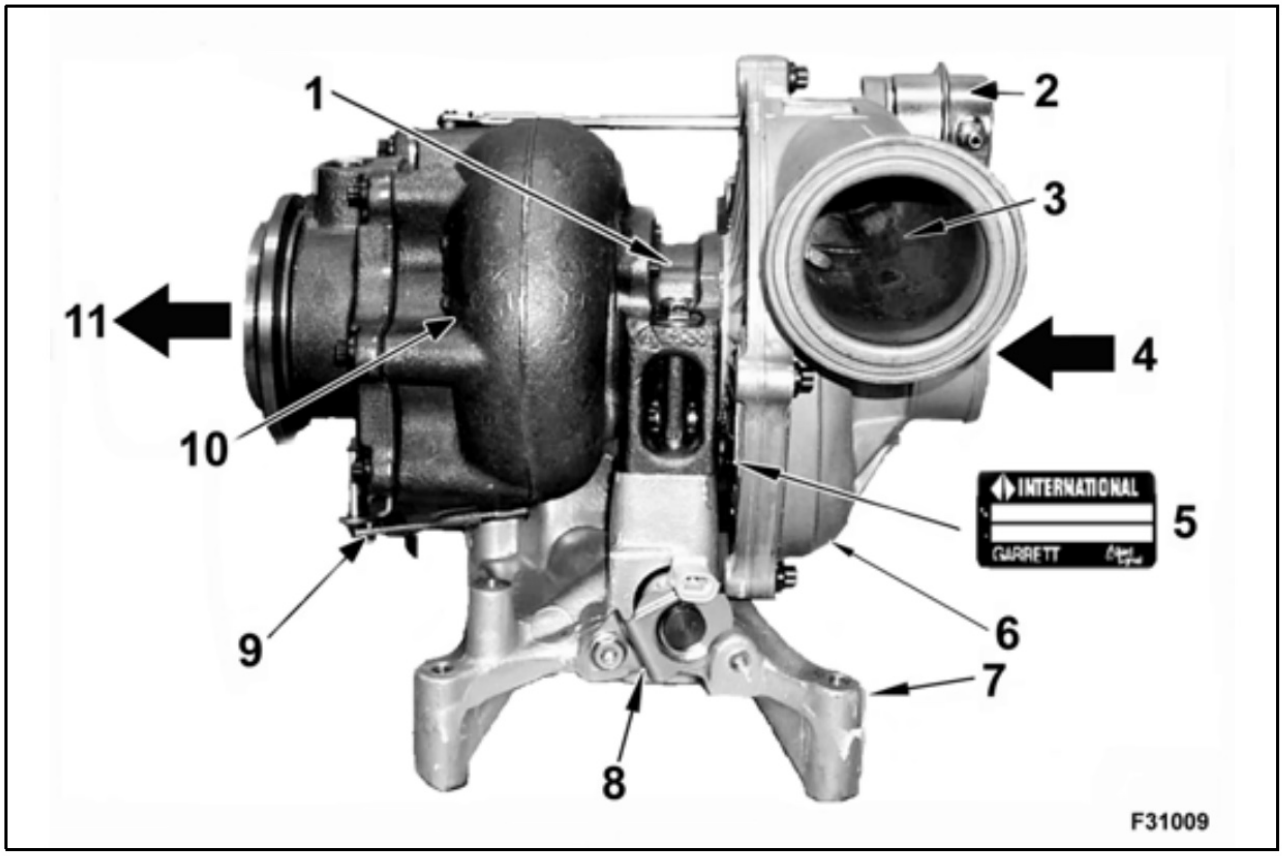

Figure 28 Standard Torque Wastegated Turbocharger Late 2000 Through 2003 Model Years (GTP-38 Model Shown)

1. Oil Cooled Center Housing
2. Wastegate Actuator
3. Compressed Air Outlet
4. Air Intake
5. Identification Tag
6. Compressor Housing
7. Pedestal
8. Exhaust Back Pressure Solenoid
9. Exhaust Back Pressure Linkage
10. Turbine Housing
11. Exhaust Outlet

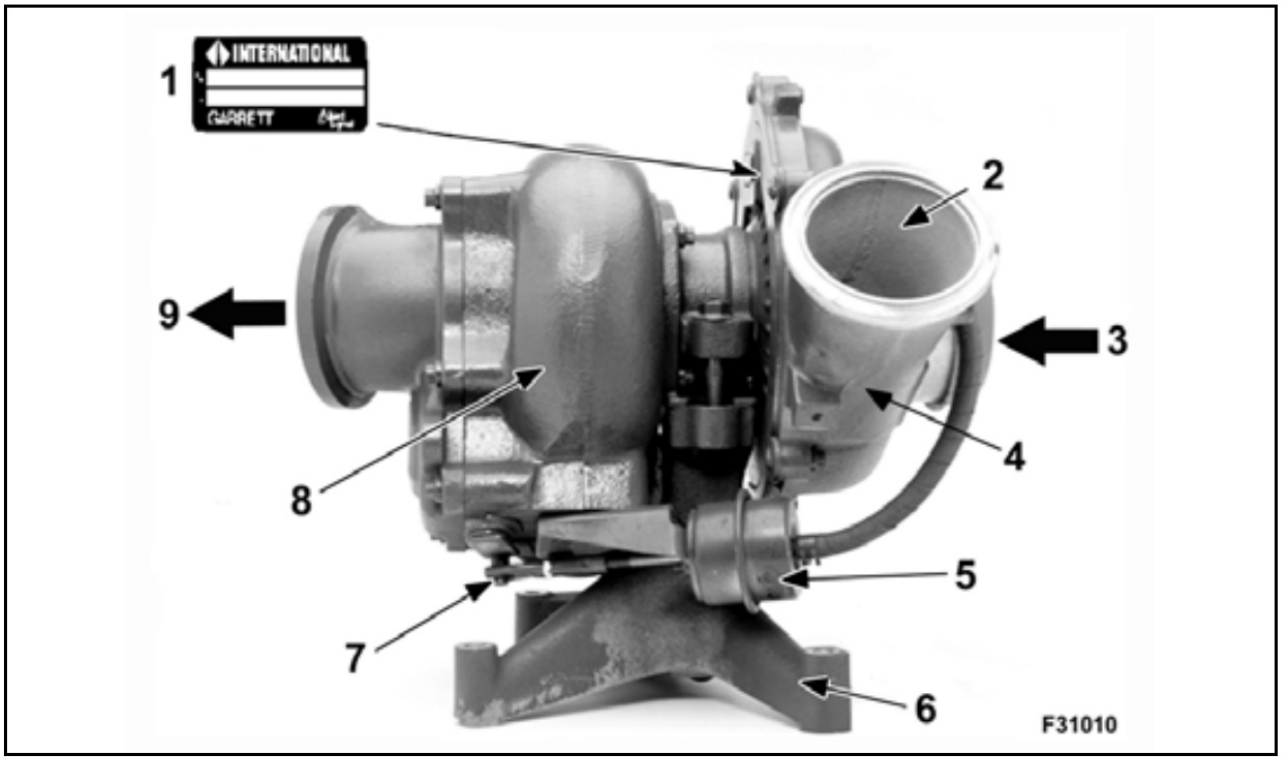

Figure 29 High Torque Wastegated Turbocharger, 1997 Through 2003 Model Years (GTP-37 Model Shown)

1. Identification Tag
2. Compressed Air Outlet
3. Air Intake
4. Compressor Housing
5. Wastegate Actuator
6. Pedestal
7. Wastegate Linkage
8. Turbine Housing
9. Exhaust Outlet

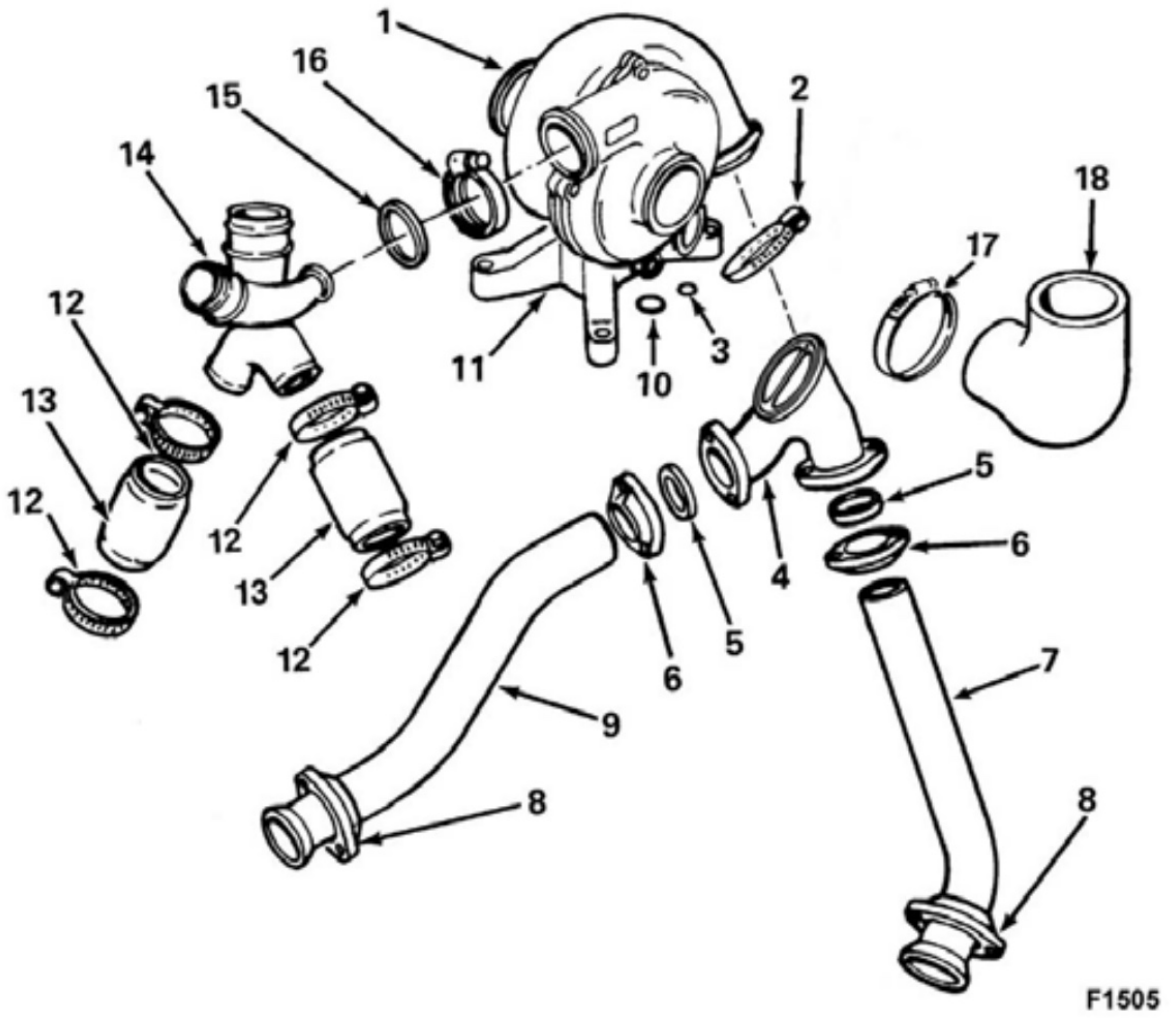

Figure 30 Standard Torque Turbocharger Piping and Components

1. Turbocharger
2. Exhaust Inlet Adapter Clamp
3. Turbocharger Oil Supply O-ring (2)*
4. Turbocharger Exhaust Inlet Adapter
5. Exhaust Tube Seal (2)
6. Turbocharger Adapter Flange (2)
7. Left Exhaust Tube
8. Exhaust Tube Flange (2)
9. Right Exhaust Tube
10. Turbocharger Oil Drain O-ring (2)*
11. Turbocharger Pedestal Assembly
12. Turbocharger Manifold Hose Clamp (4)
13. Turbocharger Manifold Hose (2)
14. Charge Air Cooling Tube and Crossover Pipe
15. Turbocharger Compressor Outlet Seal
16. Turbocharger Compressor Outlet Clamp
17. Elbow Clamp
18. Turbocharger Air Inlet Elbow Assembly

*One O-ring is between the pedestal and turbocharger mounting pad, one O-ring is between the turbocharger and pedestal.

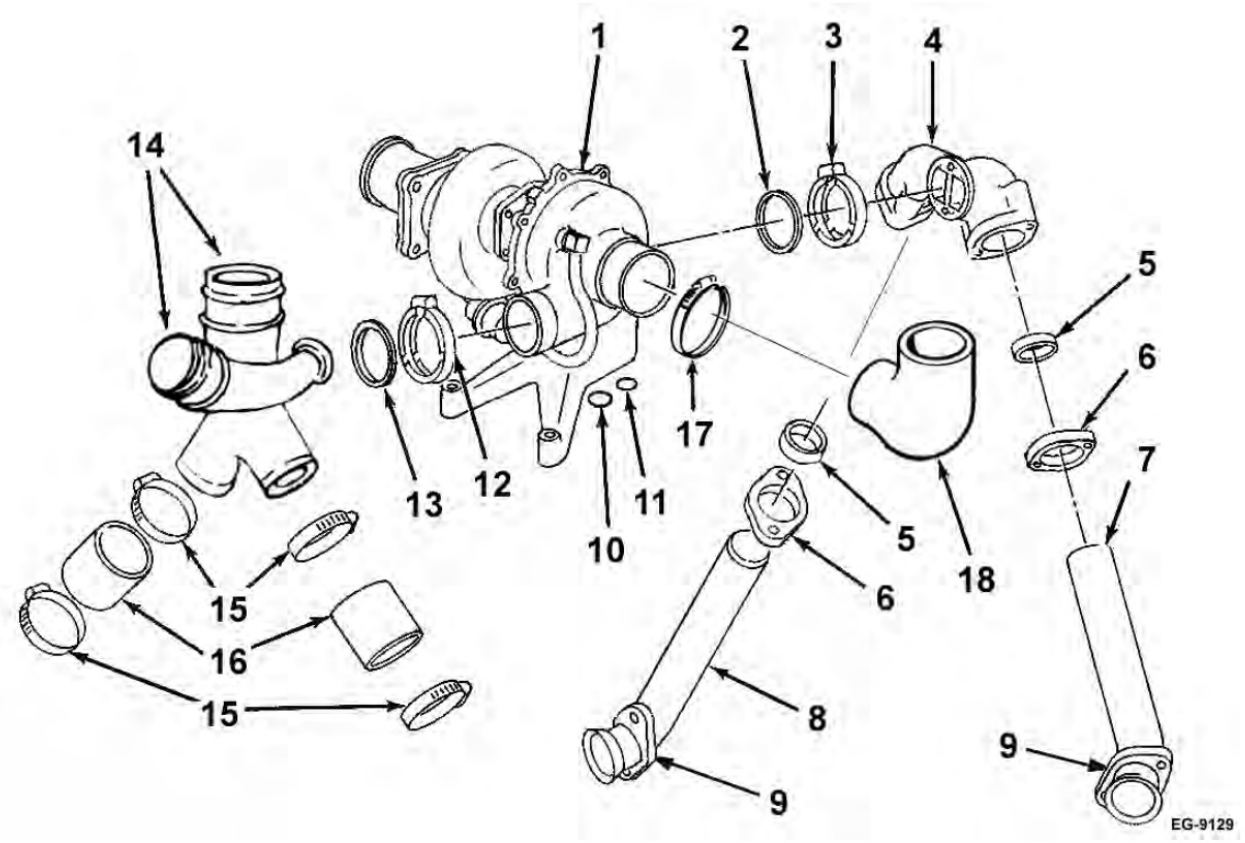

Figure 31 High Torque Turbocharger Piping and Components

1. Turbocharger
2. Exhaust Inlet Seal
3. Exhaust Inlet Clamp
4. Turbocharger Exhaust Inlet Adapter
5. Exhaust Tube Seal (2)
6. Turbocharger Adapter Flange (2)
7. Left Exhaust Tube
8. Right Exhaust Tube
9. Exhaust Tube Flange (2)
10. Turbocharger Oil Drain O-ring (2)*
11. Turbocharger Oil Supply O-ring (2)*
12. Turbocharger Compressor Outlet Clamp
13. Turbocharger Compressor Outlet Seal
14. Charge Air Cooling Tube and Crossover Pipe
15. Turbocharger Manifold Hose Clamp (4)
16. Turbocharger Manifold Hose (2)
17. Elbow Clamp
18. Turbocharger Air Inlet Elbow

*One O-ring is between the pedestal and turbocharger mounting pad, one O-ring is between the turbocharger and pedestal.

Bellows Exhaust System Feature

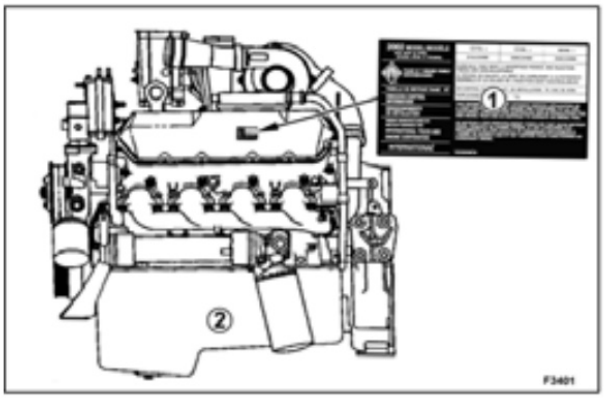

Figure 32 Emission Label Location

1. Emission Label
2. Left Side of Engine

NOTE: The Standard Torque engine is identified as T 444E. The High Torque engine is identified as T 444E HT.

The bellows exhaust system feature can be used on all International® T 444E Standard Torque and High Torque engines. All the information required for ordering the service kit is found on the exhaust emission label affixed to the left hand side valve cover. The following information is needed prior to determining which service kit to order:

- Rating
- Model year
- Horsepower rating

Service Kits For Standard Torque Engines

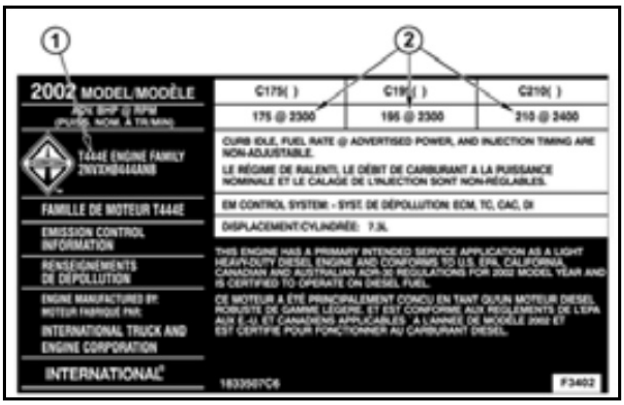

Figure 33 Standard Torque Emission Label

1. International T 444E Engine Family Identification
2. Horsepower and Torque Ratings

Beginning with serial number 1573357 all Standard Torque International® T 444E engines are equipped with the bellows exhaust system. To add the bellows exhaust feature to a standard torque engine, match the model year and engine serial number to the corresponding service kit number listed.

The standard torque engine has the following ratings:

- 160 HP
- 175 HP
- 190 HP
- 195 HP
- 210 HP

After the horsepower rating of the standard torque engine has been identified, compare the standard torque engine serial number to the table below.

Table 3 Bellows Exhaust Service Kits for Standard Torque International® T 444E Engines

Model Year	Serial Number Range	Bellows Service Kit Number
1994–1998	Prior to 843990	1843486C91
1999 and up	843990 and up	1837872C93

Service Kits for High Torque Engines

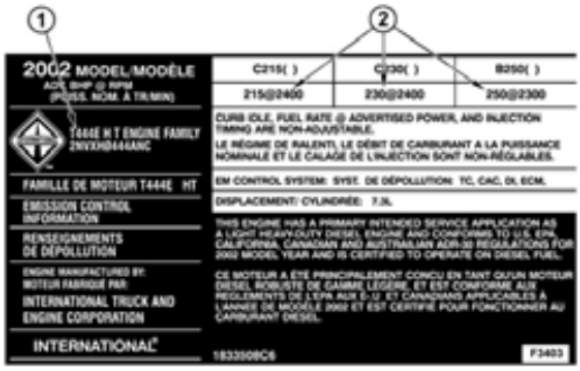

Figure 34 High Torque Emission Label

1. International® T 444E HT (High Torque) Engine Family Identification
2. Horsepower and Torque ratings

The bellows exhaust system feature can be added to any high torque engine, use service kit 1833800C91. The high torque engine has the following horsepower ratings:

- 210 HP
- 215 HP
- 230 HP
- 250 HP

Removal

Standard Torque Turbocharger

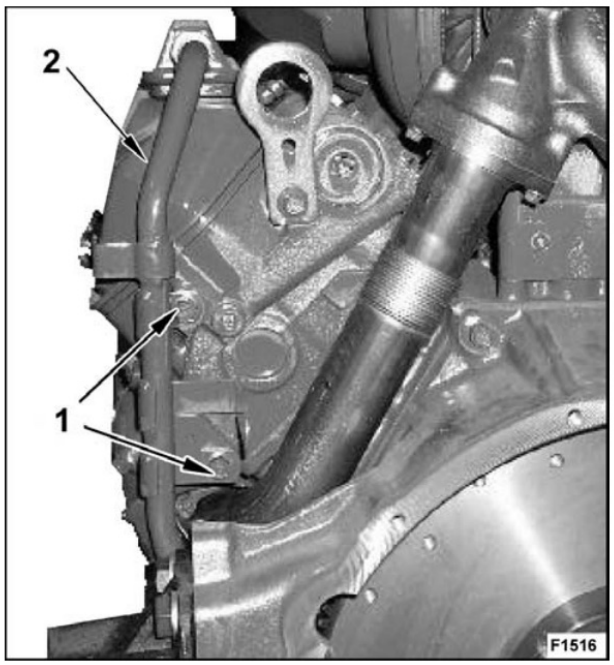

Figure 35 Removing Road Draft Tube Mounting Bolts

1. Road Draft Tube Mounting Bolts (2)
2. Road Draft Tube

1. Remove the two bolts securing the road draft tube to the crankcase. Relocate road draft tube to gain access to the left side of the engine.

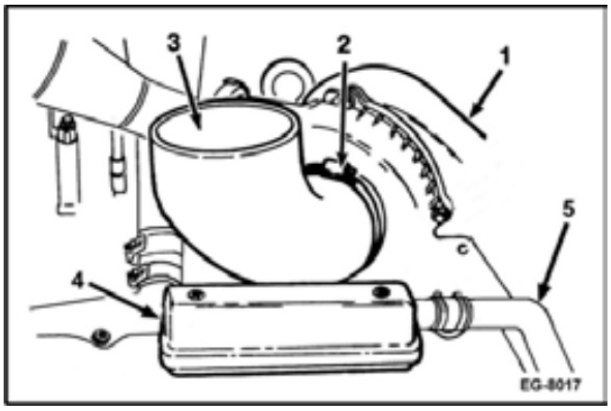

Figure 36 Removing Air Inlet Elbow

1. Turbocharger
2. Air Inlet Elbow Clamp
3. Air Inlet Elbow
4. Crankcase Breather
5. Road Draft Tube

2. Loosen the air inlet elbow clamp and remove the air inlet elbow from the turbocharger.
3. Remove exhaust pipe between the turbocharger and the muffler.

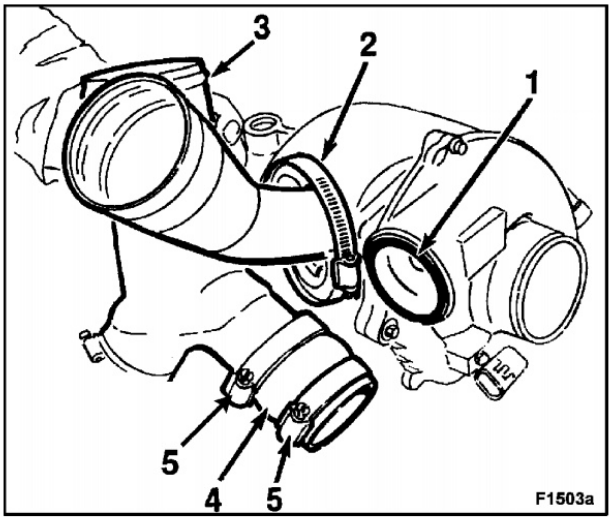

Figure 37 Removing Turbocharger Air Charging Tube/Crossover Pipe Assembly

1. Turbocharger Compressor Outlet Seal
2. Turbocharger Compressor Outlet Clamp
3. Charge Air Cooling Tube / Crossover Pipe Assembly
4. Turbocharger Intake Manifold Hose
5. Hose Clamp(s)

4. Remove the turbocharger charge air cooling tube/crossover pipe as follows:
   a. Loosen the four hose clamps (two per side) that secure the hoses to the air intake covers. The clamps are located on the manifold hoses.
   b. Loosen the turbocharger compressor outlet clamp that secures the charge air cooling tube to the turbocharger compressor housing.
   c. Remove the charge air cooling tube/crossover pipe assembly.
   d. Remove the turbocharger outlet seal from the compressor housing.
   e. Place protective caps onto the air intake manifolds.

Figure 38 EBP Wiring Harness Connection

1. Wiring Harness Clip
2. EBP Wiring Harness Connector

5. Disconnect the EBP electrical connector from the wiring harness, if equipped.

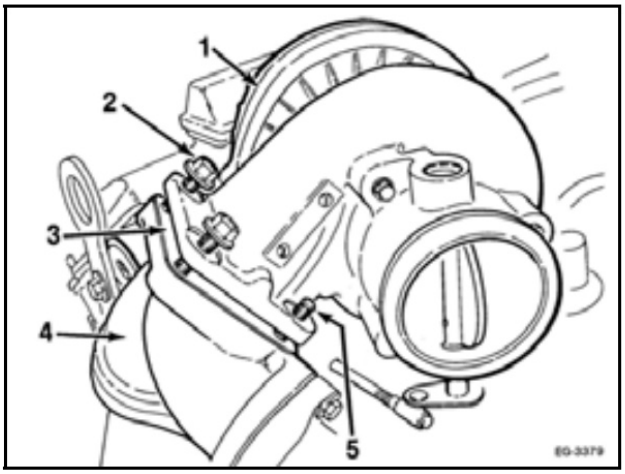

Figure 39 Removing Turbocharger From Inlet Adapter, Late 1997 Model Year Engine Without Exhaust Bellows Feature Shown

1. Turbocharger Compressor Housing
2. Retaining Bolts (2)
3. Gasket
4. Exhaust Inlet Adapter
5. Studs On Inlet Adapter (2)

6. **Late 1997 Model Year, Engines Without Exhaust Bellows Feature:** Remove two retaining bolts and the two retaining nuts at the exhaust inlet adapter to the turbine housing flange. Save these two retaining bolts. They will be reused in the assembly procedure. Discard the two retaining nuts.
7. **Late 1997 Model Year, Engines With Exhaust Bellows Feature:** Remove four retaining bolts at the exhaust inlet adapter to the turbine housing flange. Save these four retaining bolts. They will be reused in the assembly procedure.

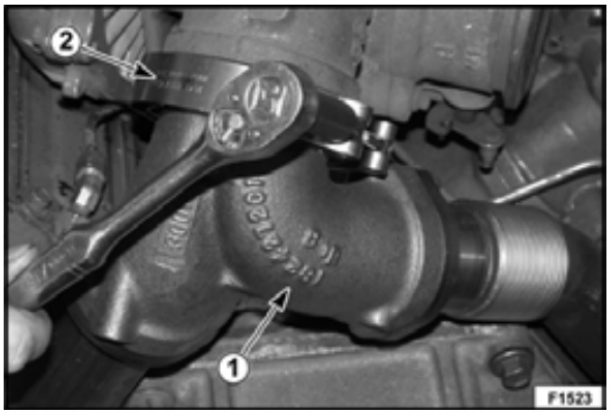

Figure 40 Removing Exhaust Inlet Adapter from Turbocharger, Engine With Exhaust Bellows Feature Shown (1998 through 2003 Model Years)

1. Exhaust Inlet Adapter
2. Clamp

8. Loosen and save turbocharger V-band clamp. Remove seal, if equipped.

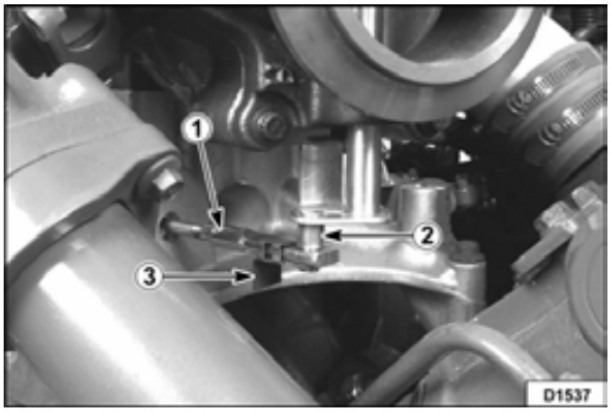

Figure 41 Disconnecting EBP Piston Rod (1998 through 2003 Model Years)

1. EBP Piston Rod
2. Control Arm
3. Slide Lock

9. Move the slide lock back and disconnect the EBP piston rod from the control arm.
10. **Late 1997 Model Year Only:**Remove the bolts securing the pedestal to the crankcase. Remove the turbocharger and pedestal assembly from the engine.

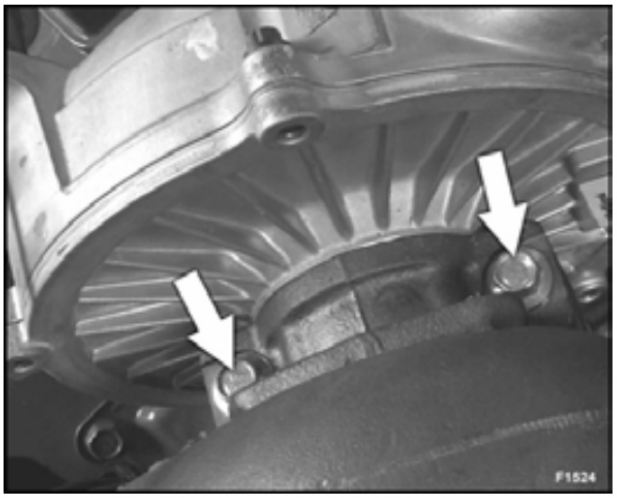

Figure 42 Removing Turbocharger Mounting Bolts (1998 through 2003 Model Years)

11. **1998 through 2003 Model Years:** Remove and save the two turbocharger mounting bolts. Remove turbocharger from the pedestal by lifting the turbocharger up.

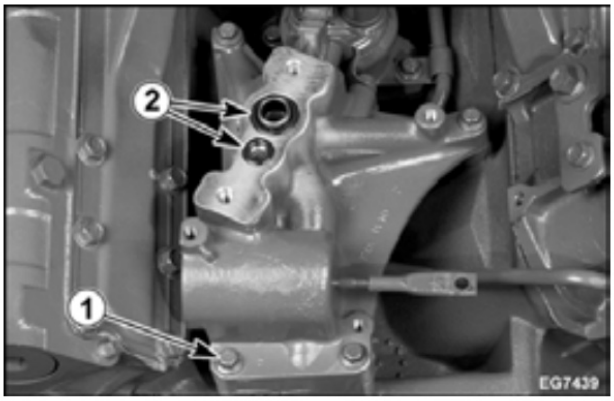

Figure 43 Removing Pedestal and O-rings (1998 through 2003 Model Years)

1. Mounting Bolts
2. Oil Supply and Oil Drain O-rings

12. **1998 through 2003 Model Years:** Remove the oil supply and oil drain O-rings from the pedestal. Remove four mounting bolts securing the pedestal to the crankcase and remove the pedestal from the engine.

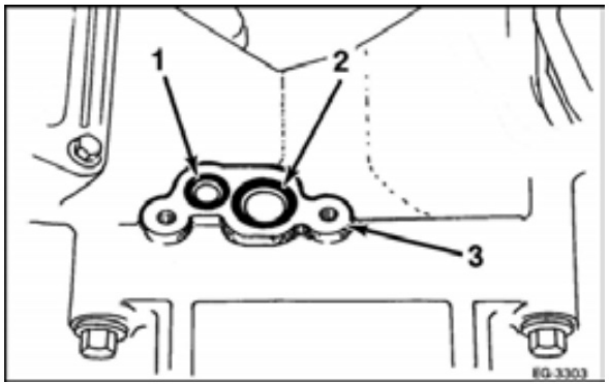

Figure 44 Turbocharger Oil Supply and Oil Drain Ports

1. Oil Supply O-Ring
2. Oil Drain O-Ring
3. Turbocharger Mounting Pad

13. Remove and discard the two O-rings located on the turbocharger mounting pad. Cover openings after removal.

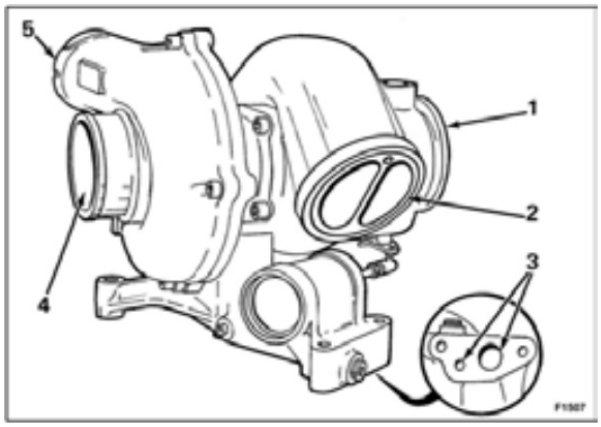

Figure 45 Turbocharger Openings to be Capped (Late 1997 Model Year Shown)

1. Exhaust Outlet
2. Turbocharger Exhaust Inlet
3. Turbocharger Oil Inlet and Oil Drain Ports
4. Turbocharger Air Inlet
5. Turbocharger Air Outlet

14. Cap all turbocharger openings to prevent contamination. If plastic caps are not available, use duct tape to cover openings.

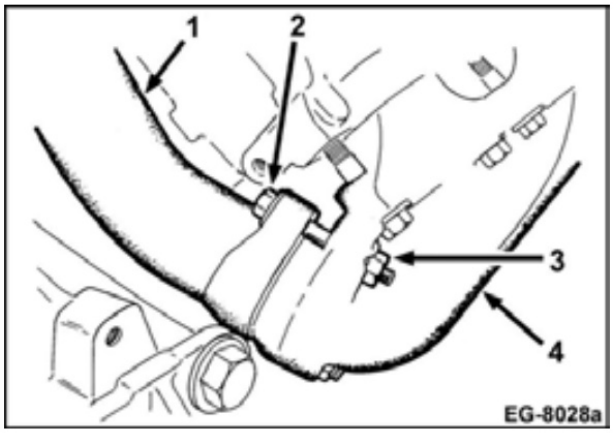

Figure 46 Removing Right Exhaust Tube Mounting Hardware at Exhaust Manifold

1. Right Exhaust Tube
2. Exhaust Tube Bolt
3. Nut
4. Right Exhaust Manifold

15. Remove two nuts and bolts from right exhaust manifold. These bolts secure the right exhaust tube to the exhaust manifold.

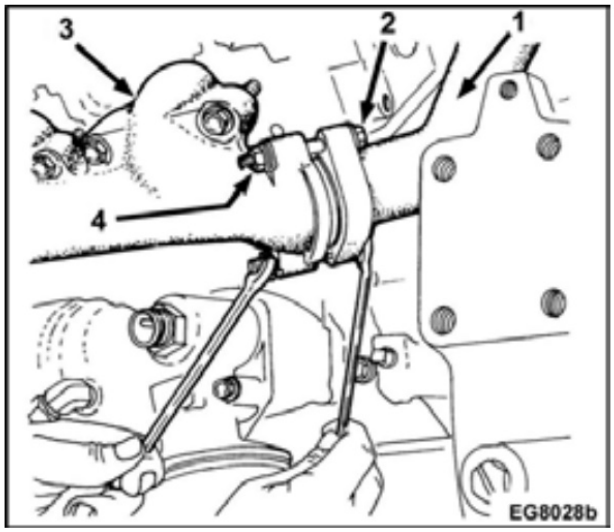

Figure 47 Removing Left Exhaust Tube Mounting Hardware at Exhaust Manifold

1. Left Exhaust Tube
2. Exhaust Tube Bolt
3. Left Exhaust Manifold
4. Nut

16. Remove two nuts and bolts from left exhaust manifold. These bolts secure the left exhaust tube to the exhaust manifold.
17. Remove the turbocharger exhaust tube assembly from the engine.

High Torque Turbocharger

1. Remove air cleaner and pipe to the turbocharger compressor inlet.
2. Remove exhaust pipe between the turbocharger and the muffler.

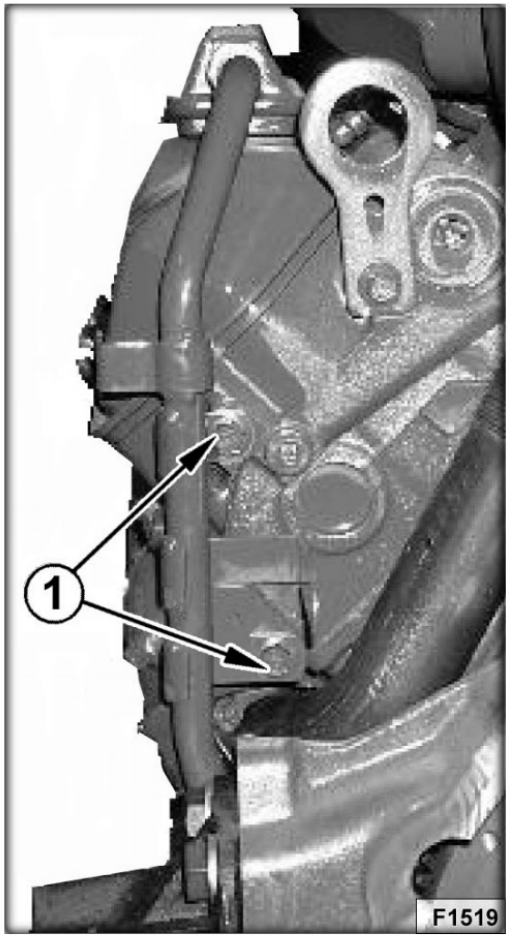

Figure 48 Road Draft Tube Mounting Hardware

1. Mounting Bolts

3. Loosen and remove the two bolts securing the road draft tube to the back of the crankcase. Relocate road draft tube to gain access to the left side of the engine.

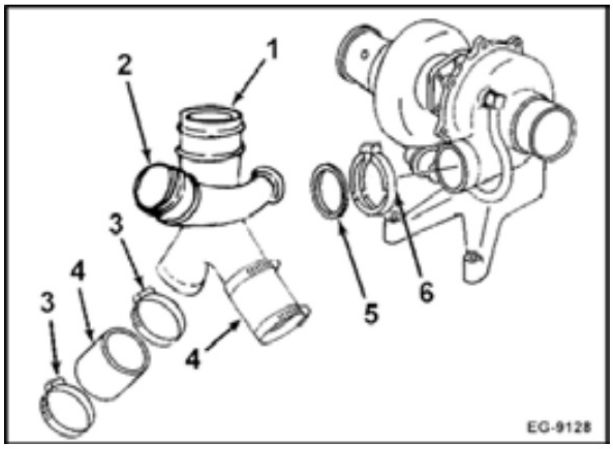

Figure 49 Removing Charge Air Cooling Tube/Crossover Pipe Assembly

1. Crossover Pipe
2. Charge Air Cooling Tube
3. Hose Clamps
4. Turbocharger Manifold Hoses
5. Turbocharger Compressor Outlet Seal
6. Turbocharger Compressor Outlet Clamp

4. Remove turbocharger charge air cooling tube/crossover pipe assembly as follows:
   a. Loosen the four hose clamps (two per side) that secure the hoses to the air intake covers. The clamps are located on the manifold hoses.
   b. Loosen the turbocharger compressor outlet clamp that secures the charge air cooling tube to the turbocharger compressor housing.
   c. Remove the charge air cooling tube/crossover pipe assembly and the two manifold hoses.
   d. Remove the turbocharger compressor outlet seal from the compressor housing.
   e. Place protective caps onto the air intake manifolds.
5. Remove and save turbocharger V-band clamp that secures the turbocharger to the exhaust outlet adapter. Remove seal.
6. Loosen and remove the two bolts that secure the turbocharger to the pedestal. Remove the turbocharger from the pedestal by lifting up.

NOTE: The turbocharger and pedestal must be removed separately from the engine.

7. Remove and discard the oil supply O-ring and oil drain O-ring located on the underside of the turbocharger or on the top of the pedestal.
8. Remove the four flange head mounting bolts that secure the pedestal to the crankcase. Remove the pedestal.

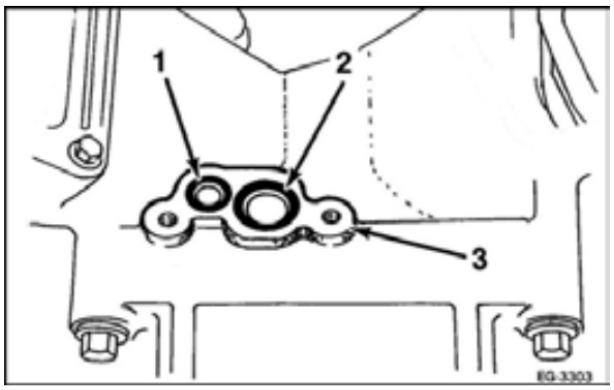

Figure 50 Turbocharger Oil Supply and Oil Drain Ports

1. Oil Supply O-Ring
2. Oil Drain O-Ring
3. Turbocharger Mounting Pad

9. Remove and discard the two O-rings located on the turbocharger mounting pad.
10. Cap all openings on the turbocharger assembly. If plastic caps are not available, use duct tape to cover openings.

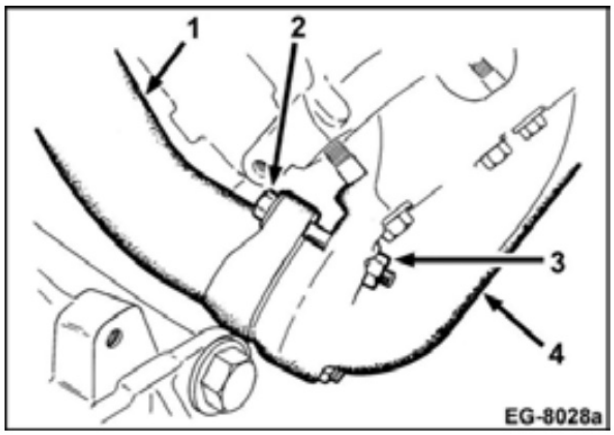

Figure 51 Turbocharger Exhaust Tube Mounting Hardware (Right Side Shown)

1. Right Exhaust Tube
2. Exhaust Tube Mounting Bolt
3. Exhaust Tube Mounting Nut
4. Right Exhaust Manifold

11. Remove the exhaust tube mounting hardware at the left and right exhaust manifolds. Remove the exhaust inlet adapter and tube assemblies from the engine.

Cleaning

NOTE: Do not use a caustic solution on the turbocharger or its related components.

Turbocharger

1. Use a suitable solvent and nylon brush to clean the turbocharger, pedestal, EBP control valve (if equipped), charge air cooling tube/crossover pipe and hoses. Use filtered compressed air to dry the parts.
2. Inspect the oil inlet and oil drain ports for restrictions. Clean as required.

Related Components

1. Thoroughly clean the piping that connects the air cleaner to the turbocharger with soap and water. Use filtered compressed air to dry the piping.
2. Before cleaning the inside of the air cleaner element housing, remove the vehicle-mounted air cleaner. Cleaning helps to prevent failure of the turbocharger or engine.

Disassembly (Standard Torque Only)

Remove EBP Control Valve

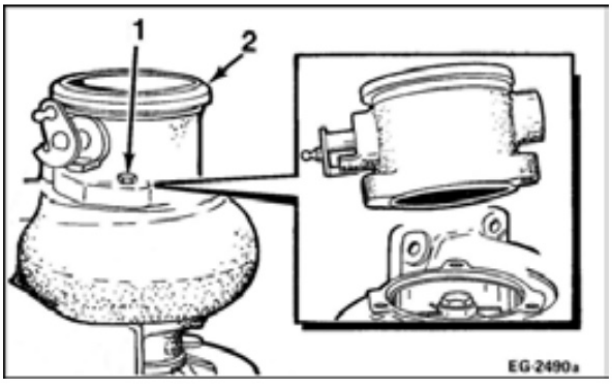

Figure 52 Removing EBP Control Valve (Late 1997 Model Year Shown)

1. EBP Control Valve Mounting Bolt (3)
2. EBP Control Valve Housing

Remove the mounting bolts and lift the EBP control valve housing from the turbocharger.

Remove Turbocharger Pedestal

NOTE: Late 1997 Model Year, the turbocharger and pedestal are removed from the crankcase as an assembly. 1998 Model Years and up, the pedestal and turbocharger are removed separately.

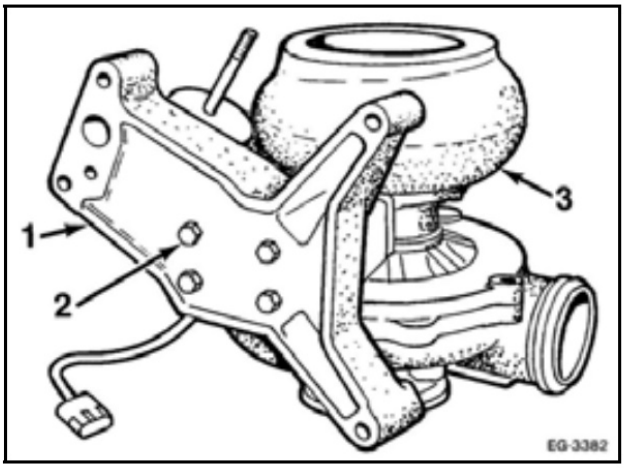

Figure 53 Removing Pedestal Mounting Bolts (Late 1997 Model Year Only)

1. Pedestal
2. Mounting Bolts
3. Turbocharger

1. Once the turbocharger and pedestal assembly have been removed from the crankcase, remove four turbocharger pedestal mounting bolts from the bottom of the pedestal.

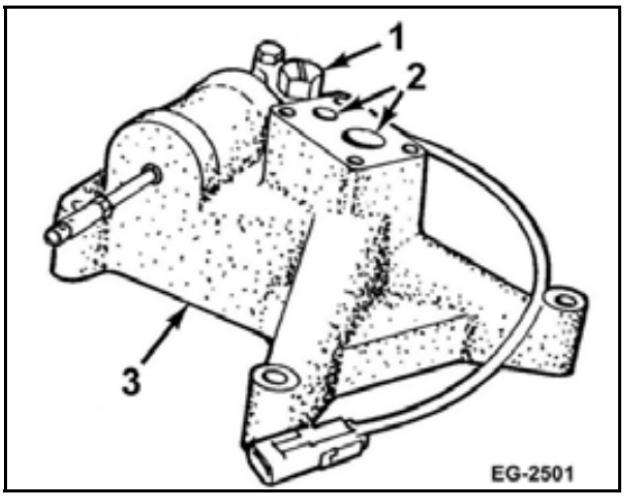

Figure 54 Turbocharger Pedestal

1. Solenoid Valve
2. O-Ring Locations (2)
3. Pedestal

2. Remove and discard the O-rings which seal the oil passages to the turbocharger.
3. Remove the solenoid valve from the pedestal, if necessary.

Inspection

Check Exhaust Inlet Adapter/Exhaust Tube Mating Surface

NOTE: This procedure should only be done if the standard exhaust tubes are being changed to exhaust tubes with bellows. If you are not changing the exhaust tubes or already have exhaust tubes with bellows on the engine, DO NOT perform this inspection.

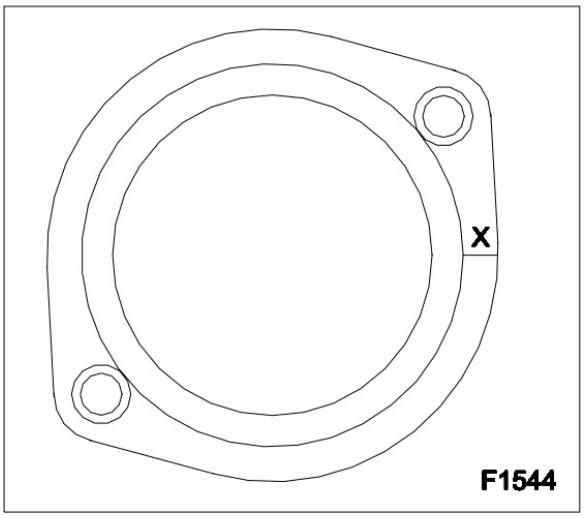

Figure 55 Exhaust Inlet Adapter/Exhaust Tube Gasket Mating Surface Dimension, Late 1997 Model Year and Up

WARNING: To avoid serious personal injury, possible death, or damage to the engine or vehicle, measure and inspect the exhaust tube mating surface of the exhaust inlet adapter. The adapter must have sufficient gasket support surface. If the width of the gasket surface (X width dimension of the figure above) on the inlet adapter measures less than 5 mm (0.19 inch) a tight seal will not be formed between the inlet adapter and the exhaust tube, causing an exhaust leak. If the gasket mating surface does not meet the minimum width, a new adapter must be ordered.

Late 1997 Model Year Only: Order exhaust turbo inlet adapter 1818163C1.

1998 Model Year Only: Order exhaust turbo inlet adapter 1826618C91.

1999 and UP Model Years: Order exhaust turbo inlet adapter 1828540C91.

Compressor Impeller, Turbine Wheel and Turbocharger Pedestal

1. Inspect the compressor impeller and turbine wheel for blade erosion, bending, breakage or deposits. Replace the entire turbocharger assembly if any blades are damaged.

   Deposits on the compressor impeller, and turbine wheel can be caused by the following conditions:

   - **High air inlet restriction** allows oil to be transferred from the turbocharger center housing, resulting in oil deposits.
   - **Excessive oil consumption** can result in turbine wheel carbon deposits.
   - **Engine overfueling** can result in excessive operating temperatures, which can cause aluminum components to melt. Such deposits may be found on the turbine wheel if such a failure occurs.

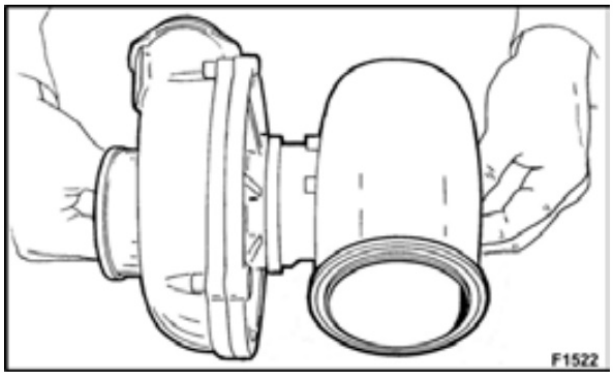

Figure 56 Checking for Turbine/Compressor Housing Wheel Rubbing

2. Set the turbocharger on a work bench with the shaft in a horizontal position. Rotate the shaft and check for any wheel rubbing within the housings. The wheels must spin freely when turned by hand.
3. Inspect the turbocharger pedestal for cracks, worn spots and other damage.

Check Axial End Play

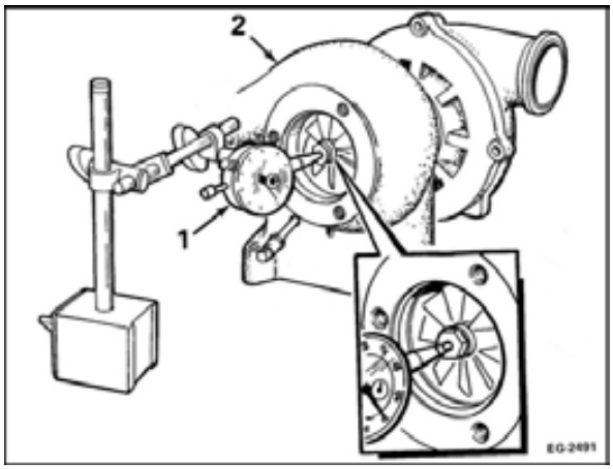

Figure 57 Checking Axial End Play

1. Dial Indicator
2. Turbine Housing

1. With the turbocharger in a stable position, place the tip of a dial indicator inline with the end of the turbine shaft. Reset the dial indicator to zero.

2. Move the shaft back and forth by hand and record the readings. If the readings exceed specifications, the turbocharger must be replaced.

Rebuild EBP Piston Rod Assembly

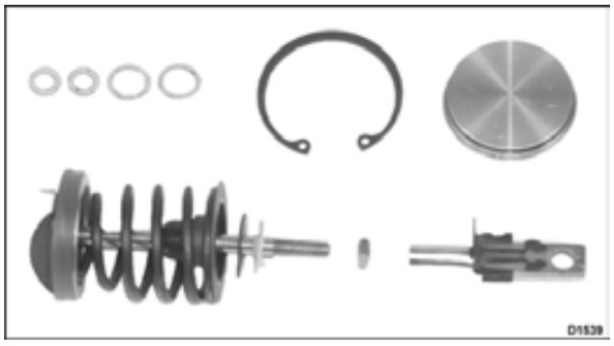

Figure 58 EBP piston rod kit contents

1. Oil supply O-ring (2)
2. Oil drain O-ring (2)
3. Retaining ring
4. End cover with O-ring
5. Piston rod assembly
6. Jam nut
7. Latch end with slide lock

If oil is leaking from the EBP piston rod housing, installing the service kit may eliminate the need to replace the entire turbocharger pedestal.

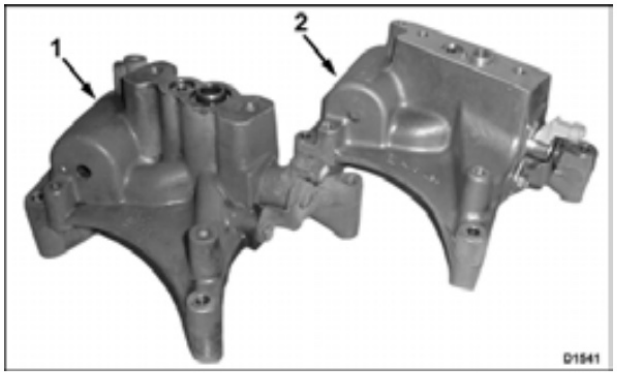

Figure 59 Different Turbocharger Pedestals

1. Hourglass-shaped pedestal
2. Blocked-shaped pedestal

NOTE: Different shapes of pedestals are used on the T 444E engines. The service kit CAN NOT be used on engines having S/N 843990 — 1825359 and using hourglass-shaped pedestals. If oil is leaking from the EBP piston rod housing on these pedestals, the entire pedestal assembly must be replaced with P/N 1831455C92.

Hourglass pedestals are still being used on some engines built after S/N 1825359. The service kit can be used on those later engines.

Turbocharger assembly P/N 1831774C93 already uses the new EBP piston rod assembly and can be serviced with this kit. The turbocharger part number is located on the identification tag attached to the turbocharger compressor housing.

The different pedestals can be identified by the following characteristics while installed on the engine:

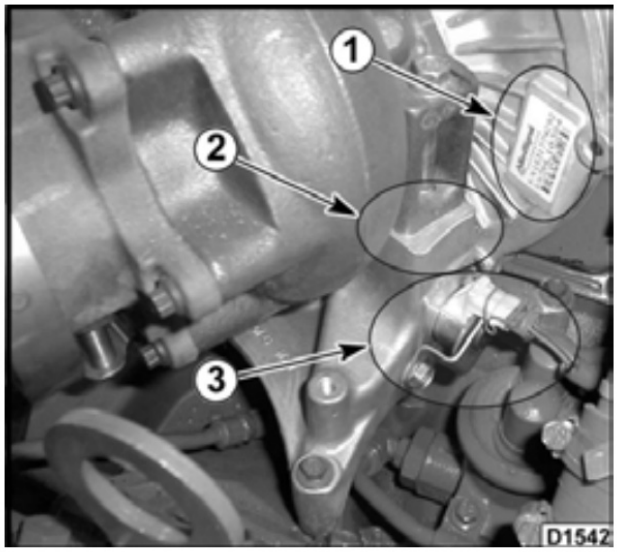

Figure 60 Block-shaped Pedestal Installed

1. Turbocharger part number (location)
2. Visible ledge
3. Solenoid valve deeper

The block-shaped pedestal has a visible ledge where the turbocharger mounts to the pedestal. Also, the solenoid valve installed in the pedestal, is set deeper into the pedestal than in the hourglass shaped one.

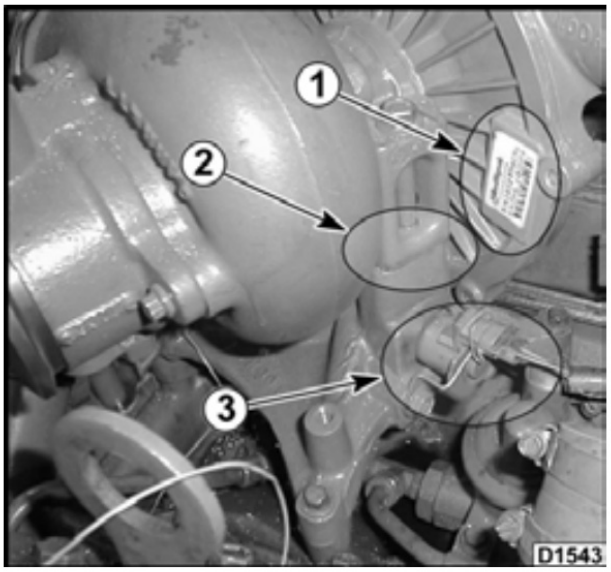

Figure 61 Hourglass-shaped Pedestal Installed

1. Turbocharger part number (location)
2. No visible ledge
3. Solenoid valve protrudes

The hourglass-shaped pedestal does not have a visible ledge where the turbocharger mounts to the pedestal. The solenoid valve installed in the pedestal protrudes out farther than in the hourglass shape valve.

If leakage is visible from the EBP piston rod housing, install a new EBP piston rod assembly as follows:

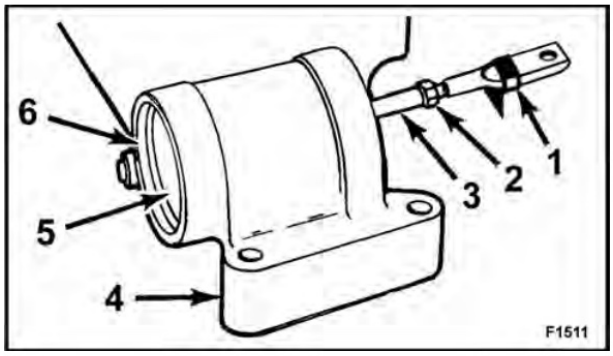

Figure 62 EBP Piston Rod Housing

1. Latch End with Slide Lock
2. Jam Nut (not included on production units)
3. Piston Rod
4. Pedestal
5. End Cover
6. Retaining Ring

1. Unscrew the latch (and jam nut, if equipped) from the end of the piston rod. Hold the piston rod securely while unscrewing the latch because it is crimped to the piston rod.
2. Remove the retaining ring from the housing.
3. Remove the end cover from the housing by gently tapping on the threaded end of the piston rod.
4. Remove the piston rod, spring, spring seat and two wiper seals (one black, one white) as an assembly from the housing. Discard the assembly.
5. Thoroughly clean and inspect the pedestal and the inside of the housing.
6. Lubricate the inside of the housing and the outside of the new EBP piston rod assembly with clean oil.
7. Install the new EBP piston rod assembly (without the jam nut and latch) into the housing far enough to install the cover and retaining ring.
8. Lubricate the O-ring on the new end cover with clean oil. Install the end cover and retaining ring in the housing.
9. Install a new jam nut, slide lock and latch on the threaded end of the piston rod.

Check Wastegate Actuator

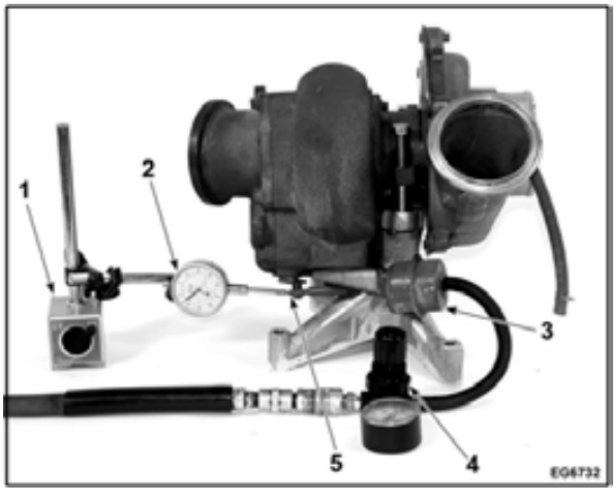

Figure 63 Checking Wastegate Actuator (high torque model shown)

1. Magnetic Base
2. Dial Indicator
3. Wastegate Actuator
4. Air Pressure Regulator
5. Wastegate Actuator Shaft

1. Place the turbocharger on a flat surface. Position a dial indicator with a magnetic base next to the turbocharger. Place the tip of the dial indicator inline and at the end of the wastegate actuator shaft. Reset the indicator needle to zero.
2. Use a hose and appropriate fittings to connect the regulated shop air hose to the wastegate actuator.
3. Connect an air hose to a shop air pressure regulator. Adjust the air pressure as specified in Table 4. Temporarily close off the air supply to let the air pressure gauge return to zero.
4. Gradually apply shop air pressure to achieve the air pressure indicated in Table 4. Record the reading on the dial indicator.
5. If the reading does not meet specifications, the wastegate actuator must be replaced.

Assembly (Standard Torque Only)

Install Turbocharger Pedestal

NOTE: Late 1997 Model Year, the turbocharger and pedestal are removed from the crankcase as an assembly. 1998 Model Years and up, the pedestal and turbocharger are removed separately.

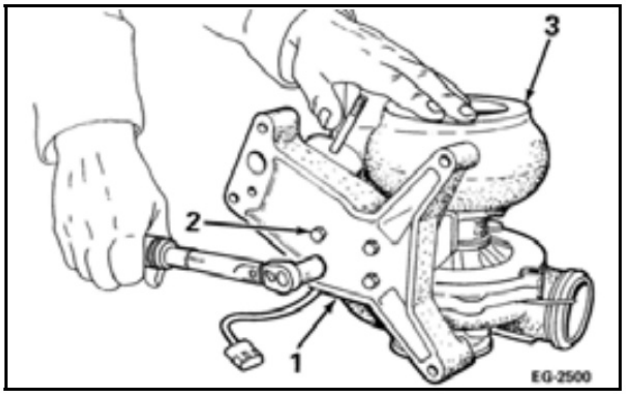

Figure 64 Attaching the Turbocharger to the Pedestal (Late 1997 Model Year Shown)

1. Turbocharger Pedestal
2. Pedestal Mounting Bolts
3. Turbocharger

1. If removed, install the solenoid valve and tighten the mounting bolt.
2. Lubricate and install new oil supply and oil drain O-rings onto the pedestal.
3. Apply Never-Seez™ to the threads of the four mounting bolts. Install and tighten the mounting bolts to the special torque value.

Install EBP Control Valve

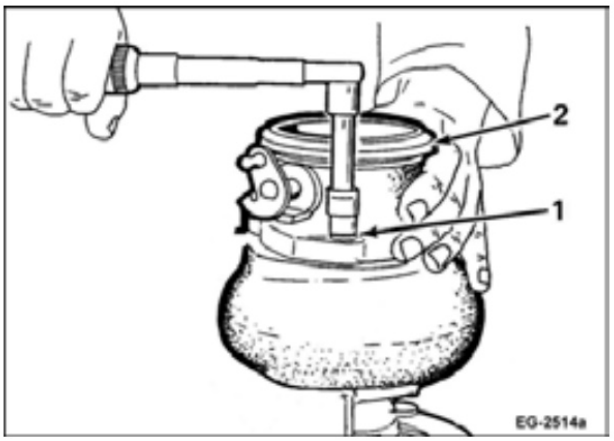

Figure 65 Installing EBP Control Valve (Late 1997 Model Year Shown)

1. EBP Control Valve Housing Bolts
2. EBP Control Valve Housing

1. Align the bolt holes of the EBP control valve housing and turbine housing.
2. Apply Never-Seez® to the threads of the EBP control valve mounting bolts. Install and tighten the mounting bolts to the special torque value.
3. Connect the EBP piston rod to the control arm.

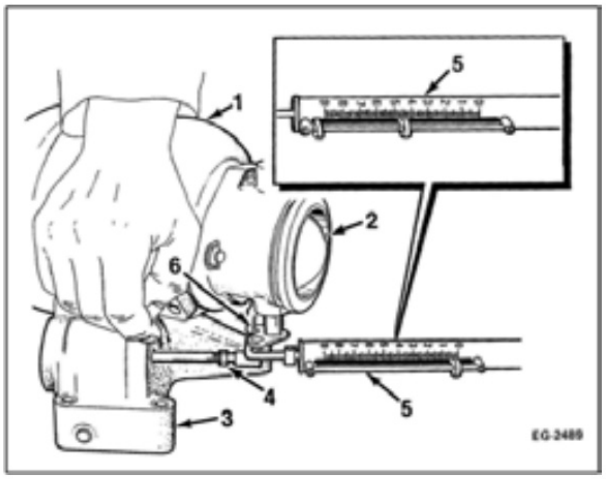

Figure 66 Testing Control Rod Preload (Late 1997 Model Year Shown)

1. Turbocharger
2. EBP Control Valve
3. Turbocharger Pedestal
4. Jam Nut
5. Spring Scale Tester

4. Check the EBP piston rod preload on a workbench as follows:
   a. Temporarily install the turbocharger onto the pedestal. Install the turbocharger mounting bolts finger tight.
   b. Connect the EBP piston rod to the control arm.
   c. To determine when the EBP control valve moves, insert a 0.01 in feeler gauge between the control valve stop and the stop on the turbocharger housing.
   d. Attach a spring scale tester to the control arm and pull on the tester. When the feeler gauge falls out, take the reading on the spring scale tester.

      The reading on the spring scale tester should be 13 N (10 lbf) when the feeler gauge falls out.

   e. If the preload of the EBP piston rod does not meet this specification, shorten or lengthen the piston rod by screwing the latch end in or out. Repeat the test procedure.

f. Lock the jam nut against the latch end when the proper preload is achieved.

g. Disconnect the EBP piston rod from the control arm. Be careful not to turn the latch end of the piston rod.

h. Continue on as follows:

- **Late 1997 Model Year Only:** The turbocharger and pedestal assemby can remain assembled. Proceed on to the Installation procedure.
- **1998 Model Years and Up:** Remove the turbocharger from the pedestal.

Installation

Standard Torque Turbocharger

NOTE:

A. Use anti-seize compound on the mounting bolts and all other bolt threads used on the exhaust system to prevent high temperature corrosion.

B. The same installation procedure is used for either engines equipped with or without the exhaust bellows feature, except where indicated.

1. Pre-assemble the right and left side tube assemblies to the exhaust inlet adapter with the exhaust flange gasket (either side up) mounted between the exhaust tube flange and the exhaust inlet adapter. Torque the exhaust inlet adapter flange bolts that secure the exhaust tubes to the exhaust inlet adapter to the special torque value.

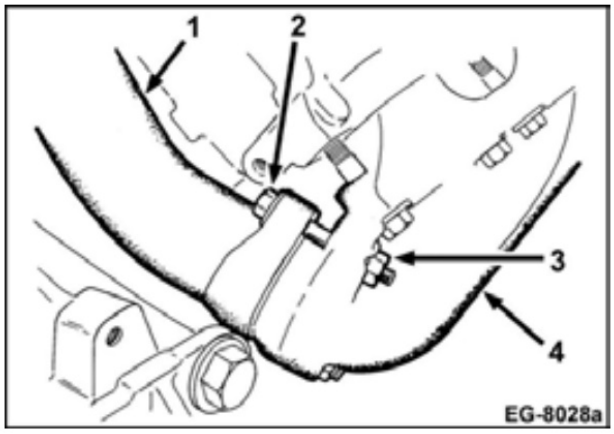

Figure 67 Installing Right Exhaust Tube Mounting Hardware at Exhaust Manifolds

1. Right Exhaust Tube
2. Exhaust Tube Bolt
3. Nut
4. Right Exhaust Manifold

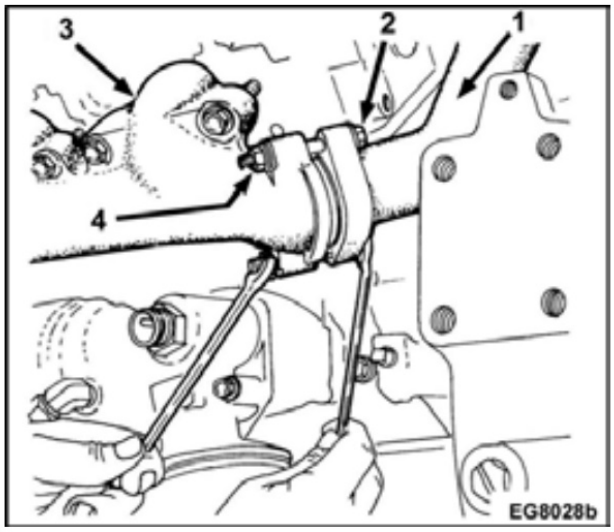

Figure 68 Installing Left Exhaust Tube Mounting Hardware at Exhaust Manifolds

1. Left Exhaust Tube
2. Exhaust Tube Bolt
3. Left Exhaust Manifold
4. Nut

2. Locate the reassembled exhaust inlet adapter and tube assembly into position and secure the exhaust tube assembly to the left and right

exhaust manifolds. Finger tighten the mounting hardware.

3. Remove all protective caps or duct tape from the turbocharger, pedestal and crankcase openings.

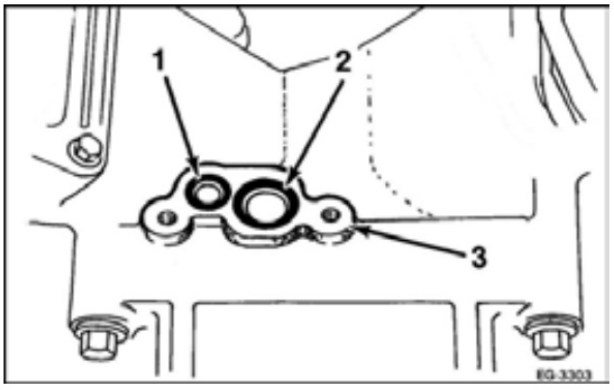

Figure 69 Turbocharger Oil Supply O-Ring and Oil Drain O-Ring

1. Oil Supply O-Ring
2. Oil Drain O-Ring
3. Turbocharger Mounting Pad

4. Apply a light coat of grease to a new oil supply O-ring and oil drain O-ring. Install the O-rings on the turbocharger mounting pad.
5. **Late 1997 Model Year Only:**
   A. Place the turbocharger and pedestal assembly onto the mounting pad.
   B. Align the pedestal mounting holes with the holes in the mounting pad.
   C. Install the pedestal mounting bolts and tighten to the special torque value.
6. **1998 and Up Model Years:**
   A. Place the pedestal on the mounting pad. Make sure the bolt holes in the pedestal are aligned with the bolt holes in the mounting pad. Install and tighten the four flange head mounting bolts to the special torque value.
   B. Apply a light coat of grease to a new oil supply O-ring and oil drain O-ring. Install the O-rings onto the pedestal.

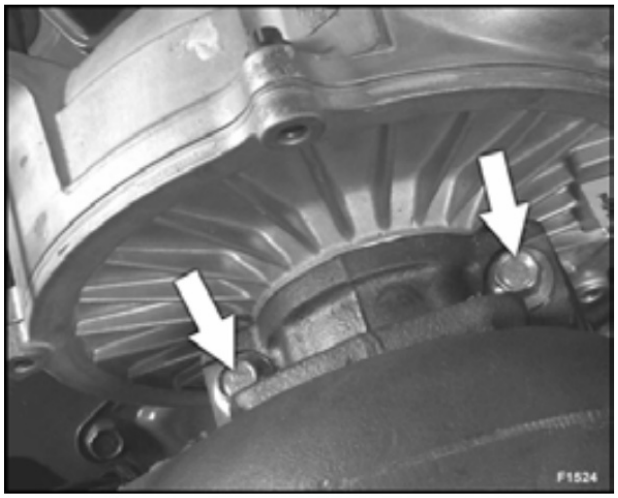

Figure 70 Installing Turbocharger To Pedestal (1998 and UP Model Years Shown)

7. **1998 and UP Model Years:**
   A. Place the turbocharger on the pedestal. Make sure the bolt holes in the turbocharger are aligned with the bolt holes in the pedestal.
   B. Install and tighten the two turbocharger mounting bolts to the special torque value.

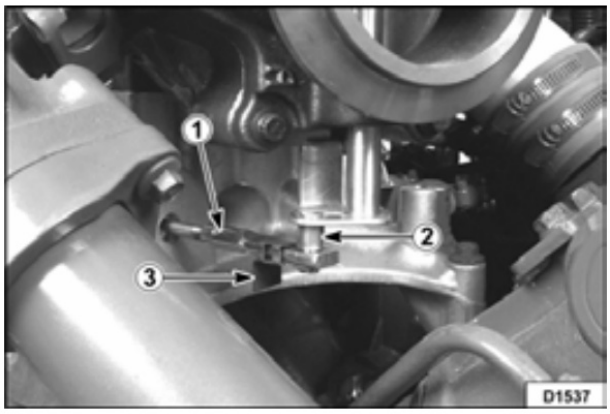

Figure 71 Connecting EBP Piston Rod (1998 and Up Model Years Shown)

1. EBP Piston Rod (Latch End)
2. Control Arm
3. Slide Lock

8. Connect the latch end of the EBP piston rod to the control arm. Move the slide lock forward to secure the latch end to the control arm.

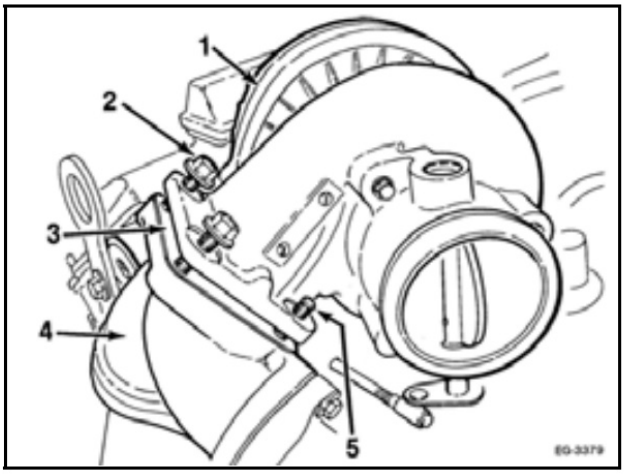

Figure 72 Installing Turbocharger To Exhaust Inlet Adapter, Late 1997 Model Year Engine Without Bellows Feature Shown)

1. Turbocharger Compressor Housing
2. Retaining Bolts (4 for engines with exhaust bellows tubes) (2 for engines without exhaust bellows tubes)
3. Gasket
4. Exhaust Inlet Adapter
5. Studs On Inlet Adapter (Used on non exhaust bellows application

9. **Late 1997 Model Year, Engines Without Exhaust Bellows Tubes:**

   A. Slide the turbocharger over the two mounting studs of the exhaust inlet adapter.

   B. Secure with two nuts and two retaining bolts. Tighten to the special torque value.

   C. Tighten the exhaust tube mounting hardware at the exhaust manifolds to the special torque value.

10. **Late 1997 Model Year, Engines With Exhaust Bellows Tubes:**

   A. Slide the turbocharger over the exhaust inlet adapter and secure with four retaining bolts. Finger tighten the bolts.

   B. Tighten the bolts to the special torque value.

   C. Tighten the exhaust tube mounting hardware at the exhaust manifolds to the special torque value.

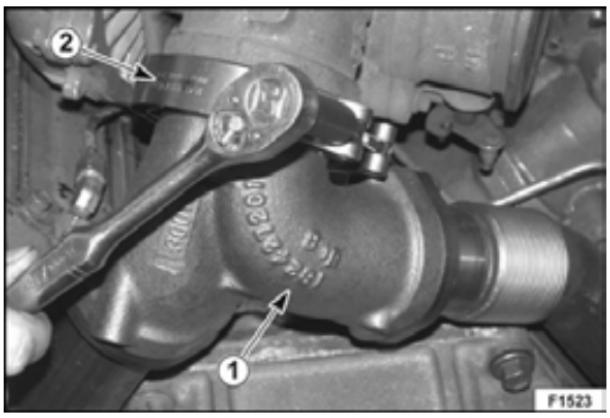

Figure 73 Installing the Exhaust Inlet Adapter to the Turbocharger (1998 and Up Model Years Shown)

1. Exhaust Inlet Adapter
2. Clamp

11. **1998 and UP Model Years:**

   A. Install the exhaust inlet adapter on the turbocharger exhaust inlet. Make sure the dowel on the adapter aligns with the hole in the lip of the exhaust inlet.

   B. Install and tighten the V-band clamp to the special torque value.

   C. Tighten the exhaust tube mounting hardware at the exhaust manifolds to the special torque value.

Figure 74 Installing the EBP Wiring Harness Connector (1998 and Up Model Years Shown)

1. Wiring Harness Clip
2. EBP Wiring Harness Connector

12. Connect the wiring harness electrical connector to the EBP solenoid.

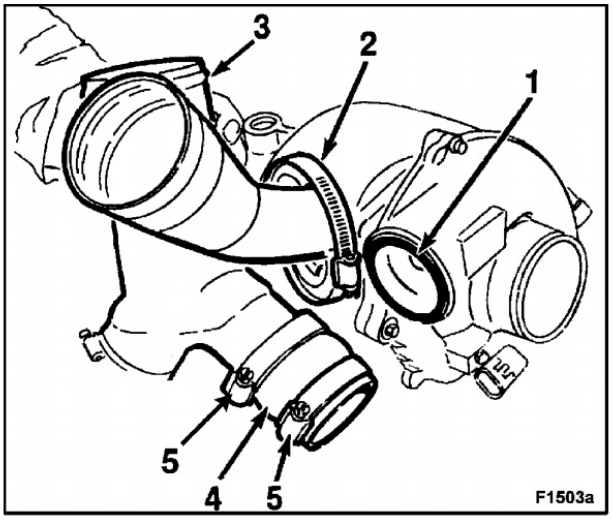

Figure 75 Installing the Charge Air Cooling Tube/Crossover Pipe Assembly

1. Turbocharger Compressor Outlet Seal
2. Turbocharger Compressor Outlet Clamp
3. Charge Air Cooling Tube/Crossover Pipe Assembly
4. Turbocharger Intake Manifold Hose (2)
5. Hose Clamp (4)

13. Remove protective caps from the air intake manifolds.
14. Lubricate a new compressor outlet seal with clean oil. Install the seal in the turbocharger compressor outlet.
15. Install the charge air cooling tube/crossover pipe assembly as follows:
    a. Install the charge air cooling tube/crossover pipe assembly to the turbocharger compressor housing and air intake hoses.
    b. To secure the charge air cooling tube to the turbocharger compressor housing, tighten the turbocharger compressor outlet clamp.
    c. Tighten the four hose clamps (two per side) to secure the hoses to the air intake manifold covers.

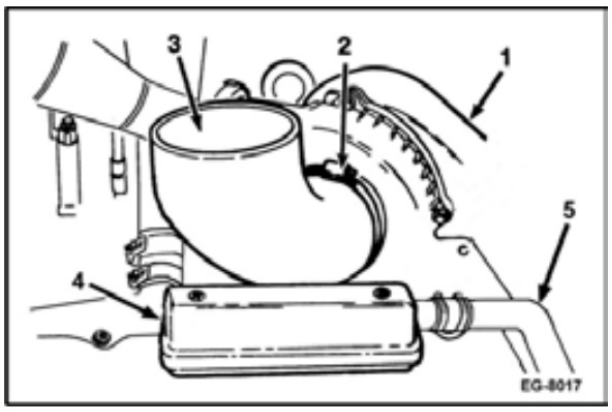

Figure 76 Installing Air Inlet Elbow

1. Turbocharger
2. Air Inlet Elbow Clamp
3. Air Inlet Elbow
4. Crankcase Breather
5. Road Draft Tube

16. Install the air inlet elbow. Tighten the clamp.
17. Install and secure the exhaust pipe connecting the turbocharger to the muffler.

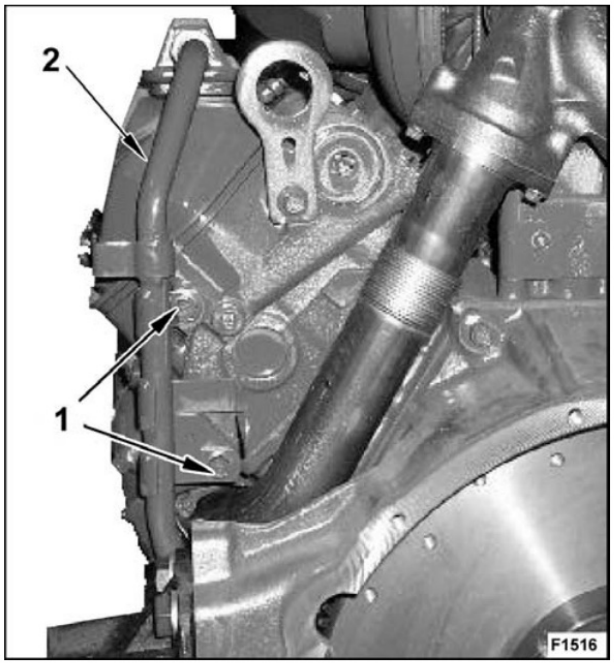

Figure 77 Install Road Draft Tube Mounting Bolts (Engine With Exhaust Bellows Feature Shown)

1. Road Draft Tube Mounting Bolt
2. Road Draft Tube

18. Move the road draft tube into the correct position.
19. Install road draft tube mounting bolts and secure to crankcase. Tighten bolts to standard torque value.

High Torque Turbocharger

NOTE: Use anti-sieze compound on the mounting bolts and all other bolt threads used on the exhaust system to prevent high temperature corrosion.

1. Pre-assemble the right and left side tube assemblies to the exhaust inlet adapter with the exhaust flange gasket (either side up) mounted between the exhaust tube flange and the exhaust inlet adapter. Torque the exhaust inlet adapter flange bolts that secure the exhaust tubes to the exhaust inlet adapter to the special torque value.

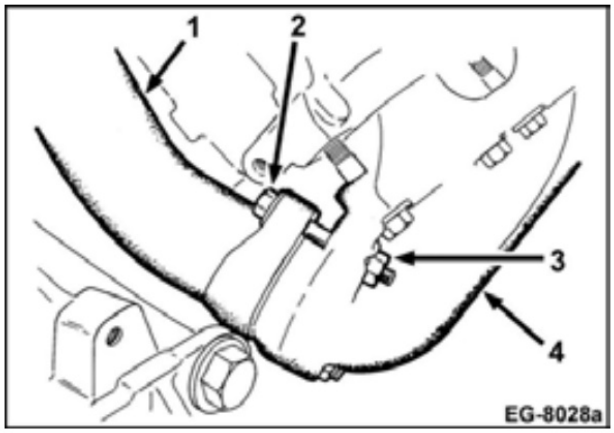

Figure 78 Turbocharger Exhaust Tube Mounting Hardware (Right Side Shown)

1. Right Exhaust Tube
2. Exhaust Tube Mounting Bolt
3. Exhaust Tube Mounting Nut
4. Right Exhaust Manifold

2. Locate the reassembled exhaust inlet adapter and tube assembly into position and secure the exhaust tube assembly to the left and right exhaust manifolds. Finger tighten the mounting hardware.
3. Remove all protective caps or duct tape from the turbocharger, pedestal and crankcase openings.

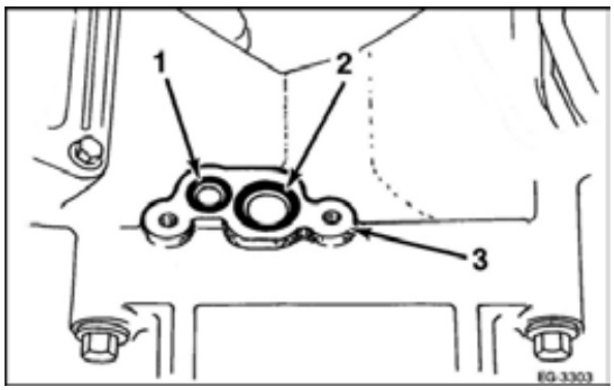

Figure 79 Turbocharger Oil Supply O-Ring and Oil Drain O-Ring

1. Oil Supply O-Ring
2. Oil Drain O-Ring
3. Turbocharger Mounting Pad

4. Apply a light coat of grease to a new oil drain O-ring and oil supply O-ring. Install the O-rings into the turbocharger mounting pad.
5. Install the turbocharger pedestal on the crankcase. Make sure the bolt holes in the pedestal align with the bolt holes in the crankcase. Install and tighten the flange head mounting bolts to the standard torque value.
6. Install new oil supply and oil drain O-rings on the top of the pedestal.
7. Align oil supply and drain ports and place turbocharger on the pedestal. Install the two mounting bolts and tighten them to the special torque valve.
8. Install the seal and align the exhaust inlet adapter with the turbine inlet. Install the V-band clamp and tighten to the special torque value.
9. Tighten the exhaust tube mounting hardware at the exhaust manifolds to the special torque value.

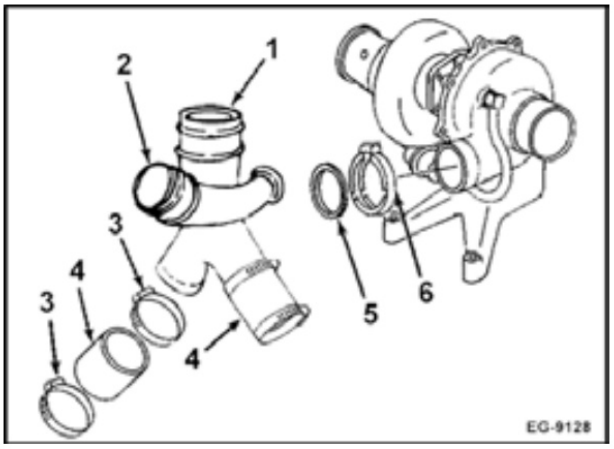

Figure 80 Installing Charge Air Cooling Tube/Crossover Pipe Assembly

1. Crossover Pipe
2. Charge Air Cooling Tube
3. Hose Clamps (4)
4. Turbocharger Intake Manifold Hoses (2)
5. Turbocharger Compressor Outlet Seal
6. Turbocharger Compressor Outlet Clamp

10. Use clean engine oil to lubricate a new turbocharger compressor outlet seal. Install the seal into the compressor housing.
11. Install the charge air cooling tube/crossover pipe assembly as follows:
    a. Install the charge air cooling tube/crossover pipe assembly to the turbocharger compressor housing and intake manifold hoses.
    b. To secure the charge air cooling tube to the turbocharger compressor housing, tighten the turbocharger compressor outlet clamp.
    c. Tighten the four hose clamps (two per side) to secure the intake manifold hoses to the air intake manifold covers.
12. Install the air inlet elbow and clamp. Tighten the clamp.

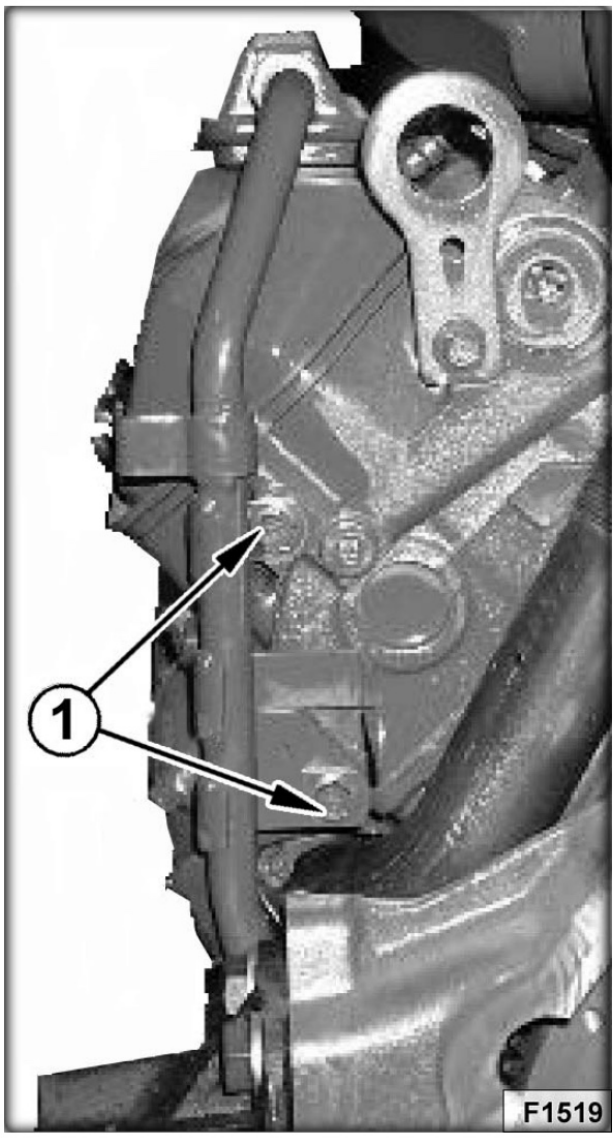

Figure 81 Installing Road Draft Tube

1. Road Draft Tube Mounting Bolts

13. Place the road draft tube into the correct position.
14. Install the road draft tube mounting bolts in the crankcase. Tighten the bolts to the standard torque value.

SPECIFICATIONS

Table 4 Turbocharger Specifications

EBP Control Rod Spring Preload	13.5 ± 3 N (10 ± 2 lbf)
Turbine Shaft Axial End Play	0.02 - 0.10 mm (0.001 - 0.004 in)
Turbine Shaft Radial Movement (Play)	0.08 - 0.15 mm (0.003 - 0.006 in)
Wastegate Actuator Movement (Standard Torque Model)	1.016 mm @ 101.35 ± 3.45 kPa (0.04 in @ 14.7 ± 0.5 psi)
Wastegate Actuator Movement (High Torque Model)	0.369 mm @ 131 kPa (0.015 in @ 19 psi)

Special Torque

Table 5 Turbocharger Special Torques

Air Inlet Hose Clamps	4 N·m (36 lbf·in)
Compressor Outlet Clamp	2 N·m (19 lbf·in)
Exhaust Back Pressure Valve to Turbine Housing Mounting Bolts	21-24 N·m (15-18 lbf·ft)
Exhaust Inlet Clamp	12 N·m (9 lbf·ft)
Exhaust Tube to Exhaust Inlet Adapter Flange Bolts	28 N·m (21 lbf·ft)
Exhaust Tube to Exhaust Manifold Flange Bolts	26 N·m (19 lbf·ft)
Intake Manifold Hose Clamps	3 N·m (30 lbf-in)
Turbocharger Pedestal to Crankcase Mounting Bolts	24 N·m (18 lbf·ft)
Turbocharger to Pedestal Mounting Bolts (Standard Torque Model)	47–51 N·m (34–37 lbf·ft)
Turbocharger to Pedestal Mounting Bolts (High Torque Model)	49 N·m (36 lbf·ft)

SPECIAL SERVICE TOOLS

Table 6 Turbocharger Special Service Tools

OEM1028	Dial Indicator with Magnetic Base
ZTSE4293	Turbocharger Intake Shield
ZTSE4296	Turbocharger Intake Cap Set
ZTSE4230	Spring Tension Scale 0–34 N·m (0-25 lbf)

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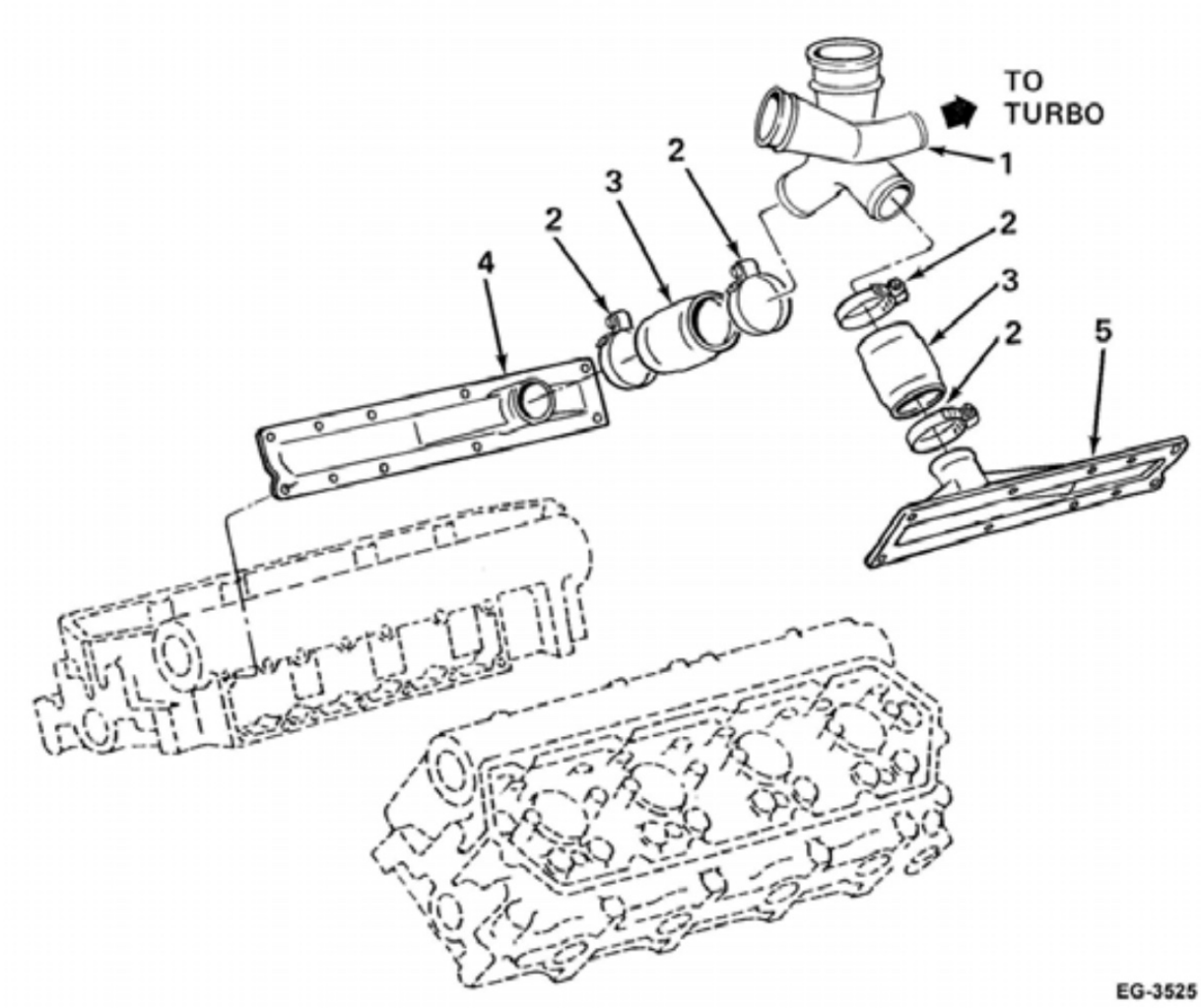

Figure 82 Intake Manifold Component Locations

1. Turbocharger Charge Air Manifold (Crossover Pipe)
2. Hose Clamp (4)
3. Turbocharger Manifold Hose (2)
4. Right Air Intake Cover
5. Left Air Intake Cover

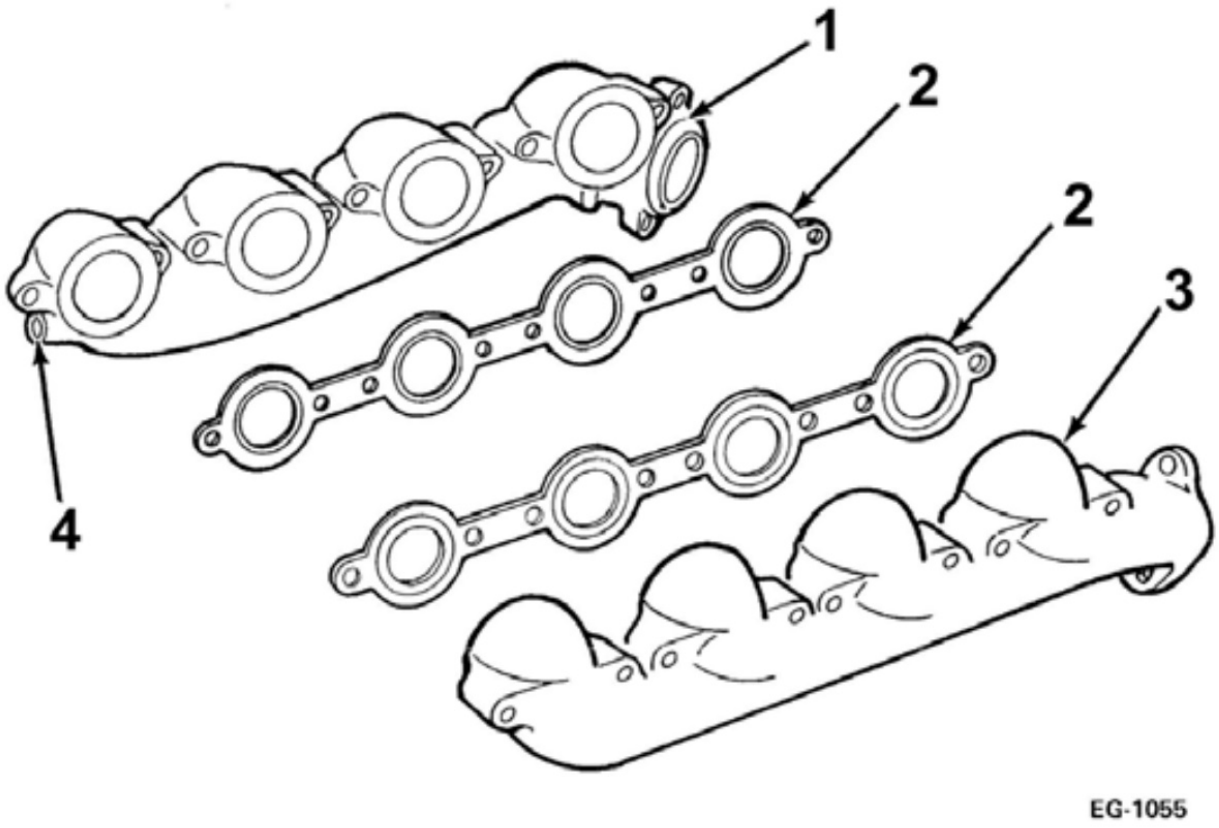

Figure 83 Exhaust Manifold Components

1. Exhaust Manifold (Right)
2. Exhaust Manifold Gasket (For Service Only)
3. Exhaust Manifold (Left)
4. EBP Tube Access Hole

Removal

Left Exhaust Manifold

1. Remove two bolts securing turbocharger exhaust tube to exhaust manifold.

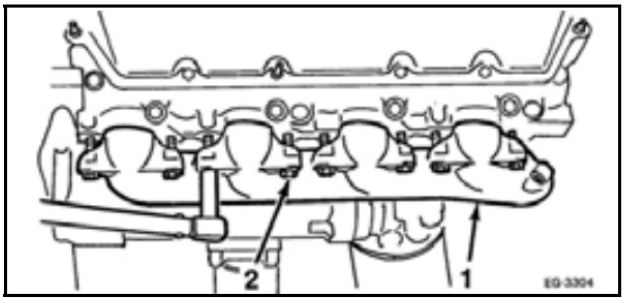

Figure 84 Removing the Left Exhaust Manifold

1. Exhaust Manifold
2. Mounting Bolts

2. Remove eight mounting bolts securing exhaust manifold to cylinder head. Remove exhaust manifold and gasket, if equipped.

Right Exhaust Manifold

1. Remove two bolts securing turbocharger exhaust tube to exhaust manifold.

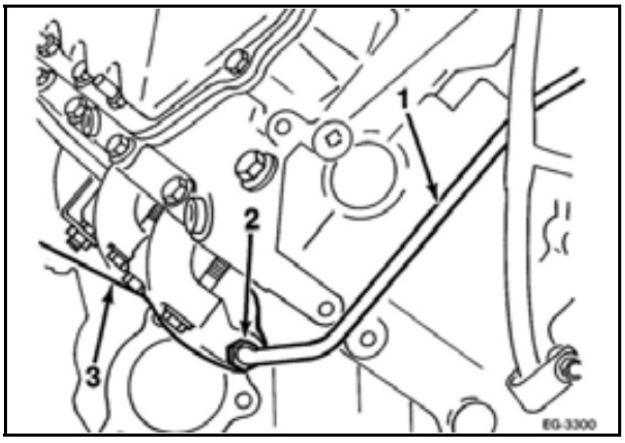

Figure 85 Removing the EBP Sensor Tube

1. EBP Sensor Tube
2. EBP Sensor Tube Nut
3. Exhaust Manifold

2. If equipped, loosen EBP sensor tube nut and pull tube away from exhaust manifold.

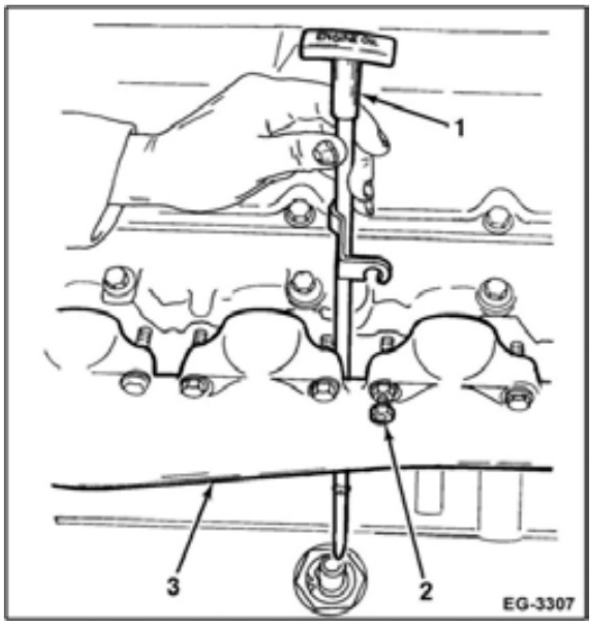

Figure 86 Removing the Oil Level Gauge

1. Oil Level Gauge
2. Nut
3. Right Exhaust Manifold

3. Remove nut securing oil level gauge bracket to stud bolt. Remove oil level gauge.

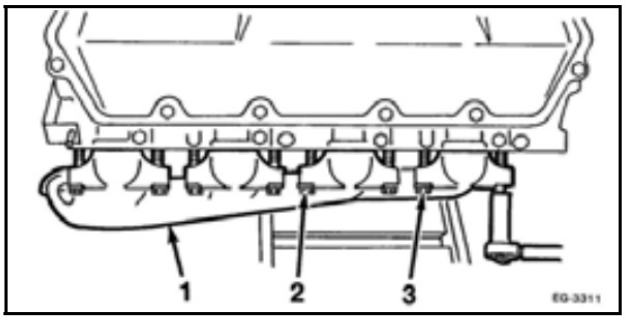

Figure 87 Removing the Right Exhaust Manifold

1. Exhaust Manifold
2. Mounting Stud Bolt (1)
3. Mounting Bolt (7)

4. Remove seven mounting bolts and one stud bolt that secure exhaust manifold to cylinder head. Remove exhaust manifold and gasket, if equipped.

Left Intake Manifold Cover

NOTE: When removing the left or right intake manifold cover be sure to do the following steps:

- Loosen compressor outlet clamp on charge air cooling and crossover pipe.
- Loosen the four turbocharger manifold hose clamps on the left and right intake manifolds and slide turbocharger manifold hoses away from manifold cover inlets.
- Remove charge air cooling and crossover pipe and turbocharger manifold hoses as an assembly.
- Remove turbocharger compressor outlet seal from turbocharger.

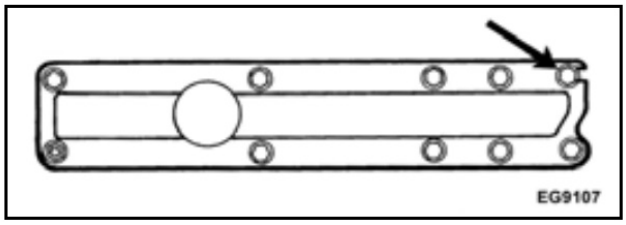

Figure 88 Left Intake Manifold Cover Bolts

1. Remove ten bolts securing intake manifold cover to cylinder head.
2. Using a RTV sealant cutting tool, cut around intake manifold cover.
3. Remove intake manifold cover from cylinder head.

Right Intake Manifold Cover

NOTE: If it is necessary to disconnect and remove the fuel filter, refer to “Fuel Filter Piping”, in the Fuel System section.

1. Remove three bolts securing the fuel filter mounting bracket to the manifold cover.

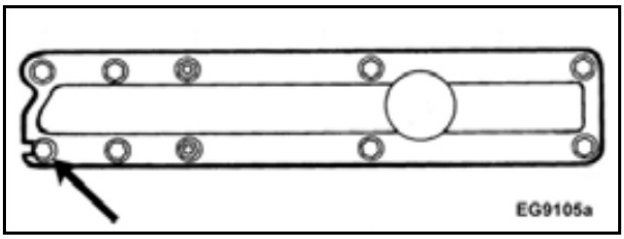

Figure 89 Right Intake Manifold Cover Slotted Bolt Hole

2. Loosen but do not remove last bolt at the slotted bolt hole.
3. Loosen and remove remaining intake manifold cover bolts.
4. Using a RTV sealant cutting tool, cut around the intake manifold cover.
5. Slide intake manifold cover off cylinder head.

Cleaning

NOTE: Be sure to clean all RTV sealant from cylinder head and manifold cover.

Manifolds may be cleaned with a suitable non-caustic solvent or steam cleaned.

Inspection

Exhaust Manifold

1. Inspect cleaned exhaust manifolds for cracks. Replace the exhaust manifold as required.

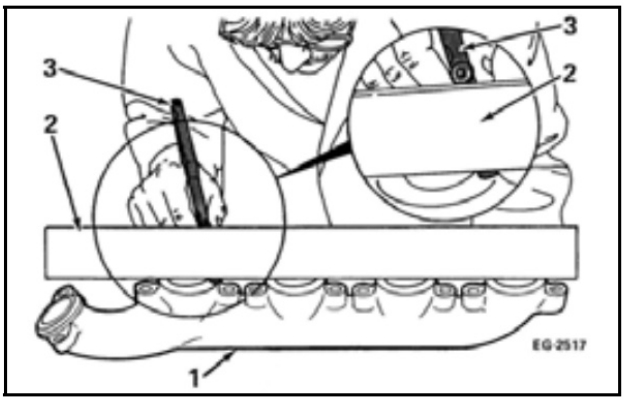

Figure 90 Inspecting Exhaust Manifold for Warpage

1. Exhaust Manifold
2. Straight Edge
3. Feeler Gauge

2. To inspect exhaust manifold for warpage, place a straight edge against mounting surface and try passing a 0.13 mm (0.005 in) feeler gauge between straight edge and mounting surface.

- If feeler gauge passes through, exhaust manifold requires a gasket. Attach a gasket to the exhaust manifold and proceed to the installation procedure.
- If a gasket was previously used on the exhaust manifold, the manifold may be machined to compensate for warpage. A maximum of 0.25 mm (0.010 in) material can be machined off to correct warpage.

Installation

NOTE: When installing exhaust manifolds, only use prevailing torque flanged-head bolts with interference thread.

Right Exhaust Manifold

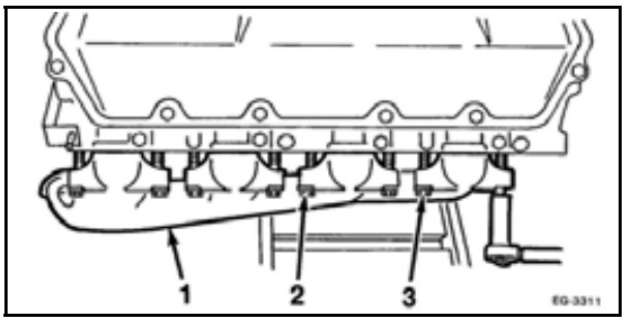

Figure 91 Installing the Right Exhaust Manifold

1. Exhaust Manifold
2. Mounting Stud Bolt (1)
3. Mounting Bolt (7)

1. Apply Never-Seez® to the threads of the bolts.
2. Install right exhaust manifold (with gasket if required). Secure with seven mounting bolts and one stud bolt. Tighten bolts in the specified sequence to the special torque value.

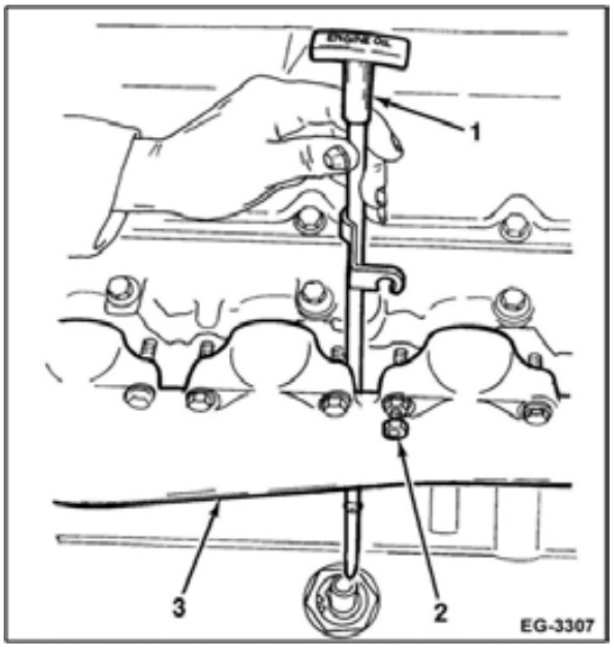

Figure 92 Installing the Oil Level Gauge

1. Oil Level Gauge
2. Nut
3. Right Exhaust Manifold

3. Install oil level gauge. Secure oil level gauge bracket to stud bolt with nut.

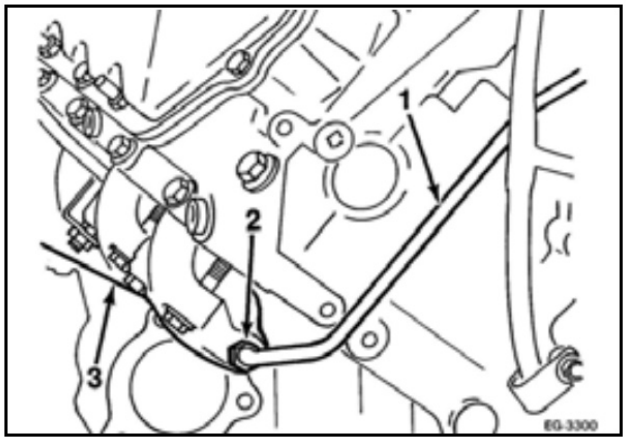

Figure 93 Installing the EBP Sensor Tube

1. EBP Sensor Tube
2. EBP Sensor Tube Nut
3. Exhaust Manifold

4. If equipped, install EBP sensor tube to exhaust manifold and tighten nut.
5. Connect exhaust manifold to turbocharger exhaust tube. Tighten bolts to the special torque value.

Left Exhaust Manifold

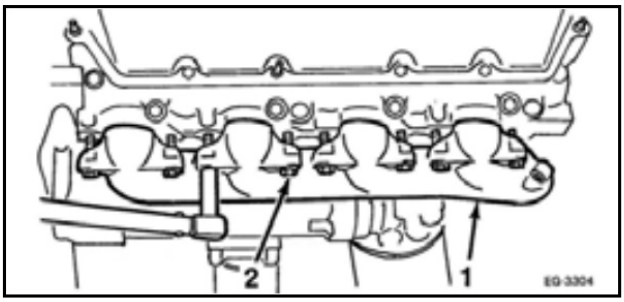

Figure 94 Installing the Left Exhaust Manifold

1. Exhaust Manifold
2. Bolt

1. Apply Never-Seez® to the threads of the manifold bolts.
2. Install exhaust manifold (with gasket, if required). Secure with eight mounting bolts. Tighten bolts in the specified sequence to the special torque value.
3. Connect exhaust manifold to the turbocharger exhaust tube. Tighten bolts to the special torque value.

Right Intake Manifold Cover

NOTE: After the left or right intake manifold covers have been installed, be sure to do the following steps:

- Inspect and if necessary replace, compressor outlet seal.
- Install the compressor outlet seal.
- Align and install charge air cooling and crossover pipe and turbocharger manifold hoses as an assembly.
- Secure charge air cooling and crossover pipe to turbocharger by tightening the compressor outlet clamp.
- Secure turbocharger manifold hoses to left, right or both intake manifold covers by tightening the four clamps (two per each hose).

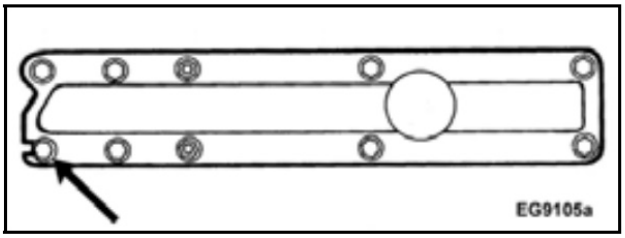

Figure 95 Right Intake Manifold Cover Bolts

1. Apply RTV sealant to mating surfaces of the intake manifold cover.
2. Install intake manifold cover onto the cylinder head. Make sure the slotted bolt hole slides under the installed bolt.
3. Place fuel filter mounting bracket onto intake manifold cover. Secure with three mounting bolts and finger tighten.

NOTE: If the fuel filter needs to be installed and connected to the fuel lines, refer to “Fuel Filter and Piping”, in the Fuel System section.

4. Install remaining manifold cover bolts and tighten all bolts in the specified sequence to the special torque value.

Left Intake Manifold Cover

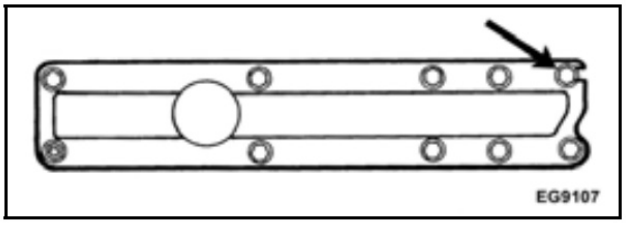

Figure 96 Left Intake Manifold Cover Bolts

1. Apply RTV sealant to mating surfaces of the intake manifold cover.
2. Install intake manifold cover onto the cylinder head. Install ten manifold cover bolts and tighten all bolts in the specified sequence to the special torque value.

SPECIFICATIONS

Table 7 Manifolds

Maximum Allowable Warpage	**Between ports:** 0.13 mm (0.005 in) **Total:** 0.25 mm (0.010 in)
Maximum Allowable Removal of Material	0.25 mm (0.010 in)

Special Torque

Table 8 Manifolds Special Torques

Intake Manifold Cover Bolts	24 N·m (18 lbf·ft)
Exhaust Manifold Mounting Bolts	61 N·m (45 lbf·ft)
Exhaust Manifold Flanges	28 N·m (21 lbf·ft)

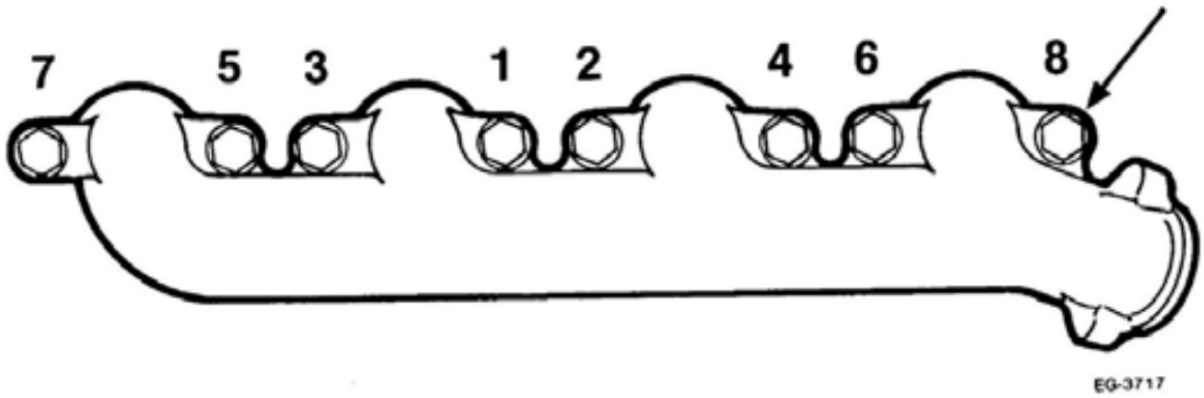

Figure 97 Exhaust Manifold Mounting Bolt Torque Sequence

1. Start all exhaust manifold mounting bolts into the holes by hand. Tighten all exhaust manifold mounting bolts to 61 N·m (45 lbf·ft) in the numerical sequence shown.
2. Tighten all exhaust manifold mounting bolts to 61 N·m (45 lbf·ft) again in an inline sequence from the rear to the front. Start at the arrow.

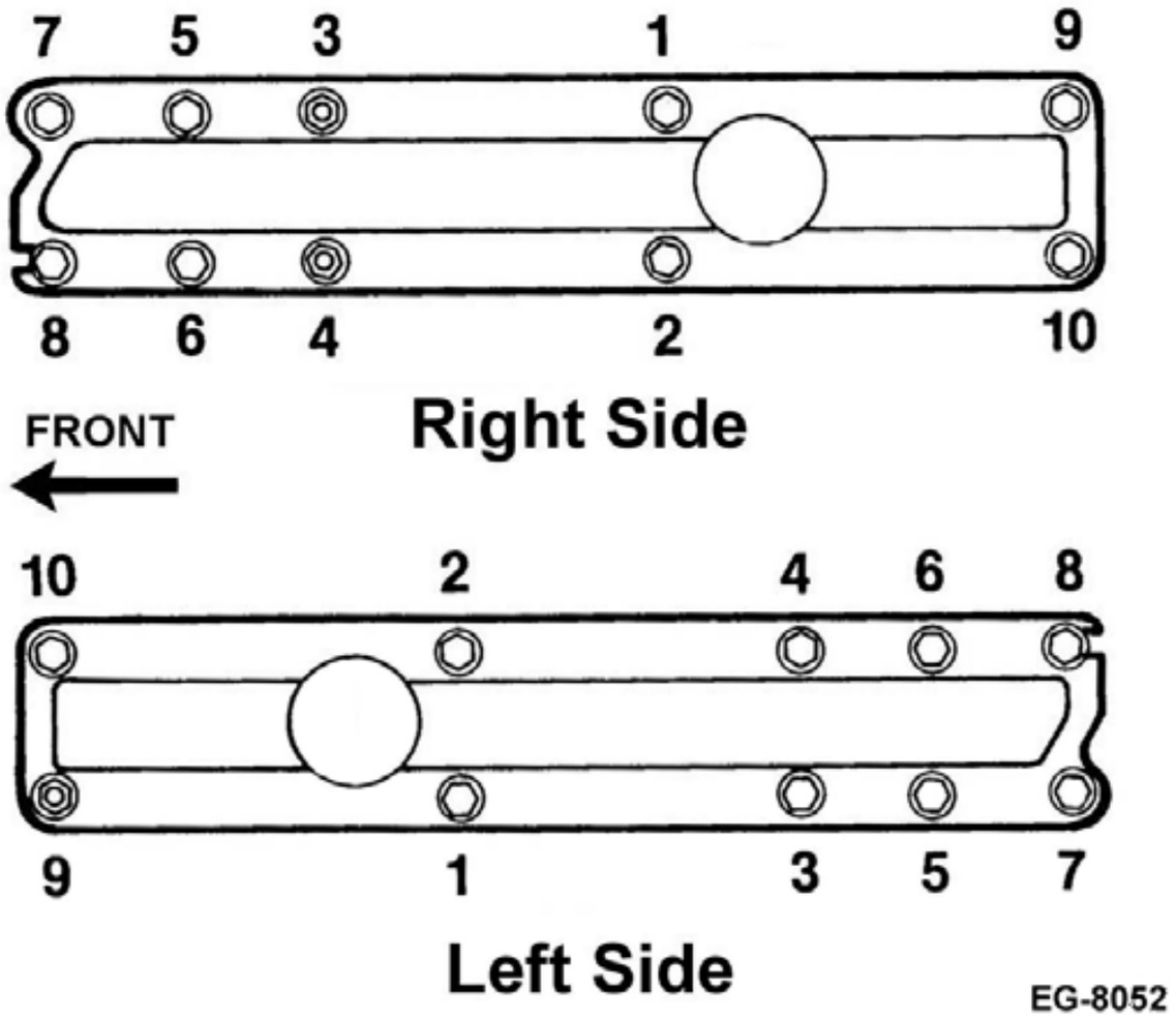

Figure 98 Intake Manifold Mounting Bolt Torque Sequence

Start all intake manifold mounting bolts into the holes by hand. Tighten the mounting bolts to 24 N·m (18 lbf·ft) in the numerical sequence shown.

SPECIAL SERVICE TOOLS

Table 9 Manifolds Special Service Tools

OEM1028	Straightedge
ZTS4385	Intake Manifold Cover Removal Tool

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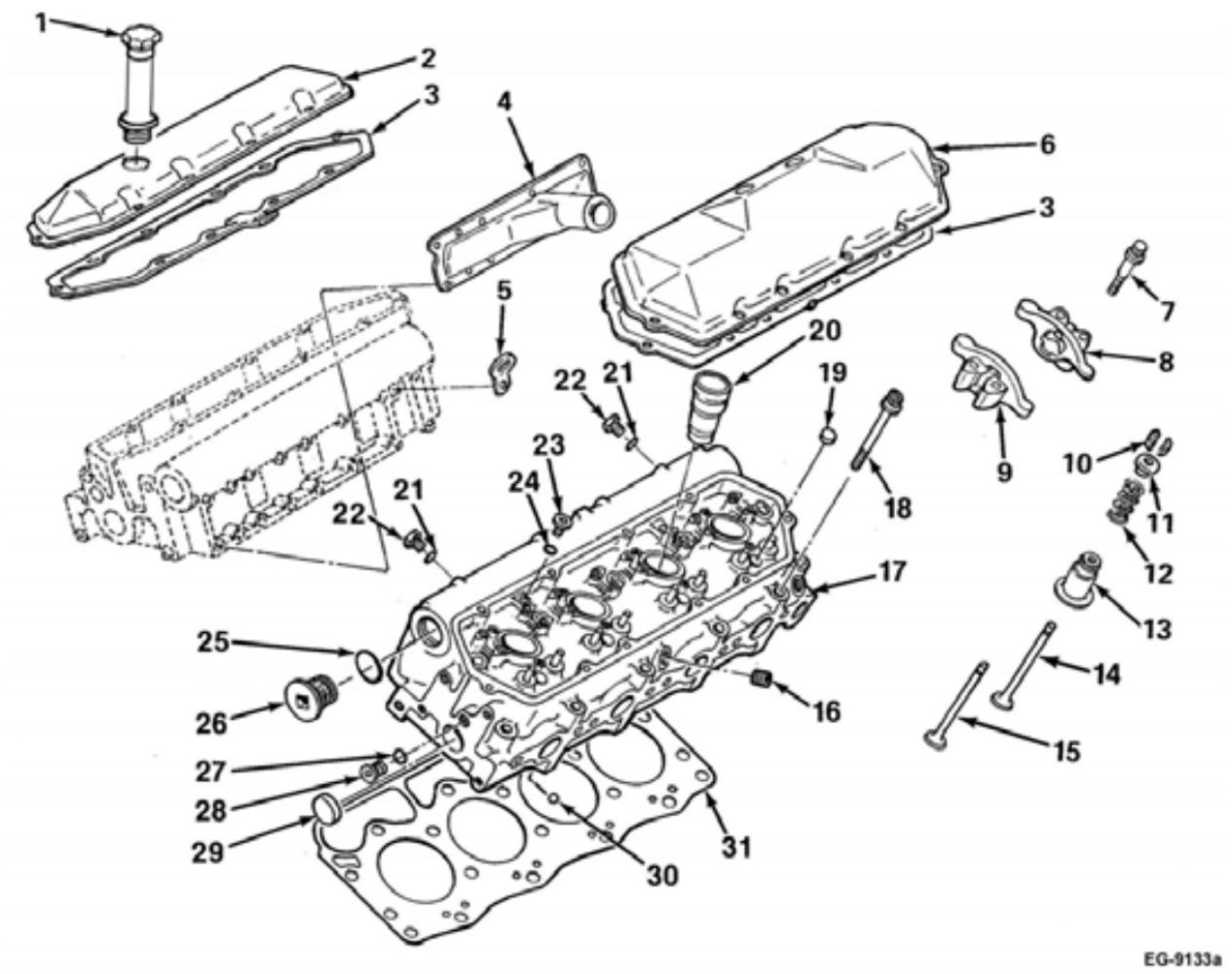

Figure 99 Exploded View of Cylinder Head, Valves and Valve Cover Components

1. Oil Filler Standpipe
2. Right Valve Cover
3. Under Valve Cover (UVC) Gasket (2)
4. Right Intake Cover
5. Lifting Eye (2)
6. Left Valve Cover
7. Valve Lever Assembly Mounting Bolt (32)
8. Intake Valve Lever Assembly (8)
9. Exhaust Valve Lever Assembly (8)
10. Valve Retainer Key (32)
11. Valve Rotator (16)
12. Valve Spring (16)
13. Valve Seal (16)
14. Intake Valve (8)
15. Exhaust Valve (8)
16. Pipe Plug (4)
17. Cylinder Head (2)
18. Cylinder Head Mounting Bolt (36)
19. Cylinder Head Plug (8)
20. Fuel Injector Sleeve (8)
21. O-Ring (6)
22. Oil Gallery Plug (6)
23. Oil Rail Drain Plug (4)
24. O-Ring (4)
25. O-Ring (4)
26. Oil Rail End Plug (4)
27. O-Ring (4)
28. Fuel Gallery Drain Plug (4)
29. Coolant Expansion Cup Plug (4)
30. Steel Ball (8)
31. Cylinder Head Gasket (2)

Cylinder Head Disassembly

Before removing the cylinder head, remove the following items. Refer to the appropriate section for the correct removal procedure:

- Fuel lines and filter assembly
- High pressure hydraulic lines
- Engine harness connections

Remove Left Valve Cover

CAUTION: To avoid damage to the engine, cover the turbocharger inlet port to eliminate induction of debris.

1. Remove the crankcase breather elbow and road draft tube.
2. Disconnect the wiring harness from the Under Valve Cover (UVC) gasket.

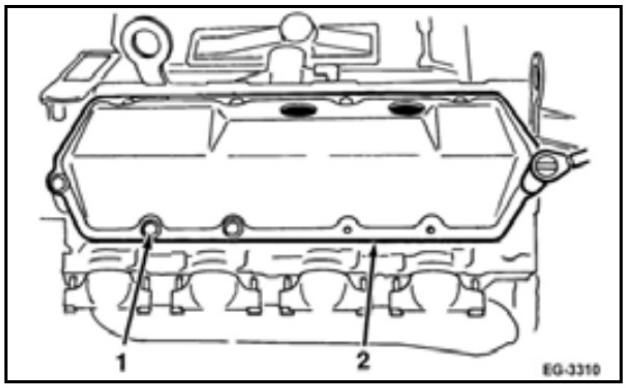

Figure 100 Removing the Left Valve Cover

1. Mounting Bolt (10)
2. Valve Cover

3. Remove valve cover mounting bolts. Remove the valve cover from the cylinder head.

NOTE: The breather does not need to be removed at this point.

Remove Right Valve Cover

1. Disconnect the wiring harness from the UVC gasket.
2. Remove the ECM and support bracket. See Engine Electrical section for the procedure.

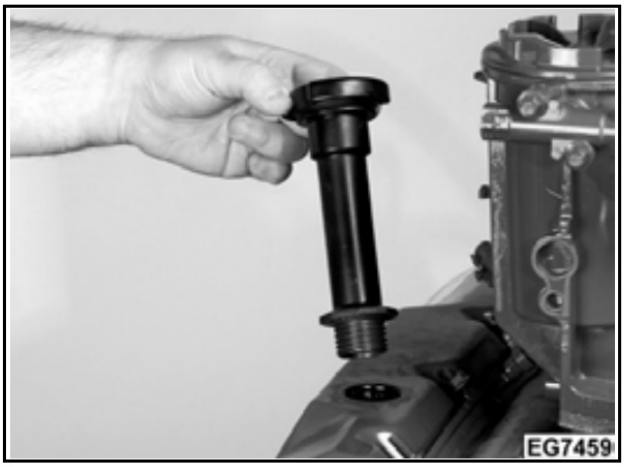

Figure 101 Removing the Oil Filler Standpipe

3. Remove the oil filler standpipe from the valve cover.

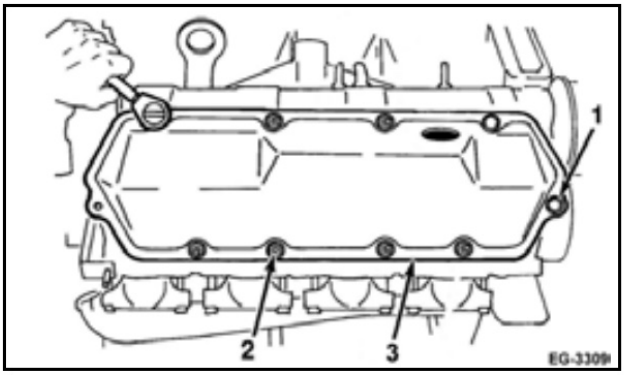

Figure 102 Removing the Right Valve Cover

1. Mounting Bolt (4)
2. Mounting Stud Bolt (6)
3. Valve Cover

4. Remove the valve cover mounting bolts. Note the location of the stud bolts. Remove the valve cover from the cylinder head.

Disconnect Under Valve Cover Harness

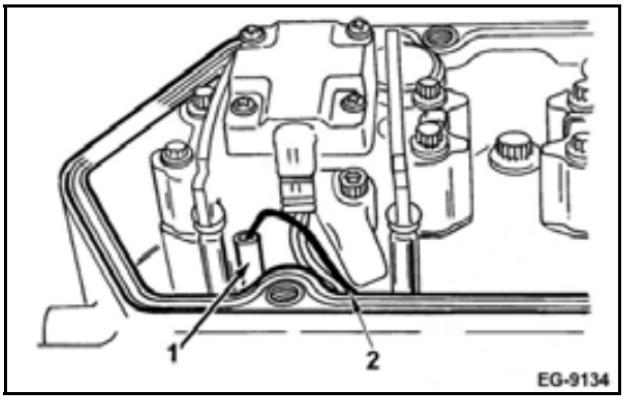

Figure 103 Glow Plug Lead Connectors

1. Glow Plug Lead
2. Glow Plug Lead Connector

CAUTION: To avoid damage to the wiring harness DO NOT pull on the wire leads when disconnecting the connectors from the glow plugs and injectors.

1. Disconnect four glow plugs by pulling the connectors away from the glow plugs. DO NOT pull on the wire leads.

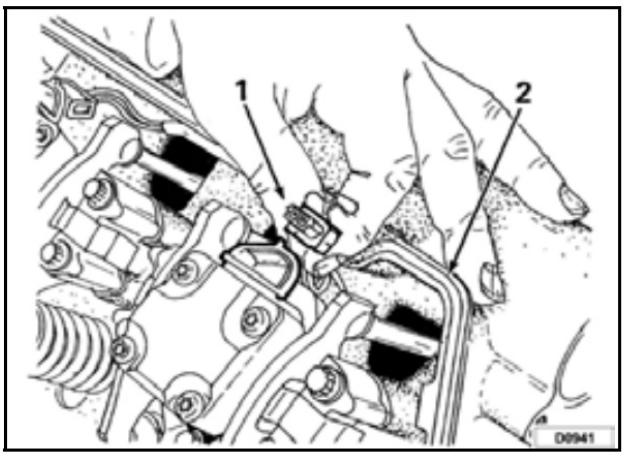

Figure 104 Disconnecting the Connector From the Fuel Injector Solenoid

1. Connector
2. Gasket Surface

2. Disconnect the solenoid connectors from the fuel injectors by pushing the metal wire bail off the solenoid and pulling the connector down.

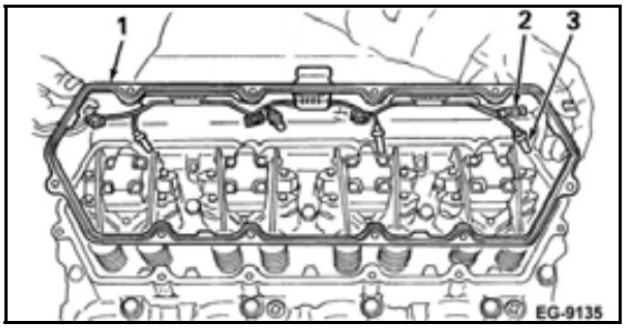

Figure 105 Removing the Valve Cover Gasket

1. Gasket With UVC Harness
2. Fuel Injector Solenoid Harness Connectors
3. Glow Plug Leads

3. Remove valve cover gasket and the UVC wiring harness from the cylinder head.

NOTE: The valve cover gasket is reusable.

Remove Glow Plug

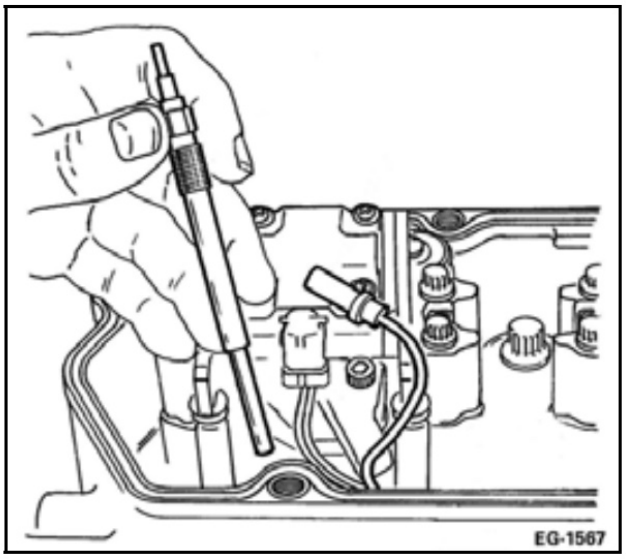

Figure 106 Removing the Glow Plug

Use a 10 mm (3/8 in.) deep socket, remove four glow plugs from each cylinder head.

Remove Oil Director Spout

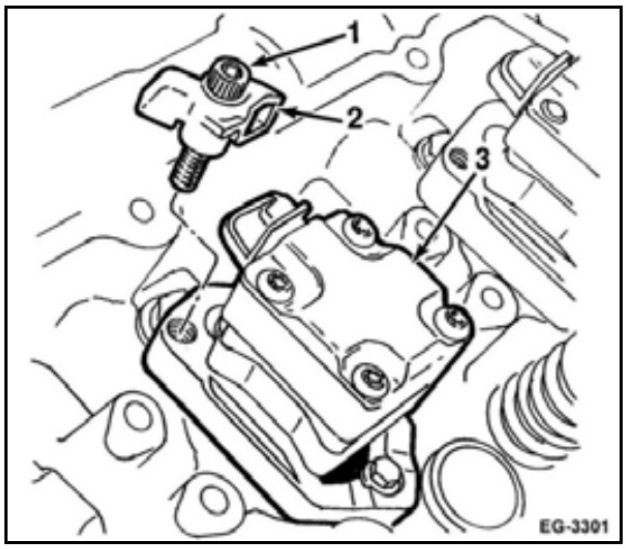

Figure 107 Removing Oil Director Spout

1. Mounting Bolt
2. Oil Director Spout
3. Fuel Injector

Remove the mounting bolt and oil director spout from each of the fuel injector hold down clamps.

Remove Valve Lever

CAUTION: To avoid engine damage, mark the location of each intake and exhaust valve lever assembly. The assemblies are different and can be installed incorrectly if not properly marked.

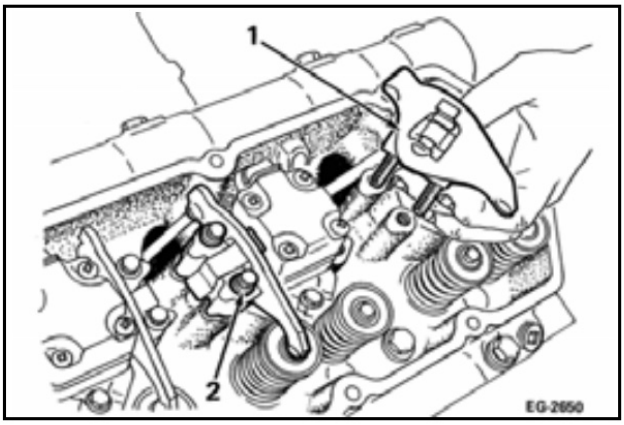

Figure 108 Removing the Valve Lever Assembly

1. Valve Lever Assembly
2. Mounting Bolt

Remove the valve lever mounting bolts. Lift the valve lever assemblies from the cylinder head.

Remove Push Rod

NOTE: BE SURE to mark each push rod so they can be installed in their original position.

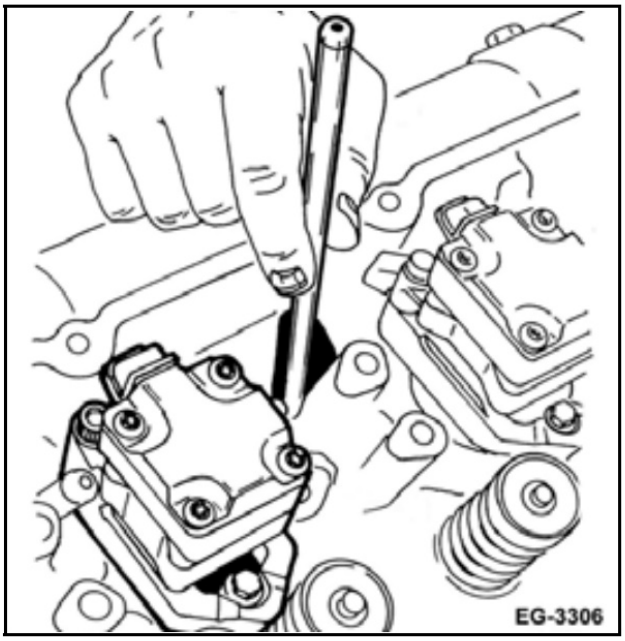

Figure 109 Removing Push Rods

Remove the push rods from the cylinder head.

Drain Fuel Gallery and Oil Rail

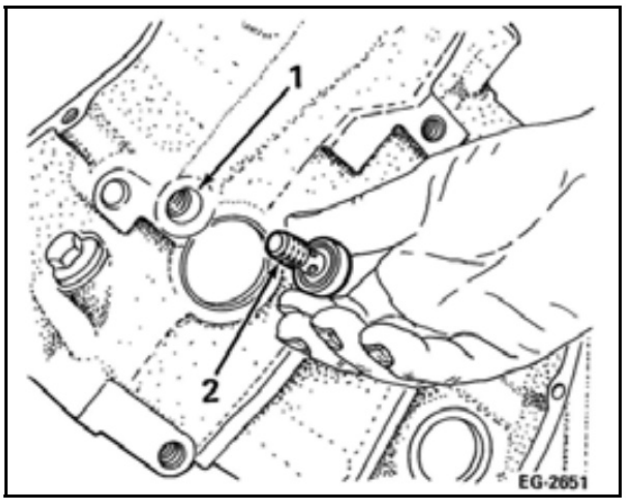

Figure 110 Front Fuel Gallery Drain Port

1. Fuel Gallery Drain Port
2. Fuel Gallery Drain Plug

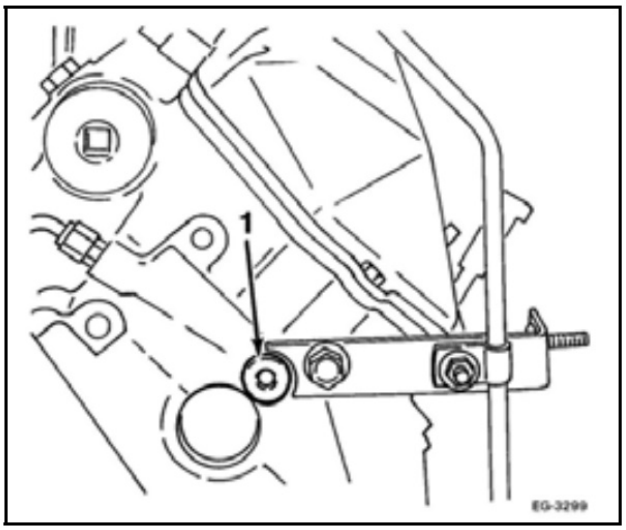

Figure 111 Rear Fuel Gallery Drain Port

1. Fuel Gallery Drain Plug

1. Drain the fuel gallery by removing the fuel gallery drain plugs located at the front and rear of the cylinder head.

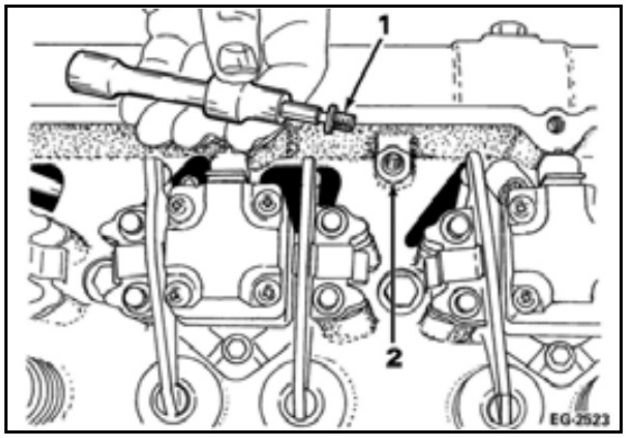

Figure 112 Oil Rail Drain Ports (two per head)

1. Oil Rail Drain Plug
2. Oil Rail Drain Port

2. Drain the oil rail by removing the oil rail drain plugs located under the valve cover in the high pressure oil rail.

Remove Fuel Injector

NOTE: Make sure the fuel rails and oil rails have been drained before removing the fuel injectors.

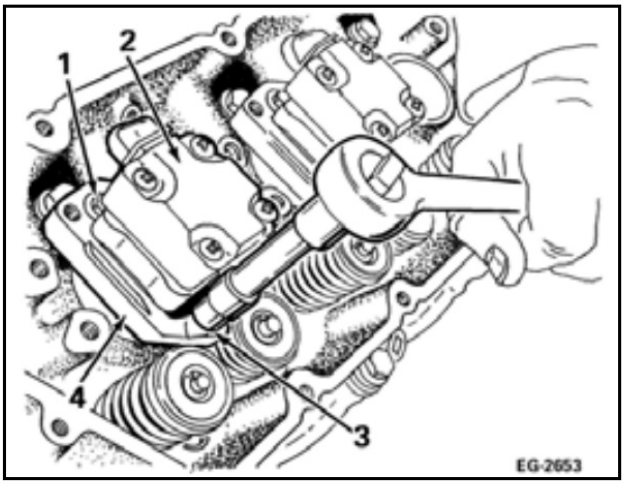

Figure 113 Removing the Mounting Bolt for the Fuel Injector Hold Down Clamp

1. Fuel Inboard Shoulder Bolt
2. Fuel Injector Solenoid
3. Mounting Bolt
4. Fuel Injector Hold Down Clamp

1. Remove all mounting bolts from the outboard (exhaust manifold side) fuel injector hold down clamps.

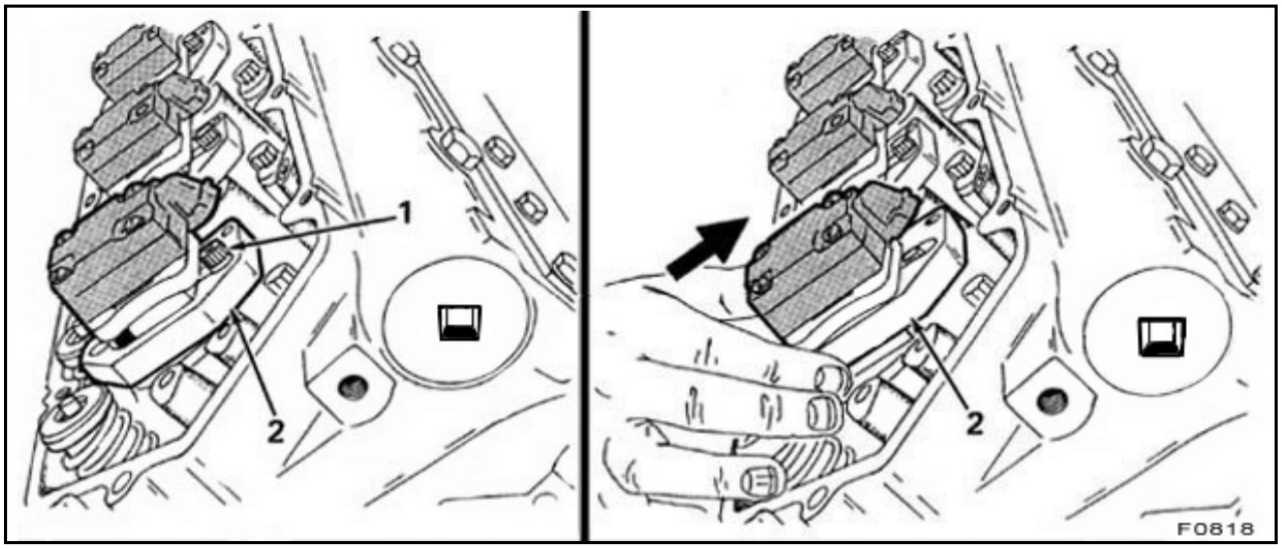

Figure 114 Disengaging the Fuel Injector Hold Down Clamp

1. Shoulder Bolt
2. Fuel Injector Hold Down Clamp

CAUTION: To prevent damage to the shoulder bolt, make sure the fuel injector hold down clamp is free of the shoulder bolt when prying up on the clamp.

NOTE: The shoulder bolts on the inboard side are not accessible and do not require removal.

2. Disengage the fuel injector hold down clamp from the inboard shoulder bolt by sliding the clamp up and away from the valve springs, then up and over the head of shoulder bolt.
3. Use a fuel injector removal tool to remove the fuel injector from the cylinder head bore. Install the "T" screw into the hold down clamp. Insert the fulcrum under the outboard side of the hold down clamp. Turn the screw until the fuel injector is unseated.

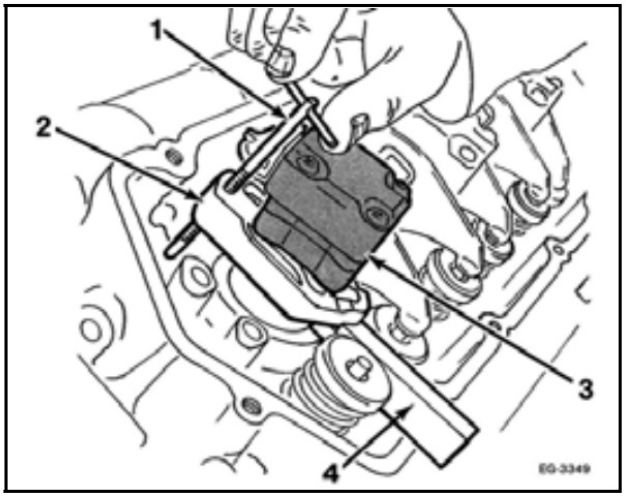

Figure 115 Installing the "T" Screw Into the Hold Down Clamp

1. "T" Screw
2. Hold Down Clamp
3. Fuel Injector
4. Fulcrum

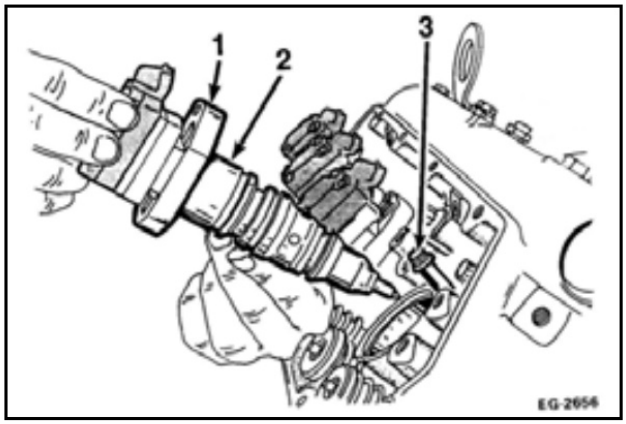

Figure 116 Removing the Fuel Injector From the Cylinder Head

1. Hold Down Clamp
2. Fuel Injector
3. Shoulder Bolt

4. Remove the fuel injector from the cylinder head bore by lifting the fuel injector straight up and out. Place the fuel injector in a fuel injector holder rack.
5. Remove the shoulder bolt (one per injector).

CAUTION: To avoid damage to the engine, always replace the O-rings and seals whenever a fuel injector is removed. Refer to the Fuel Injector O-Rings and Seals procedure in this section.

Remove EBP and ICP Sensors

NOTE: Before removing the left or right cylinder head do the following:

- RIGHT CYLINDER HEAD — Disconnect and remove the EBP sensor and tube from the right hand exhaust manifold
- LEFT CYLINDER HEAD — Disconnect and remove the ICP sensor from the cylinder head.

1. Disconnect EBP sensor from wiring harness.

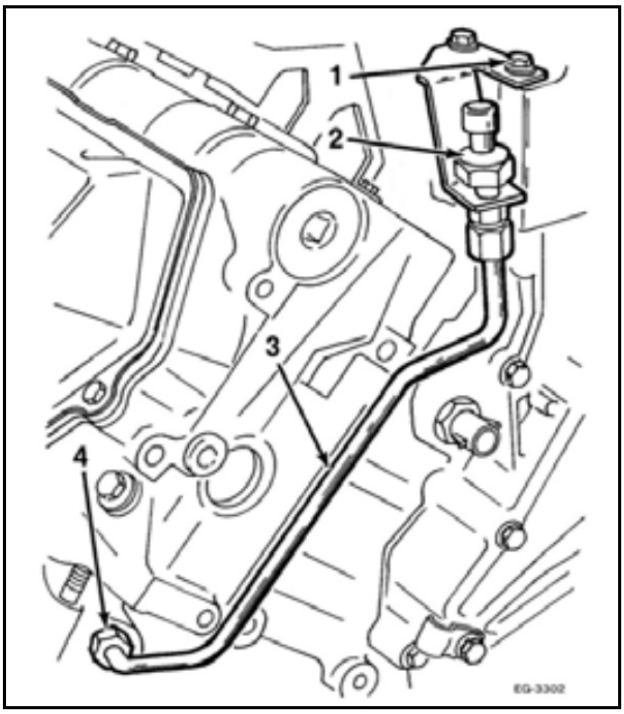

Figure 117 Removing the EBP Sensor

1. Bracket Mounting Bolt
2. EBP Sensor
3. EBP Sensor Tube
4. EBP Sensor Tube Nut

2. Loosen EBP sensor tube nut at front of right exhaust manifold. Disconnect tube from manifold.
3. Remove two mounting bolts that secure the EBP sensor bracket to the high pressure pump oil reservoir.
4. Remove EBP sensor, bracket, and tube as a unit.
5. Disconnect ICP sensor from the wiring harness.

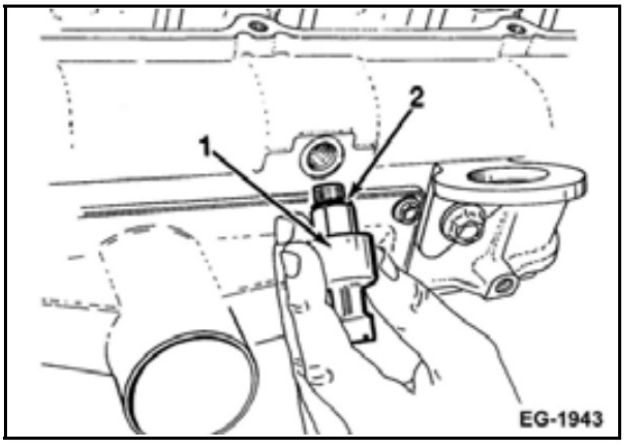

Figure 118 Removing ICP Sensor

1. ICP Sensor
2. O-Ring

6. Remove ICP sensor from left cylinder head. Discard O-ring.

Remove Cylinder Head

NOTE: Leave one mounting bolt installed at each end of the cylinder head. Remove the other mounting bolts. Cylinder head mounting bolts are flange head type that do not require washers. All cylinder head mounting bolts are the same length.

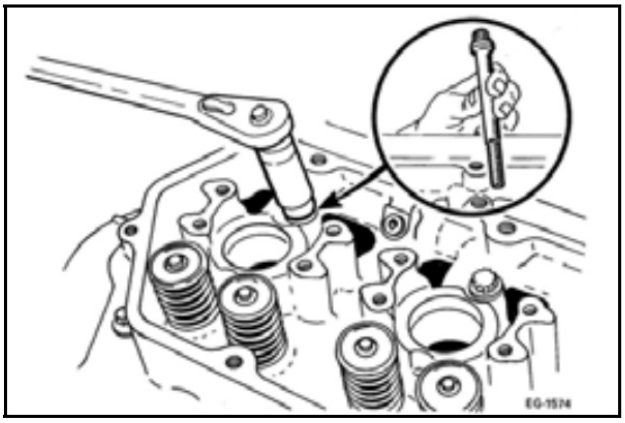

Figure 119 Removing Cylinder Head Mounting Bolts

1. Loosen the mounting bolts evenly. Begin at each end of the cylinder head and work toward the middle.

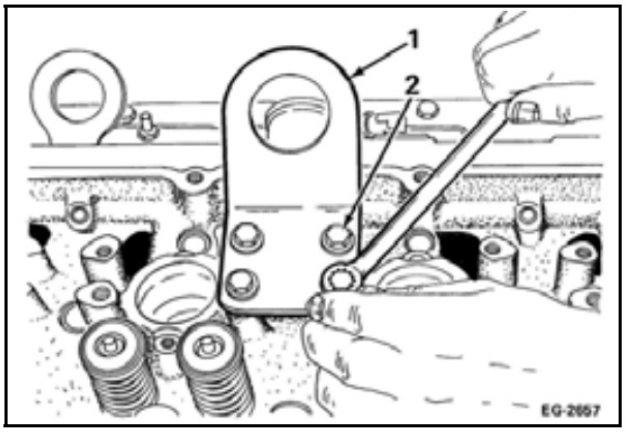

Figure 120 Attaching the Lifting Bracket

1. Lifting Bracket
2. Lifting Bracket Mounting Bolts (4)

2. Use four lifting bracket mounting bolts, secure lifting bracket to the center of the cylinder head.

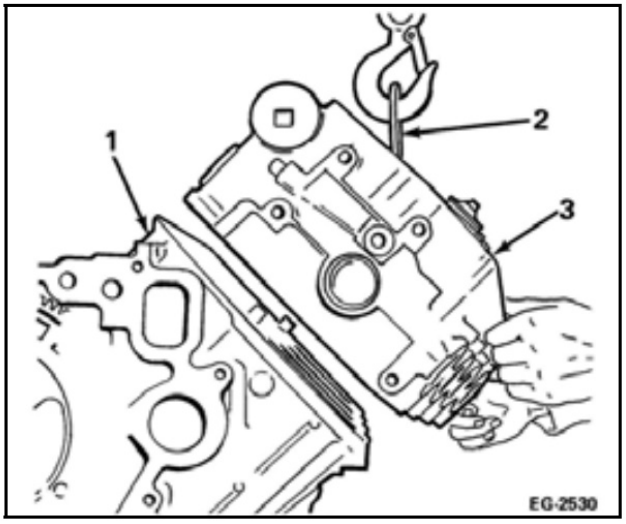

Figure 121 Removing Cylinder Head

1. Crankcase
2. Lifting Bracket
3. Cylinder Head

3. Attach a suitable lifting hook to the lifting bracket. Remove remaining two cylinder head mounting bolts.
4. Lift cylinder head squarely from the crankcase and place it on a workbench.
5. Remove cylinder head gasket.

Cleaning

Crankcase

1. Clean the crankcase to cylinder head mating surface of any gasket material, dirt, grease and any other foreign deposits.

CAUTION:

To avoid damage to the engine, clean dirt in threads or replace any damaged bolts with equivalent sized, phosphate coated bolts with a 10.9 hardness grade. Damaged threads may cause binding and result in a false torque reading.

2. Use a bottoming hand tap (M12 x 1.75) to clear the cylinder head mounting bolt threads of all grease, dirt, and other deposits.
3. Wash all cylinder head bolts with a suitable solvent and dry them thoroughly.

Cylinder Head

1. Remove lifting bracket from the cylinder head.

NOTE: When cleaning BE CAREFUL not to damage the cylinder head gasket surface.

2. With valves installed to protect the seats, use a rotary wire brush or gasket scraper with mineral spirits to remove any deposits and gasket material from the gasket surface of the cylinder head.
3. Use a suitable solvent and brush to remove any dirt, grease and other deposits from all of the bolt holes, oil return holes, water passages and fuel galleries. Rinse thoroughly with hot water and dry the cylinder heads with filtered compressed air.

Inspection

Cylinder head condition must be evaluated by checking all of the following conditions.

Check For Warp

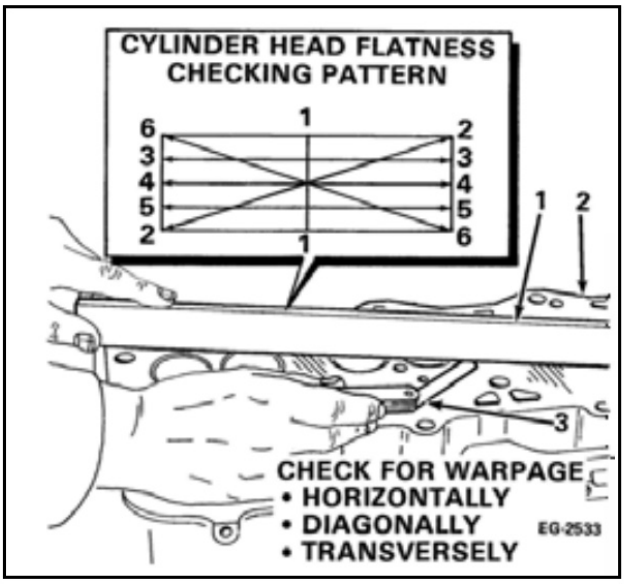

Figure 122 Checking for Cylinder Head Warp

1. Straightedge
2. Cylinder Head
3. Feeler Gauge

Use a straightedge and feeler gauge to check the cylinder head gasket surface for warp.

If specifications are not met, check thickness of the cylinder head before resurfacing. The minimum deck-to-deck dimension must be maintained after resurfacing.

Check Cylinder Head Thickness

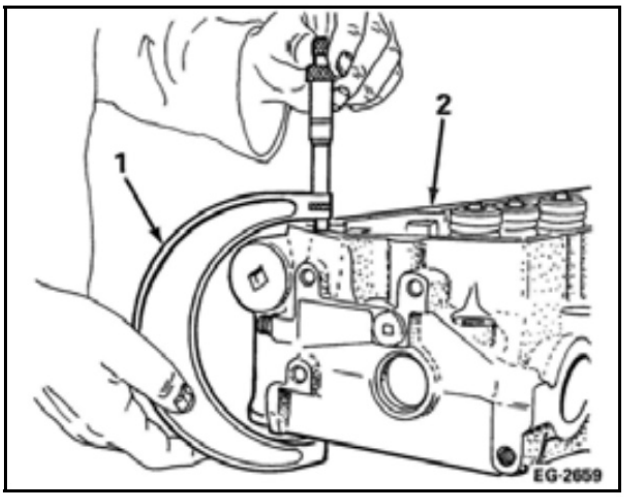

Figure 123 Checking the Cylinder Head Thickness

1. Outside Micrometer
2. Cylinder Head

1. Refer to the left and right hand intake manifold cover removal procedures, in the “MANIFOLDS” section.
2. Use a 5–6 inch outside micrometer, measure cylinder head thickness at six locations (four corners and two central points). If minimum deck-to-deck dimension is not met, replace cylinder head.

Check Valve Recession

Surface Height Gauge Method

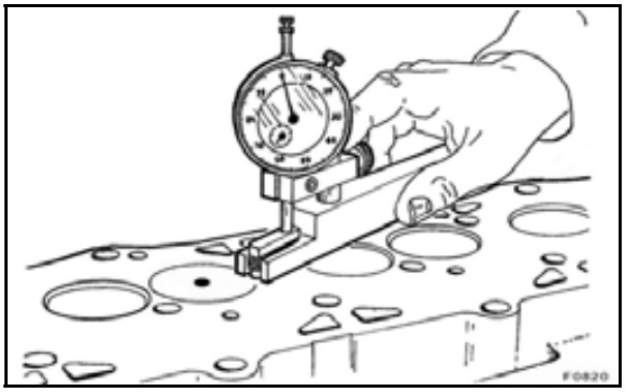

Figure 124 Checking for Valve Recession Using a Surface Height Gauge

1. Set a surface height gauge on the cylinder head deck. Zero dial indicator.
2. Move dial indicator onto the valve face. Record reading. If specification is not met, valve or cylinder head may require repair or replacement.

Straightedge and Feeler Gauge Method

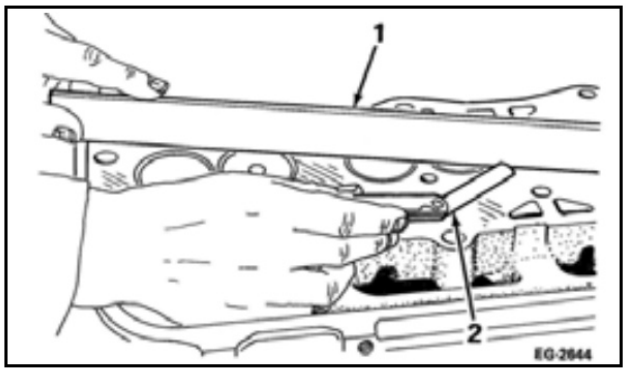

Figure 125 Checking for Valve Recession Using a Straight Edge and Feeler Gauge

1. Straightedge
2. Feeler Gauge

1. Place straightedge across valve.
2. Insert a feeler gauge of proper size between straightedge and valve face. Record reading. If specification is not met, valve or cylinder head may require repair or replacement.

Check for Valve Leakage (Using Mineral Spirits)

1. Position cylinder head on wood blocks with the gasket surface facing down.
2. Squirt mineral spirits into intake and exhaust ports.
3. Wait five minutes. Use an inspection mirror to inspect valve seat area for any indication of mineral spirits leakage.

There should be no leakage. Reconditioning is not required if the cylinder head passes this valve leakage check. If leakage is observed, the valves and seats require reconditioning.

Check for Cracks (Using Dye Penetrant)

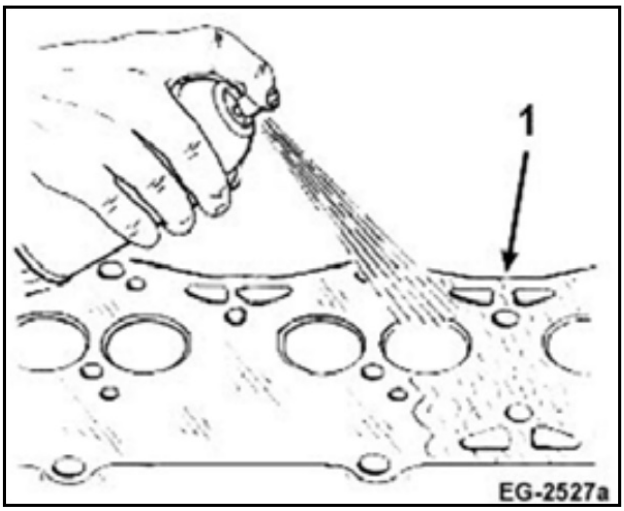

Figure 126 Checking the Cylinder Head For Cracks Using the Dye Penetrant Method

1. Gasket Surface of the Cylinder Head

1. Spray commercially available brake cleaner onto gasket surface of cylinder head. Wipe dry.
2. Spray on dye penetrant. Allow dye to remain for 1–30 minutes.
3. Wipe dye off gasket surface. Dye will remain in cracks.
4. Spray on developer. Let dry for 5–15 minutes.

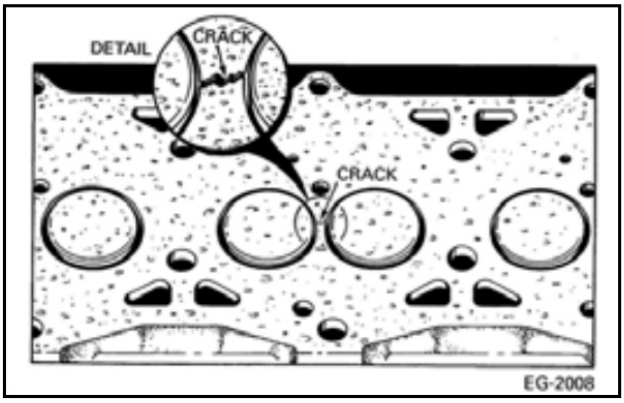

Figure 127 Crack in Cylinder Head

5. Cracks show up as purple lines against white developer. If cracks are present, replace cylinder head.

Cylinder Head Pressure Test

Pressure testing the cylinder head will reveal cracks in ports or sleeve leakage which cannot be observed using the dye penetrant method.

1. Remove the valves. Refer to **Valves, Removal** for the procedure.

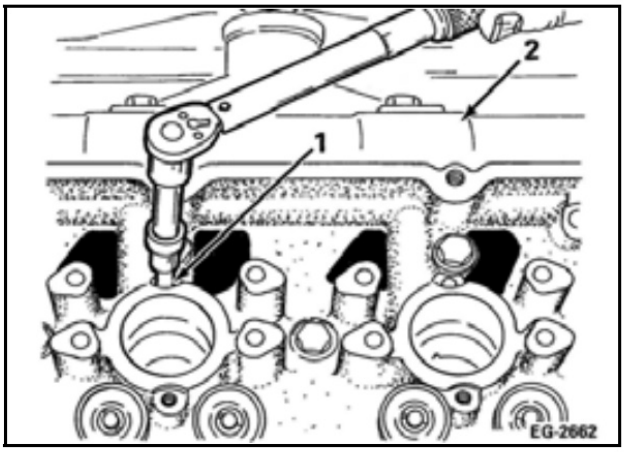

Figure 128 Installing the Fuel Injector Shoulder Bolts

1. Shoulder Bolt
2. Cylinder Head

2. If removed, install the inboard injector shoulder bolts into the cylinder head. Tighten the bolts to the special torque value

NOTE: Be careful not to damage the fuel injector tips during this procedure.

3. Install the fuel injectors into the cylinder head injector bores. Refer to **Cylinder Head Assembly, Install Fuel Injectors** for the procedure.

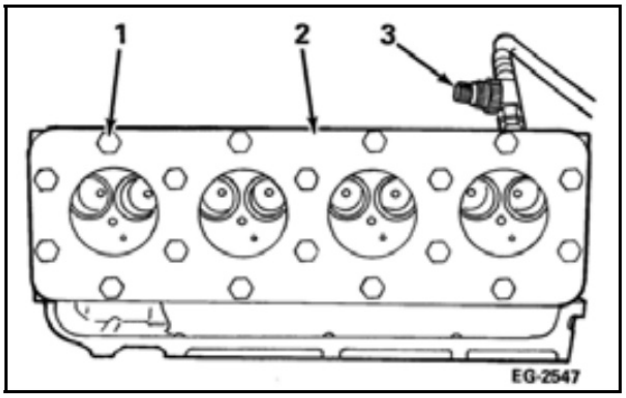

Figure 129 Installing the Cylinder Head Pressure Test Plate

1. Pressure Plate Mounting Bolts (18)
2. Pressure Plate
3. Pressure Gauge and Regulator

4. Remove the fitting or plug from the cylinder head. Install the pressure test regulator/gauge assembly.
5. Fasten the pressure plate and plate gasket to the cylinder head gasket surface with the mounting bolts and nuts supplied with the kit.
6. Spray a soapy water solution into all of the valve bores. Apply air pressure and adjust to 124-138 kPa (18-20 psi). Check for leaks at the following locations:
   - Ports
   - Upper cylinder head deck
   - Lower cylinder head deck
   - Nozzle sleeve area

CAUTION: To avoid engine damage, replace the cylinder head if leakage is observed at any port or at the upper or lower cylinder head deck.

Valves

Removal

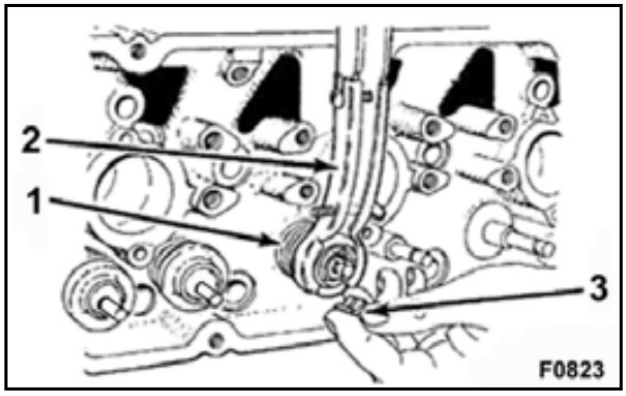

Figure 130 Removing the Valve Retainer Keys

1. Valve Spring Compressor Tool
2. Valve Spring
3. Valve Assembly Retainer Keys

1. Use a valve spring compression tool to compress the valve spring.
2. Use a small magnet to remove the valve assembly retainer keys.

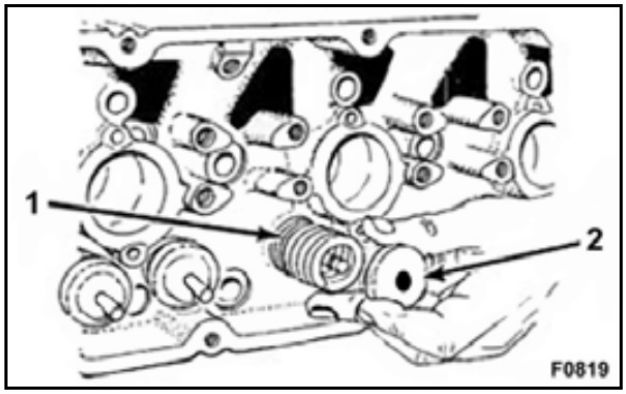

Figure 131 Removing the Valve Rotor and Spring

1. Valve Spring
2. Valve Rotator

3. Remove the valve rotator.
4. Remove the valve spring.

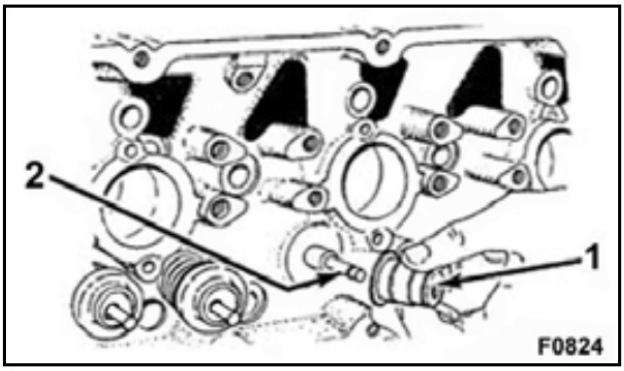

Figure 132 Removing the Valve Seal From the Valve Stem

1. Valve Seal
2. Valve Stem

5. Remove the valve seal from the valve stem and discard.
6. Remove the valve from the cylinder head.

Cleaning

Use a suitable solvent and a fine brass wire brush to remove all carbon deposits from the valve stems and valve heads.

Inspection

1. Inspect each valve. Replace any valves that show evidence of burn marks, warp, scuffing, bending or tip pitting.
2. Measure the valve stem diameter at three locations at 120° intervals. Replace any valves that do not meet the specification.
3. Use the measurements from Step 2 to determine the valve stem-to-guide running clearance. Subtract the valve stem diameter from the valve guide inside diameter. Refer to **Inspection, Valve Guides** for the procedure to determine the valve guide inside diameter. Replace the valves that exceed the specification.

Refacing

Valve Face

NOTE: Intake and exhaust valves have the same stem length and diameter. However, the exhaust valve has a dimple on the bottom of the valve.

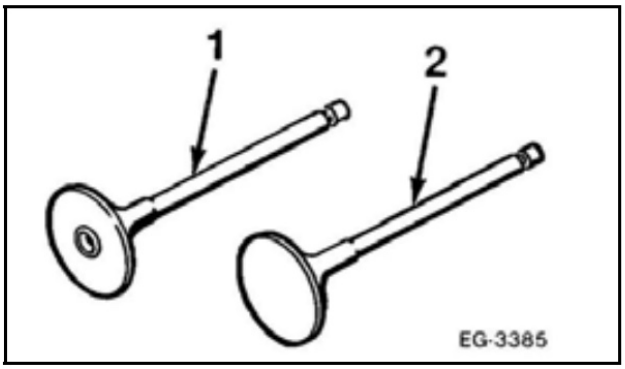

Figure 133 Intake and Exhaust Valve Comparison

1. Exhaust Valve (With Dimple)
2. Intake Valve

1. Use a dressing stud attachment or grinder to dress the cutting stone.
2. Place the valve in the grinder collet set to the specified angle. Turn on the cutting oil.

CAUTION: To avoid engine damage, the minimum valve face margin must be maintained across the entire valve face. An insufficient margin will not provide proper heat dissipation and will lead to valve warp or breakage.

NOTE: Intake and exhaust valve margins and valve face angles are different. See the Specifications for the correct measurements for each.

3. Grind the valve face. Remove only the minimum amount of material that is necessary to true the valve face. Record the amount of material removed for later reference during valve stem resurfacing.

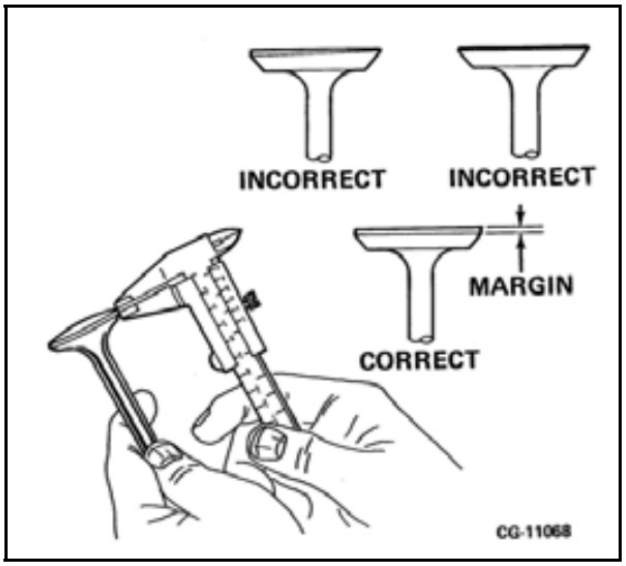

Figure 134 Measuring the Valve Face Margin

4. Use a caliper to measure the valve face margin at four locations. Replace the valve if the margin is less than the specification after grinding.

Valve Stem

NOTE: Refacing the valve stem tip provides a new wear surface for the valve lever and compensates for material that was removed during the valve refacing.

1. Dress the cutting stone by moving the dressing stud attachment across the face of the cutting stone until a uniform grinding surface is achieved.
2. Place the intake or exhaust valve into the valve stem clamping "V." Turn on the cutting oil.

CAUTION: To avoid engine damage when resurfacing the valve stem tip, leave sufficient material so the valve lever does not contact the valve spring, retainers, or rotators during operation.

3. Touch the valve stem tip to the cutting stone. Remove only a minimum amount of material. Do not remove more material than was removed at the valve face.

Valve Guides

Cleaning

With the valves removed from the cylinder head, clean all valve guides in a soap and water solution with a nylon brush. Blow out any remaining residue with filtered compressed air.

Inspection

1. Position an inspection light at the bottom of the valve guide bores and examine the walls for burning or cracking. Replace the cylinder head if it does not pass inspection.

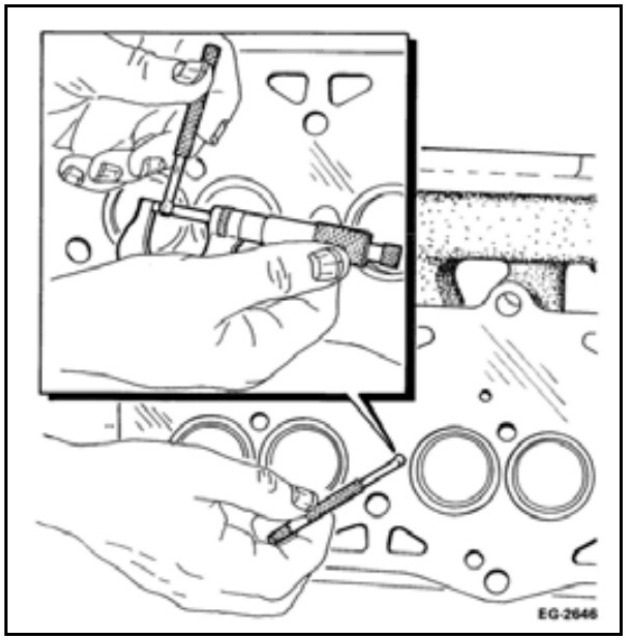

Figure 135 Measuring the Valve Guide Inside Diameter

2. Measure each valve guide for wear. Use an appropriate sized small hole gauge to check the inside diameter of the valve guide at three locations at the upper end and at the lower end. Measure the small hole gauge with a 0-1inch micrometer. Record the readings.

   If any valve guide inside diameter is over the specification, replace the cylinder head.

Valve Seats

Cleaning

Clean the valve seat area with a suitable solvent.

Inspection

Inspect the exhaust valve seats for wear or burned spots. Either of these conditions require valve seat resurfacing. If a crack is found, the cylinder head must be replaced.

Resurfacing

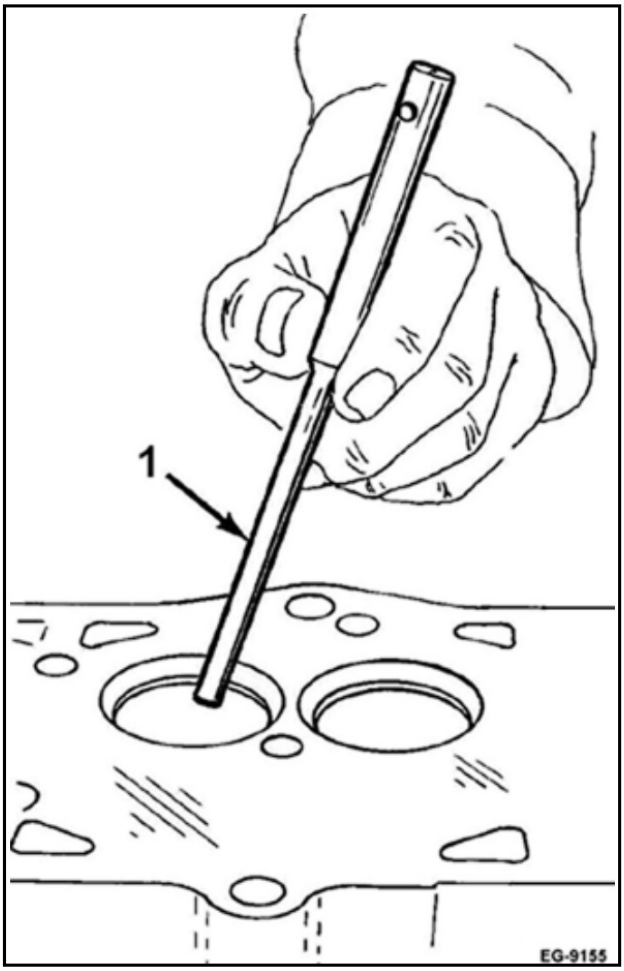

Figure 136 Installing a Pilot in the Valve Guide

1. Pilot

1. Lightly lubricate and install the correct size pilot into the valve guide bore.

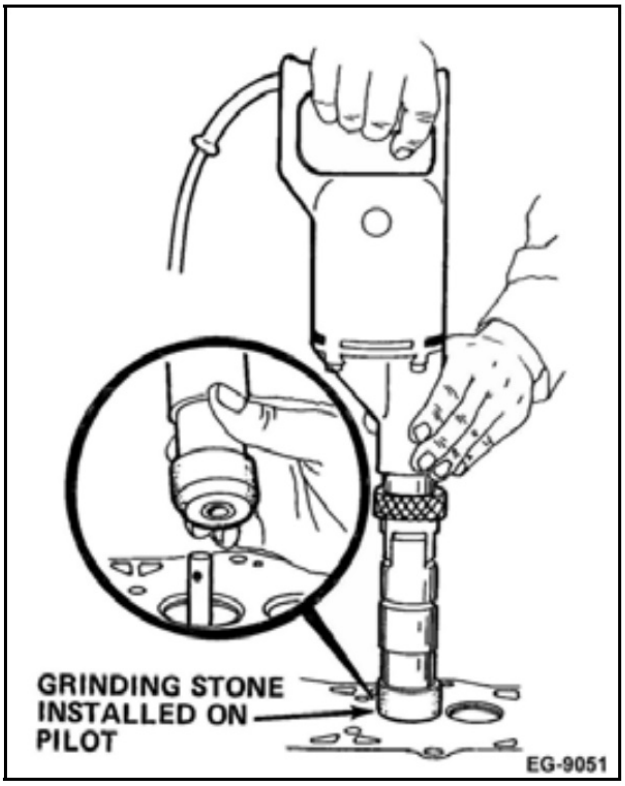

Figure 137 Using a Grinding Stone

2. Choose the correct angle grinding stone and dress the stone.
3. Install the grinding stone over the pilot.
4. Lower the grinding head over the pilot shank until the wheel contacts the valve seat. Turn on the power and gently apply the wheel to the valve seat with hardly any pressure other than weight of the grinding wheel itself.
5. Raise the wheel frequently to prevent overheating.
6. Grind the seat to a smooth even finish.
7. After grinding, use a caliper to check the width of the valve seat. If the valve seat widths are excessive, they may be corrected by grinding with a 15° or less angled stone.

NOTE: If a new valve does not correct an excessive recession condition, replace the cylinder head. If the valve face protrudes above the deck, the valve seat must be ground deeper into the cylinder head. After grinding a valve seat, check the seat width and confirm valve seat contact by using Prussian Blue™.

8. After grinding the valve seat, use a depth gauge and micrometer to check the valve recession. Valve recession should not exceed specifications.
9. After the valves have been resurfaced and the valve guides have been cleaned, insert the valves into the clean valve guide. Check the contact between the valve face and valve seat using Prussian Blue™ or equivalent as follows:
   a. Spread a thin film of Prussian Blue on the valve face. Insert the valve into its guide.
   b. Apply pressure on the center of the valve head while making a quarter turn into the valve seat.
   c. Remove the valve. Inspect the impression made on the valve seat and the valve face.
   d. A blue line should appear around the entire contact surface of the valve seat and an impression on the blue film of the valve face should be centered. Check several times to prevent error. If acceptable, proceed with valve installation.
10. For proof of results of refacing and to test seating operations, recheck the valve recession. Refer to **Inspection, Check Valve Recession** in this section.

    A poor quality grind cannot be corrected by lapping. Inspect each valve for seat dimensions and make any necessary corrections. Corrections should always be made on the seat, not the valve face. If the recession is excessive, install a new cylinder head. If the valve protrudes above the deck, grind the valve seat.

Valve Springs

Cleaning

Clean all valve springs and valve retainer keys in a suitable solvent.

Inspection

1. Inspect the inside and outside of the valve retainer keys for wear. Replace any worn retainer keys.
2. Inspect the valve springs for rust, pitting and cracks. Look for spring distortion.

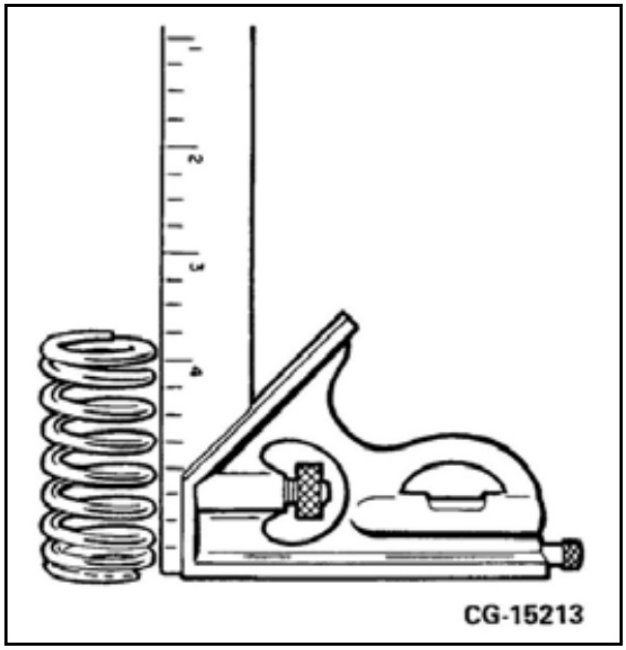

Figure 138 Checking Free Length and Flatness of the Valve Spring

3. Check the free length and flatness of the valve springs. The spring ends must be flat and square. Springs that are out-of-square place a lateral load on the stem, causing accelerated valve guide wear.

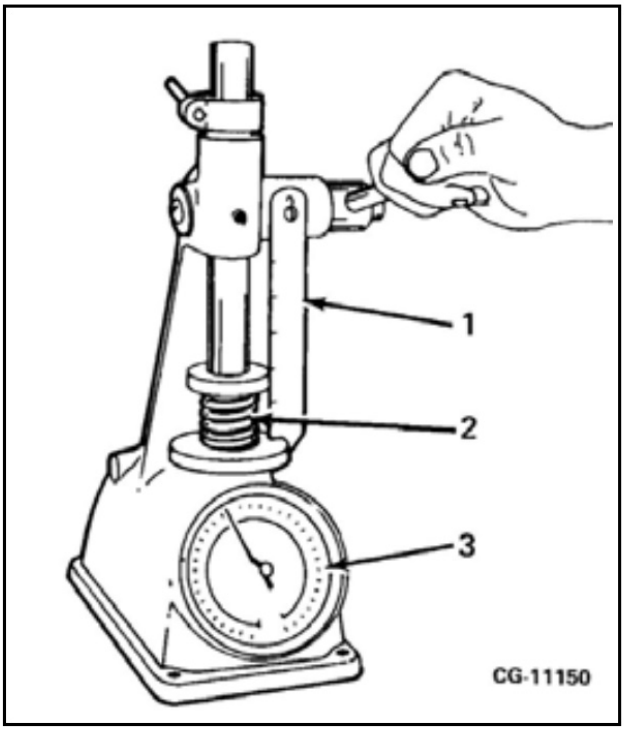

Figure 139 Checking the Valve Spring Tension

1. Linear Scale
2. Valve Spring
3. Load Indicator

4. Use a valve spring tester to measure the valve spring tension. Apply the appropriate test load to each spring and refer to the specifications. Measure maximum spring length in use (valve closed) and the minimum spring length in use (valve open).
5. Replace any valve spring that is rusted, pitted, cracked, bent or incapable of meeting the specifications.

Valve Rotators And Retainer Keys

Cleaning And Inspection

1. Clean all rotators and retainer keys in a suitable cleaning solvent.
2. Inspect retainer keys for any damage or extrusion. Replace as sets if required.

Testing Operation

CAUTION: To avoid damage, lubricate the rotator with clean engine oil before testing and reuse in the engine.

Figure 140 Testing Operation of Valve Rotators

1. Place valve spring and rotator in spring tester. Place a ball bearing between rotator and ram of the spring tester. The ball bearing must be large enough to prevent the ram from touching any part of the rotator.
2. Paint a reference line on the rotator.
3. Compress the valve spring rapidly with even pressure and observe the rotator as it turns. Replace any rotator that does not turn.

Fuel Injector Sleeve

Removal

CAUTION: To avoid engine damage, when removing the fuel injector sleeve without removing the cylinder head, place a cork plug into the bore before performing the following procedure. This will prevent debris from entering the cylinder bore.

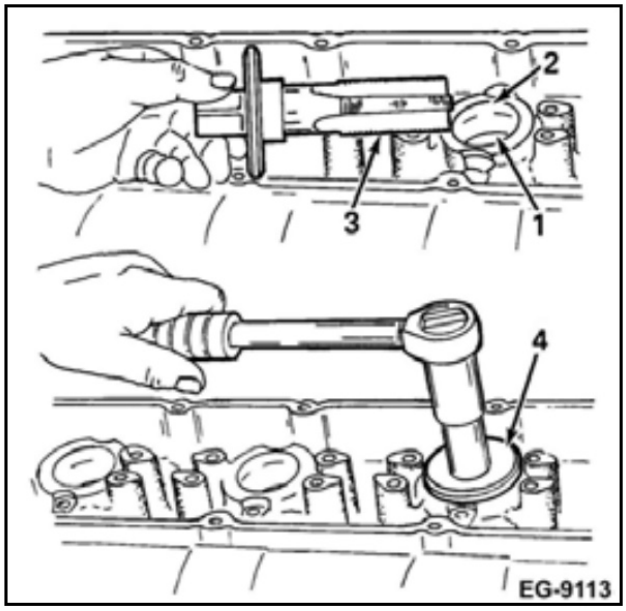

Figure 141 Removing the Fuel Injector Sleeve

1. Fuel Injector Sleeve
2. Fuel Injector Bore
3. Fuel Injector Sleeve Removal Tool
4. Centering Collar

1. Install the fuel injector removal tool into the fuel injector sleeve.
2. Turn the removal tool to cut threads into the fuel injector sleeve. Remove the tool from the bore.

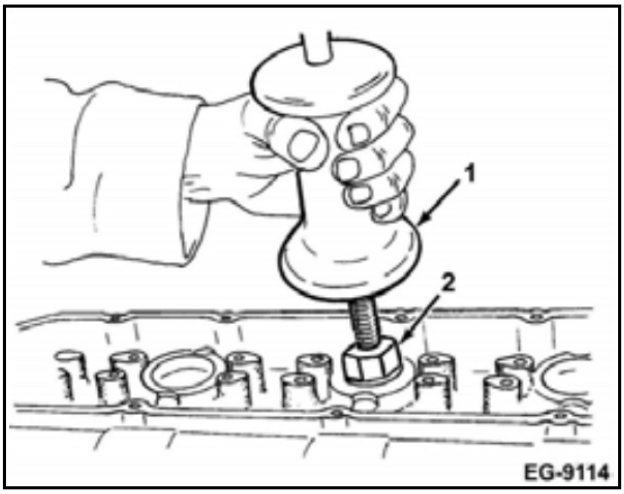

Figure 142 Removing the Fuel Injector Sleeve

1. Slide Hammer
2. Fuel Injector Sleeve Puller Tool

3. Install the fuel injector sleeve puller tool into the fuel injector sleeve and tighten the tool. Make sure the tool has been completely threaded into the fuel injector sleeve.

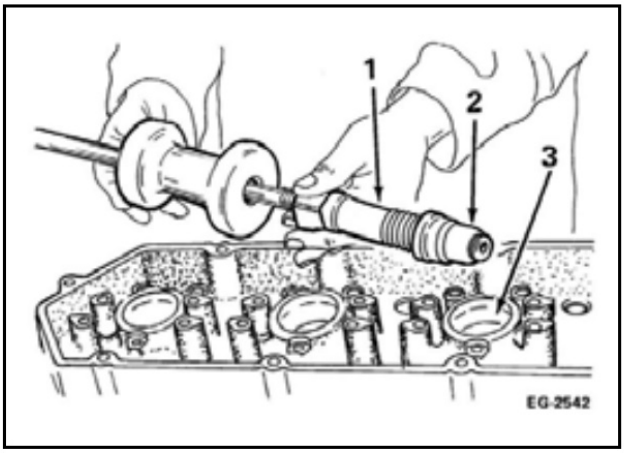

Figure 143 Fuel Injector Sleeve Removed From Bore

1. Fuel Injector Sleeve Removal Tool
2. Fuel Injector Sleeve
3. Fuel Injector Bore

4. Thread the slide hammer into the fuel injector sleeve removal tool. Remove the fuel injector sleeve from the fuel injector bore.

Cleaning Bores, Fuel Galleries and Oil Galleries

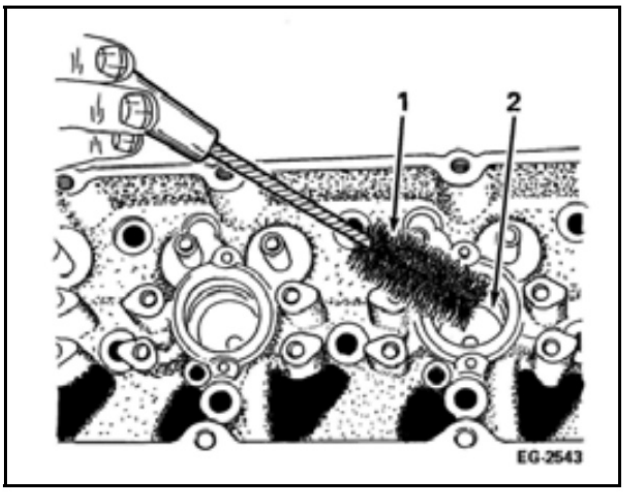

Figure 144 Cleaning the Fuel Injector Bore

1. Injector Sleeve Bottom Brush
2. Fuel Injector Bore

1. Insert the injector sleeve bottom brush into the fuel injector bore to remove deposits and hardened sealant from the bore.

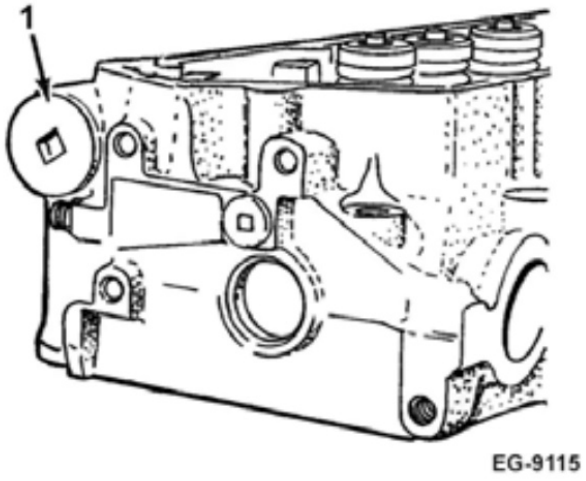

Figure 145 Oil Rail End Plugs

1. Oil Rail End Plug (two per cylinder head)

2. Remove the two oil rail end plugs (one located at each end of the cylinder head).
3. Insert a stiff nylon brush into the oil gallery.

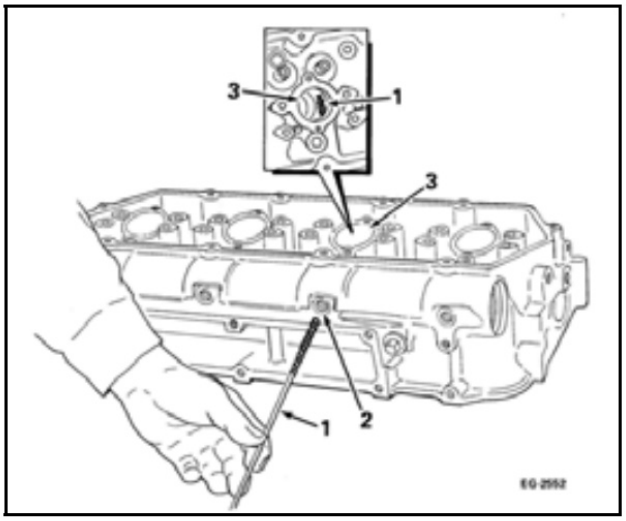

Figure 146 Cleaning the Oil Galleries

1. Small Nylon Brush In Oil Gallery Port
2. Oil Galley Port
3. Fuel Injector Bore

4. Remove the three oil gallery plugs and the high pressure oil supply fitting. Insert a small stiff nylon brush into each oil gallery.

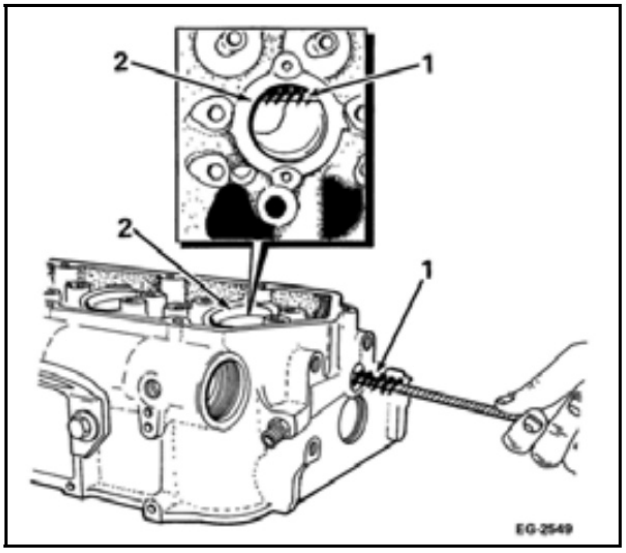

Figure 147 Cleaning the Fuel Galleries

1. Small Nylon Brush In Fuel Gallery Port
2. Fuel Injector Bore

5. Remove the two fuel gallery plugs. Insert a small stiff nylon brush into each fuel gallery.

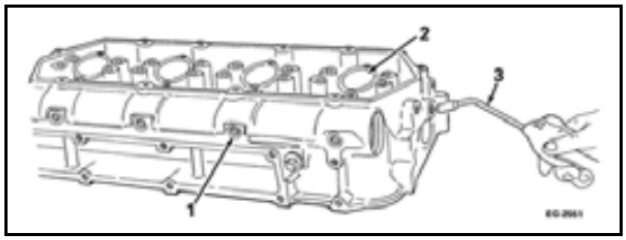

Figure 148 Cleaning the Fuel and Oil Galleries With Compressed Air

1. Oil Gallery
2. Fuel Injector Bore
3. Air Nozzle

6. Use filtered compressed air to clean out all debris from the fuel and oil gallery ports.

Installation

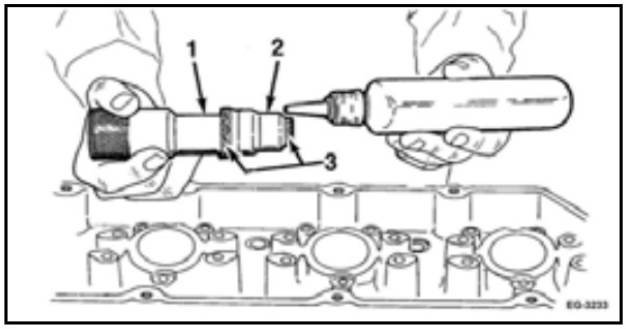

Figure 149 Preparing the Fuel Injector Sleeve for Installation

1. Installation Tool
2. Fuel Injector Sleeve
3. Loctite® Application Area

1. Attach a new fuel injector sleeve to the installation tool. Apply Loctite® #262 to the fuel injector sleeve at the end and top.
2. Use installation tool to insert fuel injector sleeve into fuel injector bore.

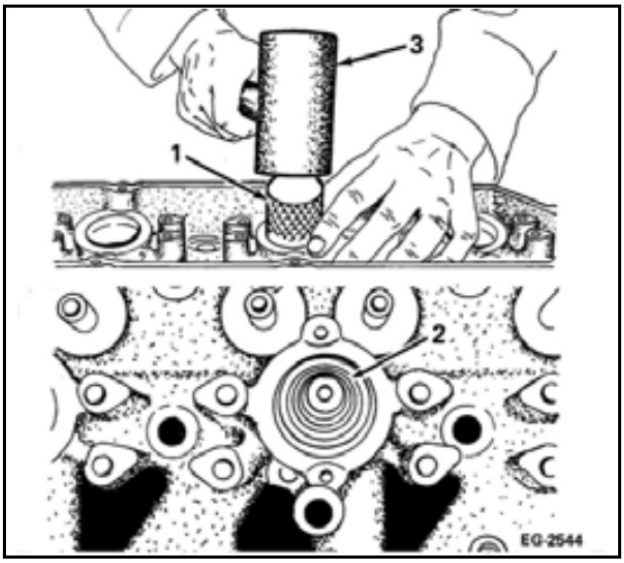

Figure 150 Inserting the Fuel Injector Sleeve

1. Installation Tool
2. Fuel Injector Sleeve
3. Hammer

3. Use a hammer to drive the fuel injector sleeve into the fuel injector bore. Remove installation tool when fuel injector sleeve is in place.
4. Inspect the fuel injector sleeve after installation. Use a shop rag to remove any debris caused by installation.

The following cutaway shows fuel injector sleeve installed into the fuel injector bore. Note areas where fuel injector sleeve lands contact the cylinder head.

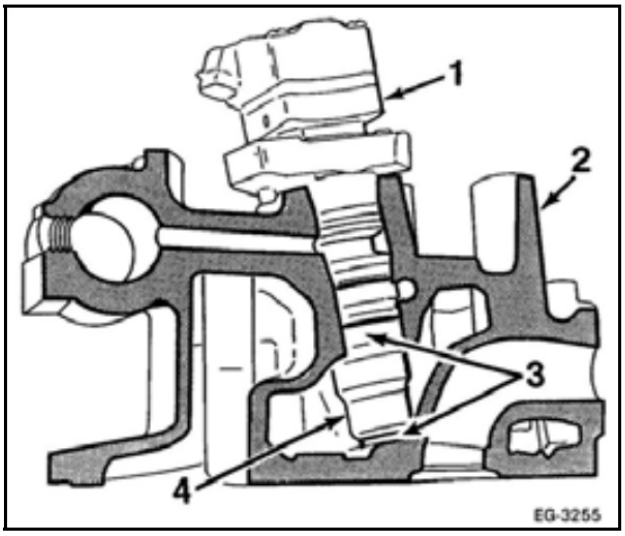

Figure 151 Fuel Injector Sleeve Installed in Cylinder Head

1. Fuel Injector
2. Cylinder Head
3. Loctite Application Area
4. Fuel Injector Sleeve

Cylinder Head Assembly

Install Valve Assemblies

NOTE: The exhaust valve stems have a dimple on the valve head.

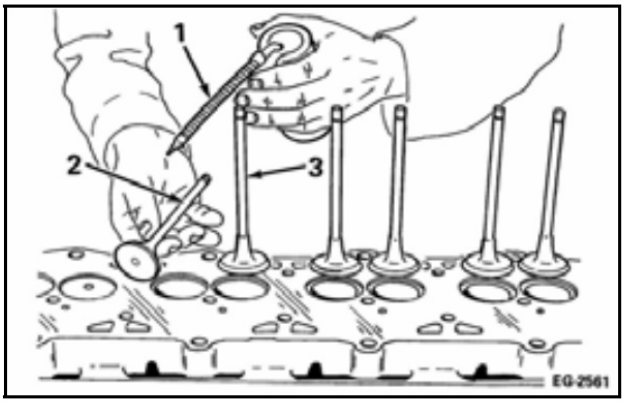

Figure 152 Lubricating the Valve Stems

1. Oil Can
2. Exhaust Valve
3. Intake Valve

1. Lubricate the valves with clean engine oil. Insert the valve stems into their respective valve guide bores in the cylinder head.

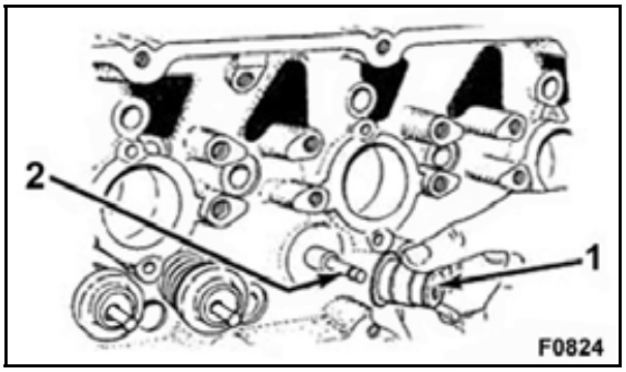

Figure 153 Installing the Valve Seal

1. Valve Seal
2. Valve Stem

2. Lubricate the inner diameter of the new valve stem seals with clean engine oil. Install the seals over each valve stem. Make sure the seal assembly is seated against the cylinder head spring pockets.

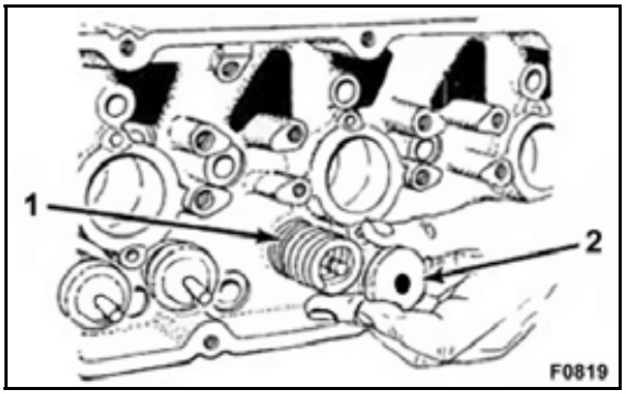

Figure 154 Installing the Valve Rotators

1. Valve Spring
2. Valve Rotator

3. Install the valve spring over the stem seal assembly.
4. Install the valve rotators.

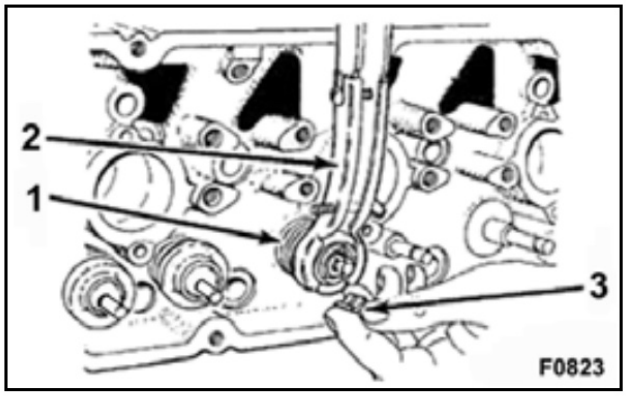

Figure 155 Installing the Valve Assembly Retainer Keys

1. Valve Spring Compression Tool
2. Valve Spring
3. Valve Assembly Retainer Key

5. Attach the valve spring compression tool and compress the valve spring. Install the valve assembly retainer keys and release valve spring compression tool. Make sure the retainer keys are correctly seated on all valve stems.
6. After valve inspection, reconditioning and replacement/installation, measure the valve head recession relative to deck to confirm a good reconditioning job. Refer to the specifications.

Install Oil and Fuel Rail Plugs

Oil Rail End Plug

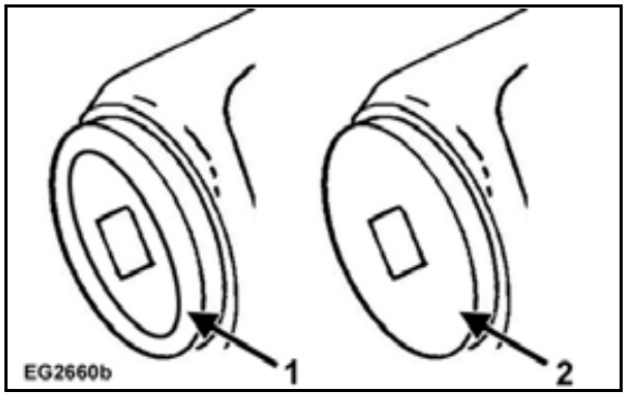

Figure 156 New and Old Style Oil Rail End Plug

1. New Style Oil Rail End Plug With ID Groove
2. Old Style Oil Rail End Plug Without ID Groove

1. Check the oil rail end plug for an identification groove. New style oil rail end plugs feature an identification groove. Replace old style end plug with new style end plug.

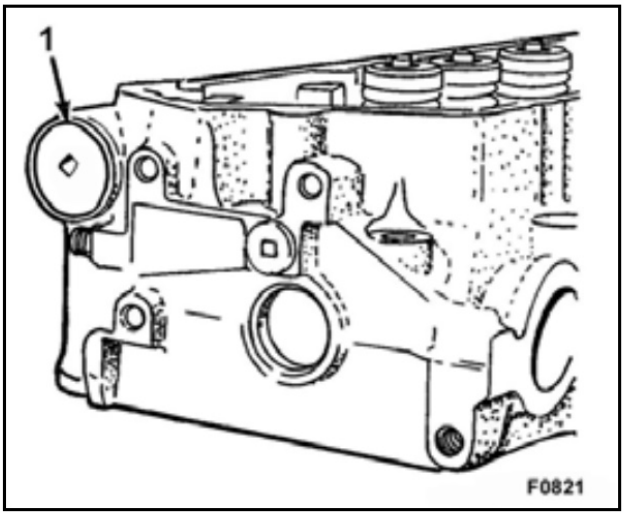

Figure 157 Oil Rail End Plugs

1. Oil Rail End Plug (two per head)

2. Use a clean dry cloth and brake cleaner to clean the cylinder head internal threads. Dry the threads before installing the plug.

CAUTION: To avoid engine damage, make sure the threads of the oil rail end plugs are free of any oily residue. Failure to do so may result in leakage past the plugs.

3. Apply clean engine oil to the seals. Install the seals onto the oil rail end plugs without getting oil on the clean threads.
4. Apply a small bead of Loctite® #277 around the threads of the oil rail end plugs. Install the plugs. Tighten oil rail end plugs to the special torque value.

NOTE: Before engine operation, wait at least one hour for the Loctite to cure.

Drain Plugs

CAUTION: To prevent engine damage, do not apply sealant to threads of the oil drain plugs. DO NOT use anti-sieze compounds, grease, or any other lubricant except engine oil. Other lubricants have an adverse effect on torque values.

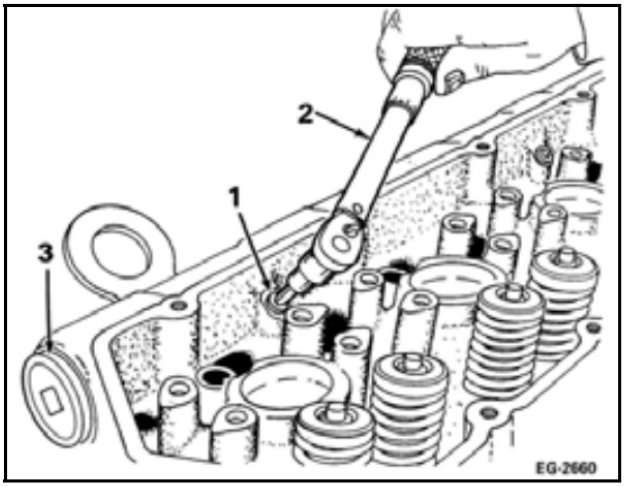

Figure 158 High Pressure Oil Rail Drain Plug

1. Oil Rail Drain Plug (two per head)
2. Torque Wrench
3. Oil Rail End Plug

1. Apply clean engine oil to a new O-ring for each of the oil rail drain plugs (two per head).
2. Install the oil rail drain plugs into the cylinder head ports. Tighten the oil rail drain plugs to the special torque value.

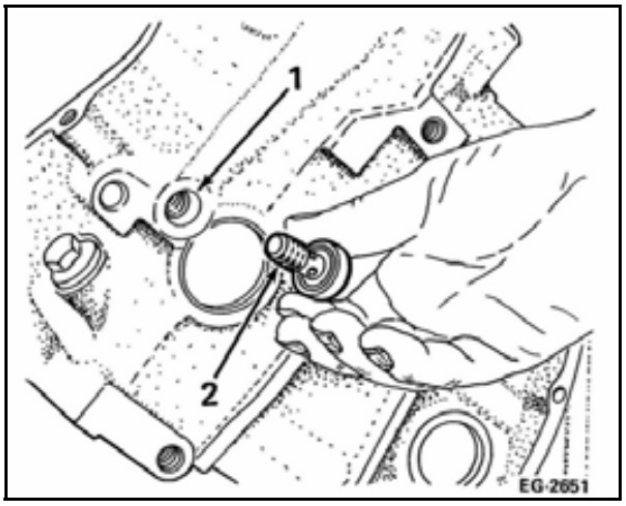

Figure 159 Location of Front Fuel Rail Drain Plug

1. Fuel Gallery Drain Port
2. Fuel Gallery Drain Plug

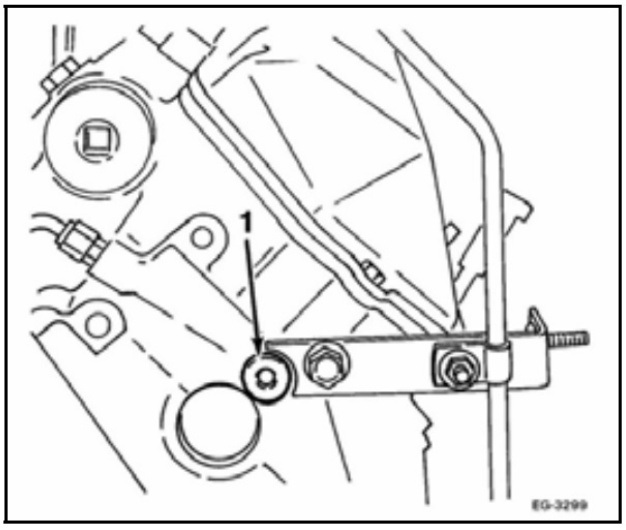

Figure 160 Location of Rear Fuel Rail Drain Plug

1. Fuel Gallery Drain Plug

3. Apply clean oil to a new O-ring for both of the fuel rail drain plugs.
4. Install the two fuel rail drain plugs into the cylinder head ports. Tighten the fuel rail drain plugs to the special torque value.

Oil Gallery Plugs

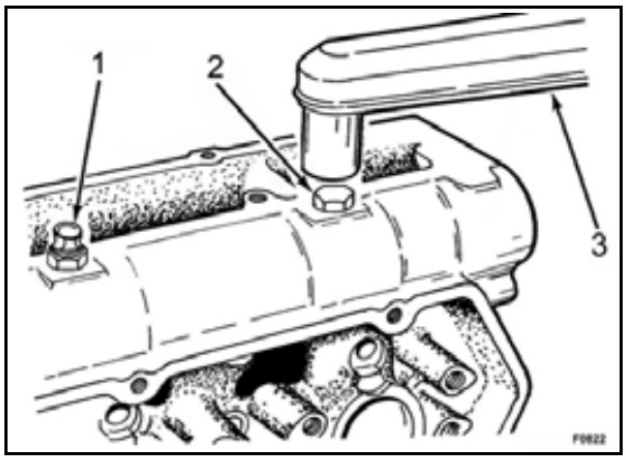

Figure 161 Installing the Oil Gallery Plugs

1. High Pressure Oil Supply Fitting
2. Oil Gallery Plugs (three per head)
3. Torque Wrench

1. Install new O-rings on the three oil gallery plugs.
2. Apply Loctite® #262 onto the threads of the three oil gallery plugs and the one high pressure oil supply fitting. Install the plugs and fitting into the oil gallery ports located above each of the fuel injector bores. Tighten the plugs and fitting to the special torque value.

Valve Lever

Disassembly

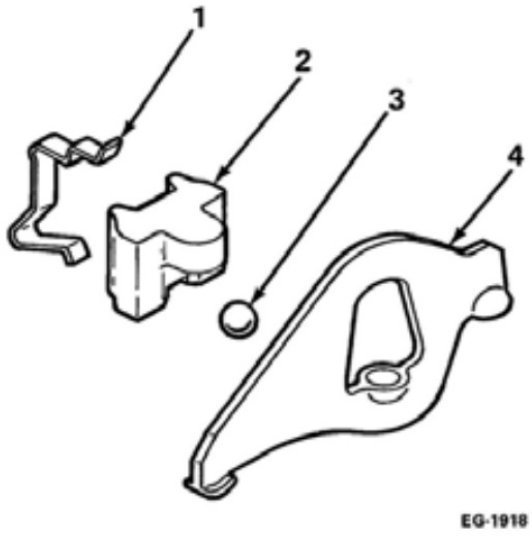

Figure 162 Disassemble the Valve Lever

1. Valve Lever Clip
2. Valve Lever Post
3. Chrome Ball
4. Valve Lever

NOTE: BE SURE to keep all items of each rocker lever together for installation in their original locations.

1. Carefully remove the valve lever clip that secures the valve lever, valve lever post, and the 10 mm (3/8 in) chrome ball.
2. Remove the chrome ball from the cup on the valve lever.
3. Separate the valve lever from valve lever post.

Cleaning

Clean all parts with a suitable solvent and dry parts using filtered compressed air.

Inspection

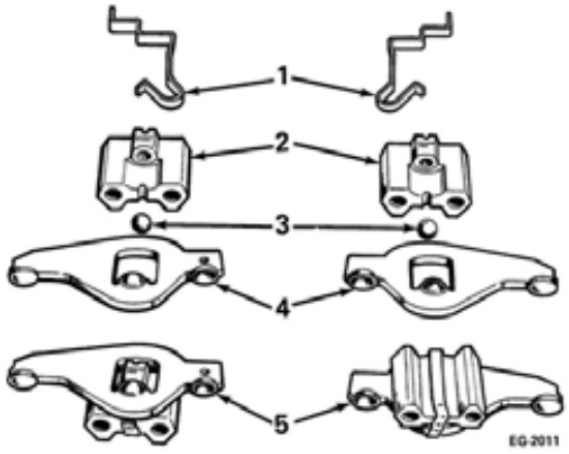

Figure 163 Valve Lever Component Relationship

1. Retaining Clip
2. Valve Lever Post
3. Chrome Ball
4. Valve Lever
5. Valve Lever Assembly

1. Inspect the valve stem ends and corresponding valve lever pads for pitting or scuffing. Inspect the chrome ball and ball socket in valve lever for scuffing. Replace the levers as required.
2. Inspect the valve lever post ball socket for excessive wear. Inspect the bolts for thread damage. Replace worn components as required.

Assembly

Figure 164 Lubricating the Chrome Ball

1. Place the chrome ball on the valve lever cup. Lubricate the chrome ball with clean engine oil.

Figure 165 Installing the Valve Lever Post

2. Place the valve lever post on the chrome ball.

Figure 166 Installing the Retaining Clip

CAUTION: To avoid engine damage, install the retaining clip correctly. Failure to do so could result in valve lever assembly coming apart in the running engine.

3. Snap the retaining clip over the valve lever post groove.

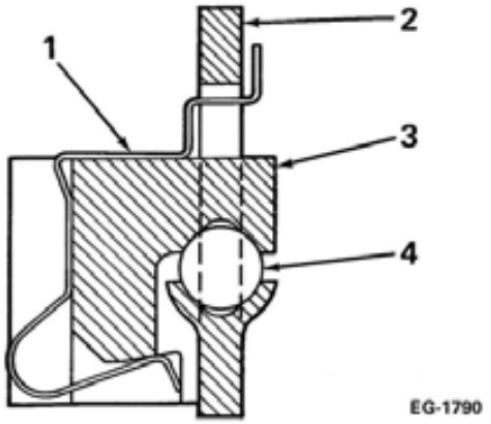

Figure 167 Valve Lever Retaining Clip Position

1. Retaining Clip
2. Valve Lever
3. Valve Lever Post
4. Pivot Ball

Fuel Injector O-rings And Seals

Removal

CAUTION: To avoid engine damage, all of the O-rings and seals on the fuel injector should be replaced anytime the fuel injector is removed. When removing or installing the O-rings and seals, be careful not to scratch the seal grooves of the fuel injector body. Use a non-metallic tool (wood or plastic) to remove the seals away from the grooves. Failure to do so could result in fuel or oil dilutions.

1. Remove the copper gasket from the bottom of the fuel injector.
2. Lift the lower O-ring out of its groove. Cut and remove the seal.
3. Lift the middle seal out of its groove. Cut and remove the seal.
4. Lift the upper O-ring out of its groove. Cut and remove the seal.
5. Lift the upper cushion ring out of its groove. Cut and remove the seal.
6. Lift one corner of the backup ring from its groove. Slide the rest of the backup ring from its groove and over the tip of the fuel injector.
7. Make sure the fuel injector is clean and free of debris. Place the fuel injector into a holder rack where it will be protected from debris and damage.

Installation

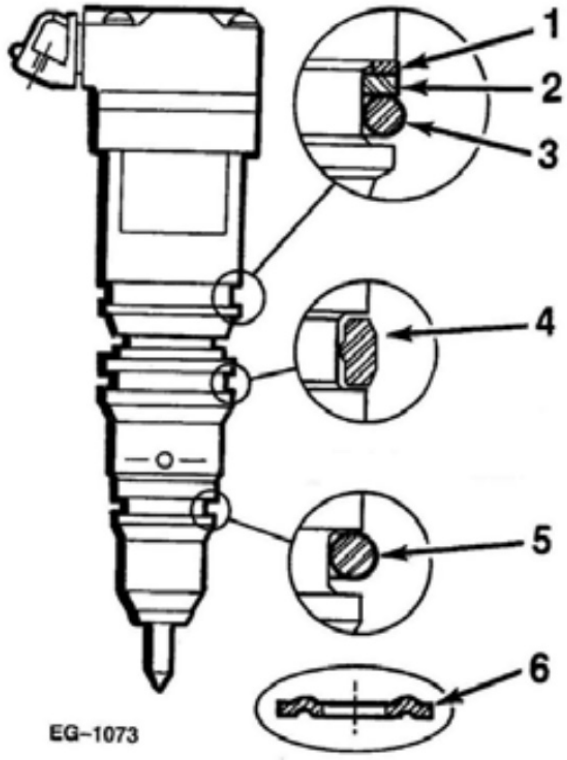

Figure 168 Fuel Injector O-Ring and Seal

1. Backup ring (Steel)
2. Upper Cushion Ring
3. Upper O-Ring Seal
4. Middle Seal
5. Lower O-Ring Seal
6. Copper Gasket

CAUTION: To avoid engine damage, when installing the O-rings and seals onto the fuel injectors, make sure all O-rings and seals are located at the top of the grooves to prevent them from rolling during installation. Also, make sure the O-rings and seals do not twist during installation. Failure to do so could result in fuel or oil dilution.

Upper Groove

1. Locate the upper grove seals.
2. Lightly lubricate the new upper groove seal with clean engine oil.

CAUTION: The backup rings acts like a spring. Be careful when installing this part. Do not twist the ring. Ring flatness is important or a tight seal will not be formed. This could result in fuel or oil dilution.

3. Gently expand the ring. Slide the backup ring over the body of the fuel injector and into the upper groove.
4. Slide the cushion ring over the body of the fuel injector. Push the cushion ring into the upper groove. Make sure the cushion ring is against the backup ring.
5. Slide the O-ring over the body of the fuel injector and push it into the groove. Make sure the O-ring is against the cushion ring.

Middle Groove

6. Locate the middle groove seal.
7. Lightly lubricate the seal with clean engine oil.
8. Slide the middle seal over the fuel injector body and push into middle groove. Make sure the middle fuel injector seal is against the groove.

Lower Groove

9. Locate the lower groove seal.
10. Lightly lubricate the lower O-ring seal with clean engine oil.
11. Slide the lower O-ring seal over the fuel injector body and into the lower groove. Make sure the lower O-ring seal is against the groove.
12. Apply a light coat of grease to a new copper gasket. Place the gasket over the fuel injector tip.
13. Place fuel injector back into the holder rack for protection from damage and dirt.

Cylinder Head Installation

NOTE: Valve lifters cannot be replaced or removed when the cylinder head is bolted onto the crankcase. Complete any required work to the valve lifters before installing the cylinder head.

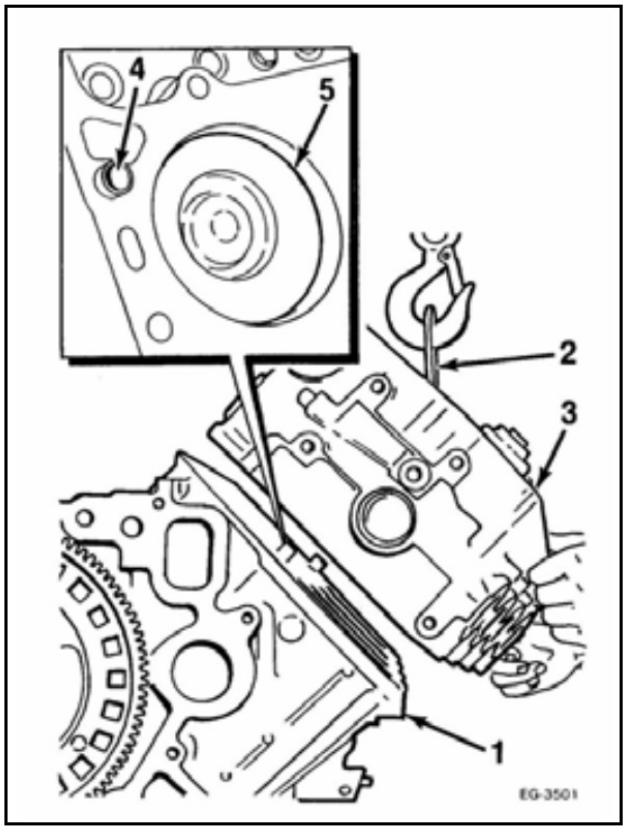

Figure 169 Installing the Cylinder Head Onto the Crankcase

1. Crankcase
2. Lifting Bracket
3. Cylinder Head
4. Dowel Sleeve
5. Piston

1. If removed, install the two dowel sleeves (one at the front and one at the rear of crankcase).
2. Place a new cylinder head gasket with the "UP" stamp facing towards the cylinder head. Do not apply sealant to the head gasket surfaces.
3. Install the cylinder head lifting bracket in the center of the cylinder head. Tighten the bracket mounting bolts.

CAUTION: To avoid engine damage, DO NOT slide or drop the cylinder head on the cylinder head gasket. Either action could damage the gasket and dowel sleeves and may result in a loss of compression or fluid leakage.

NOTE: When installing the cylinder head, align the dowel sleeves on both sides of the crankcase with the mounting holes in the cylinder head.

4. Attach a lifting hook to the lifting bracket. Raise the cylinder head and install it on the crankcase.

CAUTION: To avoid engine damage, DO NOT use anti-seize compounds, grease, or any other lubricant except engine oil. Other lubricants have an adverse effect on torque values.

Do not install painted cylinder head bolts in a position under the valve cover. Paint chips may contaminate the engine oil.

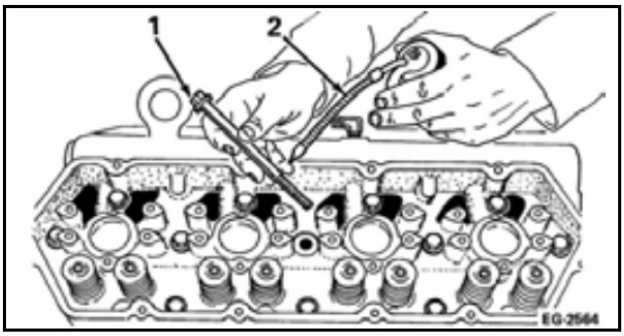

Figure 170 Lubricating the Cylinder Head Mounting Bolts

1. Cylinder Head Mounting Bolts (18)
2. Oil Can

5. Lightly lubricate all cylinder head mounting bolts (the threads and under the flange head) with clean engine oil.
6. Install the cylinder head mounting bolts. Tighten the mounting bolts in the special tightening sequences and to the special torque values.

Install Fuel Injector

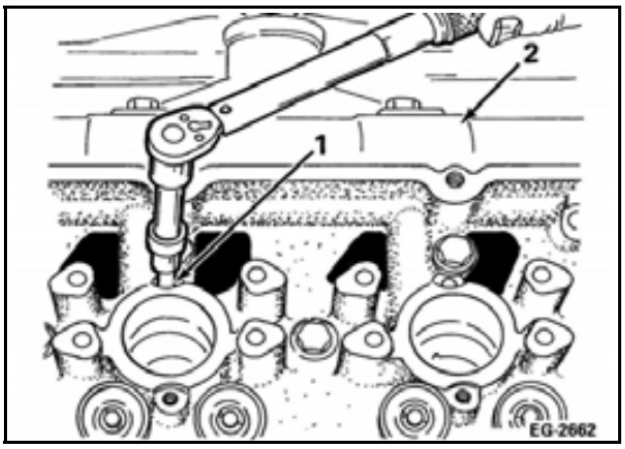

Figure 171 Installing the Shoulder Bolt

1. Shoulder Bolt
2. Cylinder Head

1. Install the shoulder bolt and tighten it to the special torque value.
2. Lubricate the fuel injector O-rings. Insert the fuel injector in the cylinder head bore.
3. Do not strike the top of the fuel injector to seat it. Use one of the following methods to seat the fuel injector in the bore.

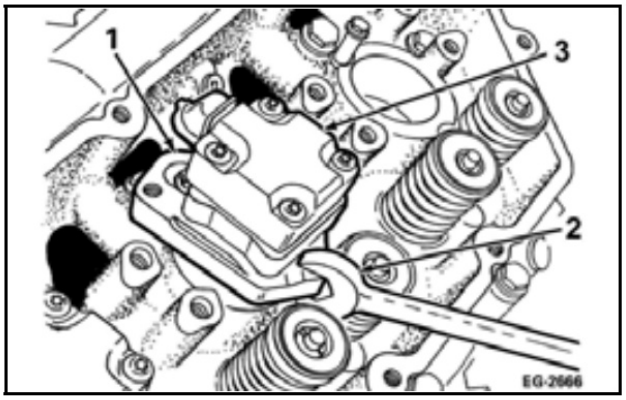

Figure 172 Open End Wrench Method

1. Hold Down Clamp
2. Wrench
3. Fuel Injector

Method One: Place the hold down clamp over the shoulder bolt. Use a 16 mm (5/8 in) open end wrench on the lower edge of the hold down clamp to seat the fuel injector.

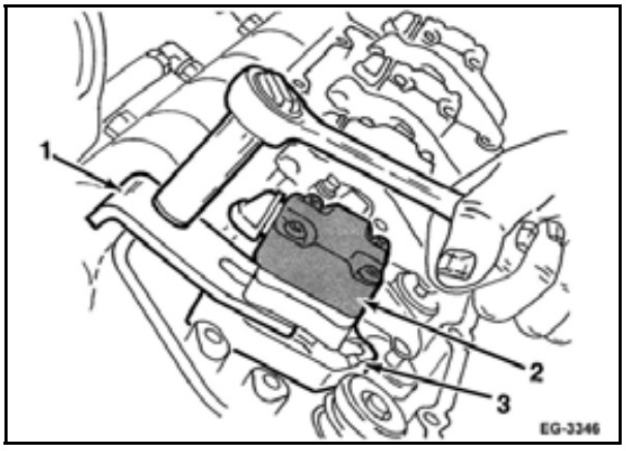

Figure 173 Installation Tool Method

1. Installation Tool
2. Fuel Injector
3. Hold Down Clamp

Method Two: Place a fuel injector installation tool onto the fuel injector. Slide the forks between the hold down clamp and the fuel injector head and rest the lip of the tool on the cylinder head. Turn the bolt on the installation tool to seat the fuel injector.

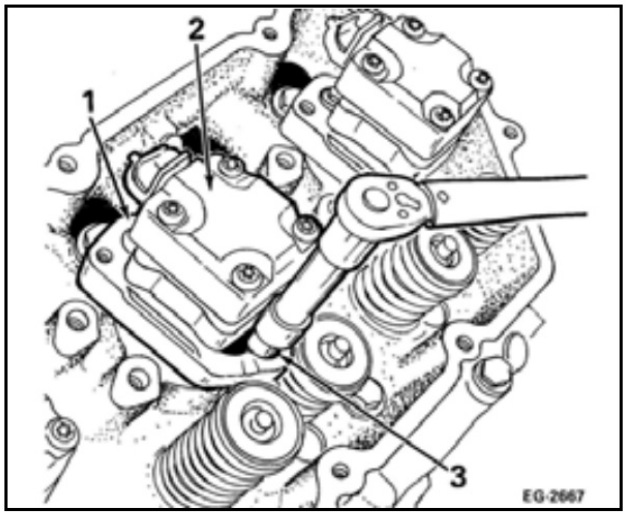

Figure 174 Installing the Fuel Injector Hold Down Clamp Mounting Bolt

1. Hold Down Clamp
2. Fuel Injector
3. Mounting Bolt

4. Install the mounting bolt for the hold down clamp. Tighten the bolt to the special torque value.

Install Oil Director Spout

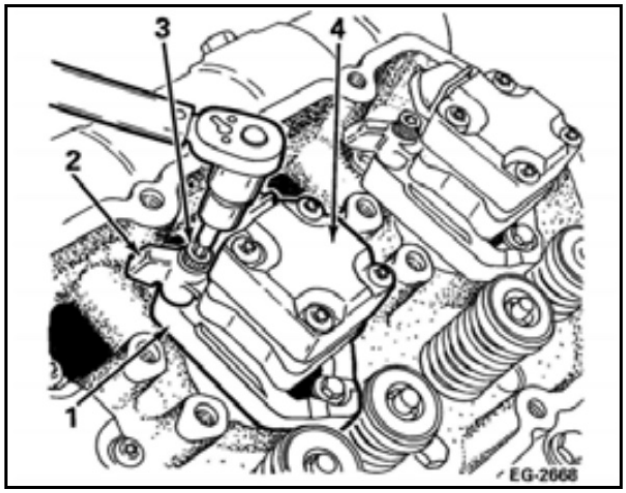

Figure 175 Installing the Oil Director Spout

1. Hold Down Clamp
2. Oil Director Spout
3. Allen Head Bolt
4. Fuel Injector

Install the oil director spout and secure it with an Allen head bolt. Tighten the bolt to the special torque value.

Install Push Rods

NOTE: Clean push rods so the copper color ball end of the push rod can be identified.

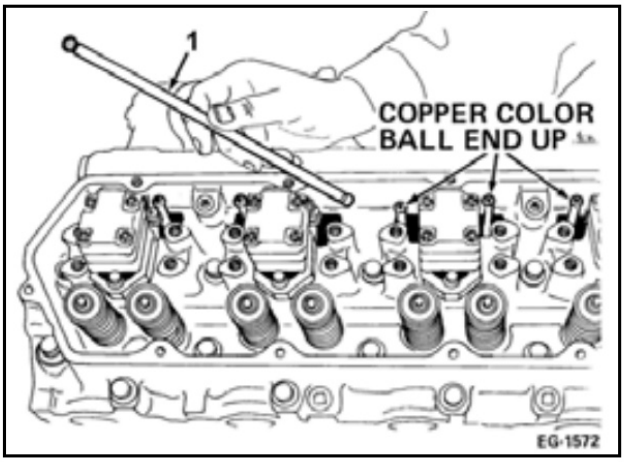

Figure 176 Installing the Push Rods

1. Push Rod

Insert the push rods into their respective positions with the copper color ball end up.

Install Valve Lever

CAUTION: To prevent engine damage, make sure the copper end of the push rods are up before proceeding. Then insert the other end into the hydraulic roller lifter seats before installing the valve lever assemblies.

1. Rotate the crankshaft until the vibration damper notch is 15° from vertical (1 o'clock position when viewed from the front of the engine). This positions all pistons below TDC so the valves cannot contact the pistons when tightening the valve lever assemblies.

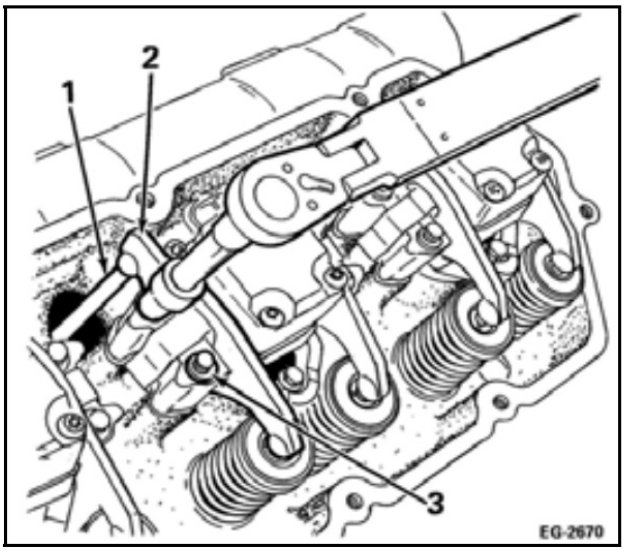

Figure 177 Installing the Valve Lever Assembly

1. Push Rod Assembly
2. Valve Lever Assembly
3. Valve Lever Mounting Bolt

2. Lubricate the valve lever assemblies and bolts with clean engine oil.
3. Place the valve lever assemblies in their original locations over the cylinder head mounting pads. Install retaining bolts finger tight.
4. Tighten the valve lever mounting bolts to the special torque value.

Install Glow Plug

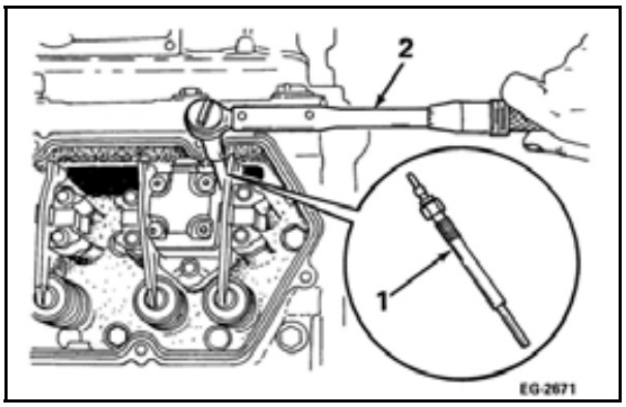

Figure 178 Installing the Glow Plugs

1. Glow Plug
2. Torque Wrench

Apply Never-Seez® to the threads of the glow plugs. Install the glow plugs into the cylinder head. Tighten the glow plugs to the special torque value.

Connecting Under Valve Cover Harness

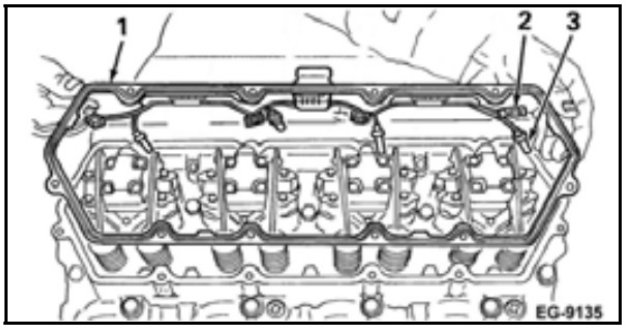

Figure 179 Installing the Valve Cover Gasket

1. Gasket With UVC Harness
2. Fuel Injector Solenoid Harness Connectors
3. Glow Plug Leads

1. Position the valve cover gasket with the UVC harness onto the cylinder head.
2. Connect the electrical leads to the glow plugs by pressing the connector onto the glow plugs.

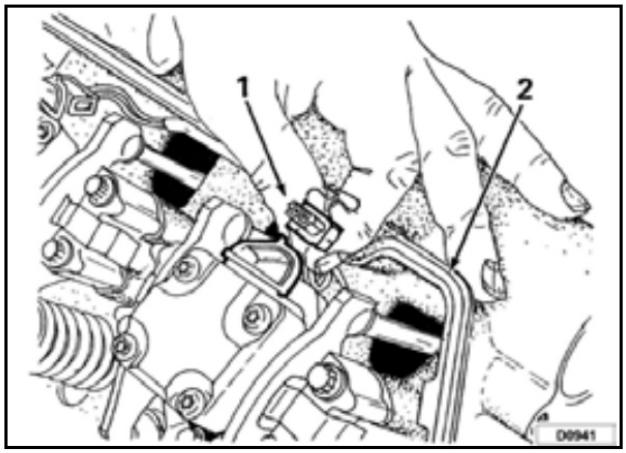

Figure 180 Connecting the Connector to the Fuel Injector Solenoid

1. Connector
2. Gasket Surface

3. Connect the fuel injector electrical connector by inserting the connector into the socket. Push the connector up and secure it with the metal wire bail.
4. Make sure all UVC wiring is free and clear of any moving parts and free of possible entrapment by the valve cover.

Installing Valve Covers

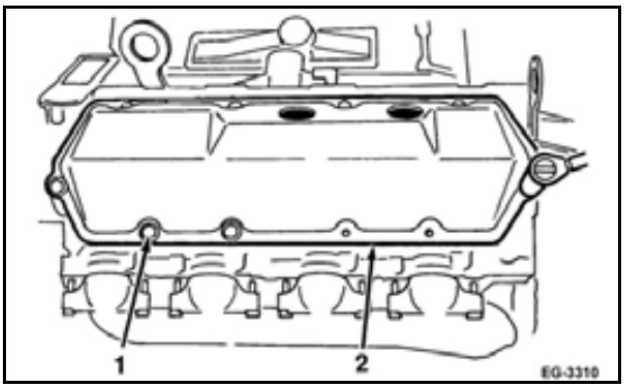

Figure 181 Installing the Left Valve Cover

1. Mounting Bolt (10)
2. Valve Cover

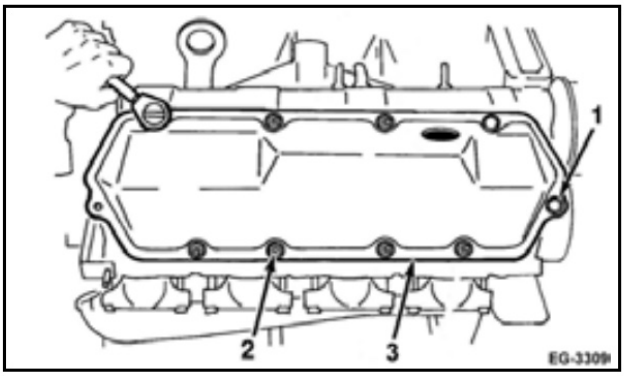

Figure 182 Installing the Right Valve Cover

1. Mounting Bolt (4)
2. Mounting Studs Bolt (6)
3. Valve Cover

1. Place the valve cover onto the gasket. Be careful to avoid pinching any UVC wires.
2. Install the mounting bolts finger tight. Make sure that the stud bolts on the right valve cover are installed in the correct locations.

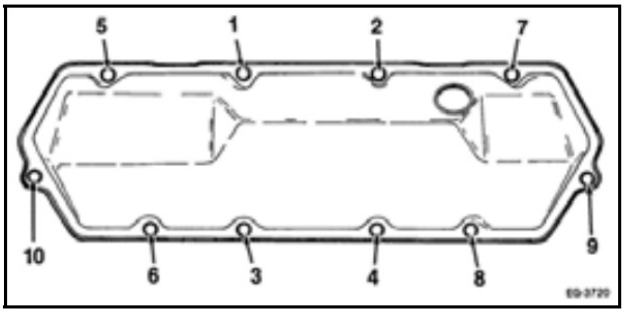

Figure 183 Valve Cover Torque Sequence

3. Tighten the mounting bolts in the specified sequence and to the special torque value.

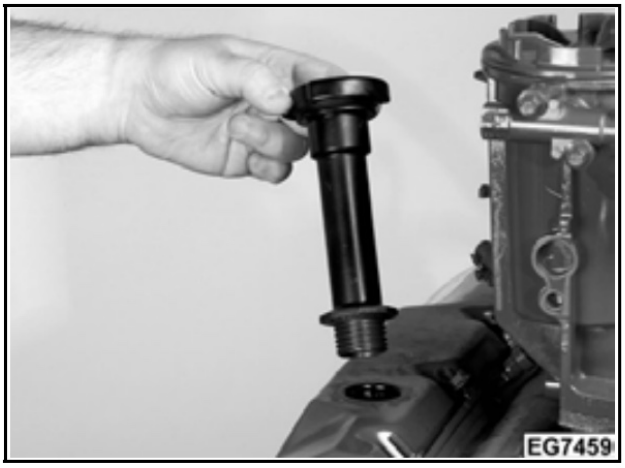

Figure 184 Installing the Oil Filler Standpipe

4. On the right valve cover, install the oil filler standpipe.
5. Connect the wiring harness connector to the UVC gasket.
6. After the valve cover is installed, refer to the appropriate procedures about installing the glow plug relay, turbocharger air inlet elbow, road draft tube, and ECM.

Crankcase Breather

Removal

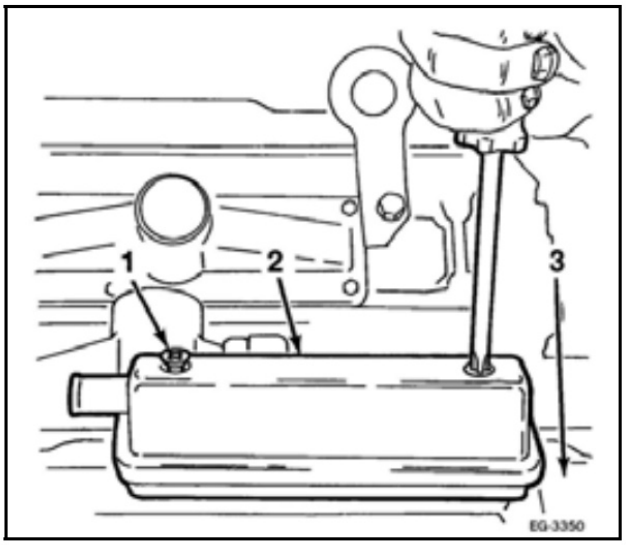

Figure 185 Removing the Crankcase Breather

1. Mounting Screws
2. Crankcase Breather Assembly
3. Left Valve Cover

1. Loosen the hose clamps that secure the road draft tube to the crankcase breather. Remove road draft tube from crankcase breather.
2. Remove the two screws that secure the crankcase breather to the valve cover. Remove the crankcase breather.

Cleaning

Clean the breather element in solvent. Dry the breather element with filtered compressed air.

Installation

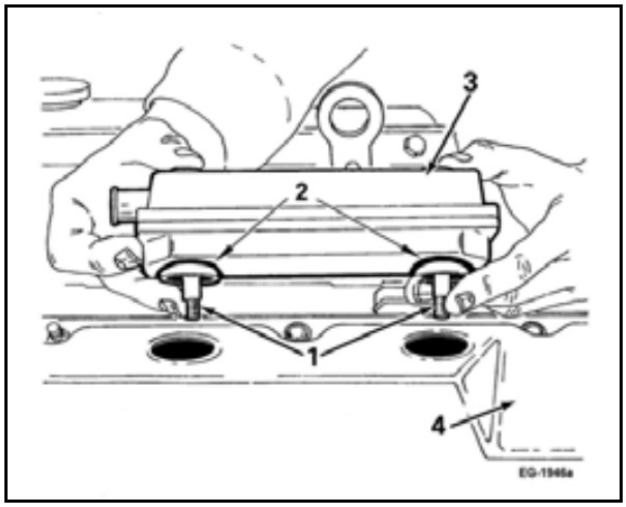

Figure 186 Installing the Crankcase Breather

1. Mounting Screws
2. Large O-Ring Seals
3. Crankcase Breather
4. Left Valve Cover

CAUTION: To avoid damage to the engine BE SURE the large O-ring seals are located on the valve cover and the small O-ring seals are under the mounting screw head. Failure to do so can result in the O-rings falling into the cylinder head causing damage to the engine.

1. Install the large O-rings onto the crankcase breather and the small O-rings onto the mounting screws.
2. Insert the mounting screws into the crankcase breather.
3. Align the crankcase breather assembly with the two mounting holes on left valve cover. Tighten the screws to the special torque value.
4. Install the road draft tube to the crankcase breather. Tighten the hose clamps that secure the tube to the crankcase breather.

Assemble the following after the cylinder head is installed. Refer to the appropriate section for correct installation procedures.

- Fuel lines and filter assembly
- High pressure hydraulic lines
- Engine harness connections
- ECM

SPECIFICATIONS

Table 10 Cylinder Head

Exhaust Valves	
Stem Diameter	7.9210-7.9388 mm (0.31185-0.31255 in)
Stem To Guide Clearance (Max. Allowable Before Replacement)	0.140 mm (0.0055 in)
Face To Stem Runout (T.I.R. Max.)	0.05 mm (0.002 in)
Valve Face Angle	37.5°
Valve Face Margin (Min.)	1.37 mm (0.054 in)
Intake Valves	
Stem Diameter	7.9210-7.9388 mm (0.31185-0.31255 in)
Stem To Guide Clearance (Max. Allowable Before Replacement)	0.140 mm (0.0055 in)
Face To Stem Runout (T.I.R. Max.)	0.05 mm (0.002 in)
Valve Face Angle	30°
Valve Face Margin (Min.)	1.67 mm (0.066 in)
Cylinder Heads	
Inside Diameter Of Valve Guide	7.978-8.004 mm (0.3141-0.3151 in)
Valve Guide Taper (Max.)	0.10 mm (0.004 in)
Valve Seat Width (intake and exhaust)	1.65-2.41 mm (0.065-0.095 in)
Valve Seat Angle (intake)	30°
Valve Seat Angle (exhaust)	37.5°
Valve Seat Run Out (T.I.R. Max.)	0.05 mm (0.002 in)
Gasket Surface Flatness	0.025 mm in 0.5 mm (0.001 in. in 2 inches) 0.10 mm (0.004 in) overall
Gasket Surface Finish (Micro Inches)	63-125
Deck To Deck Dimension (Head Thickness Overall)	129.41-129.67 mm (5.095-5.105 in)
Valve Head Recession Relative To Deck (Head Gasket) Surface On Cylinder Head	
Intake	1.17-1.47 mm (0.046-0.058 in)
Exhaust	1.32-1.63 mm (0.052-0.064 in)
Valve Spring	
Free Length	52.70 ± 3.8 mm (2.075 ± 0.150 in)
Test Length	34.34 mm (1.352 in)
Load at Test Length	102-113 kg (225-249 lbf)
Push Rod Runout/Straightness (Max. T.I.R.)	0.518 mm (0.02 in)

Special Torque

Table 11 Cylinder Head Special Torques

Crankcase Breather Screws	2 N·m (18 lbf·in)
Cylinder Head Mounting Bolts (special torque sequences)	**Initial:** 54 N·m (40 lbf·ft) **Second:** 95 N·m (70 lbf·ft) **Final:** 129 N·m (95 lbf·ft)
Fuel Injector Hold Down Clamp Mounting Bolt	14 N·m (120 lbf·in)
Fuel Injector Shoulder Bolt	14 N·m (120 lbf·in)
Fuel Rail End Plugs	16.3 N·m (12 lbf·ft)
Glow Plugs	19 N·m (14 lbf·ft)
ICP Sensor	29 ± 2 N·m (21.5 ± 1.5 lbf·ft)
Oil Deflector Mounting Bolt	12 N·m (106 lbf·in)
Oil Fill Deflector	11–16 N·m (8–12 lbf-ft)
Oil Rail Drain Plugs	6.8 ± 1 N·m (60 ± 10 lbf·in)
Oil Rail End Plugs	81 N·m (60 lbf·ft)
Oil Rail Plugs	29 ± 2 N·m (21.5 ± 1.5 lbf·ft)
Valve Cover Bolts (special torque sequence)	11 N·m (8 lbf·ft)
Valve Lever Mounting Bolt	27 N·m (20 lbf·ft)

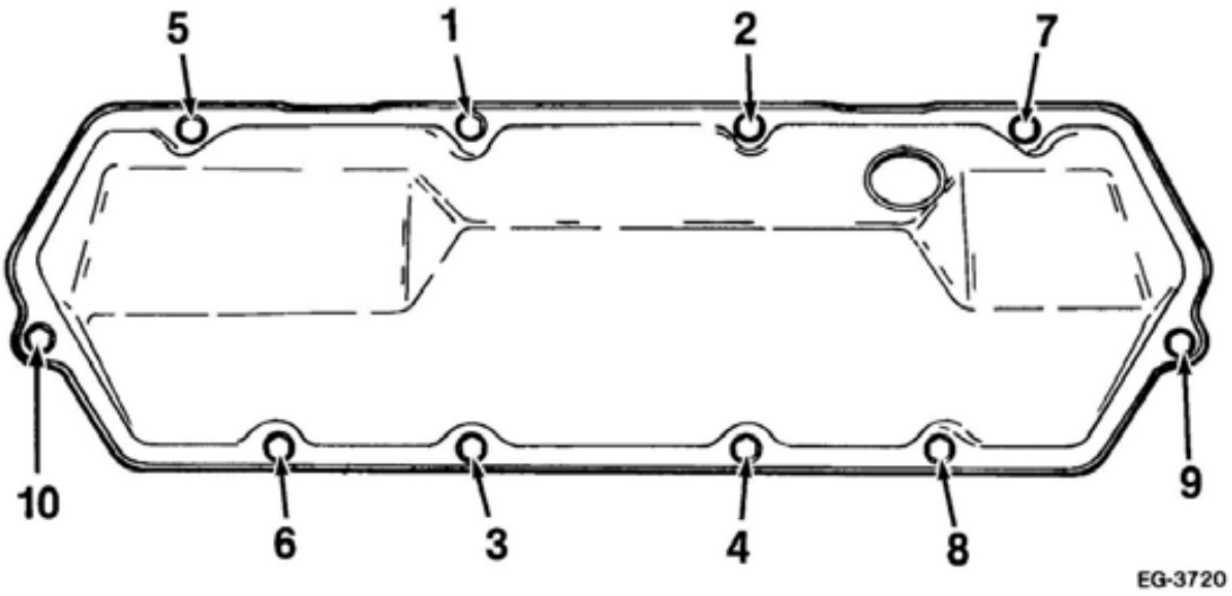

Figure 187 Valve Cover Bolt Special Torque Sequence

1. Start all bolts by hand and finger-tighten.

2. Torque bolts to the special torque value in the sequence shown.

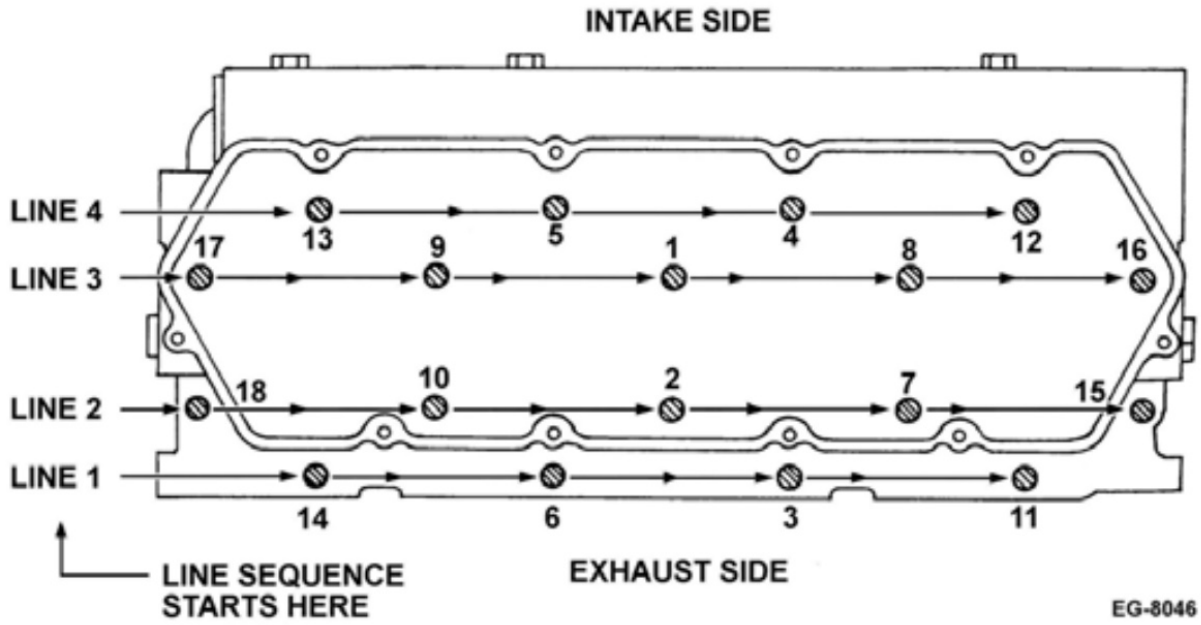

Figure 188 Cylinder Head Mounting Bolt Special Torque Sequence

1. Tighten to 54 N·m (40 lbf·ft) in numbered sequence.
2. Tighten to 95 N·m (70 lbf·ft) in numbered sequence.
3. Tighten to 129 N·m (95 lbf·ft) in line sequence.
4. Tighten to 129 N·m (95 lbf·ft) again in line sequence.

SPECIAL SERVICE TOOLS

Table 12 Cylinder Head Special Service Tools

OEM1004	Outside Micrometer (5–6 inch)
OEM1014	Dial Caliper
OEM1023	Small Hole Gauge Set
OEM1272	Defect Detection Kit (Dye Penetrant)
OEM1293	Straightedge
OEM6343	Cleaning Brush
OEM6459	Surface Height Gauge Tool
ZTSE1631A	Eccentric Valve Seat Grinder
ZTSE1846	Valve Spring Compressor
ZTSE1879	Slide Hammer Puller Kit
ZTSE2241	Valve and Clutch Spring Tester
ZTSE4296	Turbocharger Intake Cap Set
ZTSE4297	Cylinder Head Lifting Bracket
ZTSE4298	Valve Spring Compressor
ZTSE4299	Fuel Injector Holder Rack
ZTSE4300	Fuel Injector Removal Tool
ZTSE4301	Fuel Injector Tip Cleaning Brush
ZTSE4302A	Fuel Injector Sleeve Removal Tool
ZTSE4303	Fuel Injector Sleeve (Adapter) Replacer
ZTSE4304	Fuel Injector Sleeve Cleaning Brush Set
ZTSE43042	Injector Sleeve Bottom Brush
ZTSE4308	Cylinder Head Pressure Test Plate
ZTSE4320	Oil and Fuel Gallery Brush Cleaning Set (Consists of 4 brushes)
ZTSE4353	Fuel Injector Installation Tool
ZTSE4354	Fuel Injector Removal Tool
ZTSE43862	Hand Tap (Bottoming M12 X 1.75)
ZTSE43021A	Injector Sleeve Tap

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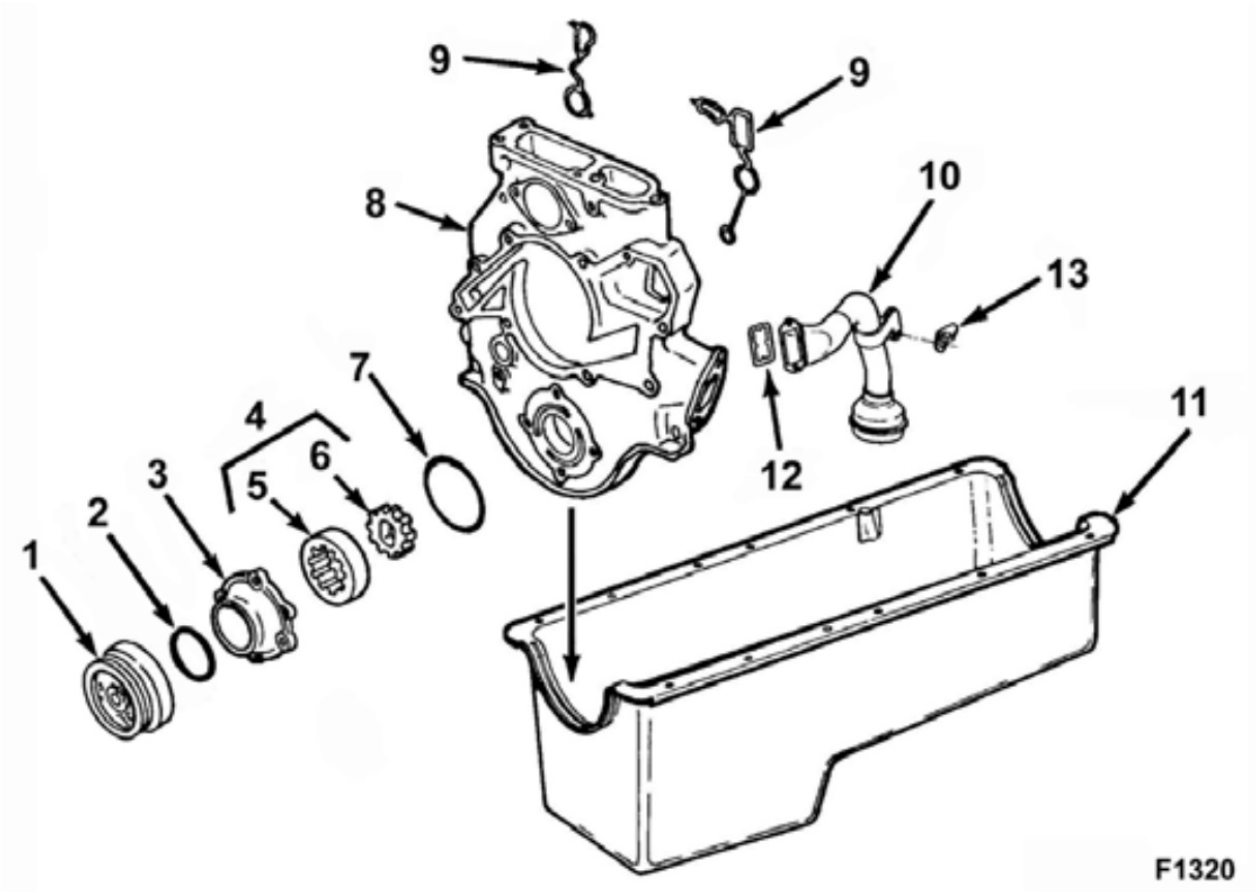

Figure 189 Oil Pump and Pick-Up Assembly

1. Vibration Damper
2. Front Seal
3. Oil Pump Housing
4. Oil Pump Gerotor Assembly
5. Outer Oil Pump Gerotor
6. Inner Oil Pump Gerotor
7. Oil Pump Housing Gasket
8. Front Cover
9. Front Cover Gasket (2)
10. Oil Pick-Up Tube Bracket
11. Oil Pan
12. Oil Pick-Up Tube Gasket
13. Oil Pick-Up Tube

Removal

Oil Pan

NOTE: BE SURE oil pan has been drained before removing.

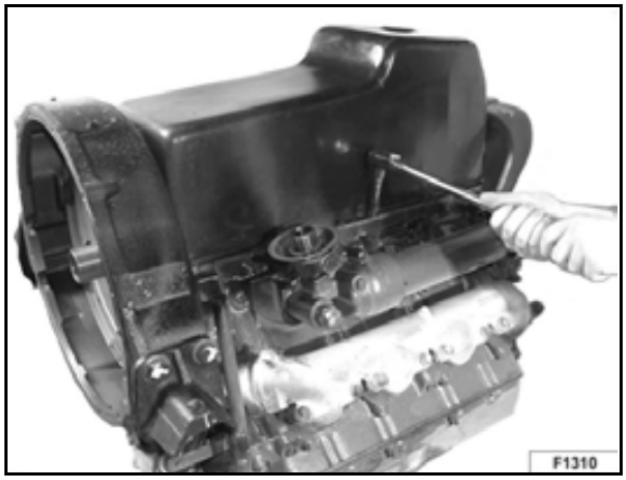

Figure 190 Removing Oil Pan Mounting Bolts

1. Remove the oil filter.
2. Remove the oil pan mounting bolts.

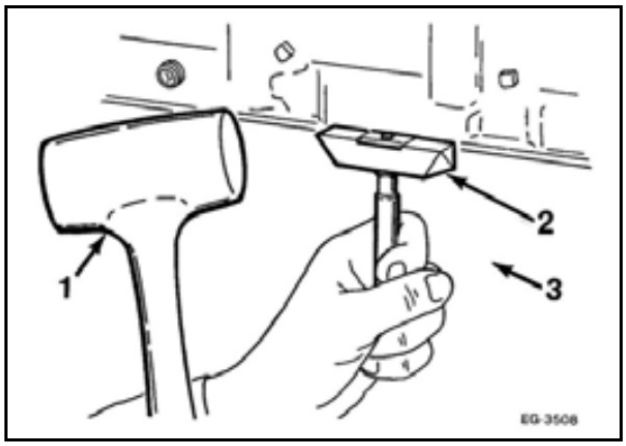

Figure 191 Cutting the RTV Sealant on the Oil Pan

1. Hammer
2. RTV Sealant Cutting Tool
3. Oil Pan

3. Use a cutting tool to cut through the RTV sealant on both oil pan rails.

Figure 192 Removing the Oil Pan From the Crankcase

4. Pry the oil pan down on one side to break the RTV sealant at the front cover and rear plate. Roll the oil pan off to the side to free it from the engine.

Oil Pick-Up Tube

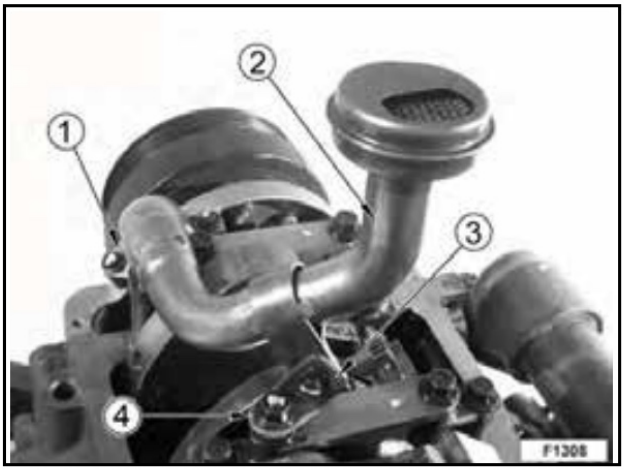

Figure 193 Removing the Oil Pick-Up Tube

1. Mounting Bolt (2)
2. Oil Pick-Up Tube
3. Support Bracket
4. Bracket Nut

Remove the two mounting bolts and the bracket nut from the oil pick-up tube. Remove the oil pick-up tube.

Vibration Damper

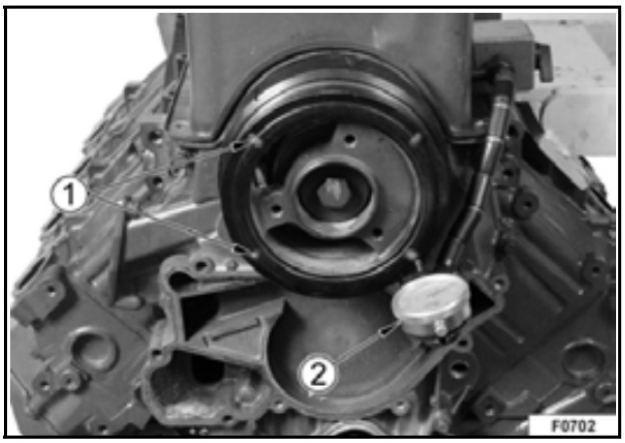

Figure 194 Checking the Vibration Damper Runout

1. Paint Removal Areas (4 locations at 90° intervals)
2. Dial Indicator

1. Before removing the vibration damper, check the vibration damper runout as follows:

   NOTE: Pry only in one direction to eliminate any possible error induced by crankshaft end play.

   a. Remove any paint from the face of the vibration damper at four points 90° apart.

   b. Attach a magnetic base dial indicator to the front of the crankcase or oil pan. Position the indicator point on the unpainted surface.

   c. Pry the crankshaft forward and zero the indicator. The zero point is now the baseline.

   d. Turn the crankshaft 90° and pry the crankshaft forward. Record the reading.

   e. Repeat Step d at each unpainted surface. If the runout exceeds specifications, replace vibration damper.

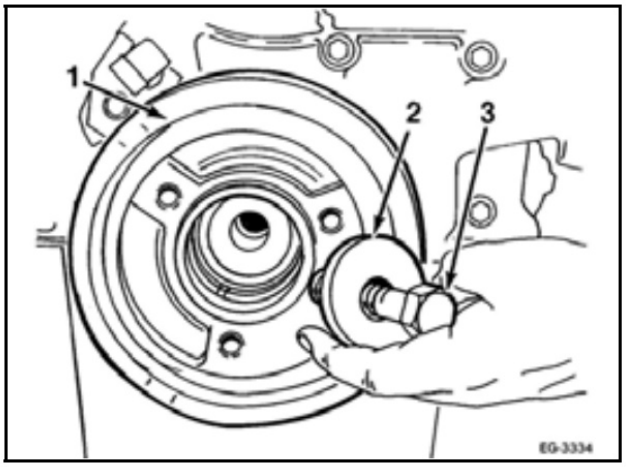

Figure 195 Removing the Vibration Damper Mounting Bolt

1. Vibration Damper
2. Washer
3. Mounting Bolt

2. Remove the vibration damper mounting bolt. Remove the washer and loosely install the mounting bolt so the puller does not damage the bolt threads during removal.

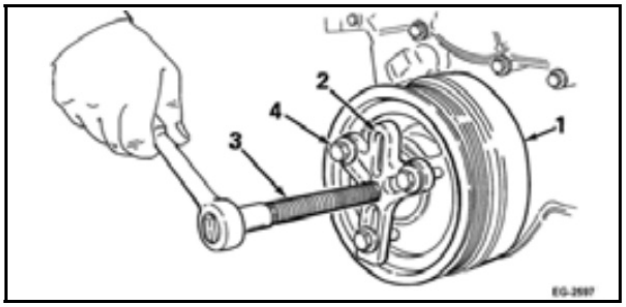

Figure 196 Removing the Vibration Damper Assembly

1. Vibration Damper
2. Puller
3. Forcing Screw
4. Removal Bolts (3)

3. Mount the vibration damper removal tool to the damper with the three bolts that are provided.

4. Insert the forcing screw and turn it in against the mounting bolt. The vibration damper will be pulled off the crankshaft. Remove the mounting bolt and the damper.

Vibration Damper Wear Sleeve

NOTE: Whenever the vibration damper is removed, the vibration damper wear sleeve must be replaced. Make sure the vibration damper has been cleaned and inspected before proceeding with the wear sleeve removal.

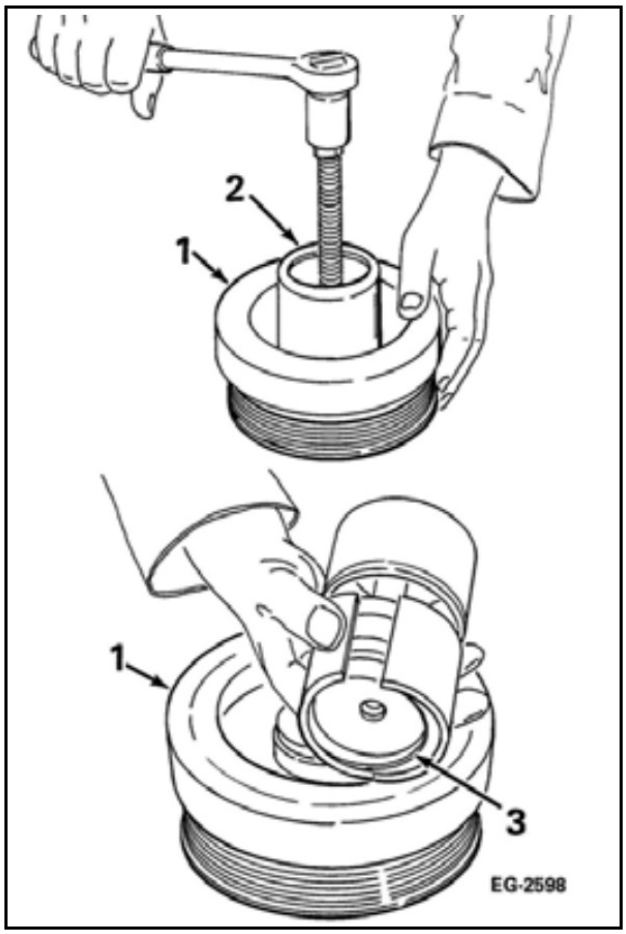

Figure 197 Removing the Vibration Damper Wear Sleeve

1. Vibration Damper
2. Wear Sleeve Removal Tool
3. Wear Sleeve

1. Install the wear sleeve removal tool on the vibration damper.
2. Turn the forcing screw to remove the wear sleeve.

Front Oil Seal

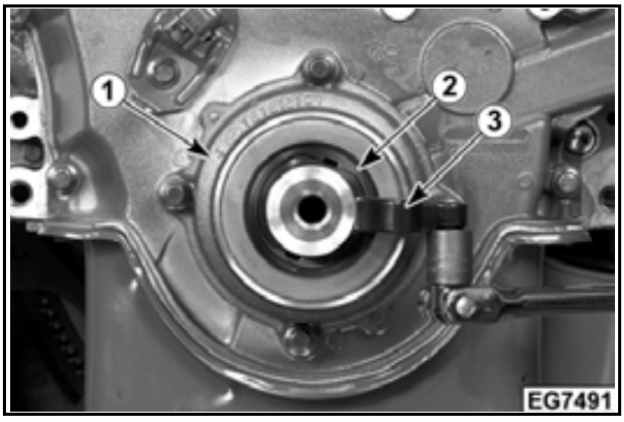

Figure 198 Removing the Front Oil Seal

1. Oil Pump Housing
2. Front Oil Seal
3. Oil Seal Removal Tool

Use the oil seal removal tool to pry the front oil seal from the oil pump housing.

Oil Pump

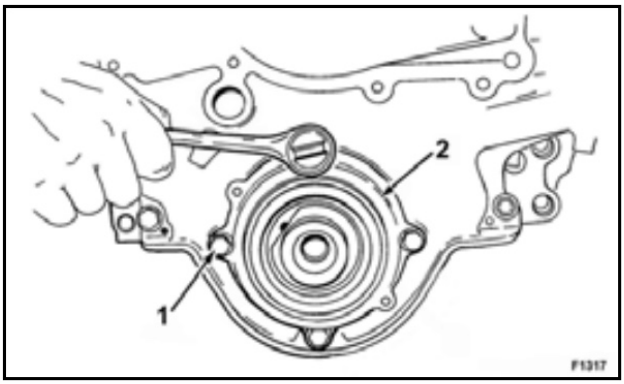

Figure 199 Removing Oil Pump Housing Mounting Bolts

1. Retainer Bolts (4)
2. Oil Pump Housing

1. Remove the four mounting bolts for the oil pump housing.

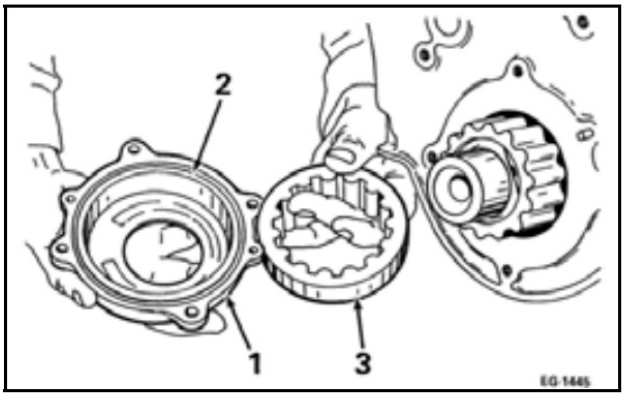

Figure 200 Removing Oil Pump Housing and Outer Gerotor Gear

1. Oil Pump Housing
2. Seal Ring
3. Outer Gerotor

2. Remove the oil pump housing with seal ring and the outer gerotor. Discard the seal ring.

NOTE: The crankshaft woodruff key can remain in place when removing the inner gerotor.

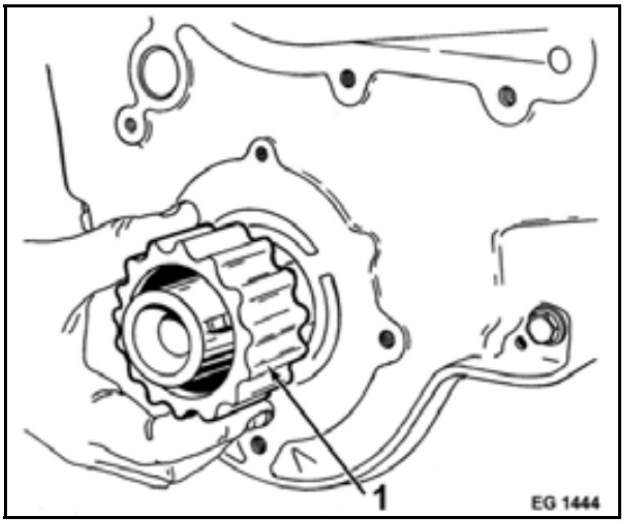

Figure 201 Removing Inner Gerotor From Crankshaft

1. Inner Gerotor

3. Remove inner gerotor gear by sliding it off crankshaft.

Water Pump

1. Remove the coolant filter from the water pump housing.
2. Remove the mounting bolts that secure the water pump to the front cover.

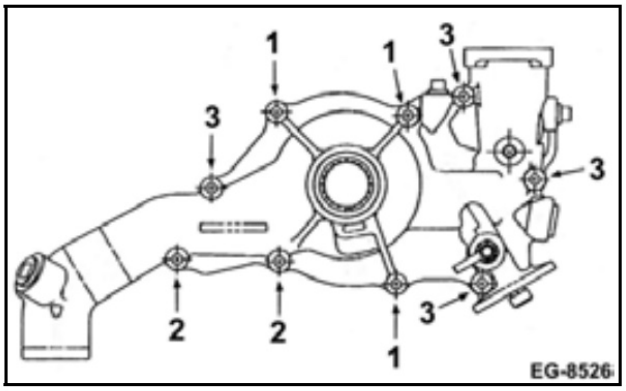

Figure 202 Water Pump Mounting Bolts

1. 30 mm (1–1/4 in)
2. 60 mm (2–1/2 in)
3. 100 mm (4 in)

3. Remove and discard the water pump gasket.

Front Cover

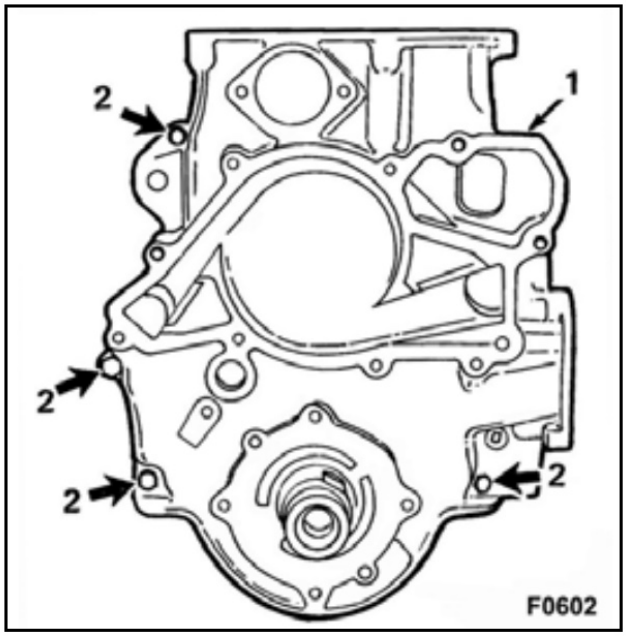

Figure 203 Front Cover and Mounting Bolts

1. Front Cover
2. Mounting Bolts

NOTE: Refer to Water Pump Removal if removing the water pump.

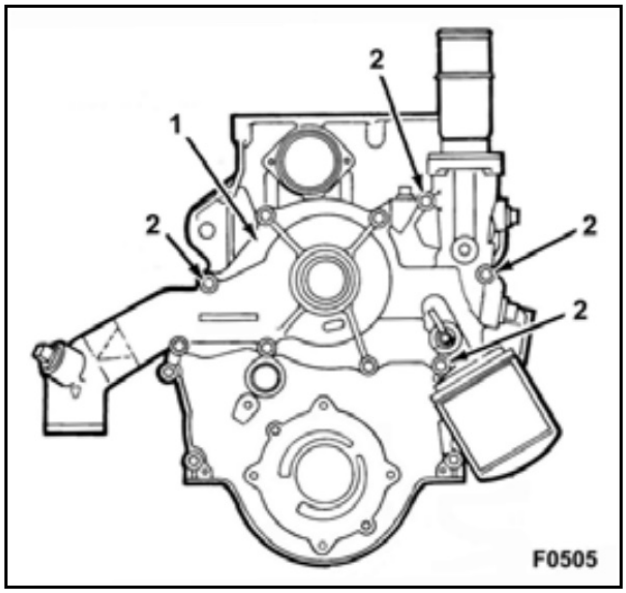

Figure 204 Water Pump and Mounting Bolts

1. Remove the four front cover mounting bolts and four water pump mounting bolts that secure the front cover to the crankcase.

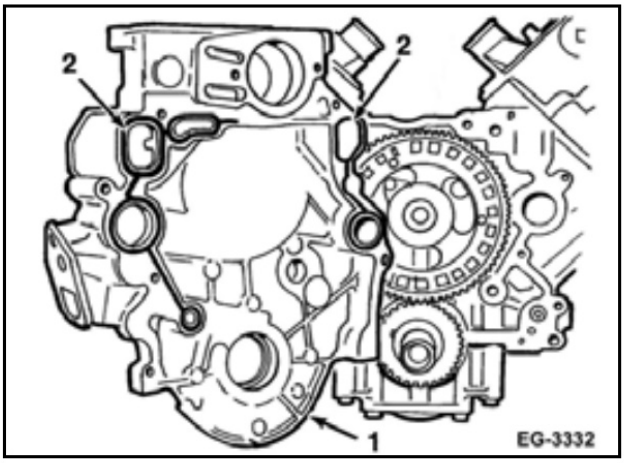

Figure 205 Removing the Front Cover From the Crankcase

1. Front Cover
2. Front Cover Gaskets

2. Remove the front cover from the crankcase.
3. Remove and discard the gaskets from the front cover.

Cleaning

Oil Pan

Thoroughly clean the RTV sealant from the oil pan and crankcase mating surfaces and from the bolt holes in the crankcase and oil pan.

Vibration Damper

CAUTION: Do not immerse the vibration damper in a petroleum based solvent. Damage to the rubber damping element may result.

Clean the vibration damper with soap and water. Dry it with filtered compressed air.

Oil Pump

Wash all parts thoroughly in a suitable solvent. Dry the parts with filtered compressed air.

Water Pump

Wash the water pump thoroughly in a suitable cleaning solvent. Dry the pump with filtered compressed air.

Front Cover

Clean the RTV sealant and gasket material from the front cover, crankcase and mating surfaces.

Inspection

Oil Pick-Up Tube

Inspect the pick-up tube for cracks at the seams and brazed connections. Replace the tube if required.

Vibration Damper

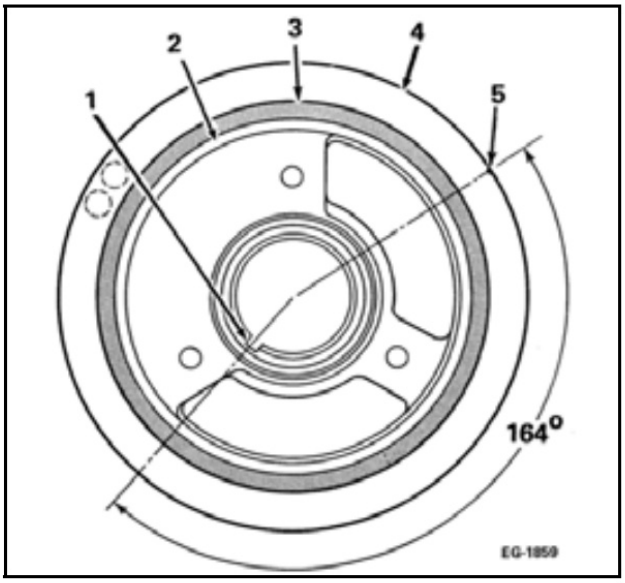

Figure 206 Vibration Damper Components

1. Keyway
2. Inner Member
3. Rubber Member
4. Outer Member
5. Timing Mark

Use a protractor to measure the angle between the timing mark and the center of the key way. If the angle is not 164°, replace the vibration damper.

Oil Pump

1. Inspect the gerotors and housing for nicks, burrs or scoring. Replace any damaged components.

CAUTION: When placing the inner and outer gerotors into the oil pump housing, make sure the word "damper" is facing the oil pump housing. Failure to do so will result in engine damage.

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

2. Place the inner and outer gerotors in the oil pump housing.

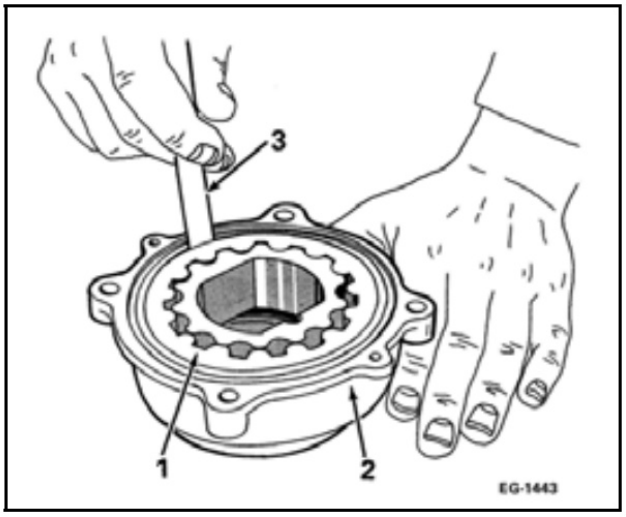

Figure 207 Inspecting Gerotors For Wear

1. Outer Gerotor
2. Oil Pump Housing
3. Feeler Gauge

3. To check for wear, use a feeler gauge to measure the radial clearance between the outer gerotor and the pump housing.

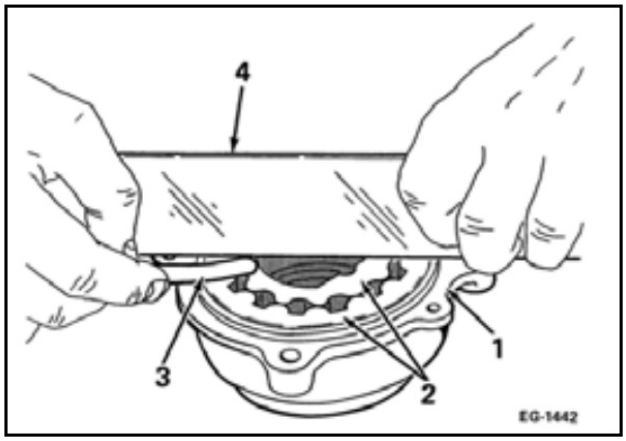

Figure 208 Checking the Oil Pump End Clearance

1. Oil Pump Housing
2. Gerotors
3. Feeler Gauge
4. Straightedge

4. Check the oil pump end clearance as follows:
   a. With the O-ring removed and the gerotors in place in the oil pump housing, place a straightedge across the housing.
   b. Insert a feeler gauge under the straightedge at the inner and outer gerotors and compare the end clearance with the specification.
5. If the measurements are not within the specifications, replace the components as required.

Water Pump

Inspect the water pump for cracks and damage. Replace the pump if necessary.

Front Cover

1. Inspect the front cover for cracks and damage.
2. Place the mounting surface of the front cover on a smooth flat surface and check for warp.
3. Replace the front cover if cracked, damaged or warped.

Installation

Vibration Damper Wear Sleeve

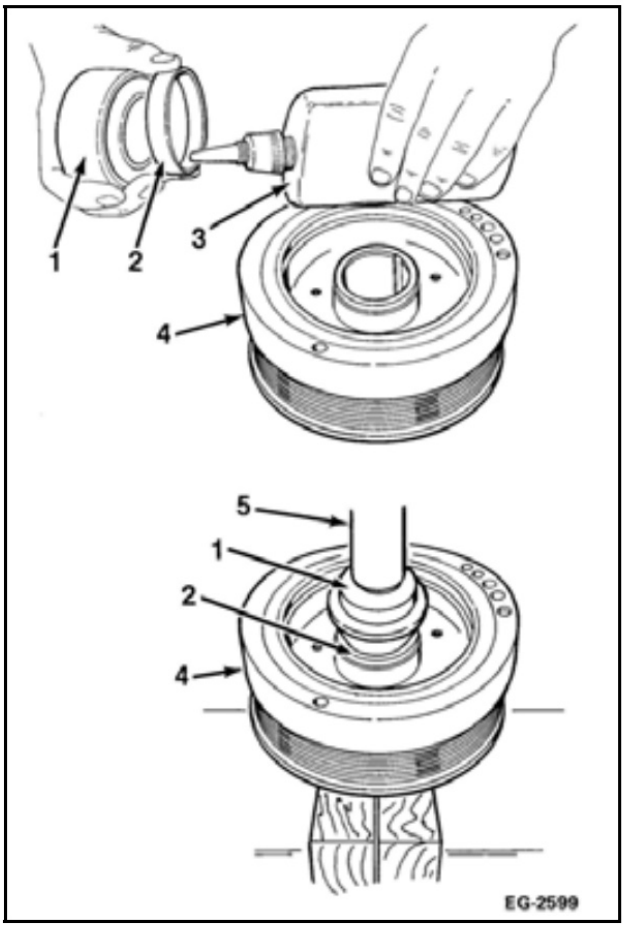

Figure 209 Installing the Vibration Damper Wear Sleeve

1. Wear Sleeve Installation Tool
2. Wear Sleeve
3. Loctite® #271
4. Vibration Damper
5. Press

NOTE: Make sure the vibration damper is clean and free of oil before installing the wear sleeve.

1. Apply Loctite® #271 around the inside diameter of the wear sleeve. Place the wear sleeve onto the wear sleeve installation tool.
2. Position the wear sleeve in the installation tool so the outer chamfer is facing toward the tool.
3. Place the installation tool on a press table. Position the vibration damper over the wear sleeve installation tool and lower the damper onto the wear sleeve installation tool.
4. Use a press to apply pressure to the inner member of the vibration damper until the installation tool bottoms out or seats.

Front Cover and Water Pump

CAUTION: Failure to properly install the front cover may result in engine damage. To properly install the front cover, the water pump must be installed before tightening the front cover mounting bolts. Four of the water pump mounting bolts also secure the front cover.

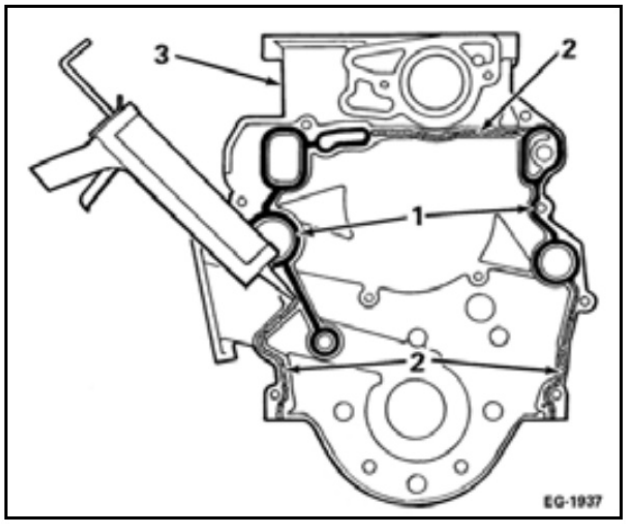

Figure 210 Installing the Gaskets and Applying RTV to the Front Cover

1. New Gaskets
2. Sealant Locations
3. Front Cover

1. Position two new gaskets on the front cover. Apply RTV sealant in the remaining grooves of the front cover and around the front cover dowel pins.

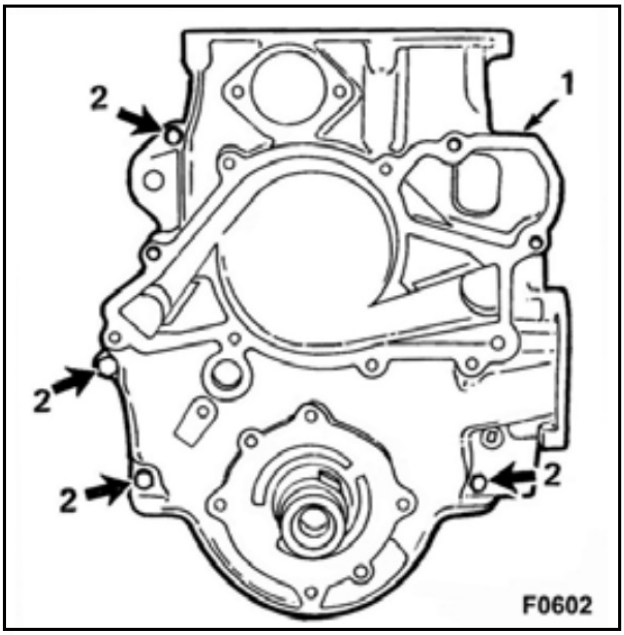

Figure 211 Installing the Front Cover to the Crankcase

1. Front Cover
2. Front Cover Mounting Bolts

2. Fasten the front cover to the crankcase. Install the front cover mounting bolts finger tight.
3. Place a new gasket in the water pump gasket groove.

CAUTION: Failure to properly mount the water pump and obtain a correct seal may result in engine damage. To properly mount the water pump and obtain a correct seal, install the water pump mounting bolts into their proper locations.

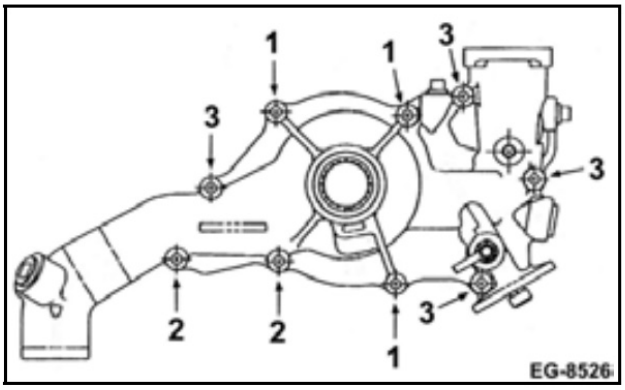

Figure 212 Water Pump Mounting Bolts

1. 30 mm (1–1/4 in)
2. 60 mm (2–1/2 in)
3. 100 mm (4 in)

4. Install the water pump on the front cover. Install the water pump mounting bolts and tighten the bolts to the standard torque values.
5. Tighten the front cover mounting bolts to the standard torque value.

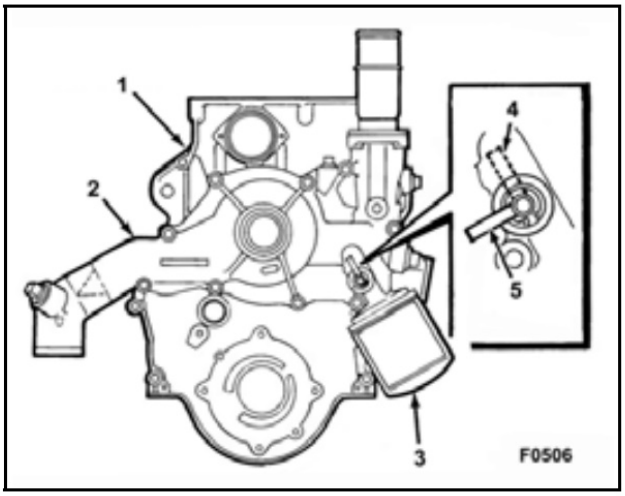

Figure 213 Installing Coolant Filter

1. Front Cover
2. Water Pump
3. Coolant Filter
4. Coolant Filter Shutoff Valve (ON Position)
5. Coolant Filter Shutoff Valve (OFF Position)

6. Apply a thin coat of new coolant to the coolant filter gasket. Thread the coolant filter onto the filter header.
7. Tighten the filter until the gasket touches the header. Tighten it by hand an additional 1/2 turn.
8. Open the coolant filter shutoff valve on the water pump.

Oil Pump

CAUTION: When installing the inner and outer gerotor, make sure the word "damper" is facing towards the front of the engine. Failure to do so will result in engine damage.

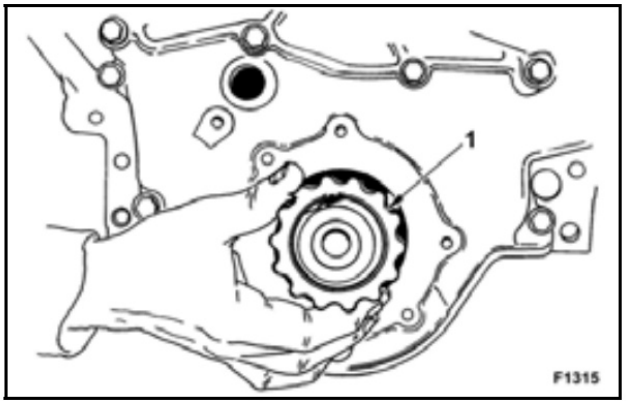

Figure 214 Installing the Inner Gerotor

1. Inner Gerotor

1. Install the inner gerotor over the crankshaft nose with the word “damper” facing the oil pump housing.

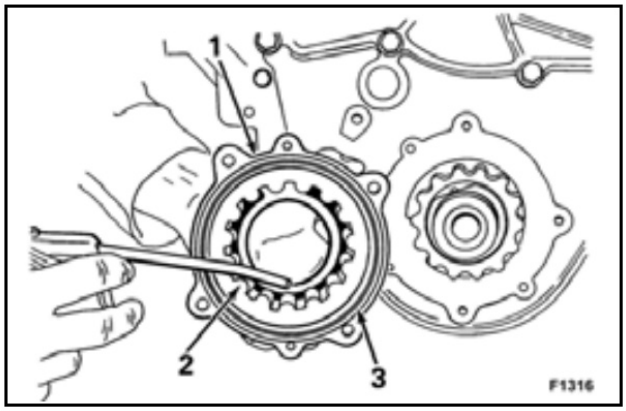

Figure 215 Installing Outer Gerotor and Square Cut Ring

1. Oil Pump Housing
2. Outer Gerotor
3. Seal Ring

2. Lubricate the outer gerotor with clean engine oil. Install the gerotor in the oil pump housing with the word “damper” facing the oil pump housing.
3. Pack cavities between and around the gerotor with an all purpose assembly grease to insure proper priming at engine startup.
4. Install square cut seal ring in the oil pump housing groove.

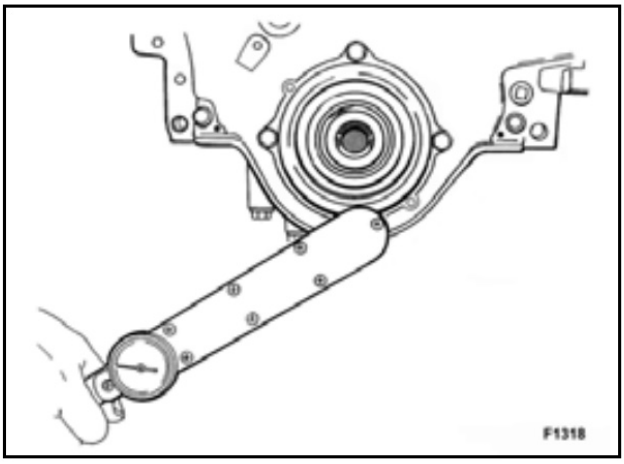

Figure 216 Installing the Oil Pump Housing

5. Align dowel pins and install oil pump housing with seal ring and large gerotor gear onto crankshaft.
6. Install four oil pump housing mounting bolts. Tighten bolts to standard torque value.

Front Oil Seal

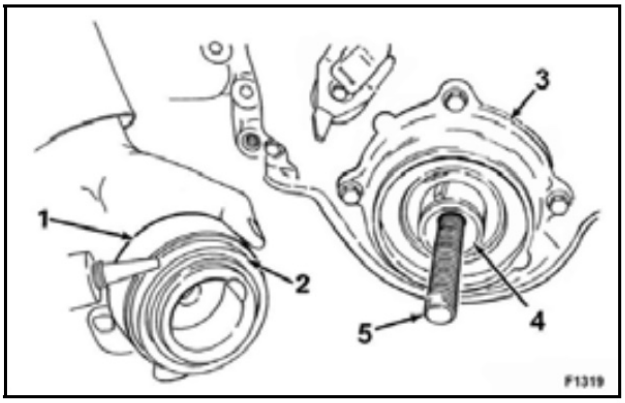

Figure 217 Installing Front Oil Seal

1. Damper/Crankshaft Oil Seal Installation Tool
2. Oil Seal
3. Oil Pump Housing
4. Crankshaft
5. Forcing Screw

1. Place front oil seal onto the installation tool. Apply a thin coat of Aviation Permatex No. 3 to the outside diameter of the seal.

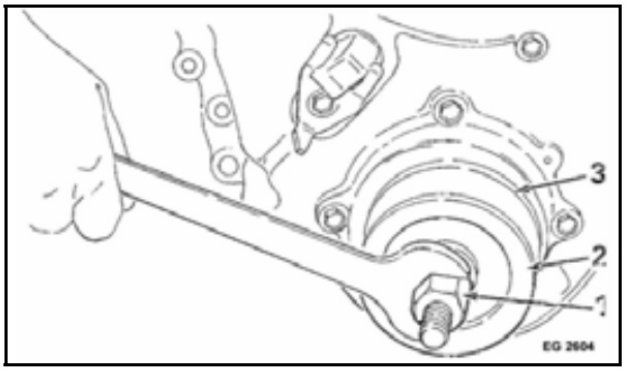

Figure 218 Seating the Front Oil Seal

1. Forcing Nut
2. Installation Tool
3. Oil Seal

2. Position the installation tool over the forcing screw and tighten the forcing nut. Make sure the tool bottoms out against the housing so the oil seal is fully seated in the housing.

Vibration Damper

1. Apply RTV sealant to the vibration damper keyway. This prevents oil seepage through damper keyway. Align the keyway in the damper with the key on the crankshaft and install the damper.

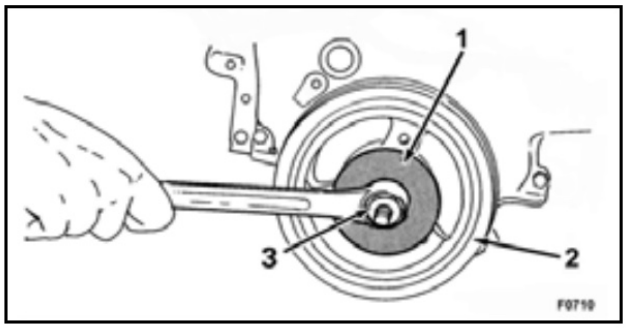

Figure 219 Installing the Vibration Damper Installation Tool

1. Installer Plate
2. Vibration Damper
3. Forcing Nut

NOTE: ZTSE4310 is a combination tool. One side is used to install the front oil seal while the other side is used to install the vibration damper.

2. Assemble the puller screw, installer plate, thrust washer and nut.
3. Turn nut to draw the vibration damper onto the crankshaft.
4. Remove the installation tool.

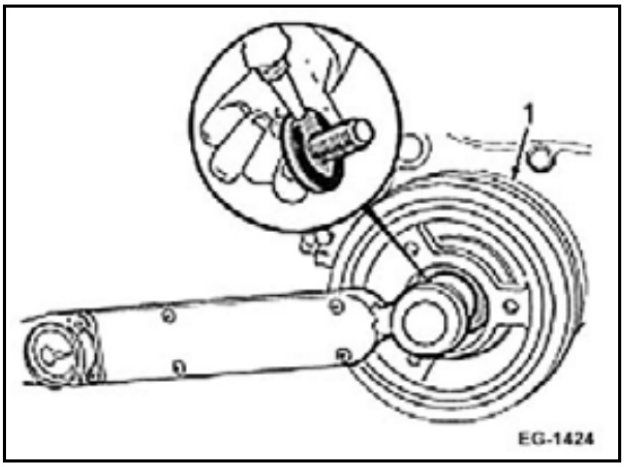

Figure 220 Securing the Vibration Damper to the Crankshaft

1. Vibration Damper

5. Apply RTV sealant to the washer and underside of the bolt head. Install the washer and mounting bolt. Tighten the bolt to the special torque value.

Oil Pick-Up Tube

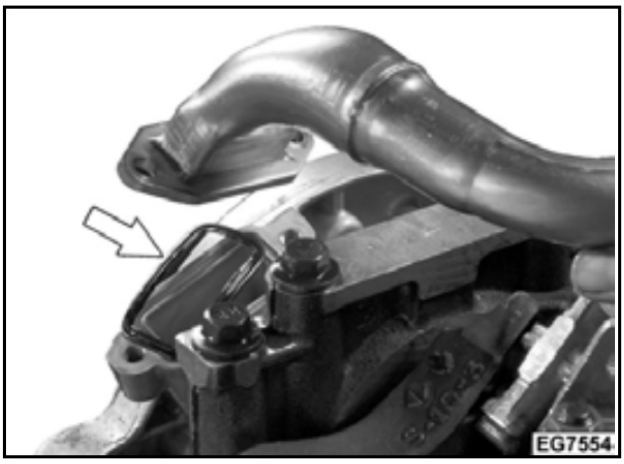

Figure 221 Installing the Oil Pick-Up Tube O-Ring

1. Install the O-ring on the oil pick-up tube mounting flange. If necessary, use a small amount of RTV sealant to hold the O-ring in place.

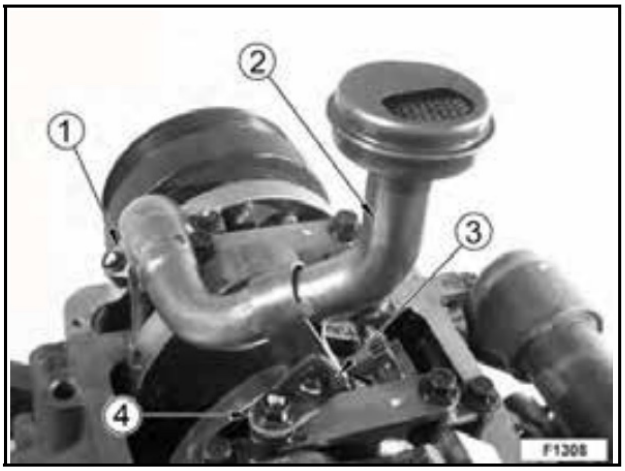

Figure 222 Installing the Oil Pick-Up Tube

1. Mounting Bolt (2)
2. Oil Pick-Up Tube
3. Support Bracket
4. Bracket Nut

2. Install the oil pick-up tube and mounting bolts. Tighten the bolts finger tight.
3. Adjust the bracket at the main bearing cap stud and install the nut. Tighten the mounting bolts to the standard torque value after alignment. Tighten the bracket nut at the main bearing cap stud last.

Oil Pan

CAUTION: Do not apply excessive amounts of RTV sealant. Some could end up in the oil pick-up screen and restrict oil flow. Such a restriction may result in engine damage. To avoid damaging the crankcase, make sure no sealant gets in the bolt holes.

1. Wipe excess oil and foreign matter from all oil pan sealing surfaces. Use brake cleaner to thoroughly degrease all sealing surfaces before applying RTV sealant.

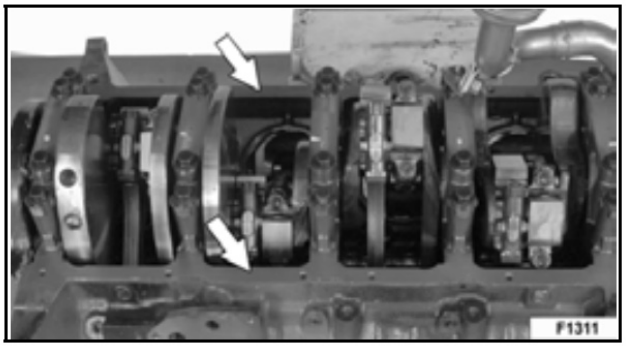

Figure 223 Apply RTV Sealant to the Crankcase Rails

2. Apply RTV sealant to the entire crankcase mounting surface to prevent leaks. Apply more at the front and rear mating surfaces. Apply the sealant between and around the bolt holes.
3. Install guide studs at two places on the crankcase to ensure proper oil pan alignment. Install the oil pan.

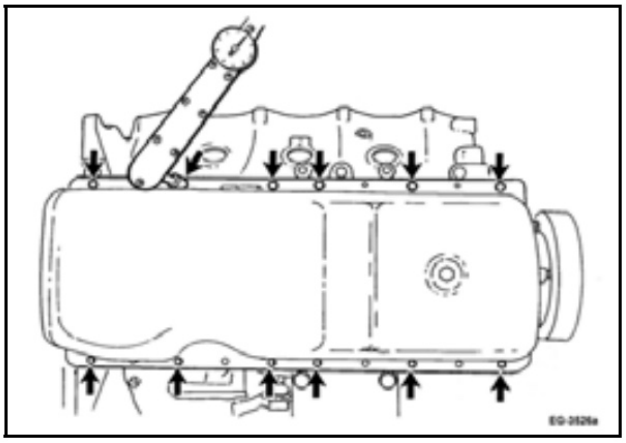

Figure 224 Oil Pan Bolt Hole Locations

4. Install mounting bolts finger tight. Remove the guide studs. Replace them with mounting bolts. Tighten all mounting bolts to the standard torque value.

SPECIFICATIONS

Table 13 Vibration Damper, Lubricating Oil Pump, Oil Pan, Oil Pick-Up Tube and Front Cover

Lubricating Oil Pump	
Type	Gerotor
End Clearance - inner and outer rotor to housing	0.02-0.08 mm (0.001-0.003 in)
Radial clearance between outer rotor housing	0.71-0.81 mm (0.028-0.032 in)
Engine Lube Oil Pressure at Operating Temperature	
At low idle speed (700 rpm) minimum	69 kPa (10 psi)
At high idle speed	241-483 kPa (35-70 psi)
Engine Oil Capacity	
Without filter	17 liters (18 quarts)
With filter	18.5 liters (19.5 quarts)
Vibration Damper	
Vibration damper mounting area runout (maximum)	0.13 mm (0.005 in)

Special Torque

Table 14 Vibration Damper, Lubricating Oil Pump, Oil Pan, Oil Pick-Up Tube and Front Cover Special Torques

Oil Pan Drain Plug	41 N·m (30 lbf·ft)
Oil Pan Mounting Bolts	34 N·m (25 lbf·ft)
Oil Pick-Up Tube Flange Mounting Bolts	24 N·m (18 lbf·ft)
Oil Level Gauge Tube Adapter Nut	34 N·m (25 lbf·ft)
Vibration Damper Mounting Bolt	287 N·m (212 lbf·ft)
Water Pump Pulley Mounting Screw	41 ± 7 N·m (30 ± 5 lbf·ft)

SPECIAL SERVICE TOOLS

Table 15 Vibration Damper, Lubricating Oil Pump, Oil Pan, Oil Pick-Up Tube and Front Cover Special Service Tools

OEM1028	Magnetic Base Dial Indicator
OEM1293	Straightedge
ZTSE229569	Vibration Damper Removal Tool
ZTSE4300	Fuel Injector/Front Oil Seal Removal Tool
ZTSE4310	Front Oil Seal/Vibration Damper Installation Tool
ZTSE4314	Vibration Damper Wear Ring Removal Tool
ZTSE4315	Vibration Damper Wear Ring Installation Tool
ZTSE4385	Oil Pan Removal Tool

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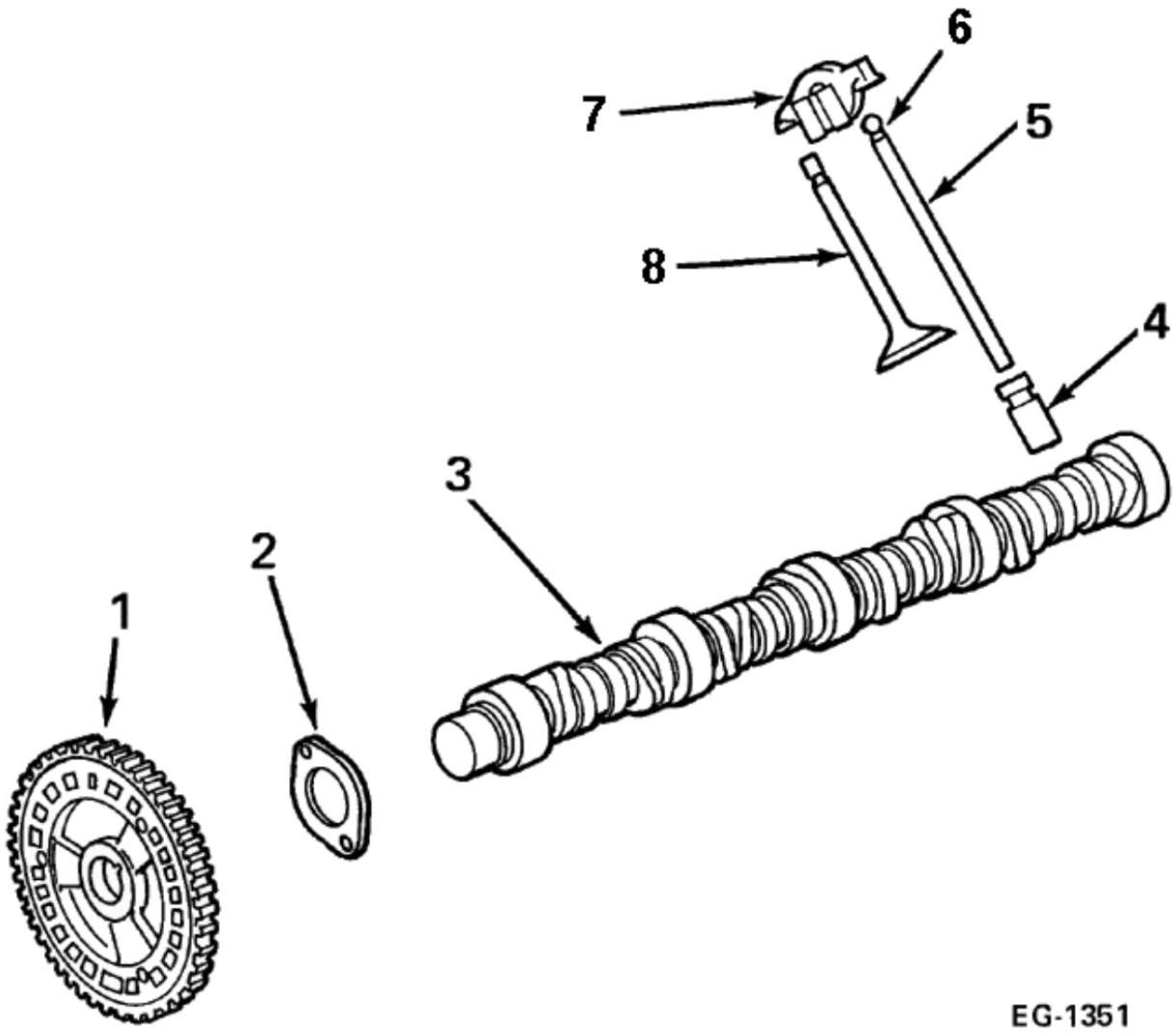

Figure 225 Valve Train Components

1. Camshaft Gear
2. Thrust Plate
3. Camshaft
4. Hydraulic Valve Lifter
5. Valve Push Rod
6. Copper Colored End
7. Valve Lever
8. Valve

Push Rods and Hydraulic Valve Lifters

Operation

NOTE: As a general rule, hydraulic valve lifters should not require any service if they are operating quietly and functioning satisfactorily.

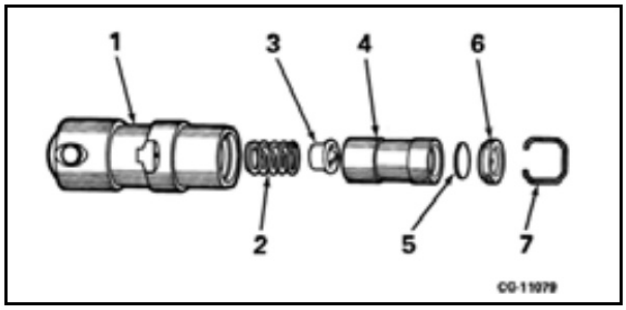

Figure 226 Valve Lifter Components

1. Lifter Body with Roller
2. Spring
3. Plunger
4. Plunger Body
5. Metering Valve
6. Push Rod Seat
7. Retainer

Lube oil from the oil gallery is supplied to the lifters through a hole in the side of the lifter body that indexes with a groove and hole in the lifter plunger. Oil is then metered past the oil metering valve, up through the push rods and onto the valve levers.

When the lifter begins to roll up the cam lobe, the metering valve is held against its seat in the plunger body by the spring. This action traps the oil in the base of the lifter body below the plunger. The plunger body and lifter body then rise as a unit, pushing the push rod up in order to open the valve. The spring force exerted on the plunger through the valve lever and push rod causes a slight amount of leakage between the plunger and lifter body.

"Leak down" is the term used to describe this leakage. Leak down allows a slow escape of trapped oil in the base of the lifter body. As the lifter rides down the other side of the cam lobe and reaches the base circle or "valve closed" position, the plunger spring quickly moves the plunger back up to its original position. This movement causes the check valve to open against the check valve spring and allows oil to be replenished from the oil gallery. This restores the lifter to zero lash.

Removal

CAUTION: To avoid engine damage, the valve lifters and push rods must be kept in order so they can be installed in their original positions.

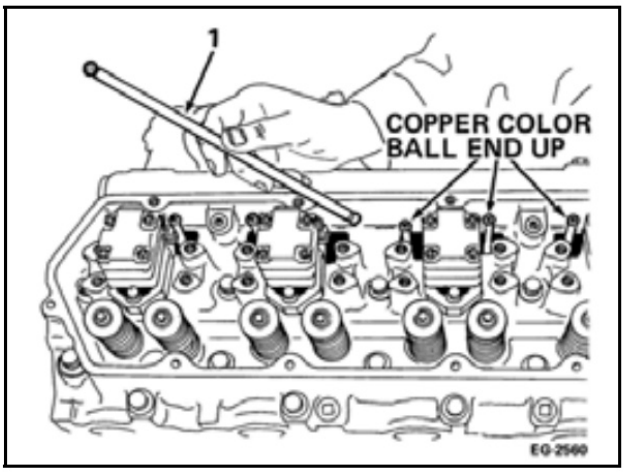

Figure 227 Removing the Push Rods

1. Push Rod

1. Remove the push rods from the crankcase.

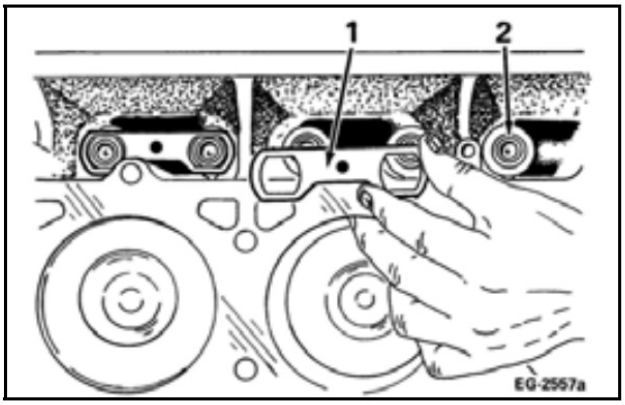

Figure 228 Removing the Valve Lifter Guide

1. Valve Lifter Guide
2. Valve Lifter

2. Remove the retaining bolt from the center of each valve lifter guide. Remove the valve lifter guides from the crankcase.

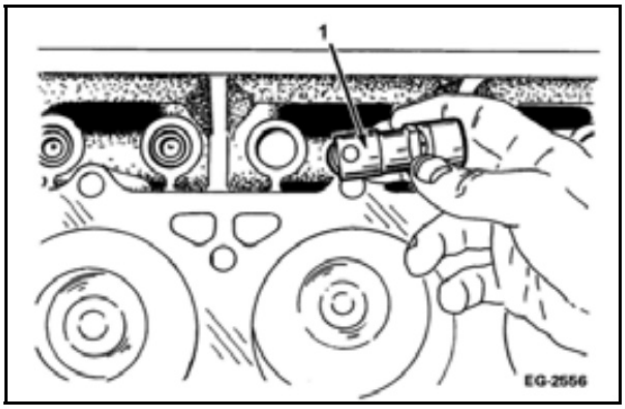

Figure 229 Removing the Valve Lifter

1. Valve Lifter

3. Remove the hydraulic valve lifters from the crankcase. Note the orientation of the lifters within the bore so they can be installed later in their original positions.

Disassembly

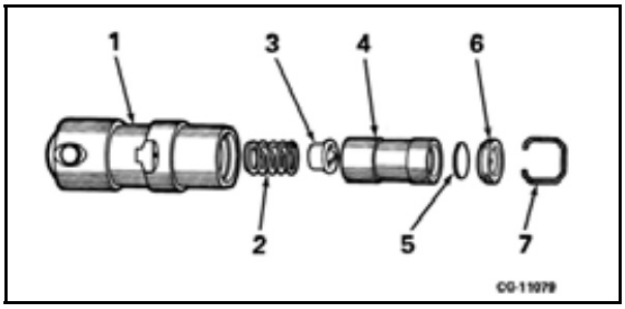

Figure 230 Disassembling the Valve Lifter

1. Lifter Body with Roller
2. Plunger Spring
3. Plunger
4. Plunger Body
5. Metering Valve
6. Push Rod Seat
7. Retainer

1. Use a small screwdriver to remove the push rod seat retainer.
2. Remove the push rod seat and metering valve.
3. Remove the plunger, plunger body, and plunger spring.

Cleaning

Clean the push rods and all the parts of the hydraulic valve lifters with a suitable cleaning solvent. Dry the parts with filtered compressed air.

Inspection

1. Inspect all disassembled parts for nicks, burrs or scoring. If signs of damage are evident, replace the entire hydraulic valve lifter.
2. Inspect each push rod for wear and deposits that may restrict the flow of oil into the valve lever assemblies. Replace the push rods as required.

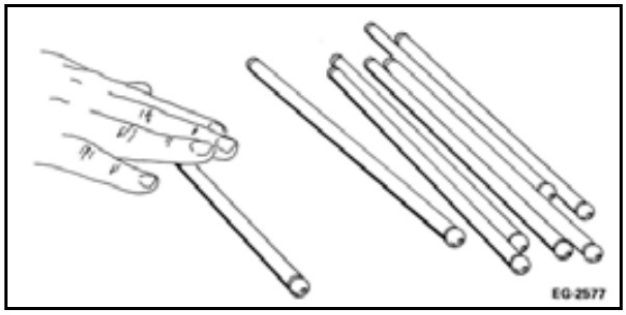

Figure 231 Checking the Push Rod Flatness

3. Check all cleaned push rods by rolling them on a flat surface. If they are not straight or are questionable, refer to the specifications for push rod runout. If the specifications are exceeded, replace the push rod.

CAUTION: If the roller fails any one of the following inspection criteria, the camshaft lobes must be inspected for damage. Failure to do so may result in damage to the engine.

4. While pushing on the valve lifter roller in a normal direction of load, check for free rotation of the roller. Check the axial movement between the pin and roller.

NOTE: the valve lifter roller is crowned by design. Therefore, a normal wear pattern will typically be centered on the roller contact surface.

5. Inspect the roller for pitting or roughness.

Assembly

CAUTION: To avoid engine damage after assembly, perform a leak down test to ensure that leakage past the plunger and lifter body is correct. This assures that the check valve is functioning properly.

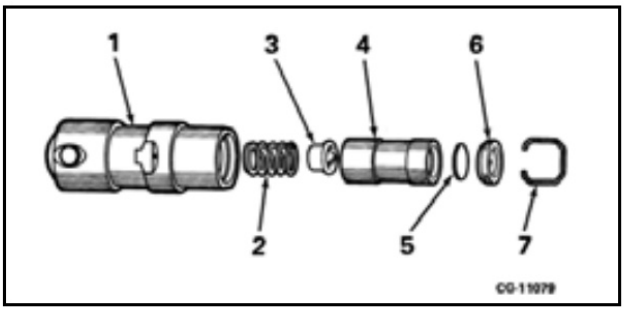

Figure 232 Assembling the Valve Lifter

1. Lifter Body with Roller
2. Plunger Spring
3. Plunger
4. Plunger Body
5. Metering Valve
6. Push Rod Seat
7. Retainer

1. Coat all hydraulic valve lifter parts with clean engine oil.
2. Install the plunger spring and plunger into the plunger body, then into the lifter body.
3. Install the metering valve and push rod seat into the valve lifter body. Secure the components with a retaining ring.

Leak Down Test

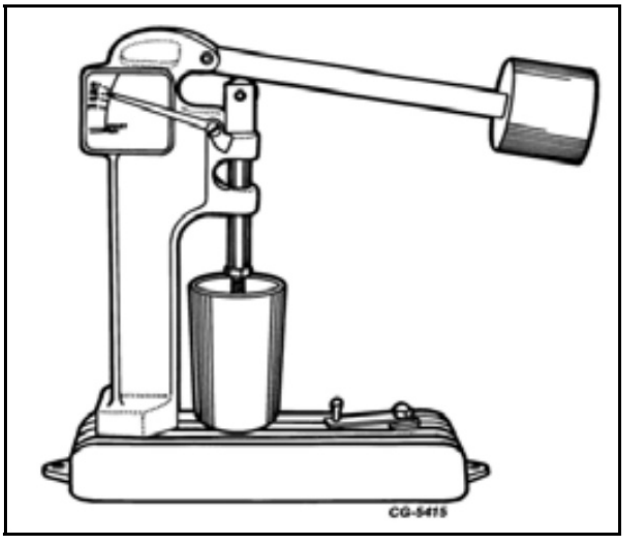

Figure 233 Valve Lifter Tester

This test is used to determine whether leakage past the plunger and lifter body is correct and whether the check valve is functioning properly.

NOTE: Use a test fluid specified by the tool manufacturer. Make sure that the fluid is at room temperature.

Use a hydraulic valve lifter tester to check the leak down rate. Follow the instructions that come with the testing unit.

The leak down rate is how many seconds it takes for the plunger to move a specified portion of the distance it will travel while under a 23 kg (50 lb) load. Refer to the specifications.

Installation

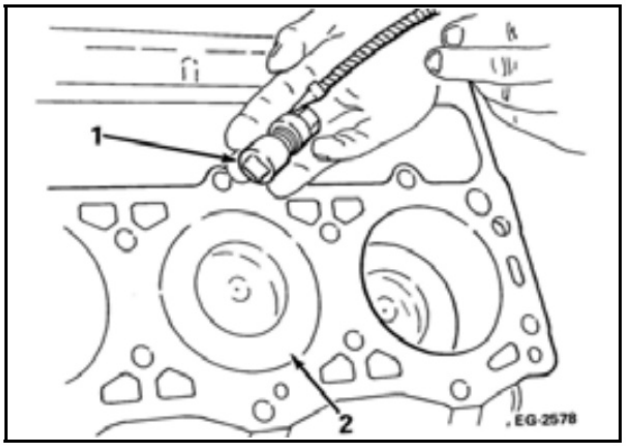

Figure 234 Installing the Valve Lifters Into the Crankcase

1. Hydraulic Valve Lifters
2. Piston

1. Lubricate the valve lifters with clean engine oil. Install the valve lifters into their respective bores within the crankcase. Maintain the original direction of rotation.

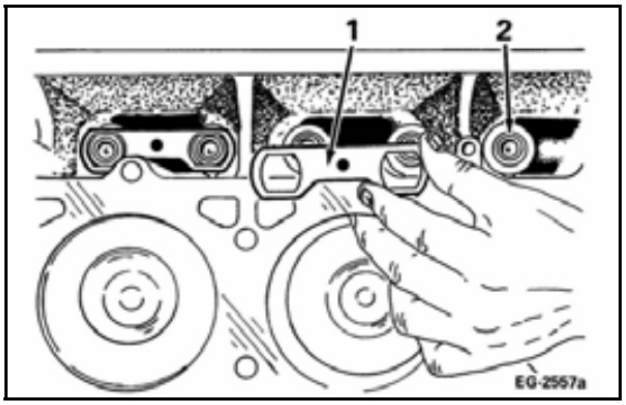

Figure 235 Installing the Valve Lifter Guide

1. Valve Lifter Guide
2. Valve Lifter

2. Install the valve lifter guides over the hydraulic valve lifters. Secure each guide to the crankcase with a retaining bolt and tighten the bolts to the standard torque value.

CAUTION: To ensure the compatibility of the metallic mating surfaces of the valve lever, push rod, and valve lifter, the copper colored end must face up when installed. Be aware that the two rounded ends of each push rod are made of different materials.

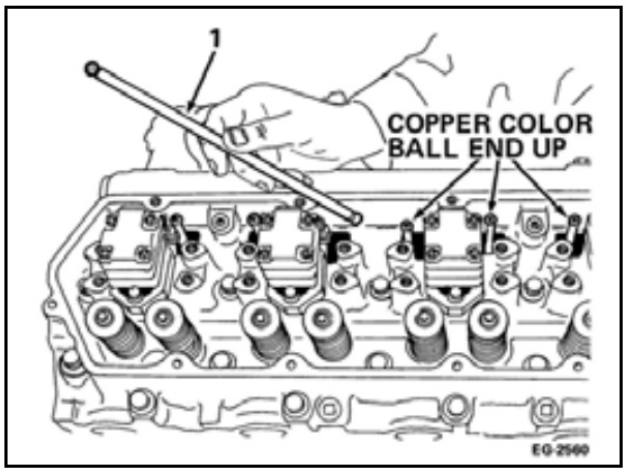

Figure 236 Installing the Push Rods

1. Push Rod

3. Make sure the copper colored ball end is facing up. Insert the push rods into their respective positions.

Camshaft and Gear

Check Gear Backlash and Camshaft End Play

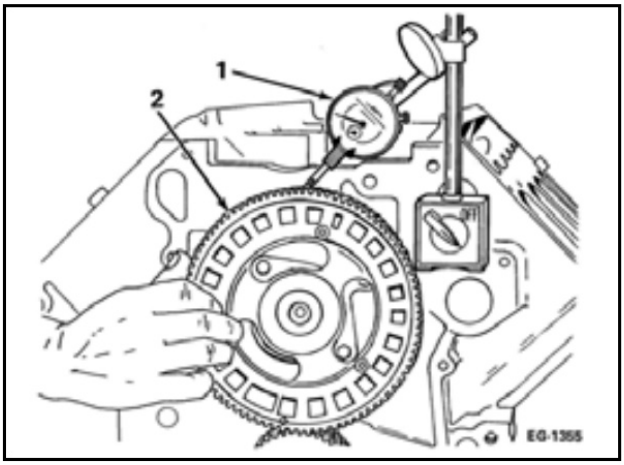

Figure 237 Checking the Camshaft-to-Crankshaft Gear Backlash

1. Dial Indicator
2. Camshaft Gear

1. Before removing the camshaft, check and record the camshaft gear-to-crankshaft gear backlash as follows:
   a. Mount a dial indicator on the front of the engine.
   b. Position the dial indicator tip on a gear tooth and remove all lash.
   c. Place a small pry bar between the camshaft and crankcase. Lightly pry the camshaft forward.
   d. Zero the dial indicator while lightly prying the camshaft forward.
   e. Rotate the gear by hand while lightly prying the camshaft forward. Record the amount of backlash.

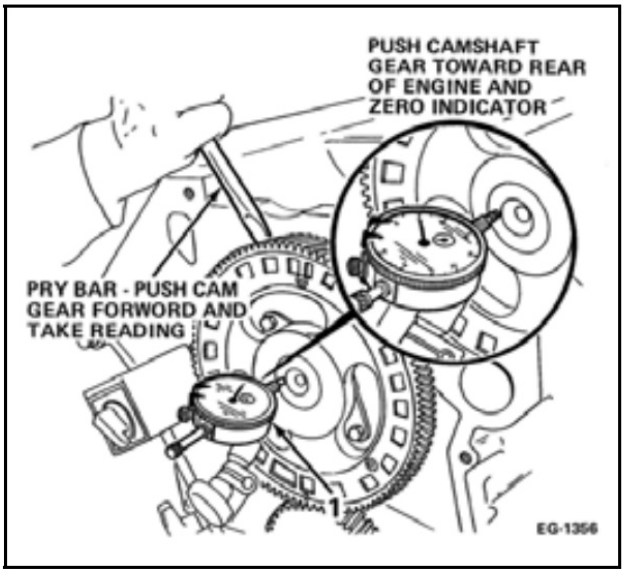

Figure 238 Checking the Camshaft End Play

1. Dial Indicator

2. Reposition the dial indicator and check the camshaft end play as follows:
   a. Push the camshaft toward rear of engine.
   b. Zero the dial indicator.
   c. Place a small pry bar between the camshaft gear and crankcase. Lightly pry the camshaft forward. Compare the dial indicator reading with the specifications.
   d. If the end play exceeds the specifications, replace the camshaft.
   e. Remove the dial indicator.

Removal

NOTE: Check the valve lifters for wear prior to any camshaft replacement. Remove the valve lifters and push rods before camshaft removal.

NOTE: If the engine is mounted on a turn over stand, rotate the engine so that the front of engine is facing up to a vertical position. This position allows for easy removal of the camshaft assembly.

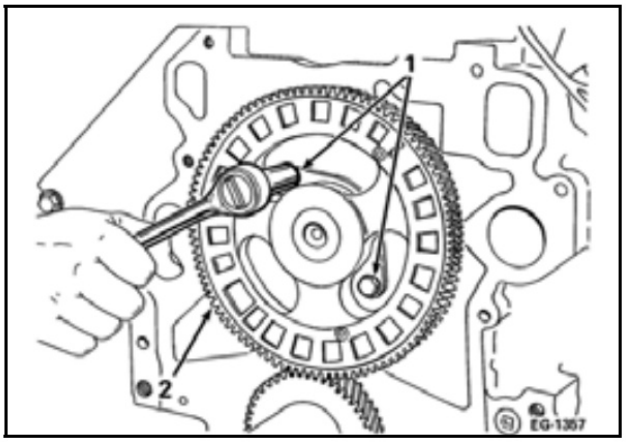

Figure 239 Removing the Cam Gear Thrust Plate Mounting Bolts

1. Cam Gear Thrust Plate Bolts
2. Camshaft Gear

1. Remove the two cam gear thrust plate mounting bolts.

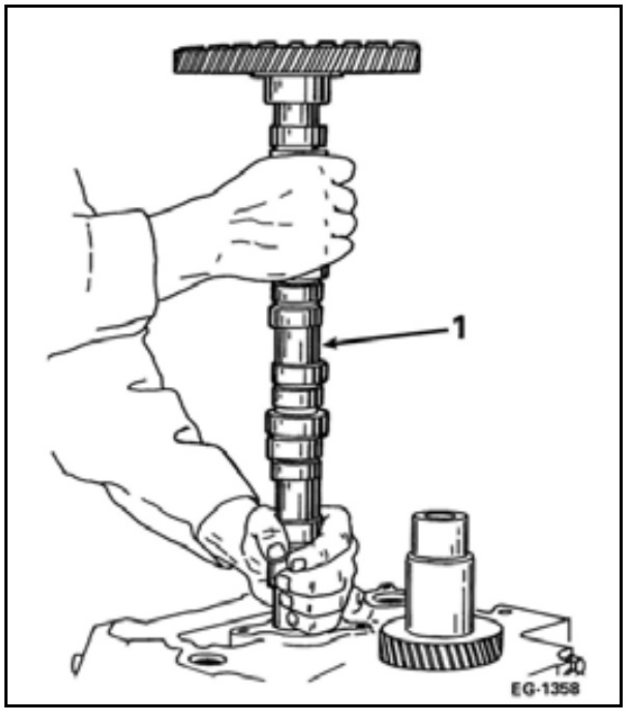

Figure 240 Removing the Camshaft Assembly

1. Camshaft Assembly

2. Remove the camshaft from the crankcase by lifting the assembly straight up.
3. Use a hydraulic press to remove the camshaft gear from the camshaft, if necessary.

Cleaning

Wash the camshaft in cleaning solvent with a soft brush. Dry it with filtered compressed air.

Inspection

NOTE: This engine uses hydraulic valve lifters with roller followers. Therefore, a lifter guide is needed to maintain proper roller-to-cam lobe orientation. Normal clearance between hydraulic valve lifter and guide allows slight tracking of the roller across the cam lobe.

The tracking of a hydraulic valve lifter roller is a normal characteristic as the roller accelerates and decelerates during typical engine operation. Consequently, a typical wear pattern on the cam lobes will exhibit tracks from side to side and will have wide and narrow areas from the loading and unloading of the follower. The visual wear pattern (tracking) is normal. It does not require camshaft replacement.

1. Inspect camshaft. If any lobes are scuffed, scored or cracked, replace the camshaft.
2. Use a micrometer to measure camshaft journal diameter. If the journals are worn beyond specifications, replace camshaft.

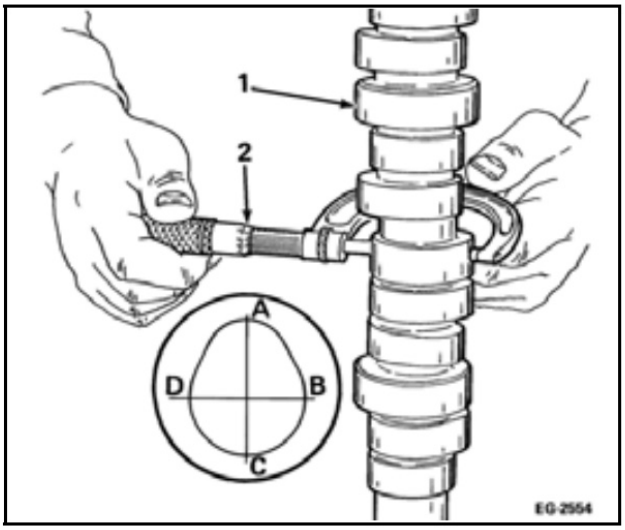

Figure 241 Checking Camshaft Lobes

1. Camshaft
2. Micrometer

3. Use a micrometer to check camshaft lobe wear. Measure across lobes (A-C and B-D). Subtract dimension B-D from dimension A-C. This is the cam lobe lift. Replace camshaft if cam lobe wear exceeds specifications.
4. Inspect the thrust plate for wear, cracks and distortion. Use a micrometer to measure thrust plate thickness. Replace the thrust plate if it is damaged or worn beyond the specification.
5. Inspect the camshaft drive gear for worn or damaged teeth. Inspect the CMP sensor timing disk attached to the front face of the cam gear. If either of these components is worn or damaged, replace the gear and timing disk as an assembly.

Assembling Cam Gear to Camshaft

WARNING: To avoid serious personal injury or possibly death, use welding gloves for this procedure.

CAUTION: The replacement cam gear and timing disk assembly have been accurately timed at the factory. Because accurate timing upon reassembly cannot be assured, do not disassemble these components. Disassembly may consequently result in engine damage.

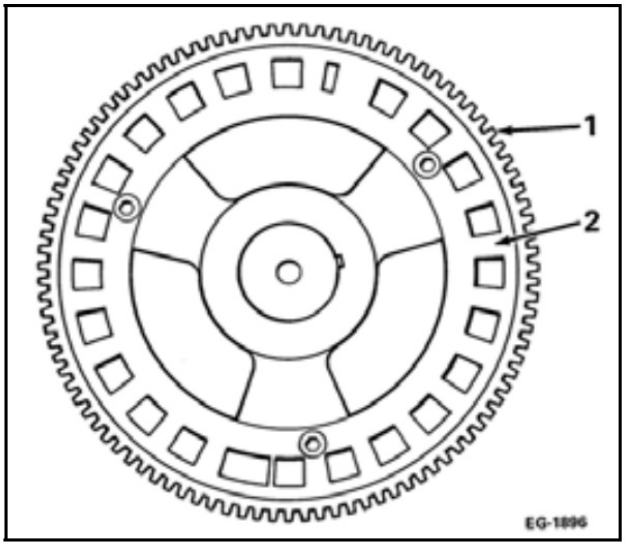

Figure 242 Assembling the Cam Gear Onto the Camshaft

1. Gear Teeth
2. Timing Disk

1. Heat the cam gear and timing disk assembly in an oven to 260°C (500°F).
2. While the assembly is heating, position the camshaft vertically near the oven. Clean the nose of the camshaft.
3. Install the thrust plate on its journal and place the cam gear key in its slot.

4. Wear welding gloves to remove the cam gear assembly from the oven. Quickly align the gear keyway with the key and position the gear assembly over the nose of the camshaft until the gear is seated against the retaining flange shoulder.
5. Allow the assembly to cool before installing the camshaft in the engine. **Do not quench**.

Installation of Camshaft

NOTE: If new parts are installed, make sure the gear backlash and end play are within specifications.

1. Coat the camshaft lobes and bushing journals with clean engine oil.

NOTE: Avoid nicking or scratching the camshaft bushings by the cam lobes.

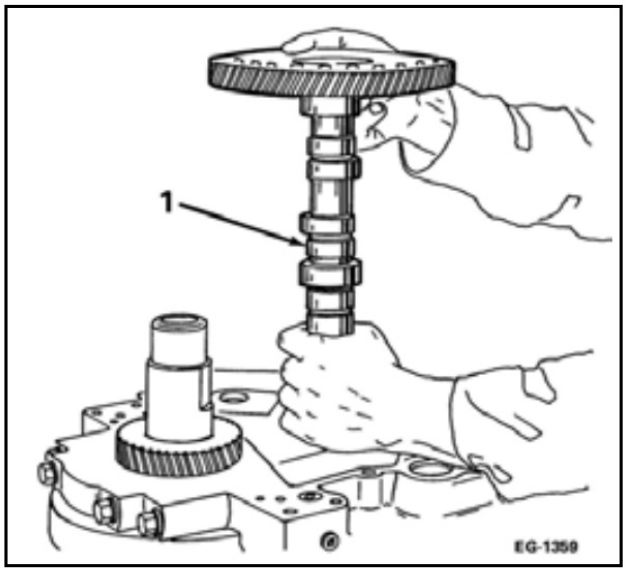

Figure 243 Installing the Camshaft Assembly

1. Camshaft

2. Position the crankcase on engine the stand with the front facing up. Carefully install the camshaft assembly.

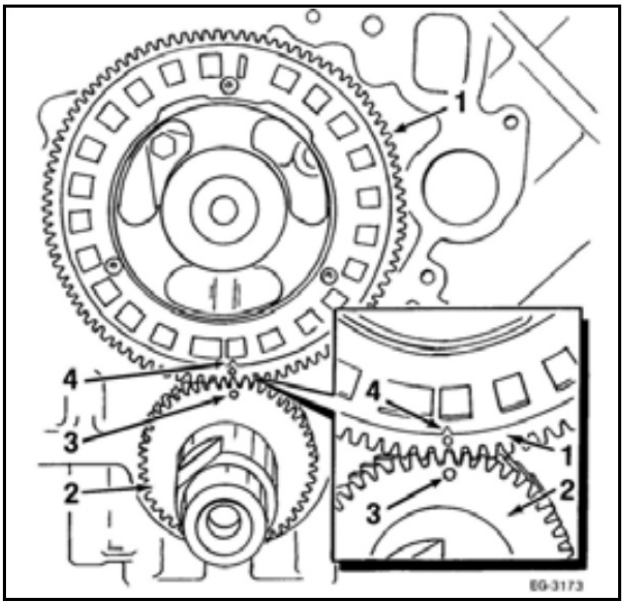

Figure 244 Indexing the Cam Gear and Crankshaft

1. Cam Gear
2. Crankshaft Gear
3. Crankshaft Gear Timing Mark
4. Cam Gear and Timing Disk Marks

3. Index the cam gear and crankshaft gear so timing marks are aligned when the camshaft is in place.

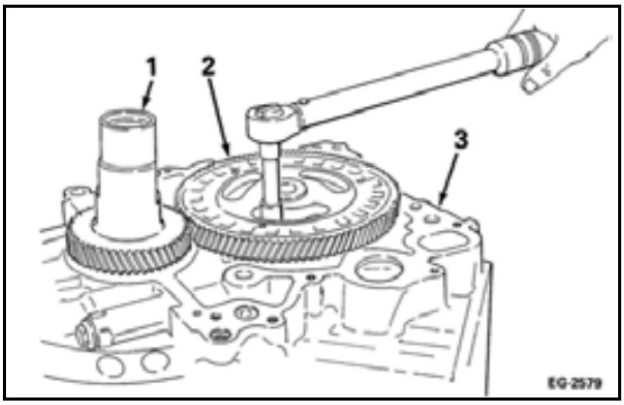

Figure 245 Installing the Thrust Plate Bolts

1. Crankshaft
2. Camshaft Gear
3. Crankcase

4. Install two thrust plate mounting bolts. Tighten the bolts to the special torque value.

SPECIFICATIONS

Table 16 Valve Train

Camshaft	
Bearing Journal Diameter (All Journals)	53.31-53.34 mm (2.099-2.100 in)
Bearing (Bushing) Inside Diameter	53.39-53.48 mm (2.102-2.105 in)
Journal/Bushing Running Clearance	0.051-0.165 mm (0.002-0.006 in)
Camshaft End Play	0.051-0.203 mm (0.002-0.008 in)
Timing Gear Backlash	0.140-0.2794 mm (0.0055-0.0110 in)
Maximum Permissible Cam Lobe Wear	0.51 mm (0.020 in)
Journal Surface Finish (microinches)	16 µin
Camshaft Thrust Plate Thickness	3.910-3.960 mm (0.154-0.156 in)
Camshaft Lobe Lift	
Intake	6.44 mm (0.2535 in) max.
Exhaust	6.43 mm (0.2531 in) max.
Valve Timing No. 1 Cylinder (Top of Ramp)	
Intake Open	17.2 ° BTDC
Closed	34.8 ° ABDC
Exhaust Open	51.2 ° BBDC
Closed	20.8 ° ATDC
Hydraulic Valve Lifters	
Diameter	23.391-23.411 mm (0.9209-0.9217 in)
Bore Diameter In Crankcase	23.439-23.477 mm (0.9228-0.9243 in)
Clearance In Bore	0.027-0.086 mm (0.0011-0.0034 in)
Bleed Down Rate – Time required for plunger to move 3.175 mm (0.125 in) under a 50 lb load using test fluid at room temperature	18-90 seconds

Special Torque

Table 17 Valve Train Special Torques

Cam Follower Guide Mounting Bolt	20 N·m (15 lbf·ft)

SPECIAL SERVICE TOOLS

Table 18 Valve Train Special Service Tools

OEM1000	Micrometer
OEM1028	Magnetic Base Dial Indicator
ZTSE1893	Hydraulic Valve Lifter Tester

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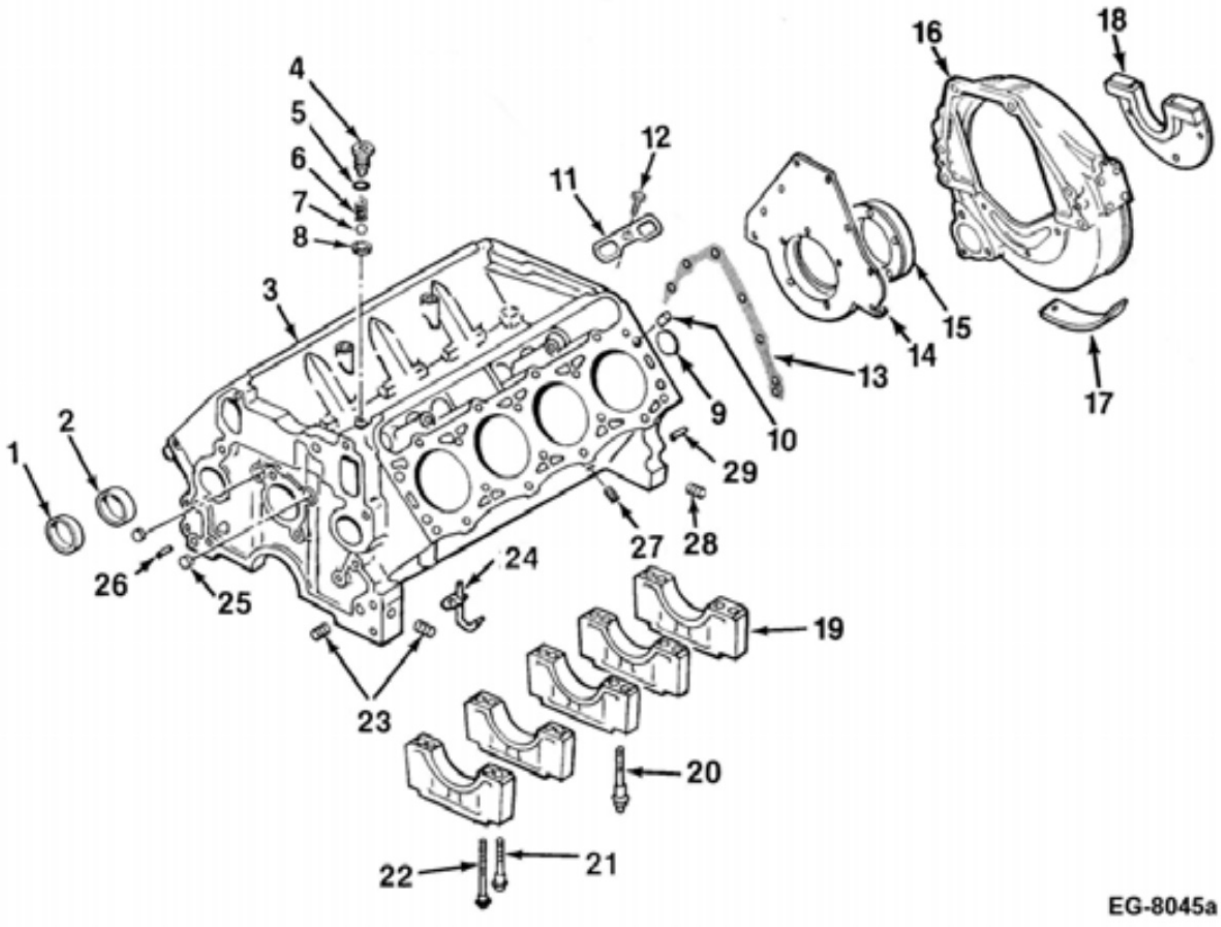

Figure 246 Crankcase, Flywheel Housing And Related Parts

1. Front Camshaft Bushing
2. Camshaft Bushing (2nd – 5th)
3. Crankcase
4. Short Circuit Oil Plug
5. Short Circuit O-Ring
6. Short Circuit Spring
7. Short Circuit Ball
8. Seat, Ball
9. Cup Plug (7)
10. Dowel Sleeve (4)
11. Valve Lifter Guide Retainer
12. Valve Lifter Guide Bolt
13. RTV, Liquid Gasket
14. Rear Crankcase Cover
15. Rear Oil Seal
16. Flywheel Housing
17. Flywheel Housing Plate Cover
18. Flywheel Housing Baffle (If Equipped)
19. Main Bearing Cap (5)
20. Main Bearing Cap Stud (1)
21. Short Mounting Bolt (10)
22. Long Mounting Bolt (9)
23. Pipe Plug (4)
24. Piston Cooling Tube (8)
25. Pipe Plug (2)
26. Dowel Pin (2)
27. Pipe Plug (5)
28. Plug (3)
29. Dowel Pin (2)

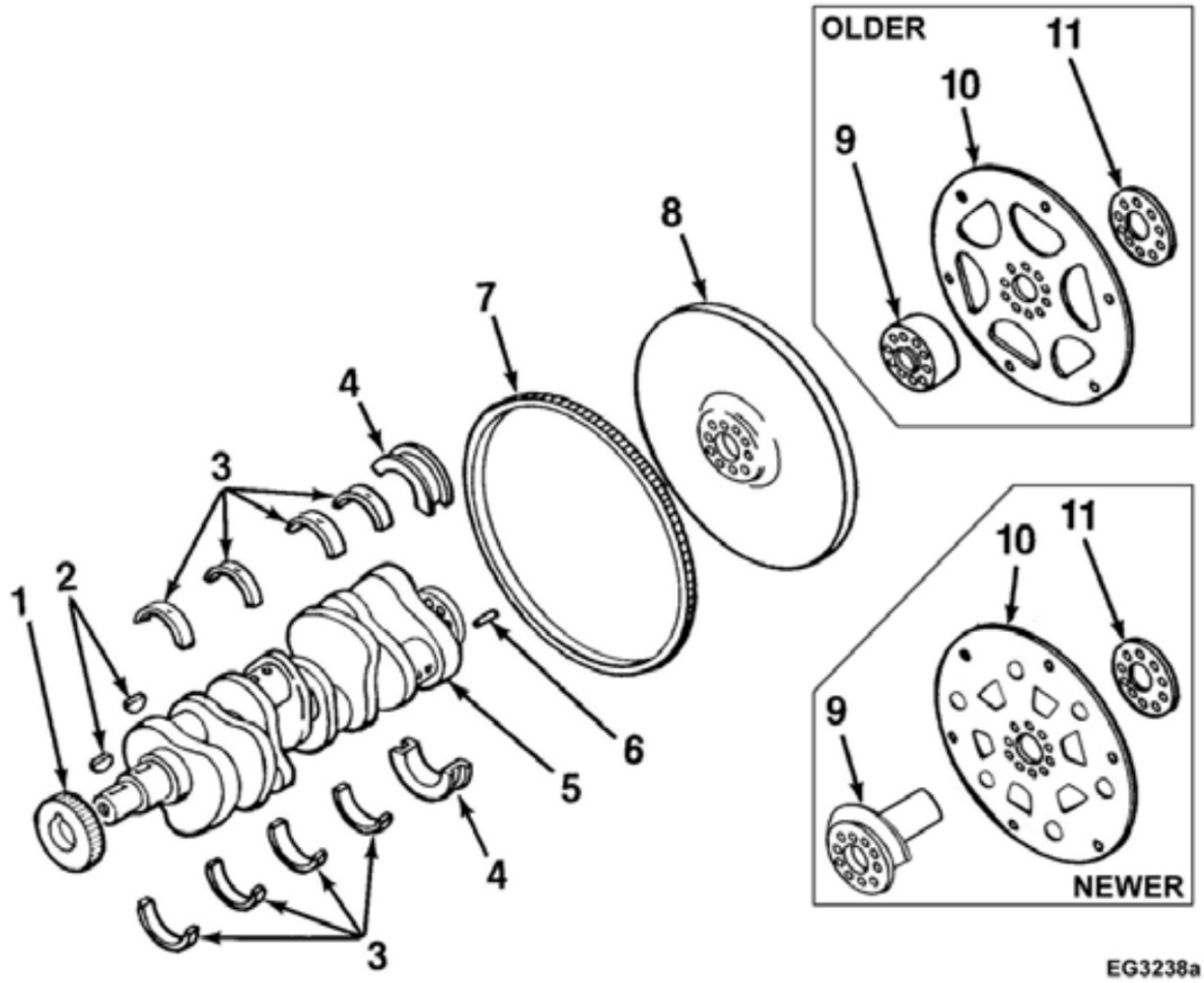

Figure 247 Crankshaft, Flywheel Or Flexplate, And Related Components

1. Crankshaft Gear
2. Crankshaft Key (2)
3. Crankshaft Bearings (Nos. 1, 2, 3 and 4)
4. Thrust Bearing No. 5
5. Crankshaft
6. Coiled Spring Pin
7. Flywheel Ring Gear
8. Flywheel (Manual transmission)
9. Flywheel Adapter (Automatic Transmission)
10. Flexplate (Automatic Transmission)
11. Reinforcement Ring (Automatic Transmission)

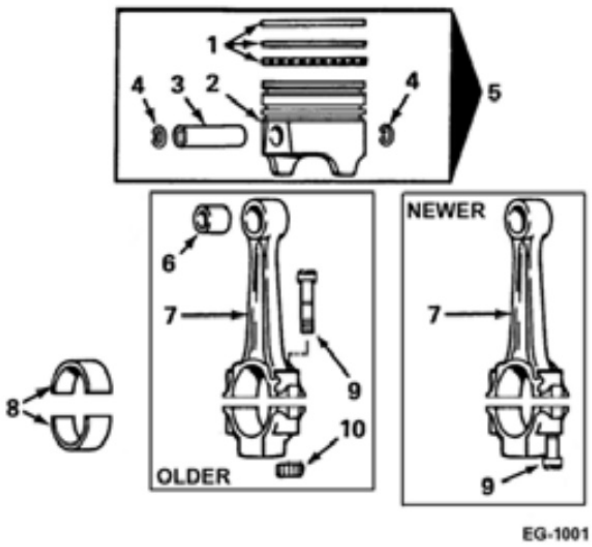

Figure 248 Connecting Rods, Pistons and Rings

1. Piston Ring Set
2. Piston
3. Piston Pin
4. Retainer Rings
5. Piston Assembly
6. Pin Bushing
7. Connecting Rod
8. Connecting Rod Bearings
9. Connecting Rod Bolts (2)
10. Connecting Rod Nuts (2)

Flywheel and Flywheel Housing

Removal

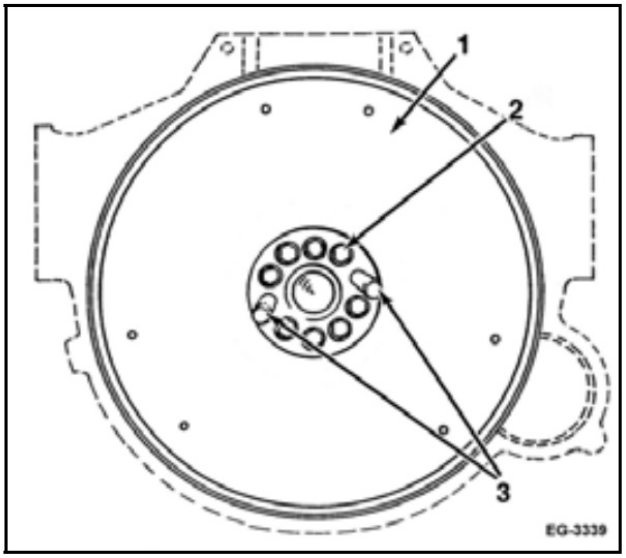

Figure 249 Removing the Flywheel

1. Flywheel and Ring Gear Assembly
2. Flywheel Mounting Bolts (10)
3. Guide Studs

NOTE: For automatic transmissions with the older style flexplate: remove the reinforcement ring, flexplate, and adapter before removing the flywheel. For automatic transmissions with the newer style flexplate, there is no flywheel. The ring gear is installed directly onto the flexplate.

1. Remove two flywheel mounting bolts, one at the 3 o'clock position and one at the 9 o'clock position. Install two guide studs in their place.
2. Remove the remaining flywheel mounting bolts. Slide the flywheel out of housing and off the guide studs. With the flywheel removed, the guide studs can be removed.

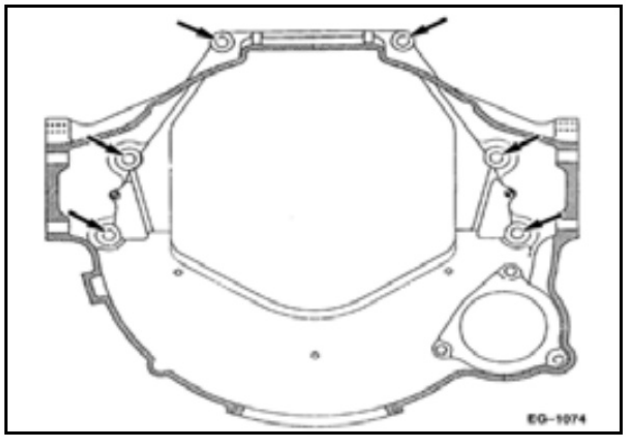

Figure 250 Removing the Flywheel Housing Flange Bolts

3. Remove six flywheel housing flange mounting bolts and slide the flywheel housing off the crankcase dowels.

Cleaning

Clean the flywheel with a non-caustic solvent. Dry the flywheel with filtered compressed air.

Inspection

WARNING: A crack or heat check in the flywheel could cause it to separate and injure the operator or bystanders. If any damage is found, discard the flywheel.

1. Inspect the flywheel for cracks, heat checks, and extensive scoring which would make it unfit for further use. Replace the flywheel if any of these defects are found or suspected.
2. Inspect the ring gear for worn, chipped or cracked teeth. If the teeth are damaged, replace the ring gear or flexplate depending on vintage.

Resurfacing (Manual Transmissions)

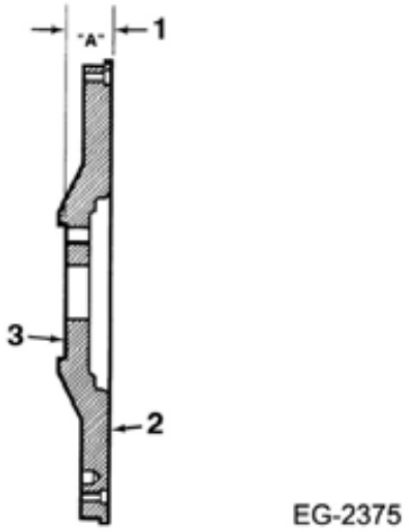

Figure 251 Flywheel Reconditioning

1. Flywheel Dimensions (NEW – 45.822 mm ± 0.254 mm (1.804 ± 0.010 in)) (Minimum Permissible After Resurfacing 36 mm (1.430 in))
2. Clutch Disc and Cover Plate Mounting Face
3. Crankshaft Flange Mounting Face

Flywheel machining information is provided for guidance only. International Truck and Engine Corporation assumes no responsibility for the results of any work performed in accordance with this information or for the ability of service personnel to detect heat cracks.

WARNING: To avoid personal injury and possible death, observe the following warnings:

- **Resurfacing should be carried out by a skilled technician using specialized equipment for this function.**
- **The flywheel may be ground to correct minor wear and scoring. New flywheels have a thickness of 45.822 mm ± 0.254 mm (1.804 ± 0.010 in). DO NOT grind beyond the minimum permissible thickness of 44.907 mm (1.768 in). Replace the flywheel if it is not repairable by surface grinding.**
- **Remove material from clutch face only.**

After resurfacing, check the flywheel for cracks and heat checks. If any cracks or heat checks are detected, replace the resurfaced flywheel with a new one.

Installation of Flywheel Housing

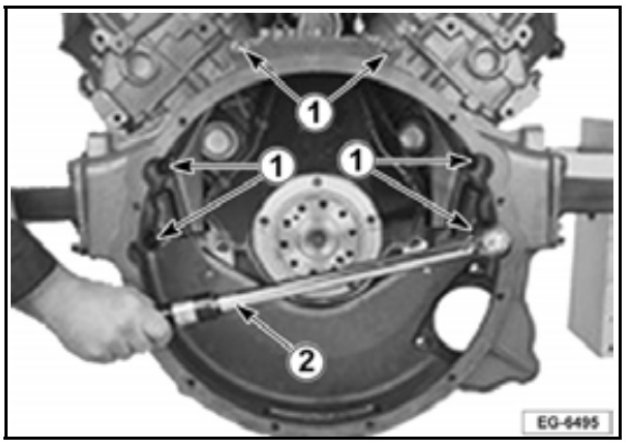

Figure 252 Installing the Flywheel Housing

1. Flywheel Housing Mounting Bolts
2. Torque Wrench

1. Slide the flywheel housing onto the guide pins.
2. Install six flywheel housing mounting bolts finger tight to secure the housing to the crankcase.
3. Tighten the mounting bolts to the standard torque value.

Check Flywheel Housing Bore Concentricity

CAUTION: Bore concentricity and face runout checks are performed to ensure proper engine to transmission alignment. Improper bore concentricity and face runout may result in reduced transmission life.

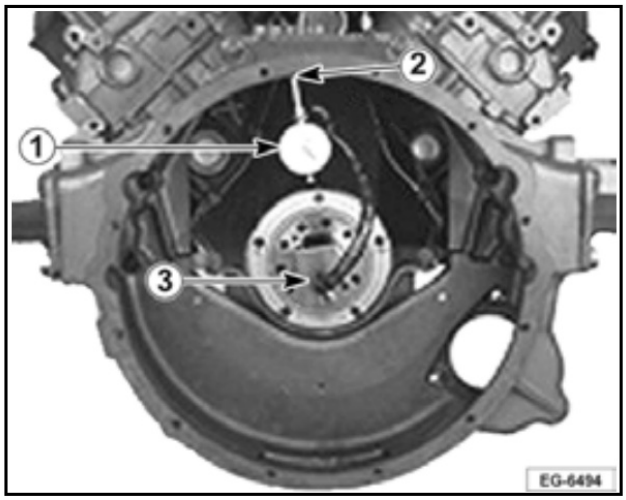

Figure 253 Checking the Flywheel Housing Bore Concentricity

1. Dial Indicator
2. Indicator Tip
3. Magnetic Base

1. Attach a dial indicator magnetic base to the crankshaft and place the indicator tip against the flywheel housing bore.
2. Zero the dial indicator.
3. Rotate the crankshaft slowly and record the total indicator variation. Compare the result to the specification for flywheel housing bore concentricity.

Check Flywheel Housing Face Runout

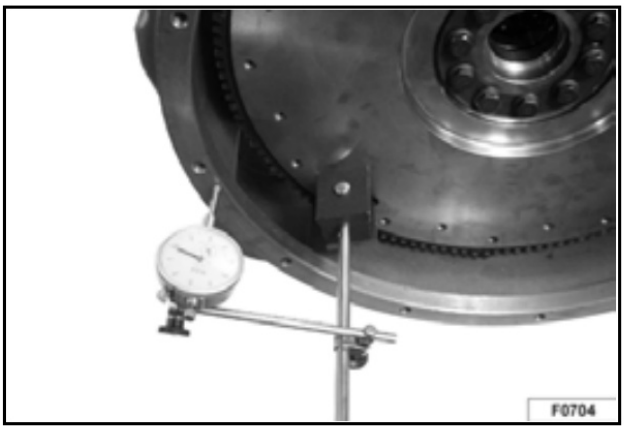

Figure 254 Checking the Flywheel Housing Face Runout

Keep crankshaft end play at zero in the same direction for all measurements.

1. Attach a dial indicator magnetic base to the flywheel and place the indicator tip against housing face.
2. Measure at four points 90° apart for a total face variation. Compare the average to the specification for the flywheel housing face runout tolerance.

Check Flywheel Surface Runout

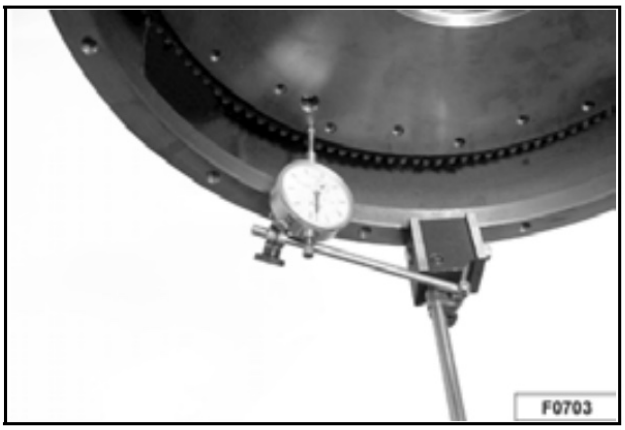

Figure 255 Checking Flywheel Surface Runout

1. Attach a dial indicator magnetic base to the flywheel housing and place the indicator tip against the flywheel surface.
2. Rotate the crankshaft slowly and record the total indicator variation. Refer to the specification for the tolerance.

Check Crankshaft Pilot Concentricity

1. Attach a dial indicator magnetic base to the flywheel housing and place the indicator tip against the flywheel pilot.
2. Rotate the crankshaft slowly and record the total indicator variation. Refer to the specification for concentricity tolerance.

Installation of Flywheel

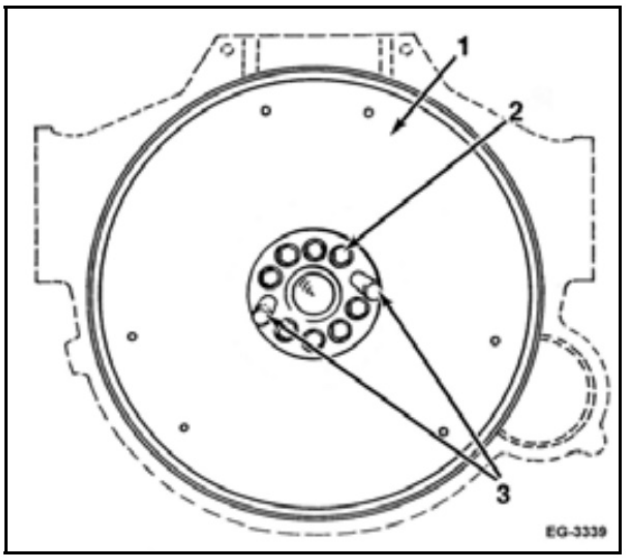

Figure 256 Installing the Flywheel

1. Flywheel and Ring Gear
2. Flywheel Mounting Bolts
3. Guide Studs

1. Install a flywheel guide stud into the 3 o'clock and 9 o'clock positions of the crankshaft.
2. Install the flywheel over the guide studs. Secure the flywheel to the crankshaft with eight mounting bolts finger tight.

NOTE: For automatic transmissions with the older style flexplate, install the flywheel adapter, flexplate, and reinforcement ring onto the flywheel. Make sure the lip of the reinforcement ring is facing outward. Then install the eight mounting bolts.

For automatic transmissions with the newer style flexplate, there is no flywheel. The ring gear is installed directly onto the flexplate.

3. Remove the two guide studs and install the remaining two mounting bolts. Tighten all ten bolts to the special torque value.

Rear Oil Seal and Wear Sleeve

Removal

Rear Oil Seal

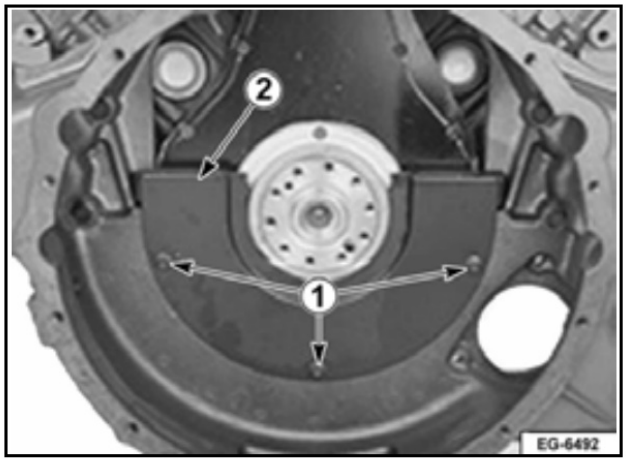

Figure 257 Flywheel Housing Baffle (if equipped)

1. Mounting Bolts (3)
2. Flywheel Housing Baffle

1. If not already done, remove the flywheel from the housing. Refer to “Flywheel and Housing — Removal” in this section.
2. If equipped, remove the three mounting bolts securing the flywheel housing baffle to the flywheel housing.
3. Remove the flywheel housing baffle.

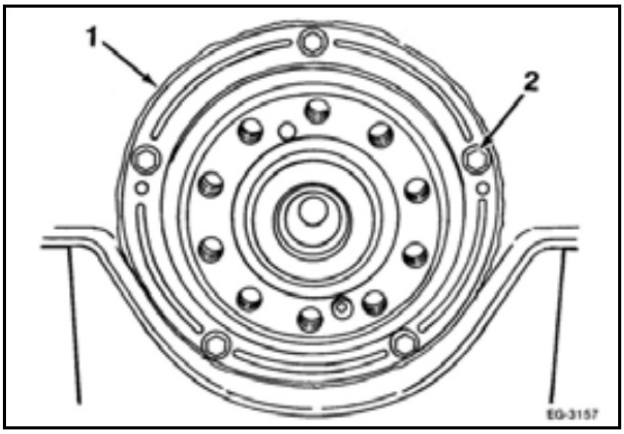

Figure 258 Rear Oil Seal Mounting Bolts

1. Rear Oil Seal/Retainer
2. Mounting Bolts (5)

4. Remove five bolts that secure the rear oil seal to the rear crankcase cover.

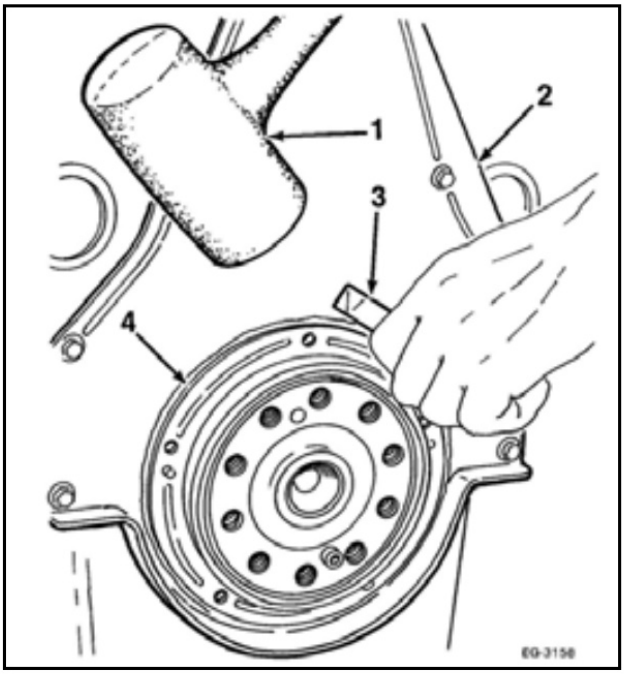

Figure 259 Cutting Through RTV Sealant

1. Hammer
2. Rear Crankcase Cover
3. RTV Cutting Tool
4. Seal/Retainer

5. Use a cutting tool to cut through the RTV sealant on the rear oil seal.
6. Remove the rear oil seal from the crankshaft and rear cover plate.

Wear Sleeve

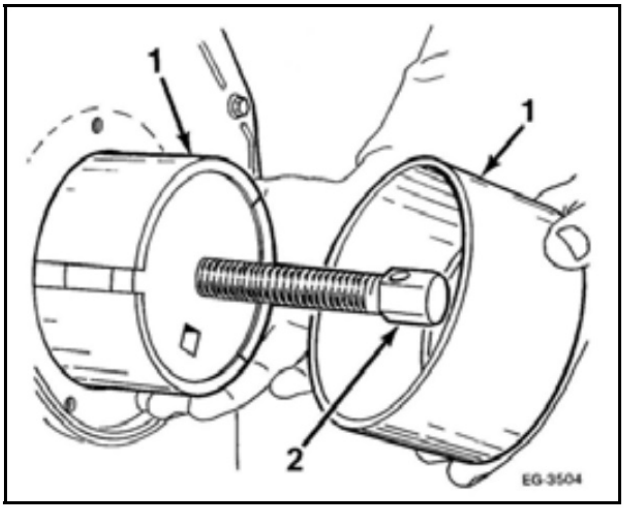

Figure 260 Installing the Wear Sleeve Removal Tool

1. Wear Sleeve Removal Tool
2. Forcing Screw

1. Mount the wear sleeve removal tool around the wear sleeve on the crankshaft flange.
2. Turn the forcing screw to remove the wear sleeve.

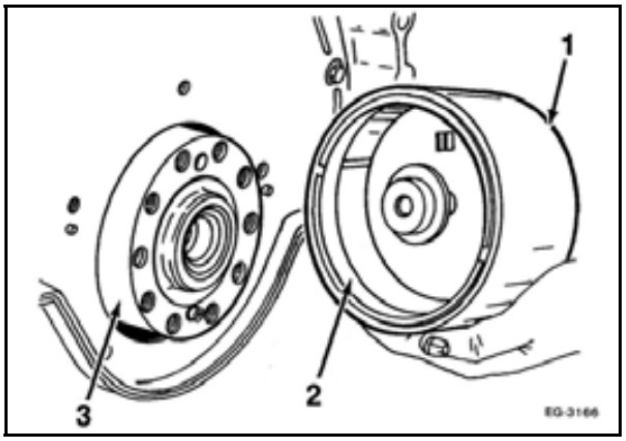

Figure 261 Removing the Wear Sleeve

1. Wear Sleeve Removal Tool
2. Wear Sleeve
3. Crankshaft

3. Discard the wear sleeve and inspect the crankshaft flange for damage.

Installation

NOTE: If the rear cover is going to be removed, do not install the rear oil seal until the rear cover is installed.

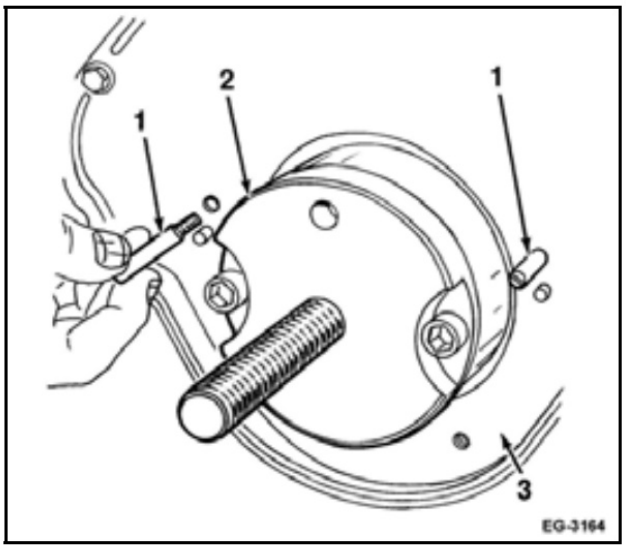

Figure 262 Installing the Rear Oil Seal Installation Tool

1. Alignment Dowels
2. Installation Tool
3. Rear Crankcase Cover

1. Install the rear oil seal installation tool onto the crankshaft flange. Install two rear seal alignment dowels.
2. Apply RTV sealant to the outer diameter of the crankshaft seal flange. Also apply a bead of RTV sealant around each bolt hole and the inside diameter of the bolt hole pattern to the crankshaft seal flange.

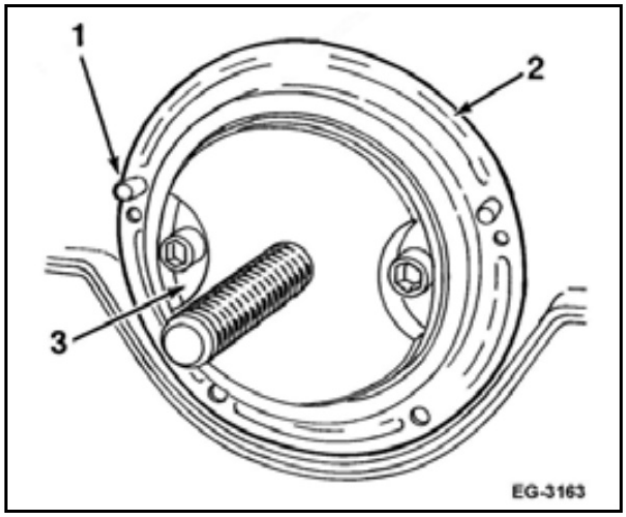

Figure 263 Installing the Rear Oil Seal

1. Alignment Dowel
2. Crankshaft Seal Flange
3. Pilot Or Centering Tool

3. Place the seal and wear sleeve assembly over the centering tool and position the seal retainer over the alignment dowels. Make sure the seal retainer and crankcase dowels align as the seal is being installed.

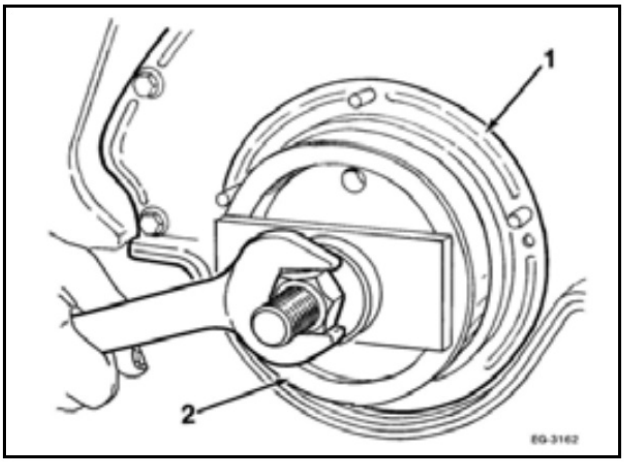

Figure 264 Installing the Rear Oil Seal Driver

1. Seal/Retainer
2. Installation Tool

4. Install the driver over the centering tool. Tighten the forcing screw to drive the wear sleeve and rear seal into position.

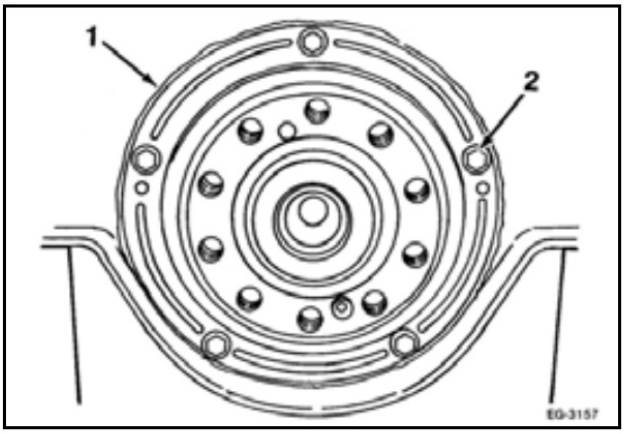

Figure 265 Installing the Rear Oil Seal

1. Seal/Retainer
2. Rear Oil Seal Retainer Bolts (5)

5. Install the retainer bolts. Tighten the bolts to the standard torque value.

Rear Cover

Removal

CAUTION: To avoid damage to the rear cover, make sure the rear oil seal is removed. Refer to "Rear Oil Seal and Wear Sleeve" in this section.

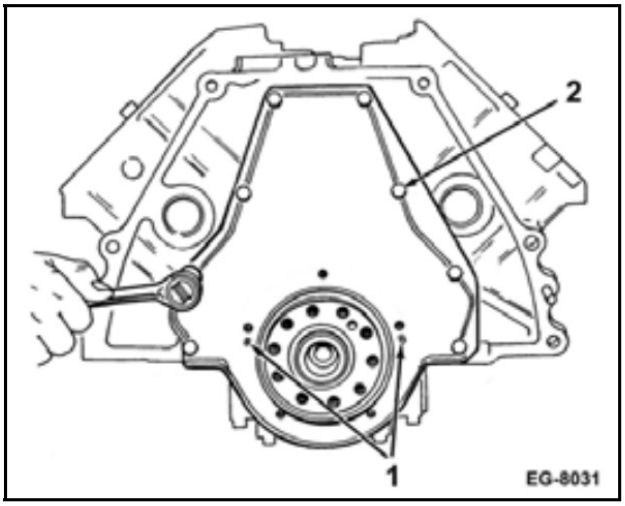

Figure 266 Removing the Rear Cover

1. Dowel Pins
2. Rear Cover Bolt Locations (8)

1. Remove rear cover mounting bolts.
2. Gently pry the rear cover away from crankcase, breaking the RTV sealant bond in the process. Do not bend the rear cover.

Cleaning

1. Use a scraper or wire brush to remove the RTV sealant and any foreign material from the rear cover/oil pan mating surfaces.
2. Use a commercially available brake cleaner to clean the crankcase and rear cover gasket surfaces. The surfaces must be free of oil for good adhesion of RTV sealant during installation.
3. Wipe and dry the surfaces with a clean shop cloth.

Installation

CAUTION: If the rear cover is bent, replace it. Failure to do so may result in engine damage.

1. Replace any missing or damaged dowel pins.

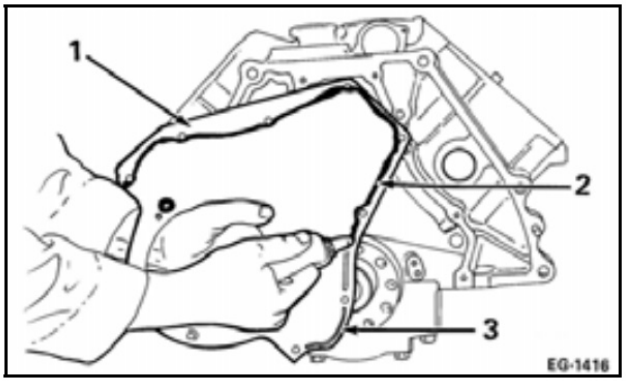

Figure 267 Applying RTV to the Rear Cover

1. Rear Cover
2. RTV Sealant
3. Rear Cover Groove

2. Apply RTV sealant to the groove in the rear cover and around the bolt and dowel pin holes.
3. Place the rear cover over alignment dowels and against the crankcase and install the mounting bolts. Tighten the mounting bolts to the standard torque value.
4. Install the rear oil seal.

Connecting Rods, Pistons and Piston Rings

Check Piston Protrusion

CAUTION: Lack of protrusion could indicate a damaged rod or a rod bearing out of position. Excessive protrusion may require replacement of rods or crankshaft. To avoid engine damage correct as required.

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

1. Check piston protrusion above crankcase as follows:
2. Turn the crankshaft so the piston is just below crankcase deck surface.
3. Place and zero a dial indicator gauge on crankcase deck surface.
4. Position tip of dial indicator gauge onto the piston head at the 3 o'clock position. (Positioning the dial indicator tip at 12 o'clock or 6 o'clock will not yield an accurate measurement).
5. Turn the crankshaft so the piston is at the highest point of its stroke and record the reading.
6. Turn the crankshaft to reposition the piston to just below the crankcase surface.
7. Reposition dial indicator tip onto piston head at the 9 o'clock position.
8. Turn the crankshaft so the piston is at the highest point of its stroke and record the reading. Then average the two readings.

Checking Connecting Rod Side Clearance

Use a feeler gauge to check connecting rod side clearance as follows:

1. Pry apart a pair of connecting rods on a crankshaft rod journal. Insert largest feeler gauge to check clearance.
2. Repeat for each pair of connecting rods on each crankshaft rod journal and compare with specifications.

Removal

CAUTION: To avoid piston damage, if a carbon ridge is evident at the top of the cylinder bore, remove carbon ridge prior to removing the connecting rod and piston assemblies. This reduces the chance of piston ring land damage during removal.

1. Use a razor knife or emery board to scrape carbon ridge from top of cylinder bore.

CAUTION: For newer style connecting rods, keep the fractured mating surfaces clean and free of lint and debris. Do not allow the mating surfaces to rest on any surface. Do not bump the mating surfaces or drop the connecting rod or cap. This could cause chipping and wear on the mating surface, resulting in improper mating during installation and possible engine damage.

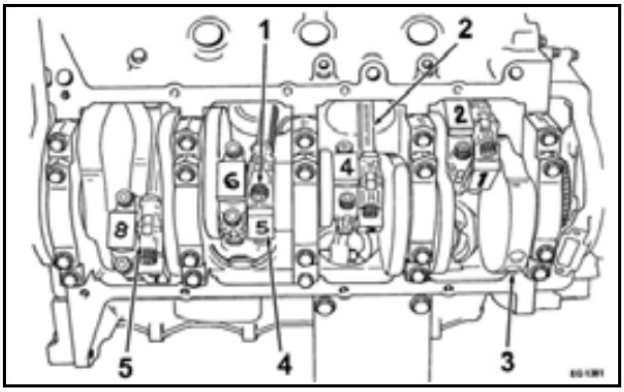

Figure 268 Connecting Rod Locations

1. Connecting Rod Nuts or Bolts (16)
2. Connecting Rod (8)
3. Crankshaft
4. Connecting Rod Location Mark
5. Connecting Rod Cap (8)

2. Rotate crankshaft to position journals for removal of connecting rod assemblies.
3. Mark each connecting rod and its respective rod cap with the cylinder number before removing them from the engine. Also mark the rod caps for correct orientation to each rod.

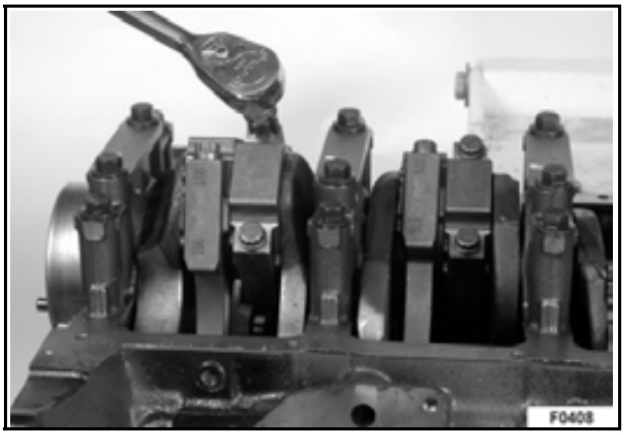

Figure 269 Removing the Connecting Rod Cap

1. Connecting Rod Cap
2. Connecting Rod Nut or Bolt

CAUTION: There are two style connecting rods being used:

- **Older style connecting rods use mounting nuts. The mounting nuts should turn freely off the connecting rod studs. If binding exists, check for bent or damaged threads to avoid engine damage.**
- **Newer style connecting rods use self-retained bolts. Connecting rod bolts should turn freely. If binding exists, check thread condition carefully during inspection to avoid engine damage.**

4. Unscrew the two connecting rod mounting nuts or bolts. Remove the connecting rod cap.
5. Remove the piston and connecting rod assemblies from the crankcase as follows:
   a. Rotate the engine into a vertical position (front end up).

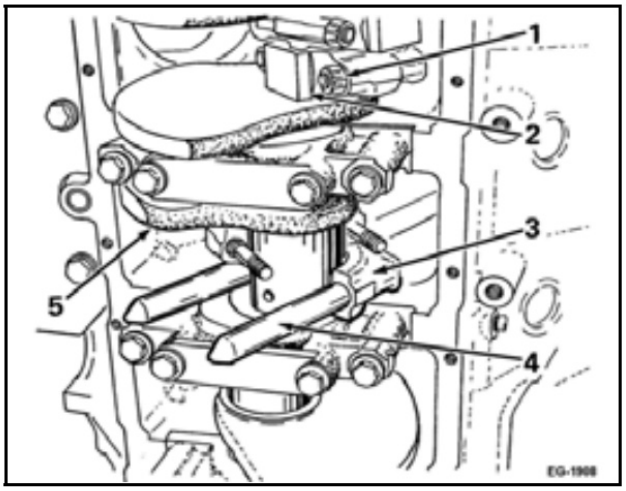

Figure 270 Installing the Connecting Rod Guide Protector Caps (Old Style Connecting Rod)

1. Connecting Rod Nut (16)
2. Connecting Rod Cap (8)
3. Connecting Rod (8)
4. Connecting Rod Guide Protector Caps (2)
5. Crankshaft

   b. Old style connecting rods: install aluminum connecting rod guide protector caps over the connecting rod studs to prevent damage to the crankshaft rod journals.

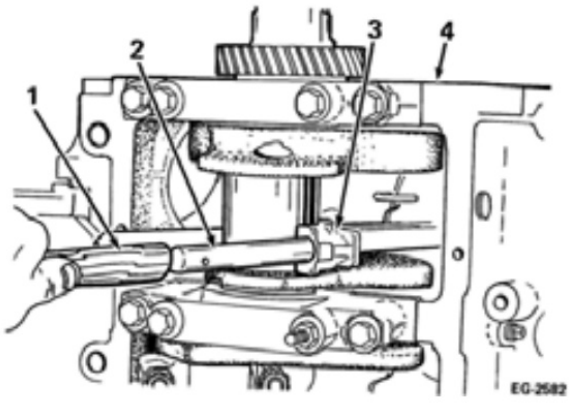

Figure 271 Pushing the Old Style Connecting Rod and Piston Out Of the Cylinder Bore

1. Wooden Handle
2. Protector Cap
3. Connecting Rod
4. Crankcase

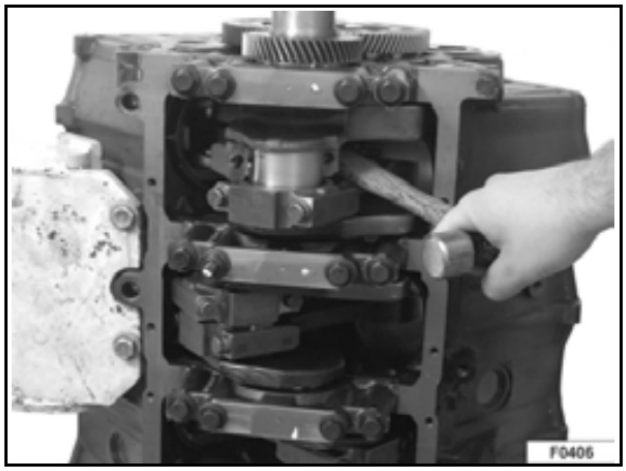

Figure 272 Pushing the New Style Connecting Rod and Piston Out Of the Cylinder Bore

c. Use a wooden or plastic handle to push the connecting rod and piston assembly out of the cylinder bore.

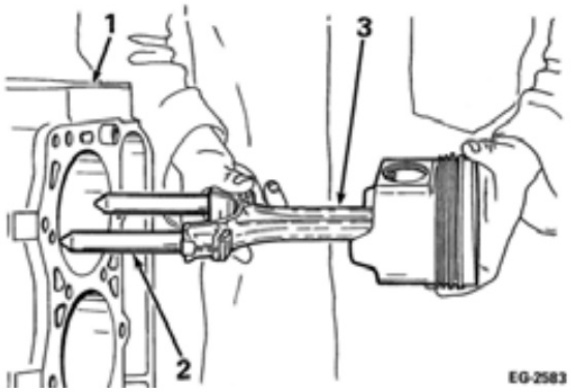

Figure 273 Removing Old Style Piston and Connecting Rod Assembly from Crankcase

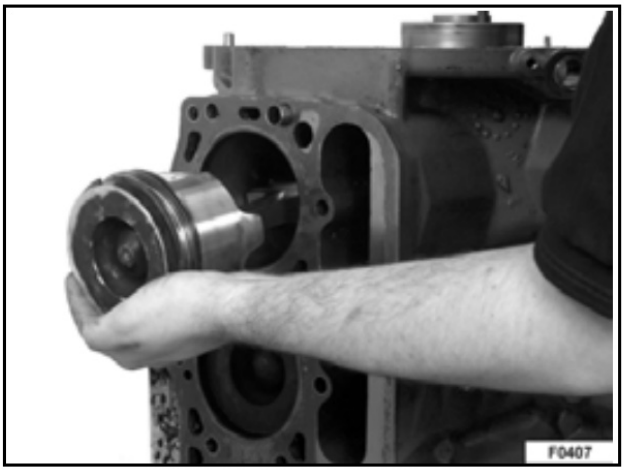

Figure 274 Removing Piston and Connecting Rod Assembly from Crankcase

d. Once the piston rings are free of the cylinder bore, remove the assembly from the top of the crankcase.

6. Mark each connecting rod and its respective bearing cap with the cylinder number from which they were removed.

CAUTION: On engines using fractured connecting rods: DO NOT alter or damage the fractured mating surfaces of the connecting rod and cap.

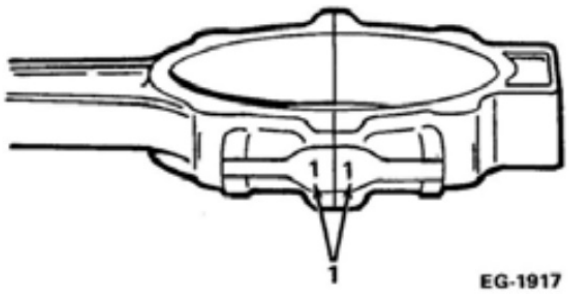

Figure 275 Matching Cap and Connecting Rod Numbers

7. Upon removal, make sure matching connecting rod and cap remain together as a set. A cap from one connecting rod is not interchangable with any other connecting rod.

Disassembly

CAUTION: To avoid engine damage, mark the pistons with the cylinder number from which each was removed. Each piston must be reinstalled into its original cylinder bore if the pistons are being reused.

CAUTION: To avoid engine damage, make a note of the engine serial number (stamped on the crankcase pad, left side rear of the crankcase) and piston part number (stamped on the piston crown). There are multiple pistons available for service applications. Do not install any pistons unless they all have matching part numbers.

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

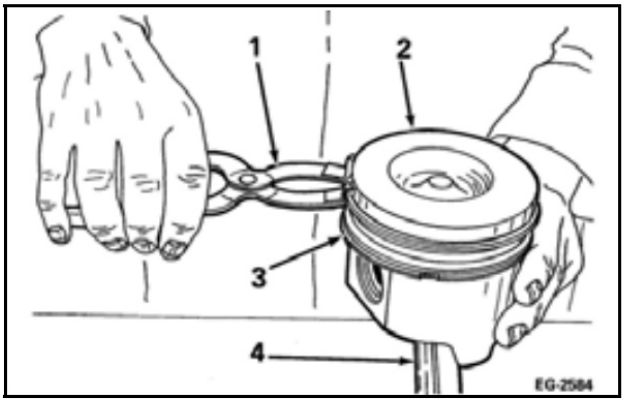

Figure 276 Removing the Piston Rings

1. Piston Ring Expander Tool
2. Piston
3. Piston Ring
4. Connecting Rod

1. Use a piston ring expansion pliers to remove the piston rings. Remove the top ring first, then the intermediate ring, and finally the oil control ring.

⚠ WARNING: To avoid personal injury, wear safety glasses when removing retaining rings.

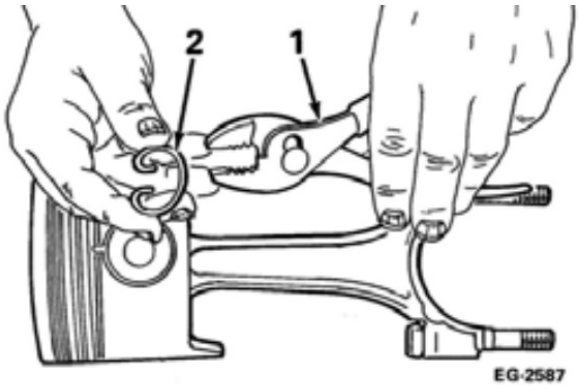

Figure 277 Removing the Piston Retaining Ring (New Style Connecting Rod Shown)

2. Separate the connecting rod from the piston as follows:
   a. Use piston retaining ring pliers to remove the two piston pin retaining rings.
   b. Remove the piston pin from the bore by hand.
   c. Separate the connecting rod from the piston.
3. Repeat procedure for each piston / connecting rod assembly which needs to be disassembled.

Cleaning

NOTE: Never use a caustic solution or a wire brush to clean aluminum pistons. Never use a bead blaster on pistons.

1. Use a soap and water solution to clean the aluminum pistons. Soak the pistons, then clean the piston with a nonmetallic brush.
2. Clean all piston ring grooves thoroughly.

3. The following disassembled components may be cleaned using a suitable solvent.
   - Piston pins
   - Piston pin retainers
   - Connecting rods
4. Thoroughly clean all connecting rod bolt holes and threads.

Inspection

1. Inspect the pistons for scuffed or scored skirts, cracked or worn ring lands, and cracked or scuffed pin bores. Replace as required.

NOTE: Faulty piston rings cannot always be detected by visual inspection. Therefore, whenever a piston is removed from a cylinder, it is recommended that the piston rings be replaced.

2. Inspect the new piston rings for cleanliness.
3. Inspect the connecting rod studs or bolts for nicks and damage.
4. Inspect the connecting rod and cap mating surfaces for fretting. The bore must be smooth and free of scoring or nicks. Replace as required.
5. Inspect the piston pins for corrosion or wear. Replace as required.

Check Width of Top Compression Ring Groove

NOTE: Top compression ring groove is a keystone design which requires measurement over gauge pins to determine ring groove wear.

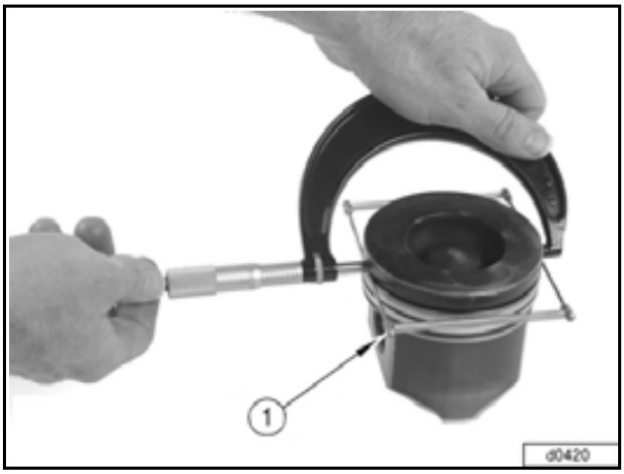

Figure 278 Measuring Top Compression Ring Groove

1. Piston gauge pins

1. Check top compression ring groove for wear as follows:

CAUTION: There are two different size gauge pins to be used as follows:

- **On old style connecting rod and piston assemblies use 3 mm (0.115 in.) gauge pins.**
- **On new style connecting rod and piston assemblies use 2 mm (0.082 in.) gauge pins.**

   A. Install a piston gauge pin from the piston groove wear gauge pin set into the top ring groove to be measured. Piston gauge pin must be parallel.

   B. Use an outside micrometer to measure diameter over piston gauge pins.

   C. If measurement over the gauge pin is not within specifications, excessive piston groove wear exists. Replace piston.

Checking Side Clearance Of Oil Control Ring And Intermediate Compression Ring Groove

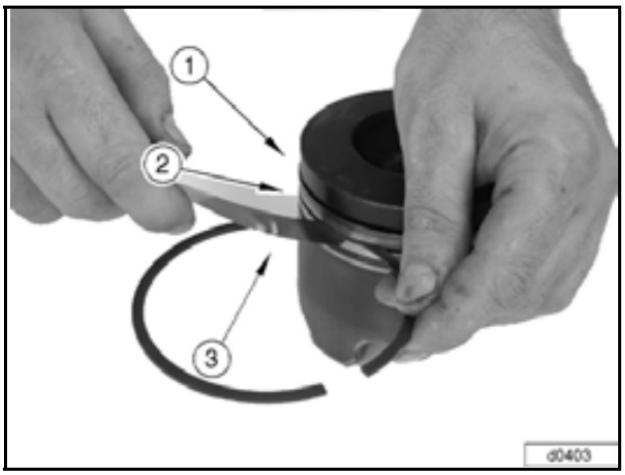

Figure 279 Checking Side Clearance Of The Intermediate Ring And Oil Control Ring Grooves

1. Compression ring groove
2. Intermediate compression ring groove
3. Feeler gauge

1. Check side clearance of intermediate ring groove as follows:
   - Place outer edge of new ring in the immediate ring groove.
   - Roll ring entirely around piston in its respective groove. Make sure ring is able to move freely in its groove.
   - Use a feeler gauge to check side clearance of each ring in its respective groove.
2. Check side clearance of oil control ring groove as follows:
   - Place outer edge of new ring in oil control ring groove.
   - Roll ring entirely around piston in its respective groove. Make sure ring is able to move freely in groove.
   - Use a feeler gauge to check side clearance of oil control ring in its respective groove.
     A. Tight side clearance may indicate carbon build up in the ring groove. Ring should be cleaned.
     B. Excessive side clearance indicates ring groove wear and requires piston replacement.

Piston Replacement

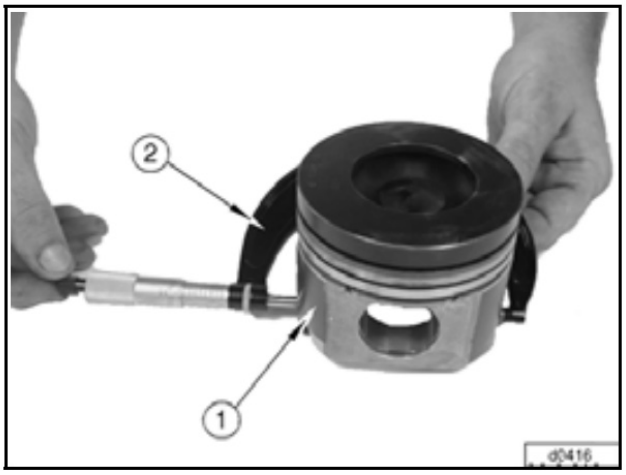

Figure 280 Measuring Piston Skirt Diameter

1. Piston Skirt
2. 3–4 inch micrometer

When the piston requires replacement, check the cylinder bores. If they exceed the out-of-round or taper specifications, boring may be required. Such cylinder bore reconditioning will require the use of oversize service pistons. Verify the piston size by measuring the skirt diameter. See the **Specifications** for the correct measurement location.

Check Piston Ring End Clearance in Cylinder Bore

Figure 281 Checking the Piston Ring End Clearance in the Cylinder Bore

1. Piston Ring
2. Feeler Gauge

NOTE: Faulty rings cannot always be detected by visual inspection. Therefore, whenever a piston is removed from a cylinder, replace the piston rings.

1. Inspect piston rings for cleanliness.
2. Before installing new piston rings on piston, check gap for each ring as follows:
   A. Push piston ring down into cylinder bore. Make sure the piston ring is square to the cylinder wall. An inverted piston head can be used to push piston ring to desired location of measurement (usually at the top of the piston stroke).
   B. Use a feeler gauge to measure the gap between the ends of each piston ring.
   C. If the gap does not meet the specification, select another piston ring or check the cylinder bore wear again.

Connecting Rods

CAUTION: On newer engines using the fractured connecting rods keep mating surfaces clean and free of debris.

- **DO NOT allow mating surfaces to rest on any other surface.**
- **DO NOT bump the mating surfaces or drop the connecting rod or cap.**

This could cause wear and chipping of the fractured surface, resulting in improper mating during installation and possible engine damage.

If the connecting rod cap is reversed when assembled to the connecting rod or a connecting rod cap is not installed in its original matching connecting rod, the fractured mating surfaces will be useless. The entire connecting rod assembly must be replaced.

1. Inspect connecting rod bolts for nicks or damage. Replace as required.
2. Inspect connecting rod and cap mating surfaces and bearing bore for any indication of damage. Bore must be smooth and free of scoring or nicks. Replace as required.

Check Inside Diameter of Piston Pin Bushing

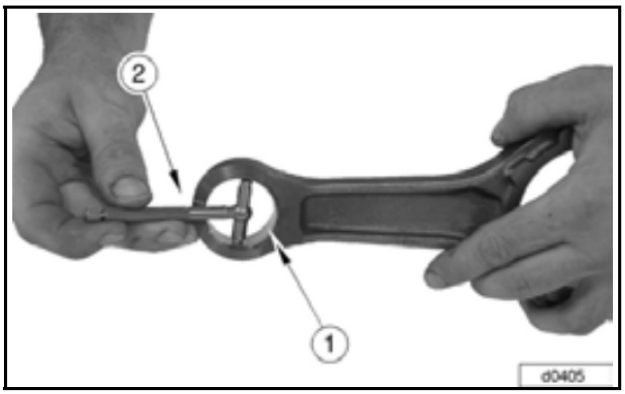

Figure 282 Measuring the Inside Diameter of the Piston Pin Bushing

1. Piston Pin Bushing
2. Telescoping Gauge

1. Use a telescoping gauge and an outside micrometer, measure the pin bore at two locations 90° apart. Record the readings.
2. If the inner diameter of the piston pin bushing exceeds the specification, replace the connecting rod.

Check Connecting Rod Bearing Bore for Out-of-Round and Taper

CAUTION: To avoid engine damage, check the connecting rods as follows:

A. On engines equipped with the older style connecting rod, be sure the nuts on connecting rods thread onto the connecting rod studs by hand. If excessive resistance is felt, clean the connecting rod studs and try a new nut. If the new nut does not thread on freely, the connecting rod must be replaced. Failure to do so may result in engine damage.

B. On engines equipped with the newer style connecting rod, the connecting rod bolts should be checked for binding. The bolts should thread into the connecting rod freely when lubricated with clean engine oil. If they do not the connecting rod must be discarded. Connecting rod threads cannot be re-tapped if bonding exists. Check thread condition carefully during inspection. Failure to do so may result in engine damage.

1. Lubricate the connecting rod nuts or bolts with clean engine oil. Assemble the cap onto its matching rod with the bearing insert removed. Tighten the nuts or bolts to the special torque value.

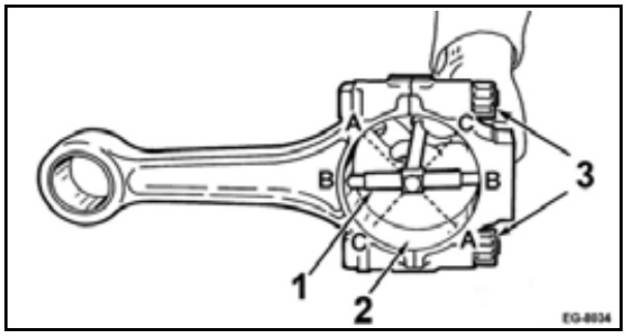

Figure 283 Measuring the Connecting Rod Bearing Bore for Out-of-Round

1. Inside Micrometer
2. Connecting Rod Bearing Bore
3. Nuts or Bolts

2. Use an inside micrometer (telescoping gauge) to measure the connecting rod bearing bore at three locations approximately 120° apart. Label them A, B and C.

3. If the difference between micrometer reading "B" and the average of reading "A" and reading "C" exceeds the out-of-round specification, the connecting rod must be replaced.

   [(A+C)÷2] – B = actual reading (If the result is negative, disregard the negative sign.)

4. Check the connecting rod bearing bore taper by measuring the bore inner diameter near the large chamfer. Record the reading. Then measure the bore inner diameter near the small chamfer. Record the reading.

   The difference between the two readings is the bore taper. If the connecting rod exceeds the specification, replace the connecting rod.

5. With the connecting rod cap removed, inspect the surface finish of the connecting rod bearing bore. The bore must be smooth and free of scoring, nicks and burrs. Replace the connecting rod as required.

Check Connecting Rod for Bend or Twist

Often, engine component wear patterns can be identified and used to diagnose a problem. Some common examples of connecting rod wear patterns include the following:

- A shiny surface on the edge of the piston pin bushing usually indicates that a connecting rod is bent or a piston pin hole is not in proper position to the piston shirt and ring grooves.
- Abnormal connecting rod bearing wear can be caused by a bent connecting rod, an improperly machined journal or a tapered connecting rod bore.
- Twisted connecting rods will not create an easily identifiable wear pattern, but severely twisted connecting rods will disturb the action of an entire piston, ring and connecting rod assembly. It may also be the cause of excessive oil consumption.

If any of these conditions exist, use a suitable alignment fixture to check the connecting rods for bends or twists. Follow the instructions of the fixture manufacturer. If bend or twist exceeds specifications, replace the connecting rod.

Check Piston Pin Clearance

1. Inspect piston pins for corrosion or wear. Replace as required.

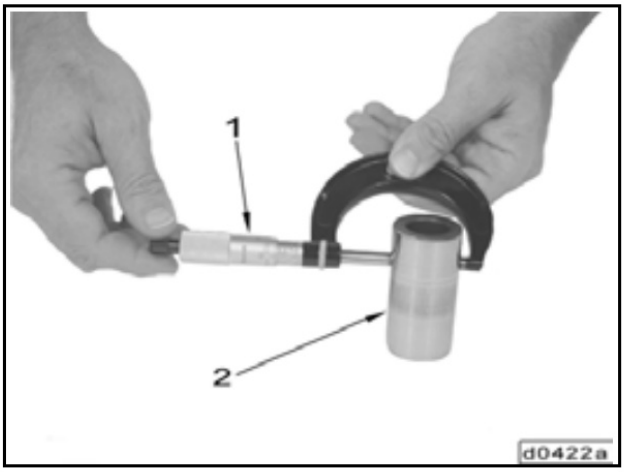

Figure 284 Checking for Piston Pin Wear

1. Piston pin
2. 1–2 inch micrometer

2. Use a 1–2 inch micrometer to measure piston pin outside diameter at two locations 90° apart. Measure each end of the pin. Record the

range of readings. If piston pin wear exceeds specifications, replace piston pin.

Figure 285 Measuring Piston Pin Bore Inside Diameter

3. Using a 1–2 inch telescoping gauge and micrometer, measure each piston pin bore inside diameter, at two locations 90° apart.
4. Check piston pin clearance, subtract piston pin outside diameter from piston pin bore inside diameter measurements. If clearance exceeds specifications, replace piston pin.

Bearing Fitting Procedure For Old Style Connecting Rod

CAUTION: To avoid engine damage, do not attempt to reduce journal-to-bearing running clearances by reworking the bearing cap and/or the bearings. Regrind or replace the crankshaft only.

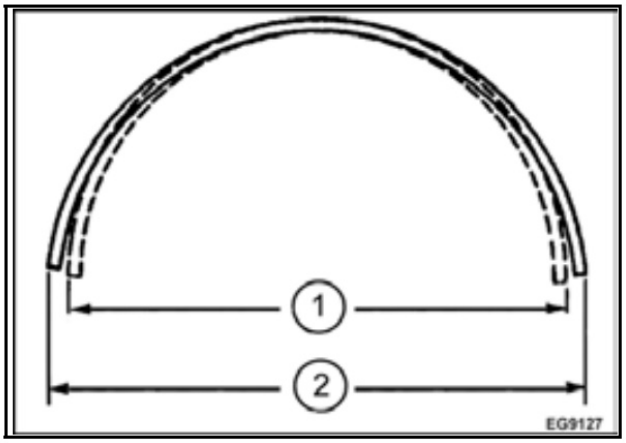

Figure 286 Effects of Bearing Crush

1. Diameter at Open Ends Before Bearing Crush Load
2. Diameter at Open Ends After Bearing Crush Load

Bearing shells must fit tightly in the bore. When bearing shells are inserted into the connecting rod and cap, they protrude slightly above the parting surface. This protrusion is required to achieve a **bearing crush**.

Across the open ends, bearing shells are slightly larger than the diameter of the connecting rod bore into which they are assembled. This condition is designed into the bearing shell, causing it to spread outward at the parting line when a bearing crush load is applied by tightening the nuts. Some snap may be lost in normal use, but bearing replacement is not required because of a nominal loss of snap.

When the assembly is drawn up tight, the bearing is compressed, ensuring a positive contact between the backside of the bearing and the machined surface of the connecting rod bore.

1. Install new bearing shells in the connecting rod and in the bearing cap. Lubricate each shell with clean engine oil.
2. Install the connecting rod on the crankshaft.
3. Install the bearing cap on the connecting rod. Tighten the nuts or bolts on the bearing cap alternately and evenly to the special torque value.

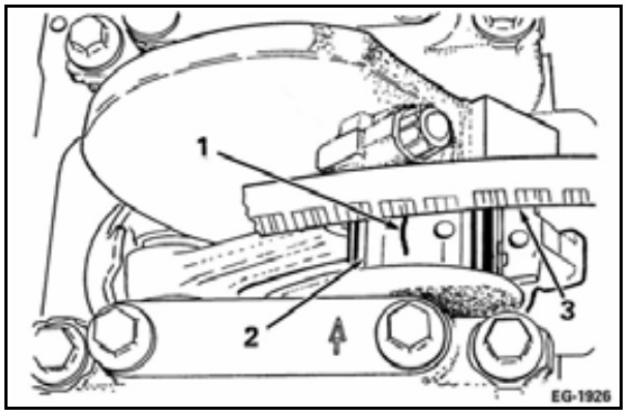

Figure 287 Measuring Bearing Running Clearance With Plastigage®

1. Plastigage® Wrapper/Scale
2. Connecting Rod Bearing Journal
3. Flattened Plastigage®

4. Measure the bearing running clearance as follows:
   a. Remove the bearing cap. Wipe the oil from the face of the bearing shell in the bearing cap and the exposed portion of the crankshaft.
   b. Place a piece of undamaged Plastigage® across the full width of the bearing shell about 6 mm (0.25 in) from the center of the bearing cap.
   c. Install the bearing cap and tighten the nuts or bolts alternately and evenly to the special torque value.

      NOTE: Do not turn the crankshaft. This will smear the Plastigage®.

   d. Remove the bearing cap. The Plastigage® material will adhere to either the bearing shell or the crankshaft. Do not remove the Plastigage®.
   e. Use the Plastigage® scale to measure the widest point of the flattened material. The numbers within the graduated marks on the wrapper/scale indicate the running clearance in thousandths of an inch or millimeters. See the specifications for the correct running clearance.
   f. Remove the Plastigage® material. Repeat the test for each connecting rod bearing.

NOTE: With the use of precision bearings, few problems should be encountered. However, if proper running clearance is not achieved, a problem with the crankshaft may still exist. Regrinding the crankshaft and using undersize bearings are probably necessary.

Also, the bearing cap bolt torque is very important. Use a torque wrench that is known to be accurate. Repeat the running clearance check procedure before condemning the crankshaft.

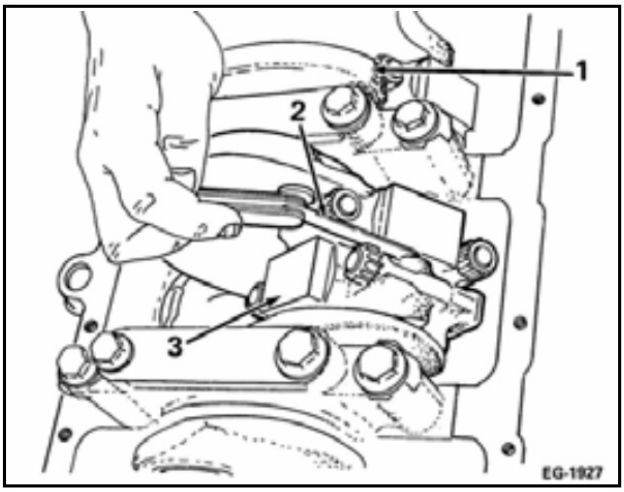

Figure 288 Checking the Connecting Rod Side Clearance with a Feeler Gauge

1. Crankshaft
2. Feeler Gauge
3. Connecting Rod Bearing Cap

5. Measure the connecting rod side clearance using one of the following tests:

Feeler Gauge Test

Pry two adjacent connecting rods apart and use a feeler gauge to measure the clearance between them. Refer to the specifications and repeat for all connecting rods.

Dial Indicator Test

   a. Place the tip of the dial indicator on the connecting rod bearing cap.
   b. Pry the two connecting rods apart with a screwdriver or prying tool. Then zero the dial indicator.

c. Pry the connecting rod in toward the dial indicator while recording the connecting rod side clearance. Refer to the specifications and repeat for all connecting rods.

NOTE: Lack of side clearance could indicate a damaged rod or a bearing that is out of position. Too much clearance may require replacement of the rods or crankshaft.

Assembly – Old Style Connecting Rod

⚠ WARNING: To avoid personal injury or possible death, wear safety glasses when installing piston pin retaining rings.

CAUTION: Make sure the connecting rod and piston are assembled correctly to avoid engine damage. The large chamfer side of the connecting rod must be located next to the crankshaft fillet.

Make sure the lock slots and forging feature on the connecting rod are opposite the "CAM" marking found on the piston head.

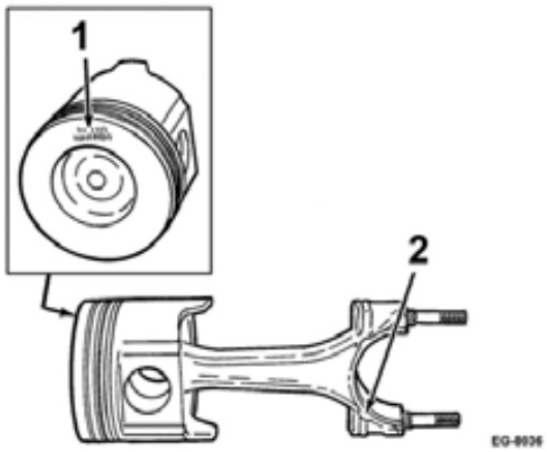

Figure 289 Assembly of the Piston and Connecting Rod

1. Piston Stamped "Cam", Part Number, (Service Pistons Include Oversize Designation)
2. Large Chamfer Side of Connecting Rod

1. Connect the piston to the connecting rod as follows:

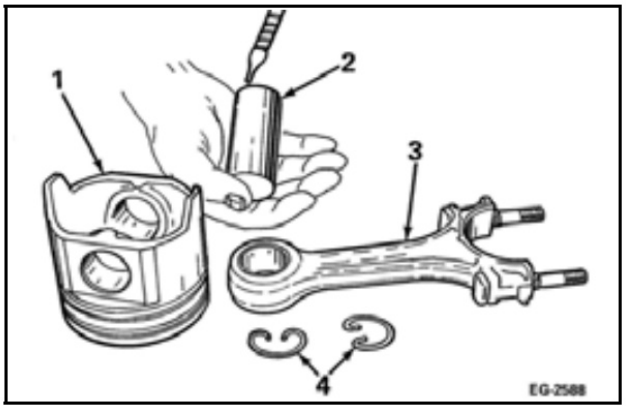

Figure 290 Installing the Piston Pin

1. Piston
2. Piston Pin
3. Connecting Rod
4. Retaining Rings

a. Lubricate the piston pin bore in the connecting rod, the piston bore and the piston pin with clean engine oil.

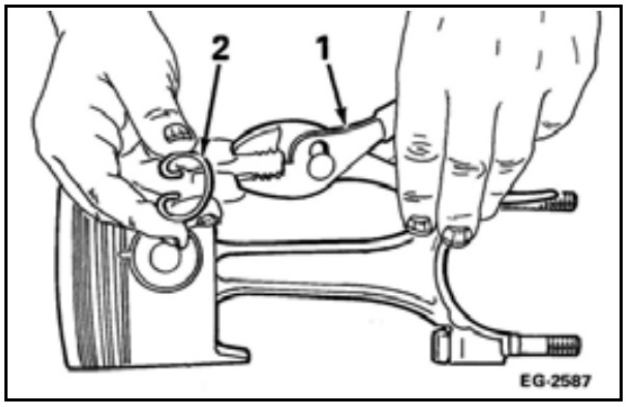

Figure 291 Installing the Piston Pin Retaining Ring

1. Pliers
2. Retaining Ring

NOTE: The retaining ring has a smooth finish side and a rough finish side. The smooth finish side faces the piston pin.

b. Use piston pin retaining ring pliers to install a piston pin retaining ring at one end of the piston pin bore.

c. Insert the connecting rod into the piston. Make sure the bored holes of the connecting rod and piston are aligned.

d. Slide the piston pin through the bored holes, stopping at the previously installed retaining ring.

e. Install the second retaining ring.

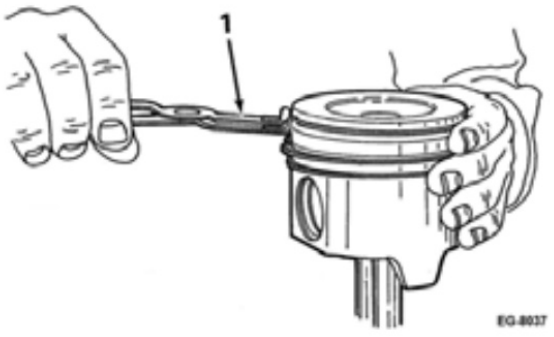

Figure 292 Installing Rings Onto Piston

2. Use piston ring expansion pliers to install piston rings onto piston.
3. Install the oil control ring into the bottom piston groove.

NOTE: The intermediate ring is identified by the two "OO" marks located on the top surface of the ring. The top ring is identified by one single “O” mark located on the top surface of the ring. Make sure the ring is installed with the identifications marks facing up.

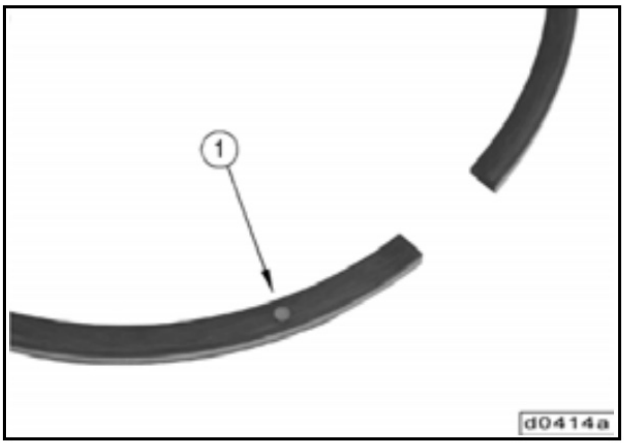

Figure 293 Piston Ring Identification Mark (top ring shown)

1. Identification Mark

4. Use the piston ring expansion tool to install the intermediate ring into the middle piston groove.
5. Use the piston ring expansion tool to install the top ring into the top piston groove.
6. Space ring gaps approximately 120° apart after ring installation.

Assembly – New Style Connecting Rod

⚠ WARNING: To avoid personal injury or possible death, wear safety glasses when installing piston pin retaining rings.

CAUTION: Make sure the connecting rod and piston are assembled correctly to avoid engine damage. The large chamfer side of the connecting rod must be located next to the crankshaft fillet.

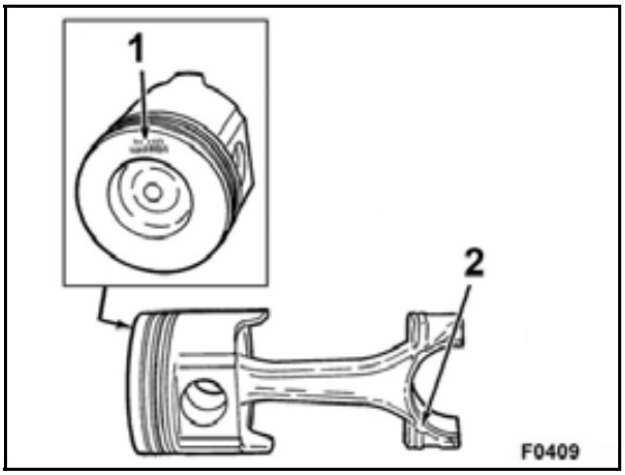

Figure 294 Proper Assembly of the Piston and Connecting Rod

1. Piston Stamped “CAM”’ Part Number, (Service Pistons Include Oversize Designation)
2. Large Chamfer Side of Connecting Rod

1. Connect piston to connecting rod as follows:

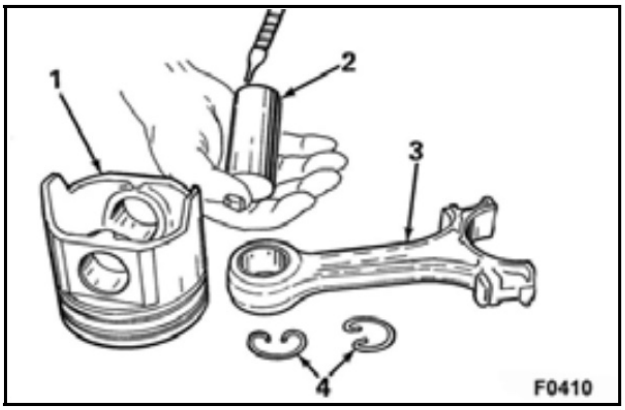

Figure 295 Installing the Piston Pin

1. Piston
2. Piston Pin
3. Connecting Rod
4. Retaining Rings

a. Lubricate the piston pin bore in the connecting rod, piston pin bore, and piston pin with clean engine oil.

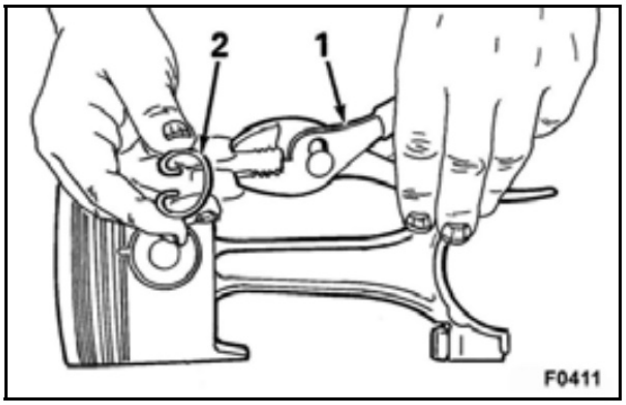

Figure 296 Installing Piston Pin Retaining Ring

1. Pliers
2. Retaining Ring

NOTE: The retaining ring has a smooth finish side and a rough finish side. The smooth finish side faces the piston pin.

b. Use pliers to install a piston pin retaining ring at one end of piston pin bore.

c. Insert the connecting rod into the piston. Make sure the bored holes of the connecting rod and piston are aligned.

d. Slide piston pin through bored holes, stopping at the previously installed retaining ring.

e. Install the second retaining ring.

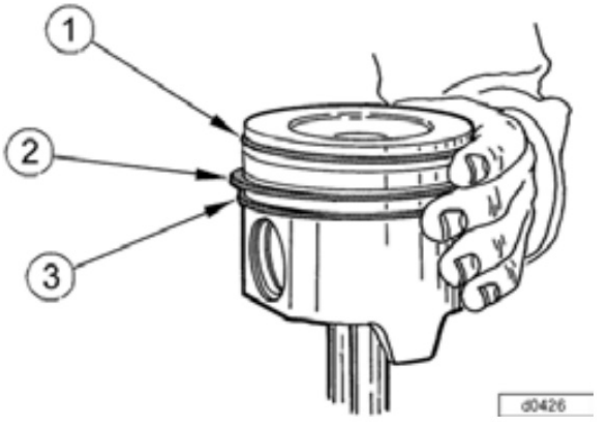

Figure 297 Piston Ring Locations

1. Top compression ring
2. Intermediate compression ring
3. Oil control ring

2. Use piston ring expansion pliers to install piston rings onto piston as follows:

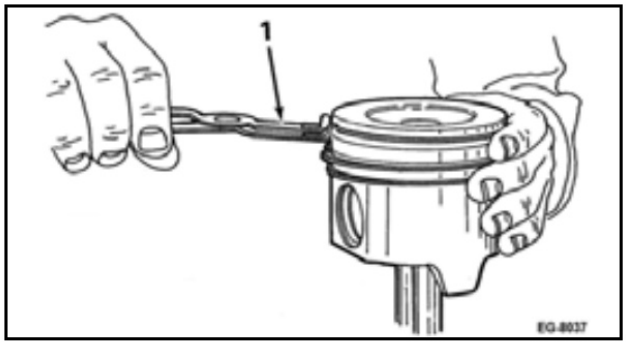

Figure 298 Installing Rings Onto Piston (Typical)

1. Piston ring expander tool
2. Piston
3. Piston ring (top compression shown)

a. Use the piston ring expansion tool to install the oil control ring into the bottom piston groove.

NOTE: The intermediate ring is identified by two “OO” marks located on the top surface of the ring. The top ring is identified by one single “O” mark located on the top surface of the ring. Make sure the ring is installed with the identification mark facing up (top of piston).

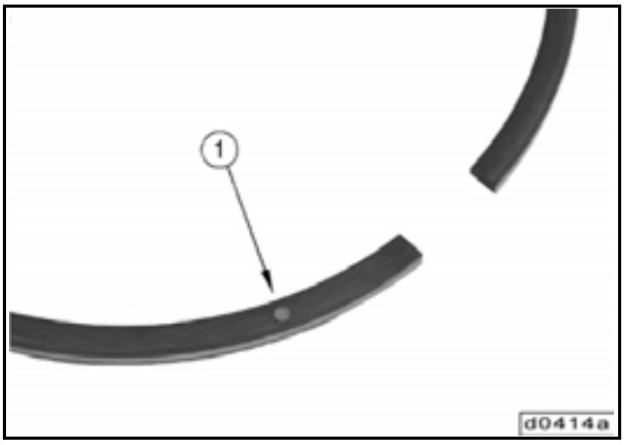

Figure 299 Piston Ring Identification Mark (top ring shown)

b. Use the piston ring expansion tool to install the intermediate ring into the middle piston groove.

c. use the piston ring expansion tool to install the to ring into the top piston groove.

3. Space ring gaps approximately 120° apart after ring installation.

Installation – Old Style Connecting Rod

CAUTION: To avoid engine damage:

- **DO NOT use any air powered tools when installing and tightening connecting rod nuts. This can cause seizure of connecting rod bolts.**
- **When installing the connecting rod and piston assembly into the cylinder bore BE SURE TO:**
  - **Install the connecting rod and piston assemble into the cylinder bore from which it was removed.**
  - **Assemble each connecting rod to the original connecting rod cap.**

NOTE: Install the piston and connecting rod assemblies after the piston cooling jets and crankshaft have been installed.

1. Turn the crankshaft so the appropriate crankpin is at the bottom of its stroke.
2. Make sure the connecting rod bearing shells are properly installed in the bearing cap and the connecting rod.

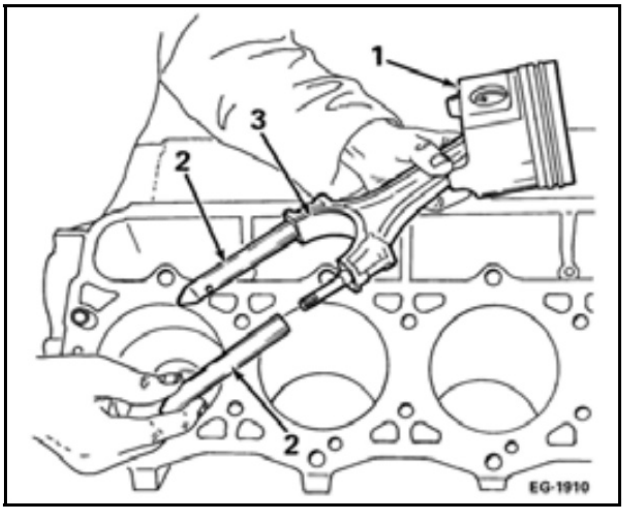

Figure 300 Installing Protector Caps on the Connecting Rod Studs

1. Piston and Connecting Rod Assembly
2. Protector Caps
3. Connecting Rod Bearing Shell (16)

3. Install aluminum protector caps over the connecting rod studs to help prevent damage to the crankshaft journals.
4. Coat the cylinder bore, crankshaft journals, pistons, piston rings and the piston installation sleeve with clean engine oil.
5. Before installing the piston into the ring compressor or the installation sleeve, make sure the ring gaps are oriented approximately 120° apart.

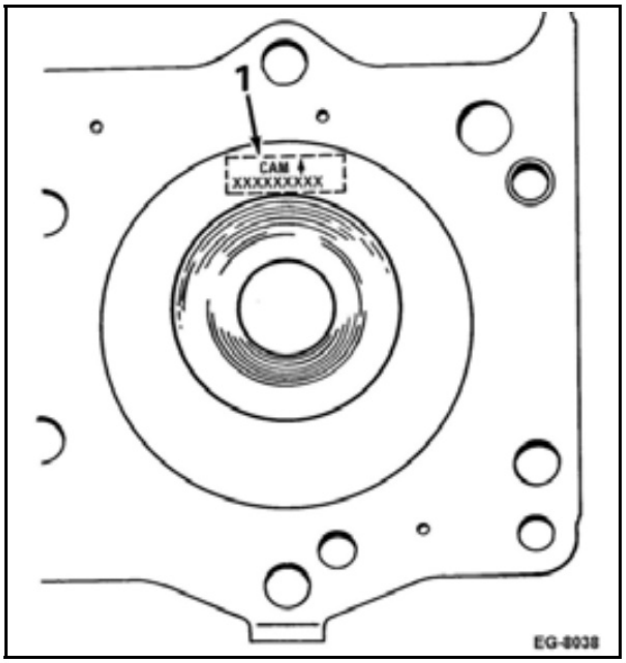

Figure 301 Correct Orientation of a Properly Installed Piston

1. Identification Marking

CAUTION: To avoid engine damage, the arrow located on top of the piston must face the camshaft side of the crankcase and the large chamfer on the connecting rod must be positioned next to the crankshaft fillet.

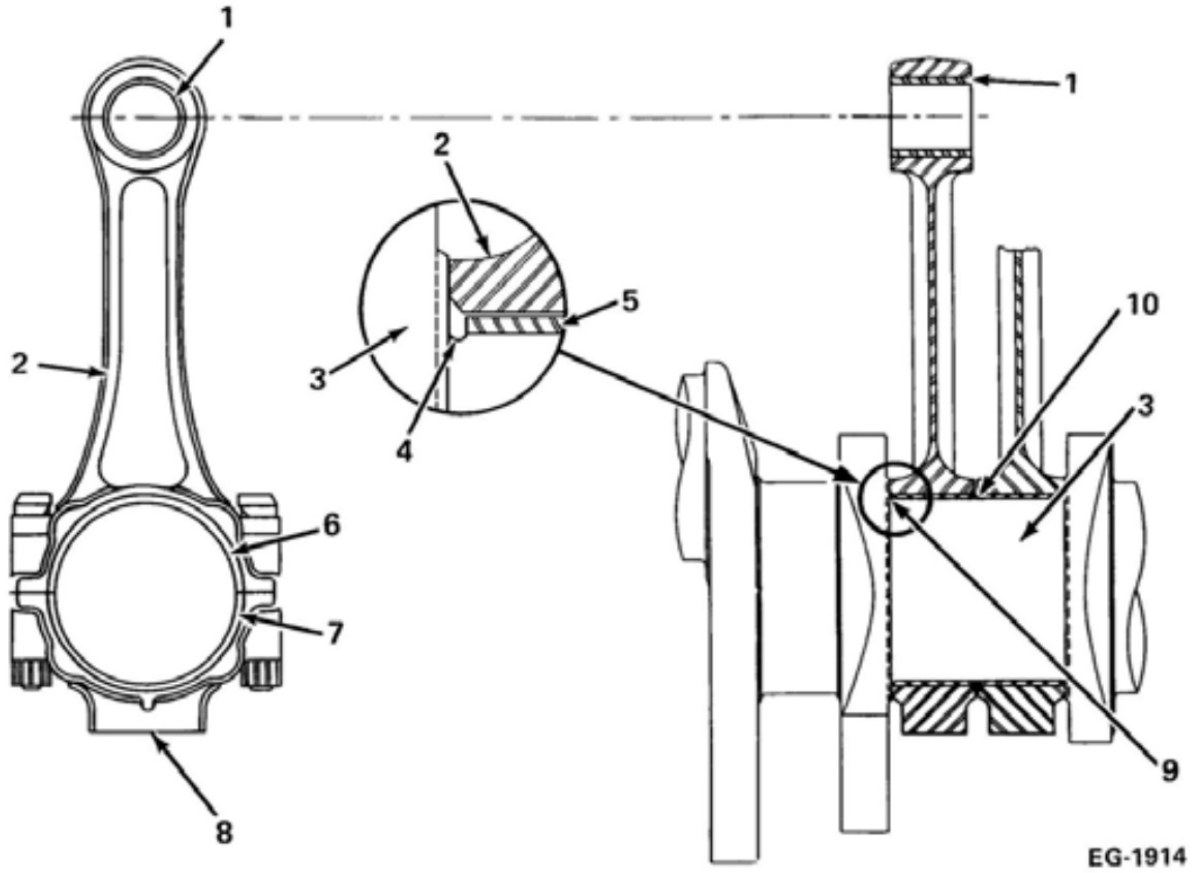

Figure 302 Proper Position of an Installed Connecting Rod

1. Piston Pin Bushing
2. Connecting Rod
3. Crankshaft
4. Crankshaft Fillet
5. Bearing
6. Connecting Rod Bearing (upper)
7. Connecting Rod Bearing (lower)
8. Connecting Rod Bearing Cap
9. Large Chamfer Side (next to fillet)
10. Small Chamfer Side

CAUTION: To avoid engine damage, when installing connecting rod and piston into cylinder bore, be careful not to damage the piston cooling tube.

6. Install the piston installation sleeve onto the piston. Make sure the rod bolts are seated. Carefully place the piston and connecting rod assembly into the crankcase bore.

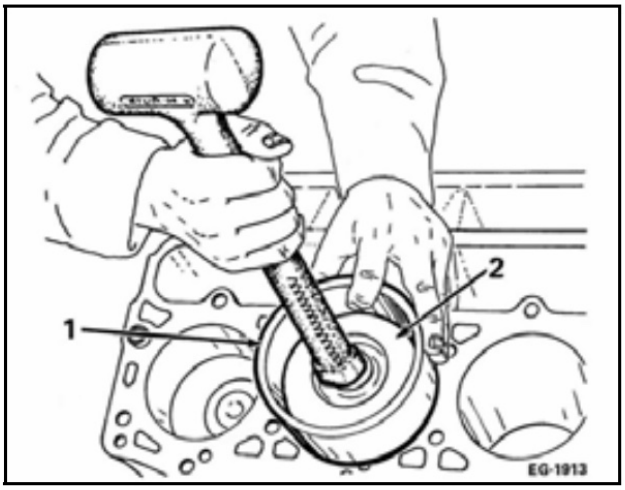

Figure 303 Seating the Piston in the Cylinder Bore

1. Piston Installation Sleeve
2. Piston

7. Use the handle of a hammer and tap the piston into the cylinder bore.
8. Remove the aluminum protector caps from connecting rod bolts.

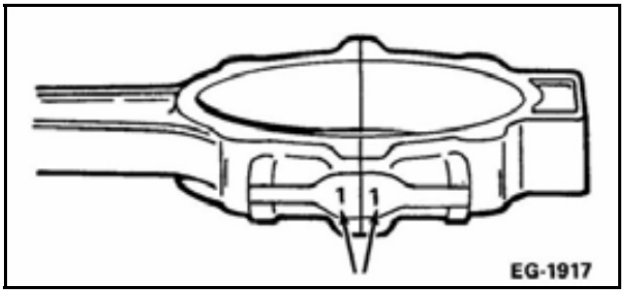

Figure 304 Connecting Rod and Cap Identification Marks

NOTE: Make sure each connecting rod is matched with the its original bearing cap on the same crankpin from which they were removed.

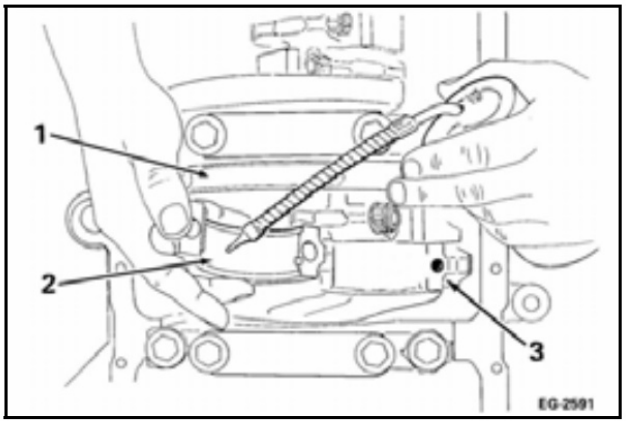

Figure 305 Installing the Bearing Caps

1. Crankshaft
2. Bearing Shell
3. Connecting Rod

9. Coat the bearing shell surfaces and connecting rod threads with clean engine oil. Install the bearing cap on the connecting rod.

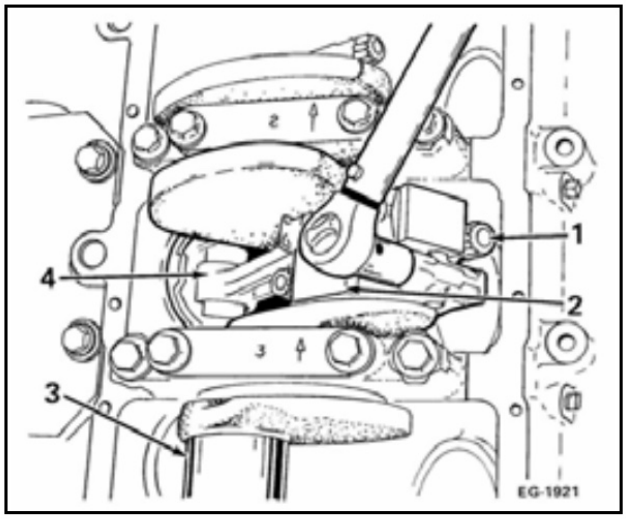

Figure 306 Securing the Connecting Rod Cap

1. Connecting Rod Nuts (16)
2. Connecting Rod Bearing Cap (8)
3. Crankshaft
4. Connecting Rod (8)

10. Install and tighten the connecting rod mounting nuts to the special torque value.
11. Check the piston protrusion above the crankcase.
12. Repeat the installation procedure for the remaining connecting rods and pistons.

Installation – New Style Connecting Rod

CAUTION: To avoid engine damage:

- **DO NOT use any air powered tools when installing and tightening connecting rod bolts. This can cause seizure of connecting rod bolts.**
- **When installing the connecting rod and piston assembly into the cylinder bore BE SURE TO:**
  - **Install the connecting rod and piston assemble into the cylinder bore from which it was removed.**
  - **Keep the fractured mating surfaces clean and free of lint and debris. Do not allow the mating surfaces to rest on any surface. Do not bump the mating surfaces or drop the connecting rod or cap. This could cause chipping and wear on the mating surface, resulting in improper mating during installation and possible engine damage.**
  - **If the rod cap is reversed when assembled to the connecting rod or a rod cap is NOT installed on its original matching connecting rod, the fractured mating surfaces will be ruined. This may cause the rod cap to come loose and cause engine damage. The entire connecting rod must be replaced.**

NOTE: Install the piston and connecting rod assemblies after the piston cooling jets and crankshaft have been installed.

1. Turn crankshaft so the appropriate crankpin is at the bottom of its stroke.
2. Make sure the connecting rod bearing shells are properly installed in the bearing cap and the connecting rod.
3. Coat piston and piston rings with clean engine oil. Coat cylinder walls, crankshaft journals, and piston cope with clean engine oil. (The cope is

a special tool designed to hold the piston rings in place during installation.)

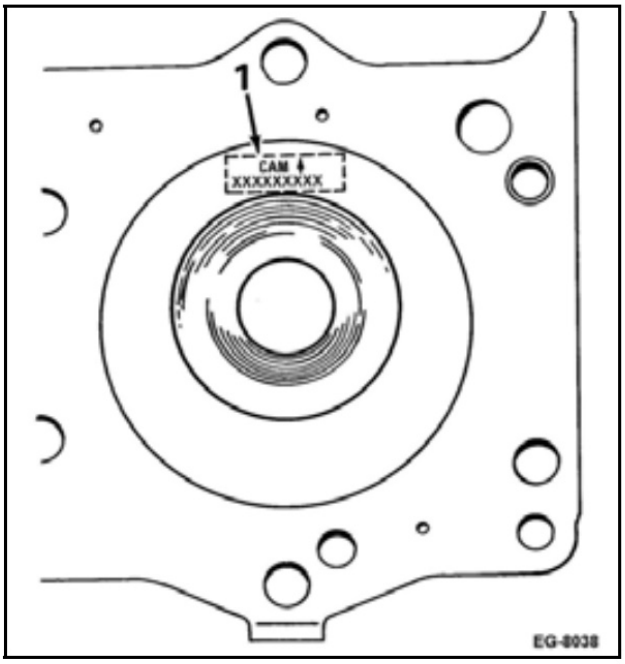

Figure 307 Correct Orientation of a Properly Installed Piston

1. Identification Marking

CAUTION: To avoid engine damage, the arrow located on top of the piston must face the camshaft side of the crankcase and the large chamfer on the connecting rod must be positioned next to the crankshaft fillet.

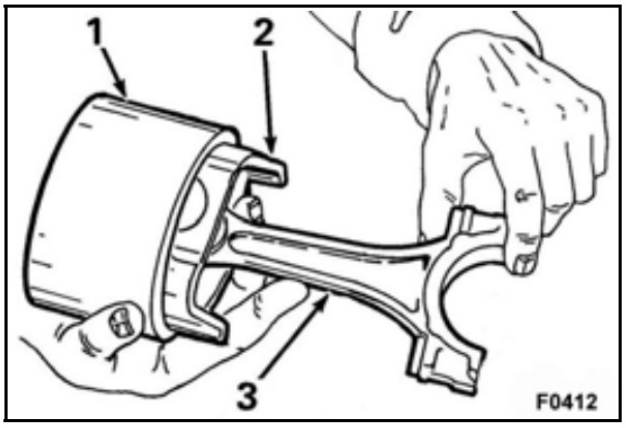

Figure 308 Installing the Piston and Connecting Rod Into the Cylinder Bore

1. Piston Installation Sleeve
2. Piston
3. Connecting Rod

4. Place the piston with rings and connecting rod installed, into the cope.
5. Install bearing shells into connecting rod and cap. Coat bearing shell in connecting rod with clean engine oil.

CAUTION: To avoid engine damage, when installing connecting rod and piston into cylinder bore, be careful not to damage the piston cooling tube.

6. Carefully insert connecting rod and piston into cylinder bore.

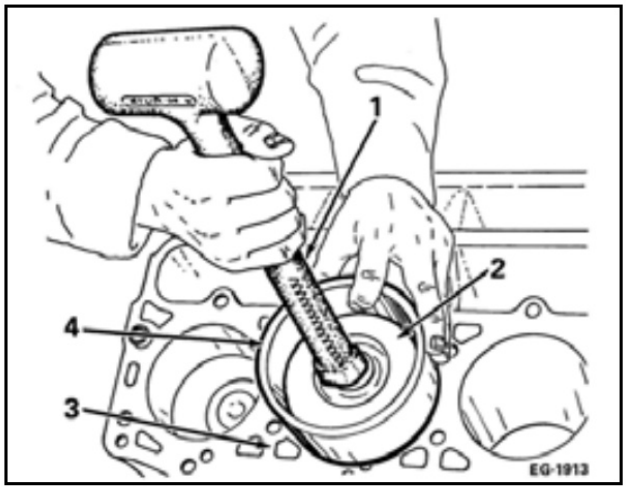

Figure 309 Seating the Piston in the Cylinder Bore

1. Piston Installation Sleeve
2. Piston

7. Once piston and connecting rod have been inserted into the cylinder bore, use the handle of a hammer to tap piston into crankcase bore. Guide connecting rod into place over crankshaft journal.

NOTE: Be sure each connecting rod is matched with the original bearing cap on the same crankpin from which they were removed.

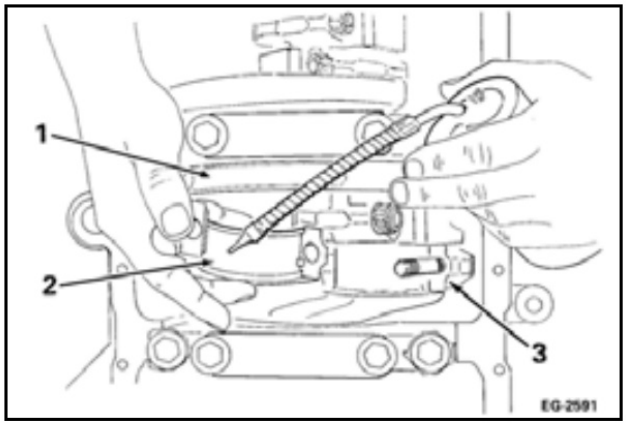

Figure 310 Installing the Connecting Rod Cap

1. Crankshaft
2. Bearing Shell
3. Connecting Rod

8. Coat the bearing shell and connecting rod surfaces with clean engine oil. Install the bearing cap on the connecting rod.

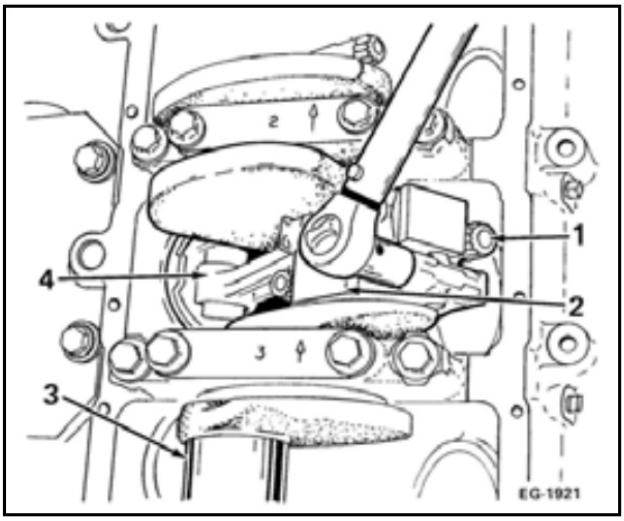

Figure 311 Securing the Connecting Rod Cap

1. Connecting Rod Nuts or Bolts (16)
2. Connecting Rod Bearing Cap (8)
3. Crankshaft
4. Connecting Rod (8)

9. Install and tighten the connecting rod mounting nuts or bolts to the special torque value.
10. Repeat installation procedure for remaining connecting rod and piston assemblies.
11. Check connecting rod side clearance with feeler gauge. Refer to “REMOVAL” in this section for the correct procedure.

Crankshaft and Main Bearings

Removal

NOTE: Crankshaft bearing caps are numbered from the front to identify their respective positions for installation. The No. 5 bearing cap accommodates a thrust flange to limit crankshaft end play.

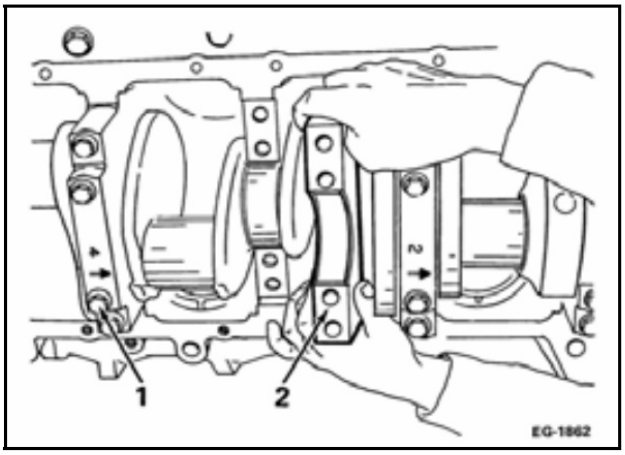

Figure 312 Removing the Main Bearing Cap

1. Main Bearing Cap Bolt
2. Main Bearing Cap

1. Loosen the main bearing cap mounting bolts.
2. Grasp the main bearing cap mounting bolts and rock them back and forth to loosen and remove the cap.
3. Remove the lower bearing shell from the main bearing cap. Keep each shell with its original cap for main bearing inspection.

WARNING: To avoid engine damage, serious personal injury or possibly death, use an appropriate lifting sling when removing the crankshaft from the crankcase.

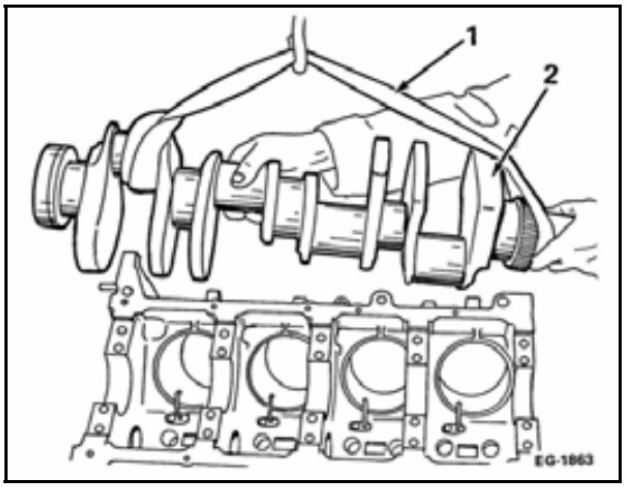

Figure 313 Removing the Crankshaft From the Crankcase

1. Lifting Sling
2. Crankshaft

4. Attach a lifting sling to the crankshaft. Lift the crankshaft straight up and out of the crankcase.
5. Remove the upper main bearing inserts by pushing them out of the main bearing saddle. Mark the upper shells and put them with the lower shells for a proper inspection.

Cleaning

1. Clean the crankshaft with a suitable solvent. Dry the crankshaft with filtered compressed air.
2. Use a stiff nylon brush to clean all of the internal oil passages of the crankshaft. Loosen all dirt, sludge, and other deposits that may have accumulated. Flush the oil passages with a suitable non-caustic solvent. Dry the oil passages with filtered compressed air.
3. Clean the bearing caps and inserts thoroughly in solvent. Dry with filtered compressed air.

Inspection

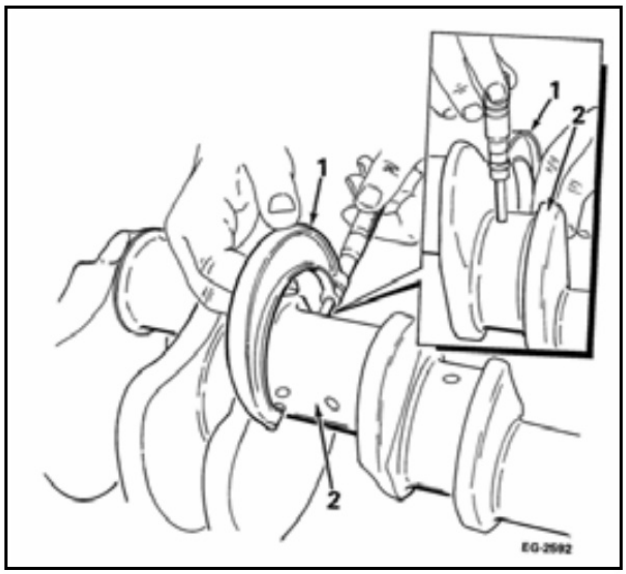

Figure 314 Measuring the Crankshaft Journals

1. Micrometer
2. Crankshaft

1. Inspect the crankshaft journals (main and connecting rod) for scratches, grooves and scoring. Use the dye penetrant method when checking for cracks.
2. Inspect all bearing inserts. Replace any main bearings that are scored, chipped or worn.
3. Use a micrometer to measure the diameter of each journal.

Check Crankshaft Journals for Out-of-Round and Taper

1. To check for an out-of-round condition, measure each end of each journal at two points, 90° apart from each other (4 measurements total).

   NOTE: When taking crankshaft measurements, it is important to keep the micrometer clear of the crankshaft fillet radius.

   a. Take the first two measurements taken in the same position (one measurement at each end of the journal) and record the average.

   b. Again, take the second set of measurements taken in the other position (at 90° to the first set, one measurement at each end of the journal) and record the average.

   c. Subtract the smaller averaged value from the larger averaged value. This will yield the amount of out-of-round.

2. To determine journal taper, use the measurements taken in Step 1.

   a. Record the average of two measurements taken at one end of the journal.

   b. Record the average of the other two measurements at the other side of the journal.

   c. Subtract the smaller averaged value from the larger averaged value. This will yield the amount of taper from one end of the journal to the other.

CAUTION: If any journals exceed either the maximum out-of-round or maximum taper specifications, the crankshaft must be replaced or reground and undersize bearings installed. Failure to do so may result in engine damage.

Installation of Crankshaft

NOTE: Make sure the crankcase has been inspected before installation.

1. Use a lint-free cloth to wipe any oil off the crankcase bearing supports.
2. Clean the bearing inserts and bearing caps thoroughly in solvent. Dry them with filtered compressed air.
3. Inspect each bearing. Replace any bearings that are scored, chipped or worn.

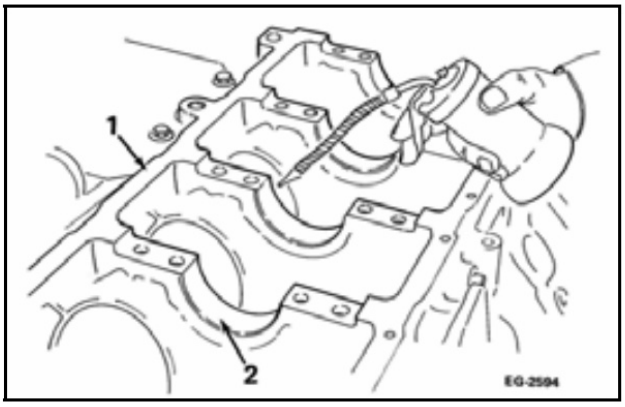

Figure 315 Lubricating the Upper Main Bearing Inserts

1. Crankcase
2. Main Bearing Insert

4. Lubricate the upper main bearing inserts with clean engine oil and insert them into the crankcase main bearing supports.

   NOTE: Make sure the locking tabs on the bearings are aligned with the slots in the crankcase saddle. Also, the oil holes in the bearing shells must line up with the oil holes in crankcase.

WARNING: To avoid engine damage, serious personal injury or possibly death, use an appropriate lifting sling when installing the crankshaft into the crankcase.

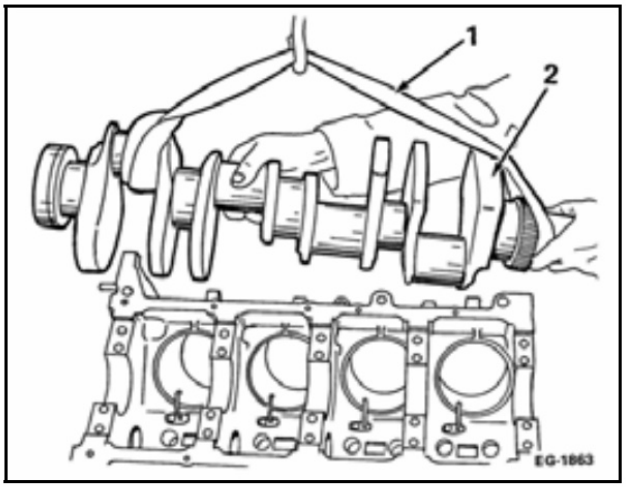

Figure 316 Installing the Crankshaft Into the Crankcase

1. Lifting Sling
2. Crankshaft

5. Attach an appropriate lifting sling to the crankshaft and carefully lower it onto the main bearing saddle in the crankcase.

Main Bearing Fitting Procedure

1. Install all of the main bearing caps. Tighten the mounting bolts to the special torque value.
2. Remove one bearing cap and insert. Leave the remaining caps tight while checking the fit of the bearing with the cap removed.
3. Clean the bearing surface and the exposed half of the crankshaft journal. Make sure these surfaces are free of oil.
4. Place a piece of Plastigage® across the full width of the bearing surface on the crankshaft journal or bearing cap insert approximately 6 mm (.250 in) off center. Install the main bearing cap and tighten mounting bolts to the special torque value.

   NOTE: Do not turn the crankshaft while the Plastigage® is on the journal.

WARNING: In chassis service only, before checking for bearing oil clearance, the crankshaft must be supported and held up against the upper main insert bearing halves. Failure to do so may result in incorrect oil clearance values and may cause personal injury or engine damage.

Use a jack and a piece of wood around the center of the crankshaft to provide adequate support. The oil clearance checking procedure is performed exactly the same as an engine that is mounted on an engine stand.

5. Remove the main bearing cap and insert. Do not disturb the Plastigage®.

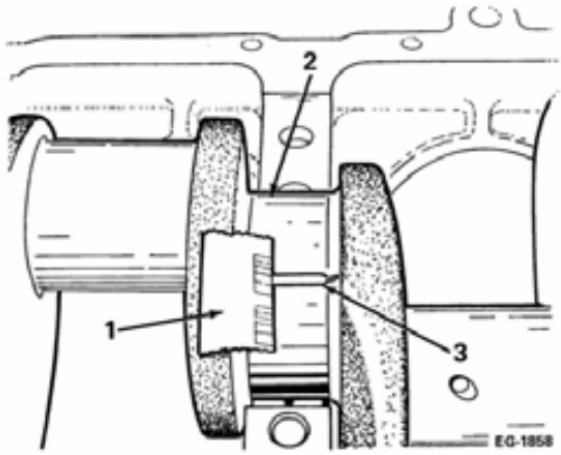

Figure 317 Checking the Bearing Clearance of the Crankshaft Journal

1. Oil Clearance Scale
2. Main Bearing Journal
3. Flattened Plastigage®

6. Use the Plastigage® scale located on the envelope/wrapper, measure the widest point of the flattened Plastigage®. This reading indicates the bearing running oil clearance in thousandths of an inch or millimeter.
7. If the bearing running oil clearance is not within specifications, the crankshaft must be replaced or machined and undersized bearings installed. Refer to Crankshaft in this section.
8. Perform this procedure for each main bearing. Then continue on to **Installation of Main Bearing Cap**.

Installation of Main Bearing Caps

NOTE: Make sure the bearing oil clearance is acceptable before installing the main bearing caps.

1. Clean the Plastigage® from the main bearing and crankshaft journal surfaces.
2. Apply clean engine oil to the main bearing cap inserts, crankshaft journals and main bearing cap mounting bolts.

CAUTION: To avoid engine damage, make sure the main bearing caps are installed in the proper order. Do not mix them. Caps must be installed with the stamped arrow facing the front of the engine. The No. 1 location is at the front of the engine.

3. Place the No. 1 through No. 4 bearing caps into position. Install the mounting bolts finger tight.
4. Use a soft hammer to tap the bearing caps until the rear machined faces of the caps are flush with the machined faces of the crankcase.

CAUTION: Make sure the rear thrust flanges are flush with each other. Aligning the main bearing caps in this manner will ensure proper cap location and may prevent engine damage.

5. Install the No. 5 rear thrust bearing cap into position. Install the mounting bolts finger tight.

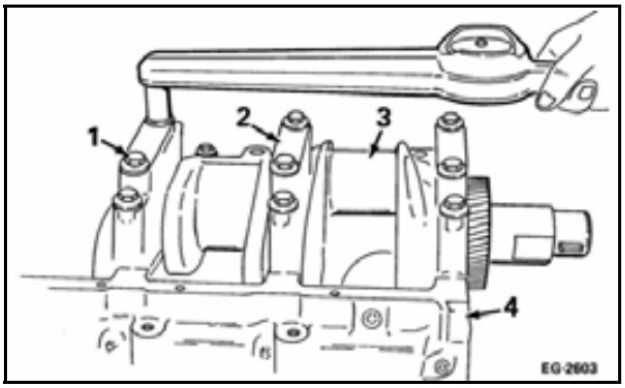

Figure 318 Tightening the Main Bearing Cap Mounting Bolts

1. Mounting Bolt
2. Main Bearing Cap
3. Crankshaft
4. Crankcase

6. Tighten the mounting bolts for main bearing caps No. 1 through No. 4 to the special torque value.

Check Crankshaft End Play

NOTE: The main thrust bearing cap (No. 5 main bearing) provides the initial location of the crankshaft end thrust in relation to the crankcase.

1. Mount a dial indicator on the crankcase with the indicator tip on the crankshaft gear.
2. Use a pry bar or equivalent to pry the crankshaft back and forth.
3. Tighten the mounting bolts of the No. 5 thrust bearing cap to the special torque value.

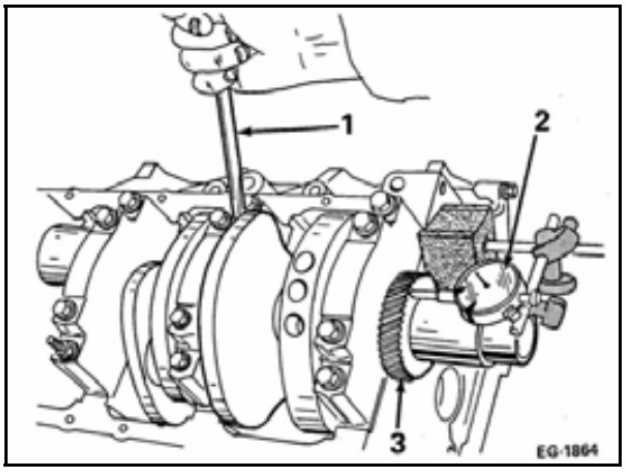

Figure 319 Checking the Crankshaft End Play

1. Pry Bar
2. Dial Indicator
3. Crankshaft Gear

4. Pry the crankshaft forward and zero the dial indicator. Check the end play by prying the crankshaft backward and reading the dial indicator. Repeat the procedure to ensure the accuracy of previous results.
5. After checking the crankshaft end play, one of the following will occur:
   - The crankshaft end play is within specifications, installation is complete.
   - The crankshaft end play exceeds specifications, replace the main thrust bearing and check the crankshaft end play again.
   - The crankshaft end play is less than the minimum specified limit, the main thrust bearing faces are damaged or dirty. Replace or clean the main thrust bearing and check crankshaft end play again.
   - If the main thrust bearing is not damaged or dirty, it was probably misaligned. Remove the main thrust bearing and repeat installation procedure again.

Piston Cooling Jets

Removal

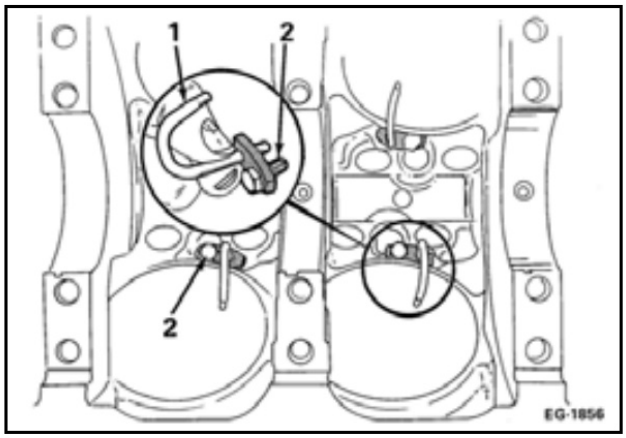

Figure 320 Piston Cooling Jet

1. Piston Cooling Jet
2. Mounting Bolt

Remove the mounting bolt that secures each piston cooling jet to the crankcase. Remove the piston cooling jets.

Cleaning and Inspection

1. Replace any piston cooling jets that are cracked or bent.
2. With the piston cooling jets removed, run an appropriate size wire through each tube to ensure there is no blockage.
3. Use filtered dry compressed air to blow out any debris from cleaning.

Installation

CAUTION: The piston cooling jets use a special patch type mounting bolt. Do not substitute or the mounting bolts will not tighten properly. This can cause the cooling jet tubes to become misaligned, or loosen and fall into the crankcase, causing severe engine damage.

If the original patch bolts are being installed, make sure the bolts threads and bolt holes are cleaned and apply Loctite to the bolts threads. This will ensure that the patch bolts will not come loose in the engine.

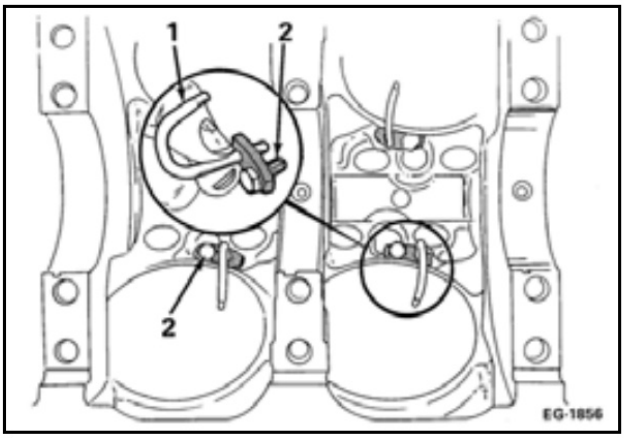

Figure 321 Installing the Piston Cooling Jet

1. Piston Cooling Jet Tube
2. Patch Bolt

NOTE: Do not perform Step 1 if new patch bolts are being installed.

1. If the original patch bolts are being reused, clean the bolt hole and bolt threads so they are free of oil residue. Apply Loctite® #242 to the threads of reused patch bolts.
2. Place the piston cooling jet tube onto the crankcase mounting pad.

NOTE: The bolt-on piston cooling jet tubes are self aligning.

3. Tighten the patch bolts to the standard torque value.

Crankcase Reconditioning

Cleaning

The best way to clean the crankcase during an engine overhaul is in a chemical bath or HOT TANK. This procedure removes all carbonized material and mineral deposits which collect in the cooling passages. However, when a HOT TANK is not available, use the following.

NOTE: Thoroughly clean and inspect crankcase before and after reconditioning.

1. Use a scraper and a sanding block to clean all old gasket material from the machined surfaces of the crankcase.
2. Clean the cylinder bores with soap, water and a nylon brush.
3. Remove the pipe plugs on front of crankcase. Thoroughly clean all of the oil passages and bolt holes.
4. Remove the main oil gallery plugs. Use a nylon brush to clean the main oil gallery.

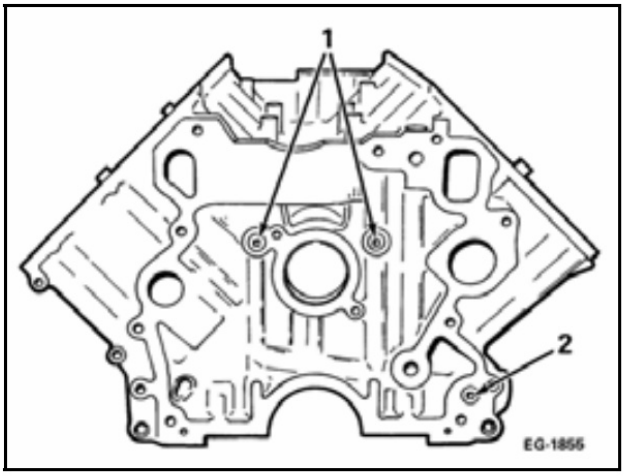

Figure 322 Valve Lifter and Main Oil Gallery Plug Locations

1. Valve Lifter Oil Gallery Plugs
2. Main Oil Gallery Plug

5. Remove the valve lifter oil gallery plugs located in the rear of the crankcase and discard them. Use a nylon brush to clean to clean the valve lifter oil galleries.
6. Apply Aviation Permatex No. 3 to the main oil gallery plug and install it into the crankcase. Make sure the top of main oil gallery plug is below the surface level of the crankcase.
7. Apply Aviation Permatex No. 3 to the new valve lifter oil gallery plugs and install them into the crankcase.

Inspect Short Circuit Valve

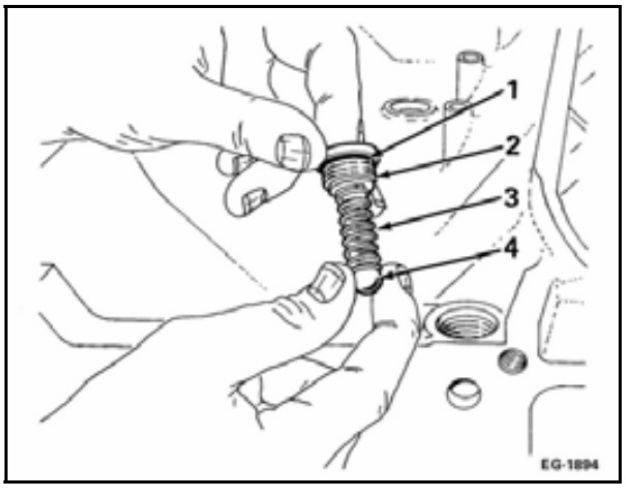

Figure 323 Short Circuit Components

1. O-Ring
2. Plug
3. Spring
4. Check Ball

1. Use a hex head wrench to remove the plug located in the top left front of the crankcase.
2. Inspect the plug, O-ring, spring, and the check ball for wear. Also check the ball seat in the valve port of the crankcase. Replace any worn items.
3. Install the ball and spring into the valve port. Apply clean engine oil to the O-ring and place it onto the plug.
4. Screw the plug into the crankcase. Tighten the plug to the standard torque value.

Replace Crankcase Cup Plugs

1. Use a hammer and punch to drive a hole into the side of the cup plug (near the edge). Then pry

out the cup plug. Be careful not to damage the expansion bore.

2. Use a cup plug driver to install new cup plugs. Coat the edges of the plug with Aviation Permatex No. 3. The driver installs the plug to the proper depth.

Check Crankcase Surface for Flatness

CAUTION: The threads in the crankcase bolt holes must be cleaned and blown dry with filtered compressed air. Dirt or oil left in the holes may cause binding or a false torque reading during reassembly.

CAUTION: Do not resurface the crankcase. Surface defects beyond those listed are not correctable. To avoid engine damage, replace the crankcase.

1. After cleaning, inspect the crankcase for scoring, roughness, cracking or wear at the cylinder bores.

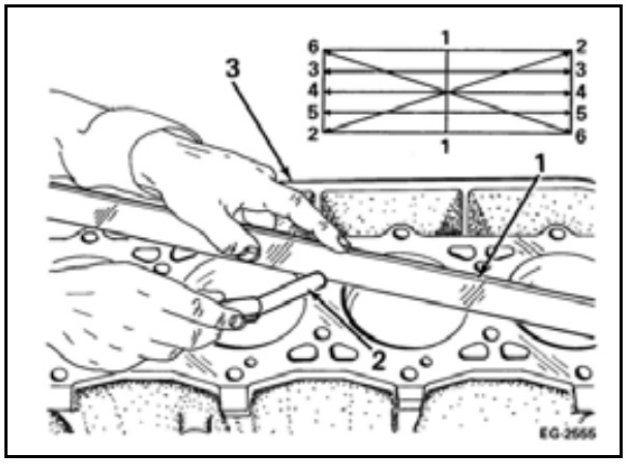

Figure 324 Checking the Crankcase Deck for Flatness

1. Straightedge
2. Feeler Gauge
3. Crankcase

2. Using a straightedge, check the top surface of the crankcase for flatness by attempting to insert a 0.10 mm (0.004 in) feeler gauge between the straightedge and the crankcase head surface. If the gap exceeds 0.10 mm (0.004 in), the crankcase must be replaced.

Check Cylinder Bore for Out-of-Round and Taper

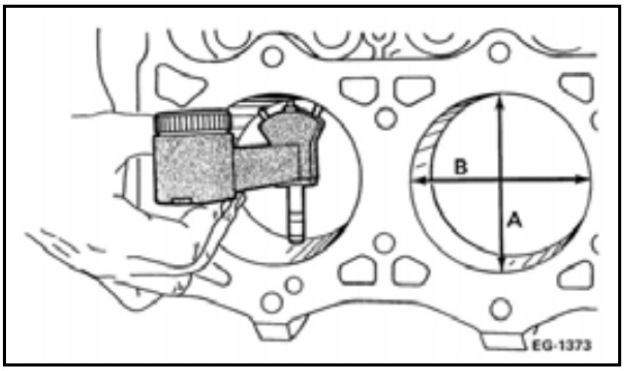

Figure 325 Checking the Cylinder Bore for Out-Of-Round

1. Check for an out-of-round condition as follows:
   a. Measure the diameter of each cylinder bore at the top of the piston ring travel (Dimension "A"). For each cylinder, measure Dimension "A" at a right angle to the center line of the crankshaft. Record each reading.
   b. Measure each cylinder bore so the gauge reading coincides with the centerline of the crankshaft (Dimension "B"). Record the reading.
   c. Subtract the smaller value from the larger value. The difference in measurements will be the out-of-round condition at the top of the cylinder bore.
   d. Repeat the same procedure at the bottom of the ring travel to check for an out-of-round condition.

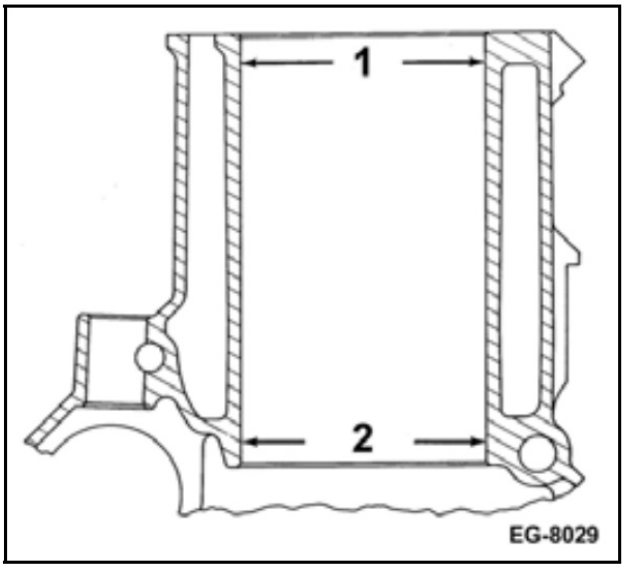

Figure 326 Checking Cylinder Bore Taper

1. Measurement at the top of the cylinder
2. Measurement at the bottom of the cylinder

2. Determine the taper of the cylinder bore by calculating the difference between the diameters of the top and bottom of the cylinder bore.
3. If the cylinder bore is within specifications, standard size pistons and rings may be used. If a cylinder bore is suitable for use without reconditioning, deglaze the cylinder bore with a glaze breaking brush and continue with assembly. Refer to **Deglazing** in this section.

   If the cylinder walls have minor surface damage, but are otherwise within specifications, it may be possible to remove such damage by honing.

   If any of the cylinder bores are deeply scored and exceed any of the out-of-round or taper conditions, machining the cylinders to the next oversize is necessary.

Deglazing

1. Remove the piston cooling jets. Refer to **Piston Cooling Jets, Removal** for the procedure.

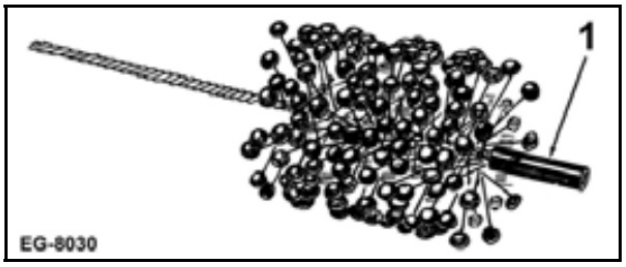

Figure 327 Glaze Breaking Brush

1. Rubber Hose Over Shaft

2. Cylinder bore can be deglazed using a 120 grit glaze breaking brush. Install a 50 mm (2 in) section of rubber hose over the end of the shaft (Figure 327).

   This silicone carbide-tipped nylon flexible brush quickly deglazes cylinder walls and produces a cross-hatch pattern on the cylinder wall surface in a single operation. The brush contours itself to the cylinder wall and conditions the wall surface without altering the cylinder bore.

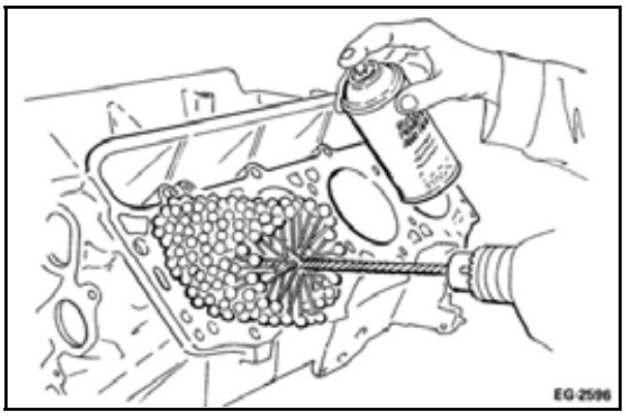

Figure 328 Preparing Glaze Breaking Brush for Deglazing

3. Obtain a 355 ml (12 oz) can of PE-12 Solvent and Penetrating Fluid manufactured by AGS (or equivalent), available at any well-stocked auto supply house. This spray contains colloidal graphite and works well for this application. Spray both the cylinder to be deglazed and the glaze breaking brush.

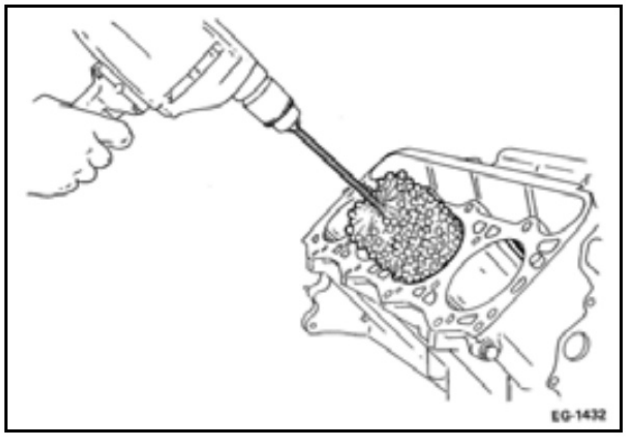

Figure 329 Deglazing the Cylinder Bore

4. Deglaze the cylinder as follows:
   a. Attach the glaze breaking brush to a variable speed electric or air powered drill motor.
   b. Deglaze the cylinder wall for about 15 seconds while stroking the bore up and down at a rate of one complete up and down stroke per second.

      A speed of approximately 100-120 rpm is required. Speed adjustment is required for the procedure to be successful.
   c. Withdraw the glaze breaking brush from the cylinder bore while the brush is rotating. Wipe a portion of the cylinder wall and inspect the cross-hatch pattern. Compare it to an untouched cylinder bore. The crosshatch pattern should be approximately 45°.
   d. If the pattern is "flatter" than required, increase the up and down stroke speed or slow down the drill rotation.
   e. Continue deglazing the cylinder bore for 10-15 seconds or 20-25 strokes.
   f. Wipe the cylinder bore clean and inspect the bore for a proper 45° cross-hatch pattern.
5. After deglazing, thoroughly clean the cylinder bores with a soft bristle brush, soap and water. Dry the bores with filtered compressed air and lubricate the bores with clean engine oil.
6. Install the piston cooling jets before assembly. Refer to **Piston Cooling Jets, Installation** for the procedure.

Camshaft Bushings

Check for Wear and Proper Running Clearance

1. Use a micrometer to measure each camshaft bearing journal diameter at two locations 90° apart. Record the average of these two measurements.
2. With the camshaft bushings installed in the crankcase, use a telescoping gauge and micrometer to measure each camshaft bushing inner diameter at two locations 90° apart. Record the average of these two measurements.
3. Subtract the two averages to determine the running oil clearance. If the result exceeds the specification, replace the camshaft bushings.

Removal

CAUTION: When servicing the camshaft bushings, the crankshaft and main bearings must be removed from the crankcase to avoid contamination from debris. Such a contamination may result in engine damage.

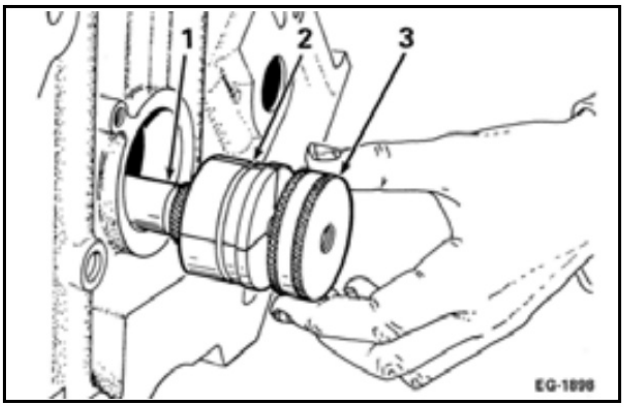

Figure 330 Assembling and Installing the Camshaft Bushing Removal Tool

1. Pulling Screw
2. Expanding Collet
3. Backup Nut

1. Use the camshaft bushing removal tool and select the proper size expanding collet and backup nut. Assemble the parts onto the expanding mandrel.

2. With the expanding collet collapsed, install the collet assembly into the camshaft bushing. Tighten the backup nut on the expanding mandrel until the collet fits on the camshaft bushing.

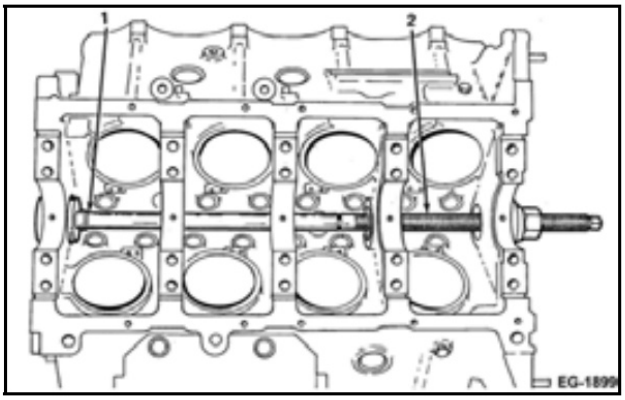

Figure 331 Attaching the Puller Screw

1. Expanding Mandrel
2. Puller Screw

3. Assemble the puller screw onto the expanding mandrel. Wrap a cloth around the threads of the puller screw to protect the front camshaft bushing.

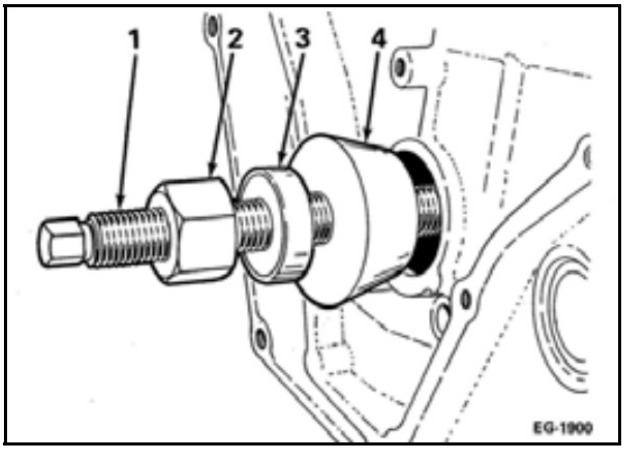

Figure 332 Installing the Pulling Plate and Thrust Bearing

1. Puller Screw
2. Backup Nut
3. Thrust Bearing
4. Pulling Plate

4. Attach the pulling plate, thrust bearing and backup nut to puller screw. Tighten the nut against the thrust bearing and pulling plate to remove the camshaft bushing. Hold a wrench on the end of the puller screw to prevent it from turning.

Inspection

1. Inspect each bushing bore in the crankcase for burrs or debris that could damage new bushings when they are installed.
2. Remove any burrs and clean bores thoroughly before installing new camshaft bushings.

Installation

CAUTION: The bushings are interchangeable from one bore to another except for the No. 1 (front) bushing, which is wider than the others. To avoid engine damage, identify the No. 1 (front) bushing from the Nos. 2– 5 (intermediate and rear) bushings.

1. Lubricate the new camshaft bushings and the crankcase bores with clean engine oil.

CAUTION: Failure to use the correct expanding collet can cause severe bushing damage.

2. Use the camshaft bushing installation tool to install the new bushing onto the expanding collet. Tighten the collet by turning the backup nut until the bushing is held securely.
3. Mark the oil hole location on the backup nut of the installation tool as an aid in aligning the oil holes in the bushing and crankcase. This step must be repeated for each camshaft bushing that is installed.

CAUTION: To ensure proper oil circulation throughout the crankcase, make sure all camshaft bushing oil holes are in alignment with the oil holes in the crankcase. Failure to do so may result in engine damage.

4. Install the intermediate and rear camshaft bushings through the front of the crankcase. Then pull them into place from the rear of the crankcase by turning the pulling nut on the puller screw. Remove the installation tool and inspect the oil hole alignment.

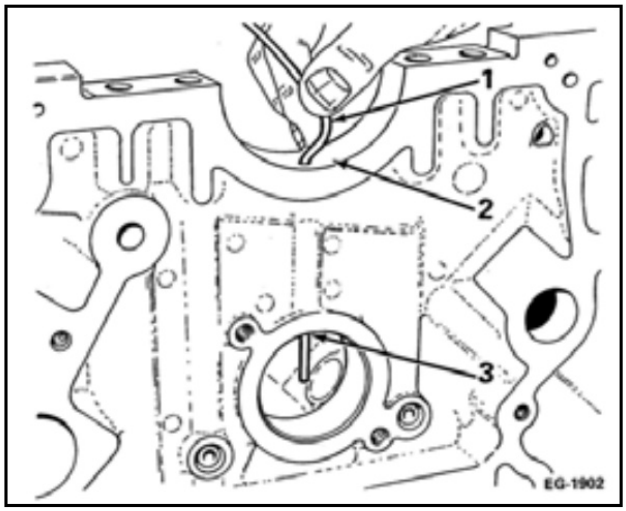

Figure 333 Checking the Camshaft Bushing / Crankcase Oil Hole Alignment

1. Alignment Wire
2. Main Bearing Saddle
3. Camshaft Bushing Oil Hole

5. After all of the camshaft bushings have been installed, use a wire to verify oil hole alignment.
6. Install the front camshaft bushing by pulling it into place from the rear of the crankcase.

SPECIFICATIONS

Table 19 Crankcase, Camshaft Bushing, Crankshaft and Main Bearing, Connecting Rod and Piston

CRANKSHAFT	
Main Bearing Journal Diameter	
Standard Size	79.3191 - 79.3394 mm (3.1228 - 3.1236 in)
0.254 mm (0.010 in) Undersize	79.0651 - 79.0854 mm (3.1128 - 3.1136 in)
0.508 mm (0.020 in) Undersize	78.8111 - 78.8314 mm (3.1028 - 3.1036 in)
0.762 mm (0.030 in) Undersize	78.5571 - 78.5774 mm (3.0928 - 3.0936 in)
Main Bearing Journal Maximum Out-of-Round	0.00559 mm (0.00022 in)
Main Bearing Thrust Face Runout (T.I.R. maximum)	0.0254 mm (0.001 in)
Main Bearing Journal Taper (max. per inch)	0.381 mm (0.0015 in)
Main Journal Fillet Radius, Journal No. 1, 2, 3 and 4	3.302 mm (0.130 in)
Main Journal Fillet Radius, Journal No. 5	3.99 - 4.14 mm (0.157 - 0.163 in)
Rod Journal Fillet Radius	3.68 mm (0.145 in)
Oil Seal Journal Runout (maximum)	0.05 mm (0.002 in)
Flywheel Housing Bore Concentricity (maximum)	0.20 mm (.008 in)
Flywheel Housing Face Runout (maximum)	0.51 mm (0.020 in)
Flywheel Surface Runout (maximum)	0.05 mm (0.002 in)
Flywheel Thickness (minimum) (See flywheel reconditioning Figure 251.)	44.907 mm (1.768 in)
Thrust Taken By	No. 5 Main
Thrust Bearing Journal Length	31.509 - 31.585 mm (1.2405 - 1.2435 in)
Main Bearing Inner Diameter (Installed)	79.385 - 79.436 mm (3.1254 - 3.1274 in)
Main Bearing to Crankshaft Running Clearance	0.046 - 0.117 mm (0.0018 - 0.0046 in)
Connecting Rod Journal Diameter	
Standard Size	63.45 - 63.47 mm (2.498 - 2.499 in)
0.254 mm (0.010 in) Undersize	63.20 - 63.22 mm (2.488 - 2.489 in)
0.508 mm (0.020 in) Undersize	62.94 - 62.96 mm (2.478 - 2.479 in)
0.762 mm (0.030 in) Undersize	62.69 - 62.71 mm (2.468 - 2.469 in)
Connecting Rod Journal, Maximum Out-of-Round	0.0056 mm (0.00022 in)
Connecting Rod Journal Taper (max. per inch)	0.0066 mm (0.00026 in)
Connecting Rod Bearing to Crankshaft Running Clearance	0.038 - 0.114 mm (0.0015 - 0.0045 in)
Crankshaft Flange Outer Diameter	111.05 - 111.15 mm (4.372 - 4.376 in)
Crankshaft End Play	0.063 - 0.216 mm (0.0025 - 0.0085 in)
Crankshaft End Play Maximum Wear Limit	0.51 mm (0.020 in)

Table 19 Crankcase, Camshaft Bushing, Crankshaft and Main Bearing, Connecting Rod and Piston (cont.)

Rod to Crankshaft Side Clearance	0.30 - 0.61 mm (0.012 - 0.024 in)
Crankshaft Straightness (T.I.R. Maximum)	0.10 mm (0.004 in)
Crankshaft Gear Backlash	(0.1397 - 0.02794 mm (0.0055 - 0.0110 in)
CRANKCASE	
Crankcase Deck Flatness	0.025 mm per 50.8 mm, 0.10 mm Total (0.001 in. per 2 inches, 0.004 in Total)
Crankcase Main Bearing Bore Diameter	84.206 - 84.231 mm (3.3152 - 3.3162 in)
Crankcase Cam Bearing Bore Diameter	56.655 - 56.693 mm (2.2305 - 2.2320 in)
Valve Lifter Bore Diameter	23.439 - 23.477 mm (0.9228 - 0.9243 in)
Valve Lifter Outer Diameter	23.391 - 23.411 mm (0.9209 - 0.9217 in)
Oil Jet Tube Bore Diameter (Spray Hole Diameter)	0.91 - 1.32 mm (0.036 - 0.052 in)
Cylinder Bore Taper (Top to Bottom)	0.076 mm (0.003 in)
Cylinder Bore Diameter	104.384 - 104.402 mm (4.1096 - 4.1103 in)
Cylinder Bore Maximum Out-of-Round	0.05 m (0.002 in)
Centerline of Main Bearing Bore to Head Deck	287.73 - 287.83 mm (11.328 - 11.332 in)
Oil Seals (Front and Rear Seal Face Runout With Plates Installed On Engine)	0.38 mm (0.015 in) T.I.R. Max.
CONNECTING RODS	
Connecting Rod Length Center to Center	181.10 mm (7.130 in)
Bushing Bore Diameter (Pin End)	33.235 - 33.243 mm (1.3085 - 1.3088 in)
Piston Pin Bushing Inner Diameter	32.83 - 32.84 mm (1.2924 - 1.2929 in)
Bearing Bore Diameter (Crankshaft End)	68.339 - 68.364 mm (2.6905 - 2.6915 in)
Bearing Bore Maximum Out-of-Round	0.013 mm (0.0005 in)
Bearing Bore Maximum Taper / Inch	0.013 mm (0.0005 in)
Connecting Rod Bearing Inner Diameter	63.513 - 63.564 mm (2.5005 - 2.5025 in)
Connecting Rod Bearing Running Clearance	0.038 - 0.114 mm (0.0015 - 0.0045 in)
Connecting Rod Side Clearance	0.30 - 0.61 mm (0.012 - 0.024 in)
Twist	0.05 mm/in (0.002 in/in)
Bend	0.025 mm/in (0.001 in/in)
Weight - Complete Rod Without Bearing (Old Style)	1.058 - 1.446 kg (1058 - 1446 g)
Weight - Complete Rod Without Bearing (New Style)	1.202 - 1.216 kg (1201.5 - 1215.5 g)
Pin to Bushing Clearance	0.010 - 0.023 mm (0.0004 - 0.0009 in)
PISTONS	

Table 19 Crankcase, Camshaft Bushing, Crankshaft and Main Bearing, Connecting Rod and Piston (cont.)

Skirt Diameter — Measure 43 mm (1.684 in) below oil groove, at 90° angle to the piston pin. Measure only at room temperature of 19-21°C (66-70°F).	104.34 - 104.44 mm (4.108 - 4.112 in)
Service Piston	
Standard Size	104.25 - 104.27 mm (4.104 - 4.105 in)
0.254 mm (0.010 in) Oversize	104.50 - 104.52 mm (4.114 - 4.115 in)
0.508 mm (0.020 in) Oversize	104.75 - 104.77 mm (4.124 - 4.125 in)
0.762 mm (0.030 in) Oversize	105.02 - 105.03 mm (4.134 - 4.135 in)
Piston Protrusion Above Crankcase Deck	0.58 – 0.84 mm (0.023 – 0.033 in)
Clearance In Cylinder Bore No. 1 – 8	0.112 - 0.1491 mm (0.0044 - 0.00587 in)
Top compression ring groove width - Measure over 2.92 mm (0.1150 in) gauge pins:	
Upper Limit	104.85 mm (4.128 in)
Replacement Limit	104.06 mm (4.097 in)
Piston Pins	
Length	75.9 - 76.2 mm (2.99 - 3.00 in)
Diameter	33.220 - 33.226 mm (1.3079 - 1.3081 in)
Pin fit @ room temperature, 19-21°C (66-70°F):	
Clearance In Rod	0.010 - 0.023 mm (0.0004 - 0.0009 in)
Clearance In Piston	0.007 - 0.018 mm (0.0003 - 0.0007 in)
End Clearance	0.10 - 0.76 mm (0.004 - 0.030 in)
Piston Rings	
Ring Diameter (Standard)	
Compression Top (Full Keystone (Barrel Face) Plasma Coated)	104.4 mm (4.11 in)
Compression 2nd (Rectangular Negative Twist - Tapered Face)	104.4 mm (4.11 in)
Oil Control (One Piece Conformable with Chrome Expander Spring)	104.4 mm (4.11 in)
Fit in Groove (Side Clearance)	
2nd	0.05 - 0.10 mm (0.002 - 0.004 in)
Oil Control	0.023 - 0.074 mm (0.0009 - 0.0029 in)
Ring Gap in Bore	
Top	0.35 - 0.61 mm (0.014 - 0.024 in)
2nd	1.57 - 1.82 mm (0.062 - 0.072 in)
Oil Control	0.30 - 0.61 mm (0.012 - 0.024 in)

Special Torque

Table 20 Crankcase, Crankshaft, Connecting Rods and Piston Special Torques

Connecting (4 lbf-ft) Rod Mounting Nuts (Old Style)	**First Step:** 71 N·m (52 lbf·ft) **Final Step:** 108 N·m (80 lbf·ft)
Connecting Rod Bearing Bolts (New Style)	**First Step:** 71 N·m (52 lbf·ft) **Final Step:** 122 N·m (90 lbf·ft)
Flywheel gear access cover bolts	5 N·m (4 lbf-ft)
Flywheel Mounting Bolts	121 N·m (89 lbf·ft)
Main Bearing Cap Mounting Bolts	**First Step:** 102 N·m (75 lbf·ft) **Final Step:** 129 N·m (95 lbf·ft)
Oil Pick up Tube Flange Bolts	24 N·m (18 lbf·ft)
Piston Cooling Jet Mounting Bolts	11 N·m (100 lbf·in)

SPECIAL SERVICE TOOLS

Table 21 Crankcase, Crankshaft, Connecting Rods and Piston Special Service Tools

D81L6002B	Plastigage®
OEM1000	Micrometer
OEM1022	Telescoping Gauge Set
OEM1023	Telescoping Gauge
OEM1028	Magnetic Base Dial Indicator
OEM1032	Dial Bore Gauge
OEM1293	Straight Edge
OEM6270	120 Grit Glaze Breaker Brush
OEM6453	Piston Retaining Ring Pliers
ZTSE1897E	Camshaft Bushing Removal/Installation Set
ZTSE1942A	Crankshaft Rear Oil Seal Installation Tool
ZTSE3020	Piston Groove Wear Measuring Tool Set
ZTSE4155A	Expansion Plug Replacement Tool
ZTSE4220	Piston Ring Expander
ZTSE4311	Connecting Rod Installation/Remover Guide Pins
ZTSE4317	Crankshaft Wear Ring Removal Tool
ZTSE4318	Rear Oil Seal Installation Tool
ZTSE4375	Flywheel Installation/Removal Guide Studs
ZTSE4385	Oil Pan/Rear Oil Seal Cutting Tool
ZTSE4389	Oil Galley Cleaning Brush

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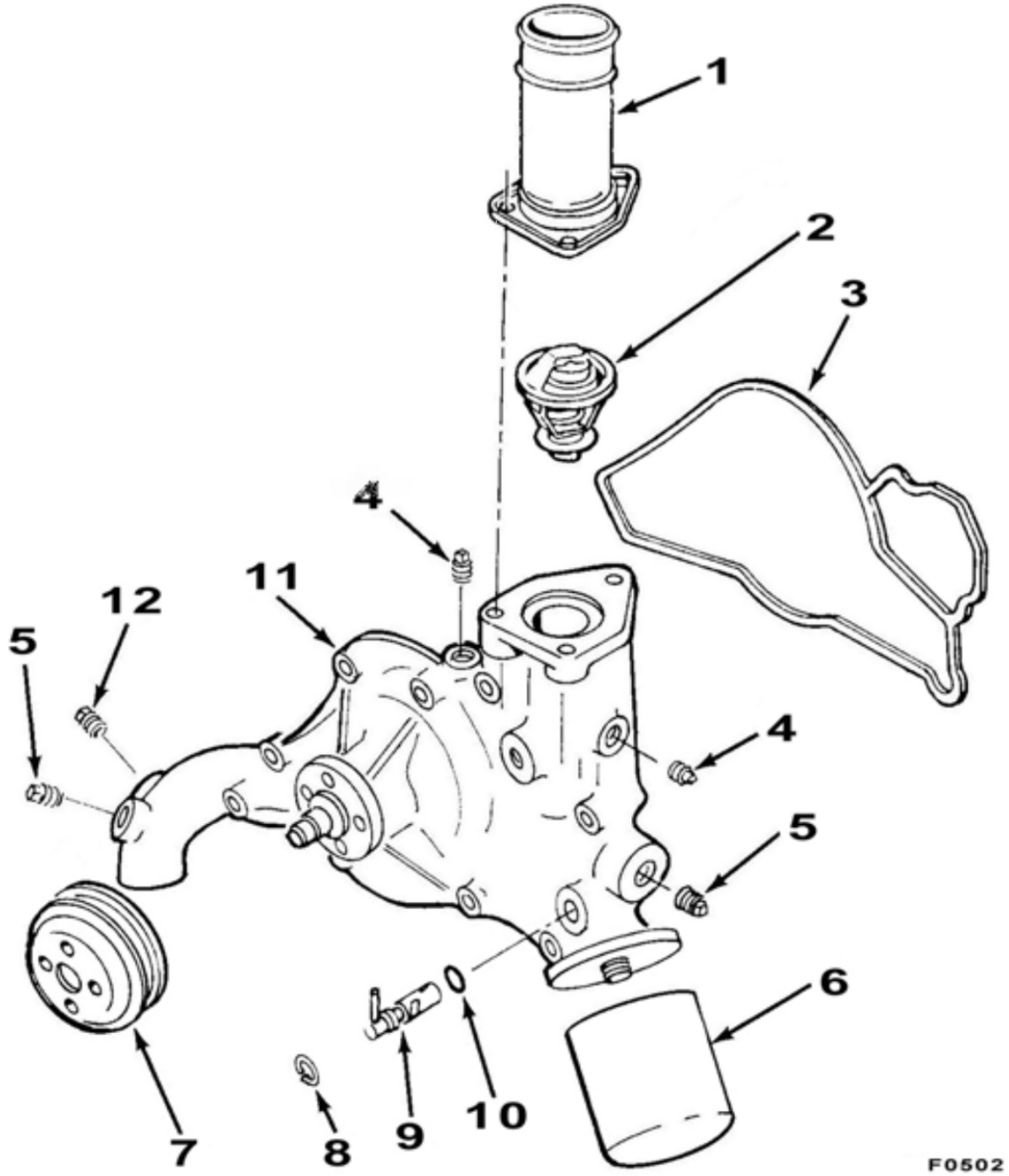

Figure 334 Water Pump and Thermostat

1. Water Outlet Pipe
2. Thermostat with integral seal
3. Water Pump Gasket
4. Plug, 3/8 NPTF (2)
5. Plug, 3/4 NPTF (2)
6. Coolant Filter
7. Water Pump Pulley
8. Retaining Ring
9. Coolant Filter Shutoff Valve
10. O-ring
11. Water Pump Assembly
12. Plug, 1/2 NPTF

Thermostat

Removal

WARNING: To avoid personal injury or possibly death, always allow engine to cool first. Wrap a thick, heavy cloth around radiator cap. Push down and loosen the cap slowly to its first notch position. Then pause a moment. This will avoid possible scalding by hot water or steam. Continue to turn the cap to the left and remove it.

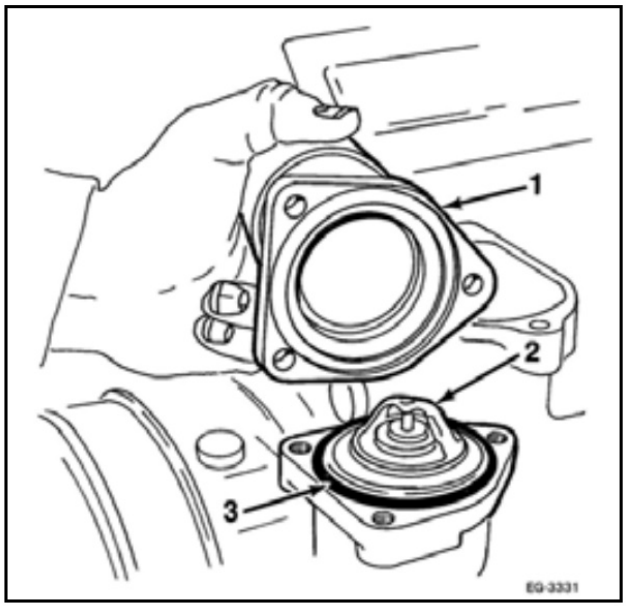

Figure 335 Thermostat Outlet Tube

1. Coolant Outlet Tube
2. Thermostat
3. Thermostat Gasket (Square Cross Section)

1. Remove the three bolts that secure the outlet tube to the water pump housing.

NOTE: Some engines were equipped with a thermostat having a separate gasket. Remove and discard thermostat and thermostat gasket. Replace with new thermostat with integral seal. Refer to “Installation”.

2. Remove thermostat with integral seal from the water pump housing.

Testing Operation

WARNING: To avoid serious personal injury or possibly death, use caution to avoid burns when dealing with hot coolant and objects. Use heat resistant gloves and wear appropriate eye protection.

CAUTION: When servicing the thermostat, it is essential that the thermostat opens fully at the specified temperature. A thermostat that functions properly will reduce the risk of engine damage caused by overheating.

NOTE: Only genuine INTERNATIONAL® thermostats ensure proper coolant flow and positive sealing characteristics. INTERNATIONAL® thermostats are required to provide proper engine cooling. Make sure the thermostat is a INTERNATIONAL® thermostat that has the correct temperature range.

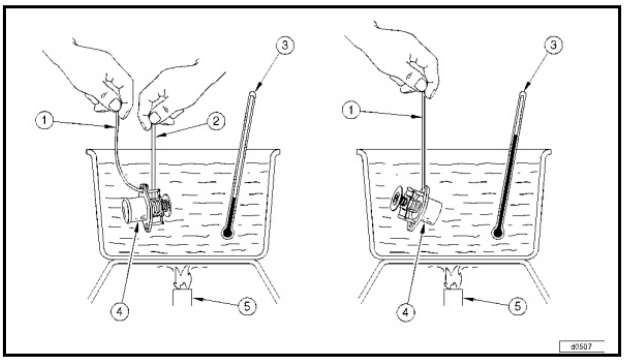

Figure 336 Testing Thermostat Operation

1. Suspension Line
2. Ribbon
3. Thermometer
4. Thermostat
5. Heat Source

1. Manually open the thermostat just enough to insert a nylon ribbon under the valve seat. Suspend the thermostat in a container so the thermostat does not touch the bottom of the container.

2. Heat the container filled with water to the START-TO-OPEN temperature. Observe the thermometer and record the temperature as soon as the thermostat drops from the nylon ribbon. This is the actual START-TO-OPEN temperature.

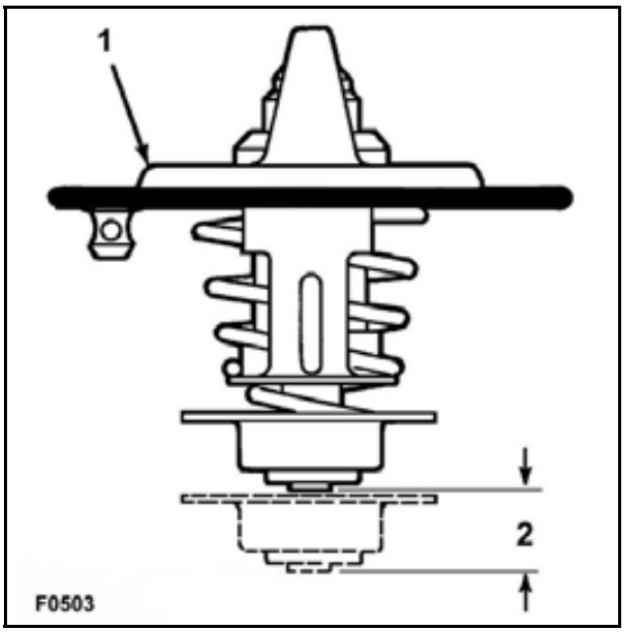

Figure 337 Thermostat Sleeve Travel

1. Typical Thermostat
2. Minimum Sleeve Travel

3. Continue to heat the water to the FULL-OPEN temperature. Observe the thermometer and movement of the thermostat sleeve when the FULL-OPEN temperature is achieved. The minimum sleeve travel at the FULL-OPEN temperature is 8.0 mm (0.315 in).
4. Remove the thermostat from the container. Quickly inspect the seat area for pitting and foreign deposits before the thermostat closes.
5. Replace thermostat if it does not operate as described or if it does not meet the inspection criteria.

Installation

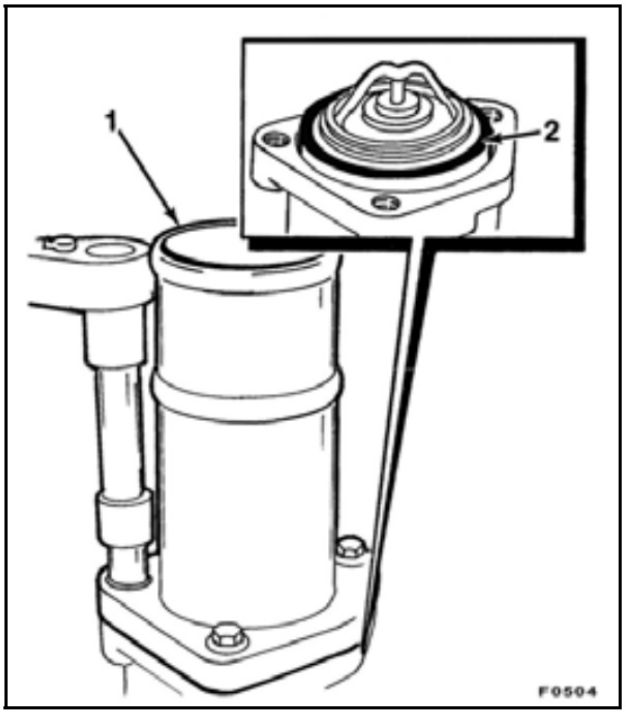

Figure 338 Installing the Thermostat and Outlet Tube

1. Coolant Outlet Tube
2. Thermostat with integral seal

1. Install thermostat with integral seal into the water pump housing. Make sure the arrow on the thermostat is pointing toward rear of the engine or toward the rear flange bolt.
2. Put the coolant outlet tube on the water pump housing. To ensure a tight fit, make sure the outlet tube flange is not bent or distorted.
3. Install three mounting bolts finger tight. Then tighten the mounting bolts evenly to the standard torque value.

Coolant Filter and Header

Removal (Front of Engine)

WARNING: To avoid serious personal injury or possibly death, always allow the engine to cool first. Wrap a thick, heavy cloth around the radiator cap. Push down and loosen the cap slowly to its first notch position to relieve any pressure. This will avoid possible scalding by hot water or steam.

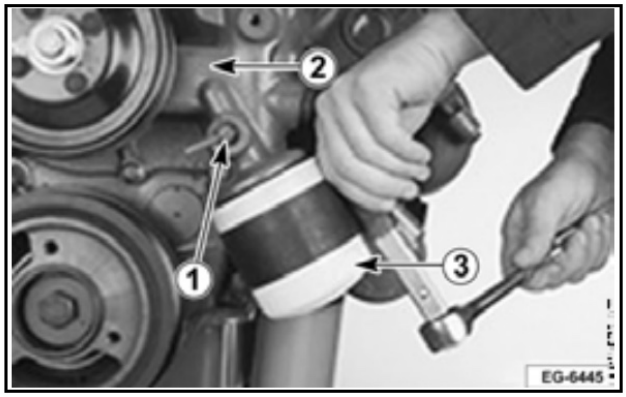

Figure 339 Coolant Filter Located on the Front of the Engine

1. Shut Off Valve (OFF Position)
2. Water Pump Housing
3. Coolant Filter

1. Loosen radiator cap.
2. Turn coolant filter shut off valve to OFF.
3. Use a strap type wrench to remove the coolant filter from the water pump housing.

Installation (Front of Engine)

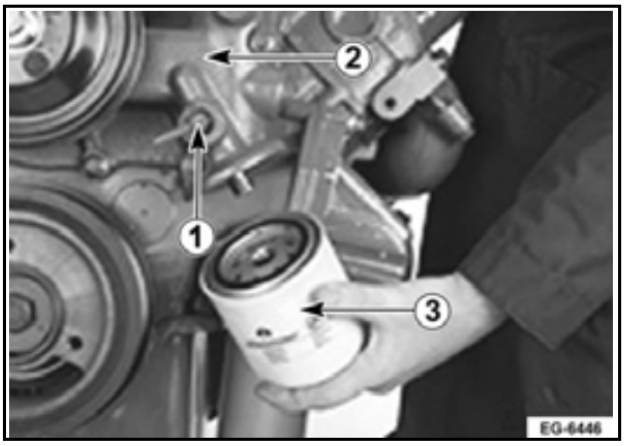

Figure 340 Coolant Filter Located on the Front of the Engine

1. Shut Off Valve (OFF Position)
2. Water Pump Housing
3. Coolant Filter

1. Apply coolant to the gasket of the coolant filter.
2. Install new coolant filter to front cover. Tighten filter one full turn after the gasket contacts the water pump housing.
3. Turn coolant filter shut off valve to the OPEN, allowing coolant to flow through the filter.
4. Tighten radiator cap.

SPECIFICATIONS

Table 22 Thermostat and Coolant Filter

Thermostat	
Type	Poppet Valve, Pellet Operated
Operating Start-to-Open Temperature	89 ± 2°C (192 ± 4°F)
Maximum Full-Open Temperature	104°C (219°F)
Sleeve Travel at Full-Open Temperature	8 mm (0.315 in)
Coolant Filter	
Type	Spin-On
Length of Filter	106 mm (4.18 in)

SPECIAL SERVICE TOOLS

Table 23 Thermostat and Coolant Filter Special Service Tools

OEM6413	Strap Wrench

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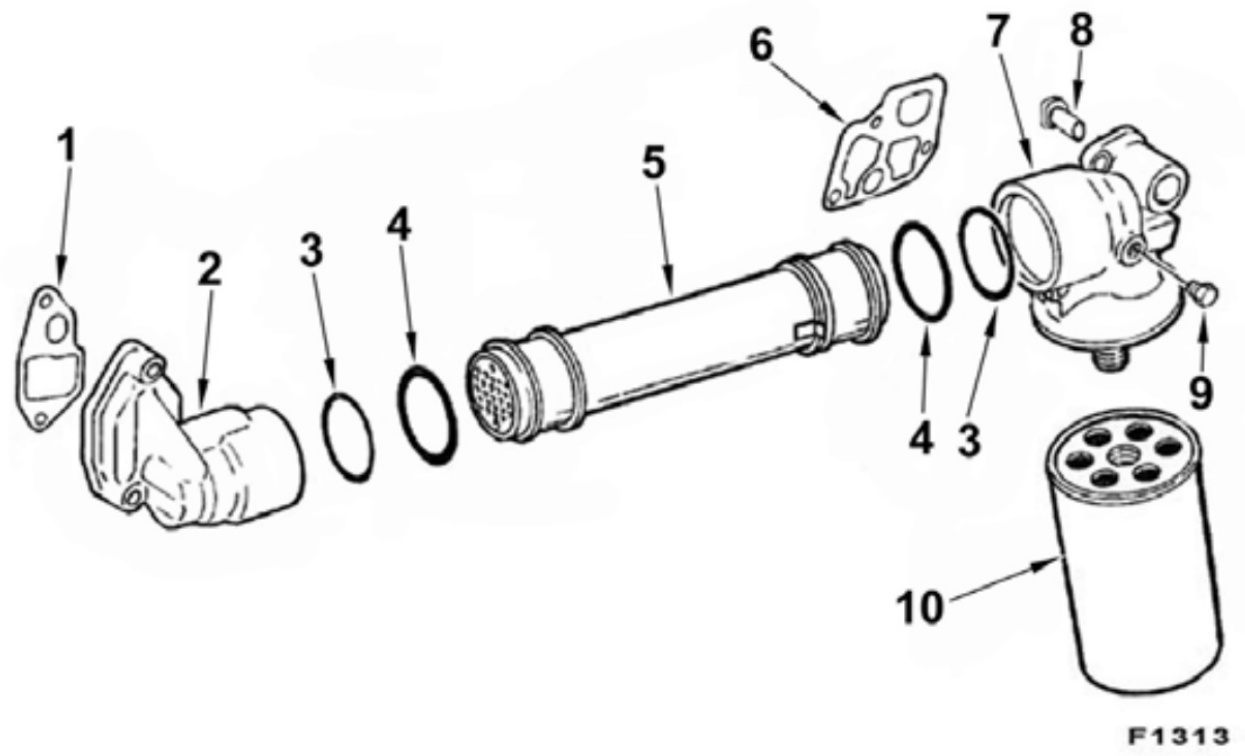

Figure 341 Oil Cooler Assembly

1. Front Header Gasket
2. Front Oil Cooler Header
3. O-Ring (Thin)
4. O-Ring (Thick)
5. Oil Cooler Bundle
6. Rear Filter Header Gasket
7. Rear Oil Cooler Header Assembly
8. Valve, Pressure Regulating
9. 6 mm (1/4 in) Hex Head Plug
10. Lube Oil Filter

Oil Cooler

Removal

1. Drain coolant from the engine.

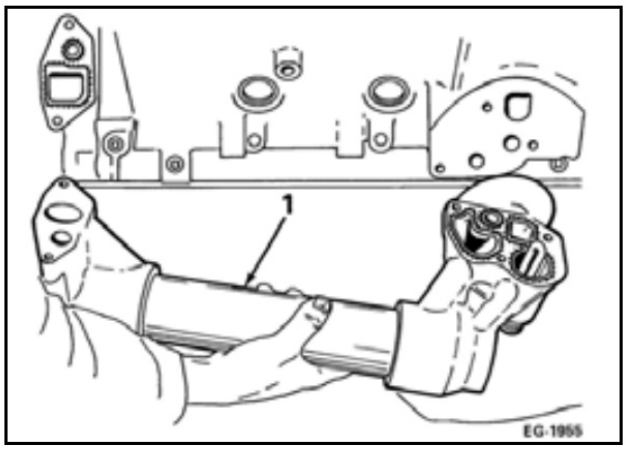

Figure 342 Removing Oil Cooler Assembly

1. Oil Cooler Assembly

2. Remove and discard oil filter.
3. Remove oil cooler assembly from crankcase and front cover mounting pads.

Leakage Test

Inspect oil cooler assembly for leaks by using the following air pressure test:

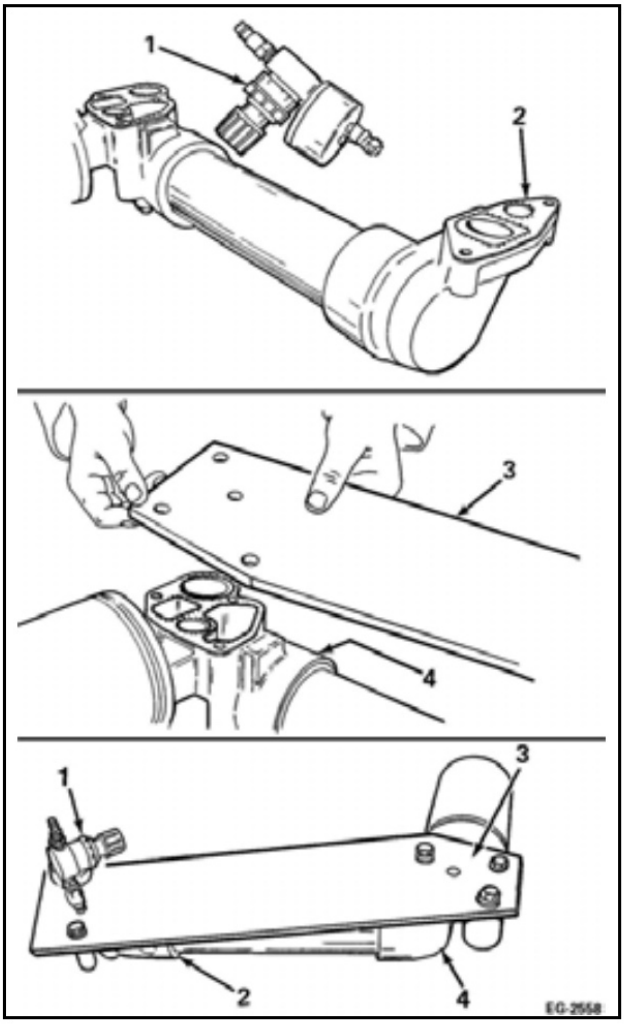

Figure 343 Air Pressure Test

1. Pressure Gauge and Regulator
2. Oil Cooler Front Header
3. Test Plate
4. Oil Cooler Filter Header

1. Remove heater and block the heater plug.
2. Install a new oil filter and all pipe plugs in the headers.
3. Fasten oil cooler test plate to oil cooler.
4. Fasten pressure gauge and regulator to test plate.

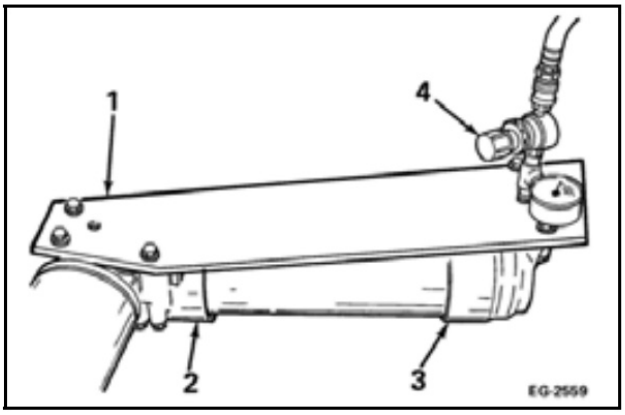

Figure 344 Oil Pressure Check

1. Test Plate
2. Oil Cooler Filter Header
3. Oil Cooler Front Header
4. Pressure Gauge and Regulator

5. Perform oil pressure check as follows:
   a. Leave water side 1/4 NPTF hole in the test plate open.
   b. Install an air pressure hose to the oil side of the 1/4 NPTF hole in the test plate.
   c. Immerse the assembly in a container of clean water.
   d. Apply 276 – 414 kPa (40 – 60 psi) of air pressure while the assembly is immersed.
   e. Inspect the header castings, O-rings and water side 1/4 NPTF hole for moving or growing bubbles. Replace components as required.
6. Perform water side oil cooler check as follows:
   a. Leave the oil side 1/4 NPTF hole in the test plate open.
   b. Install an air pressure hose to the water side of 1/4 NPTF hole in the test plate.
   c. Immerse assembly in a container of clean water.
   d. Apply 276 – 414 kPa (40 – 60 psi) air pressure while the assembly is immersed.
   e. Inspect header castings, O-rings and oil side 1/4 NPTF hole for moving or growing bubbles. Replace components as required.

Disassembly

Gently tap headers to loosen the O-rings. Twist headers and separate them from oil cooler bundle.

Cleaning

CAUTION: To avoid engine damage, should a bearing failure occur, the oil cooler bundle must be replaced because debris from a failed bearing cannot be removed from the cooler bundle.

1. Immerse oil cooler, front header and filter header in a suitable solvent. Flush and drain oil cooler to remove any residue.
2. Dry all components thoroughly with filtered compressed air.

Inspection

1. Inspect oil cooler for blocked tubes and corrosion where the tubes are assembled to the oil cooler bundle. Replace the oil cooler bundle if required.
2. Inspect filter header for blocked orifices and damaged threads at the oil filter threaded inserts.
3. Remove any debris that may be blocking the oil flow passages.
4. If thread damage is apparent, replace the header.

Assembly

1. Install new O-rings on the oil cooler bundle.
2. Lubricate the oil cooler bundle headers and O-rings with clean engine oil.
3. Carefully press the assembly together. Make sure the header is not cocked and the locating clip of the oil cooler rear header is aligned in the slot of the cooler bundle.

Installation

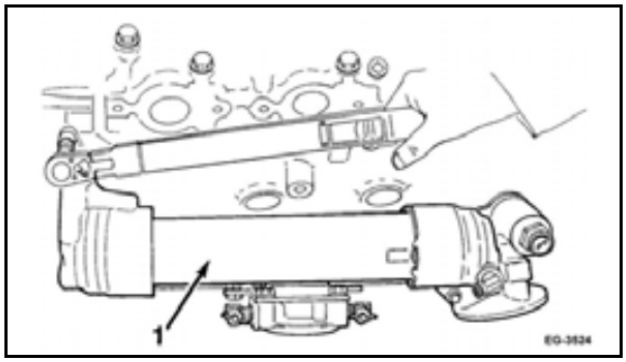

Figure 345 Installing the Oil Cooler

1. Oil Cooler Assembly

1. With the oil cooler and headers assembled, install the assembly with a new gaskets to the left side of the crankcase. Tighten the bolts to standard torque.

NOTE: Do not overtighten the filter. A damaged filter may fracture or leak.

2. Lubricate a new filter gasket with clean engine oil.
3. Spin the oil filter on the threaded adapter until the gasket contacts the oil filter header. Tighten the oil filter an additional 3/4 to 1 turn.

Filling Crankcase With Oil

1. Fill the crankcase with 18.5 L (19.5 qt.) of oil if the oil filter has been changed or 17 L (18 qt.) of oil if the oil filter has not been changed. If the oil cooler was removed or drained of oil, add an extra 0.94 L (1 qt.) of oil.
2. Start the engine and check for leaks. Fix leaks as needed.
3. Shut down the engine and check the oil level. Add oil or drain oil as needed to bring the oil level within the FULL and ADD marks on the oil level gauge. Do not overfill past the FULL mark.

Table of Contents

Description

NOTE: Refer to the following for electrical system troubleshooting:

EGES190, *T 444E Diesel Engine / Vehicle Diagnostic Manual*

EGED195, Hard Start / No Start Performance Engine Diagnostics Form

EGED200, Electronic Control System Diagnostics Form

CAMSHAFT POSITION (CMP) SENSOR

Figure 346 CMP Sensor

The CMP sensor is a Hall effect type sensor stacked in front of a magnet with a signal conditioning integrated circuit. It responds to a rotating actuator positioned on the camshaft gear. The actuator has 24 stamped windows. This produces a rectangular wave pulse for each tooth as the actuator rotates past the sensor. The pulses are used to indicate engine speed and camshaft position for control of fuel quantity, injection timing, and overspeed shutdown. The sensor is located above the vibration damper on the right side of the engine front cover.

EXHAUST BACK PRESSURE (EBP) SENSOR

Figure 347 EBP Sensor

The EBP sensor is a ceramic diaphragm sensor that measures the exhaust back pressure. It provides feedback to the ECM for closed loop control of the exhaust back pressure. The result is faster engine warm-up at cold ambient temperatures. If equipped, the sensor is mounted on a bracket located on the top right side of the hydraulic reservoir.

ENGINE OIL PRESSURE (EOP) SENSOR

Figure 348 EOP Sensor

The EOP sensor is a ceramic diaphragm sensor that detects engine oil pressure and sends the pressure signal to the ECM. The sensor is located on top of the high oil pressure pump reservoir.

ENGINE COOLANT TEMPERATURE (ECT) SENSOR

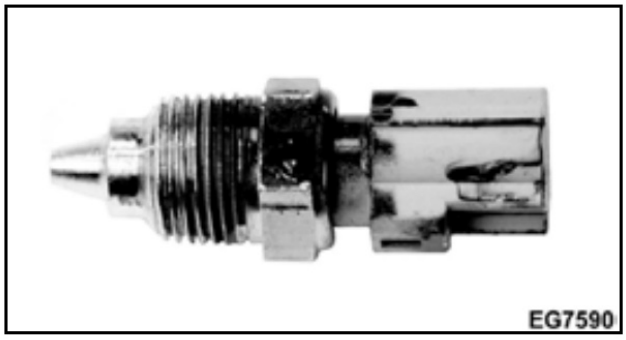

Figure 349 ECT Sensor

The ECT sensor is a thermistor type sensor that detects changes in engine coolant temperature. The sensor is located above the water pump on the right side of the engine front cover.

ENGINE OIL TEMPERATURE (EOT) SENSOR

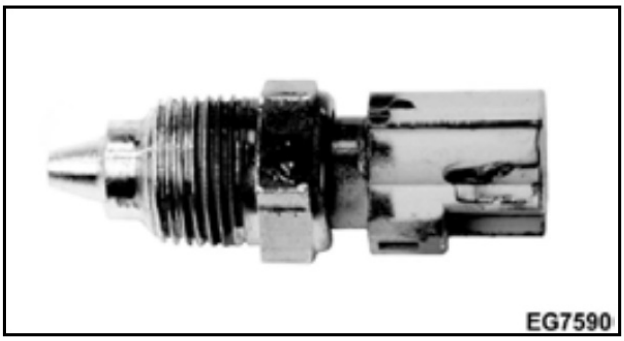

Figure 350 EOT Sensor

The EOT sensor is a thermistor type sensor that detects the engine oil temperature and sends the engine temperature signal to the ECM. The ECM then uses the information for fuel rate and timing adjustments. The sensor is located on the rear left side of the high pressure oil reservoir.

INJECTION CONTROL PRESSURE (ICP) SENSOR

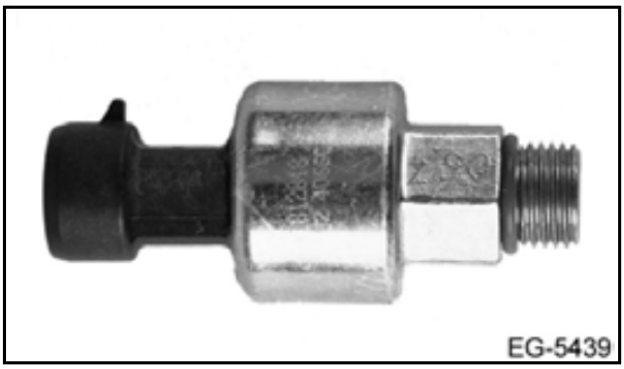

Figure 351 ICP Sensor

The ICP sensor is a ceramic diaphragm sensor that measures the injection control pressure. It provides gallery pressure feedback to the ECM for a closed loop control of the injector oil pressure. The sensor is located toward the front of the engine on the left cylinder head, in the high pressure oil rail.

INJECTION PRESSURE REGULATOR (IPR) VALVE

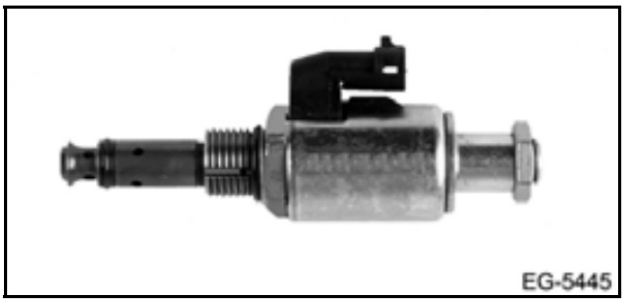

Figure 352 IPR Valve

The IPR valve is a pulse width modulated valve that regulates the injection control pressure by receiving a signal from the ECM. The valve is located on the left side of the high pressure oil pump.

MANIFOLD ABSOLUTE PRESSURE (MAP) SENSOR

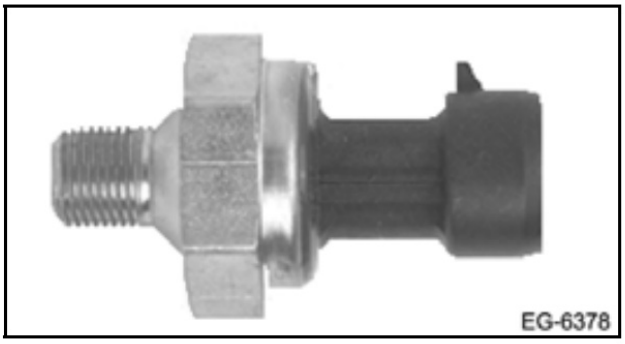

Figure 353 MAP Sensor

The MAP sensor is a ceramic diaphragm sensor that indicates manifold boost pressure or vacuum by receiving a signal from the ECM. The sensor is located on the right side of the intake manifold pipe.

INTAKE AIR TEMPERATURE

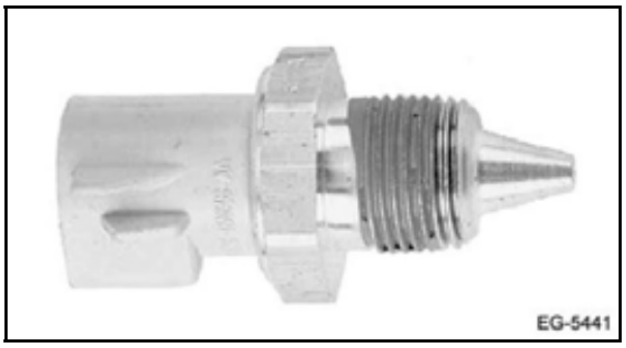

Figure 354 IAT Sensor

The Intake Air Temperature (IAT) sensor is a thermistor type sensor that has a variable resistance which changes when exposed to different temperatures. The IAT sensor measures intake air temperature in order to control timing and fuel rate while starting the engine in cold weather to limit smoke emissions.

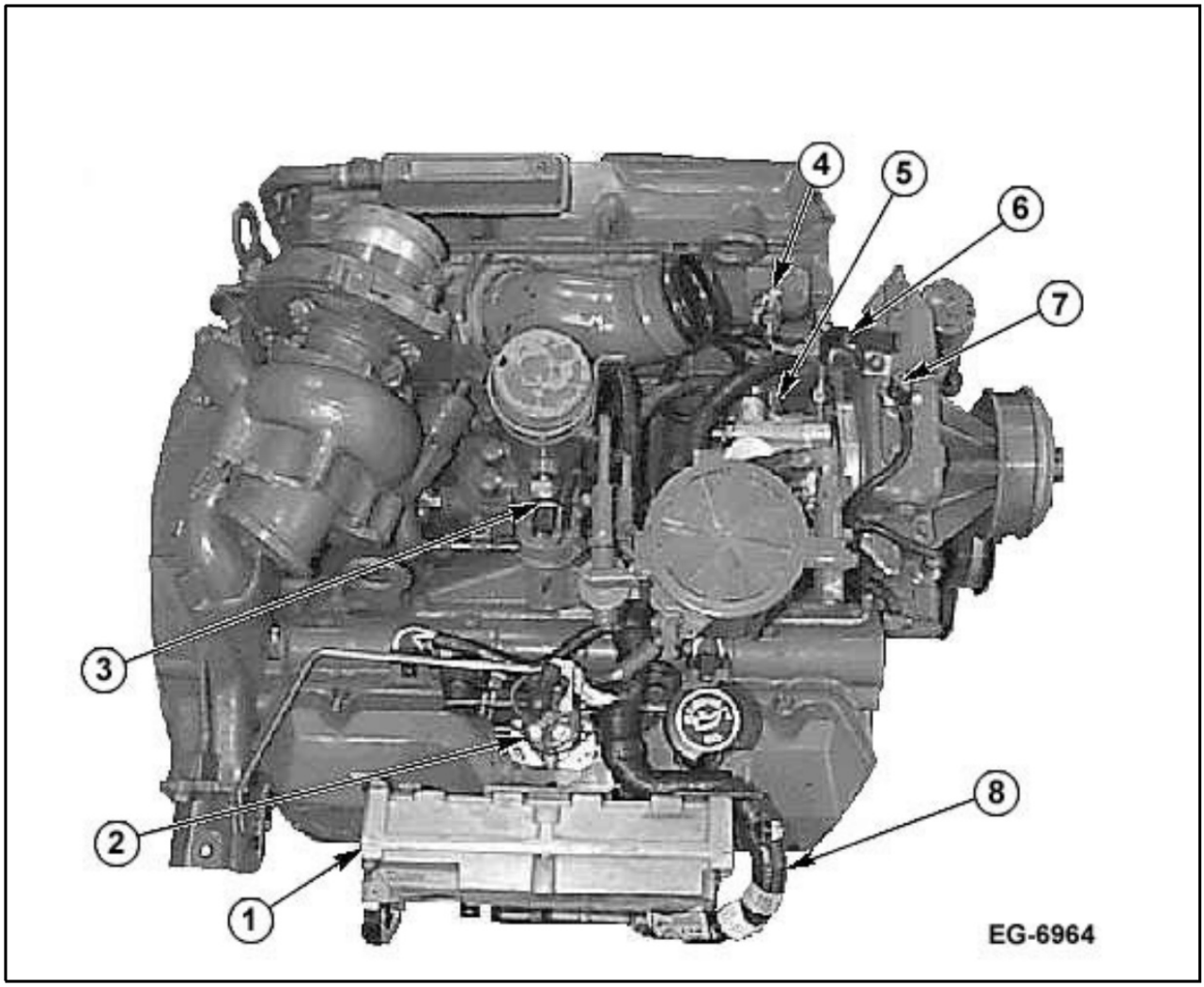

Figure 355 Engine Top View

1. Electronic Control Module (ECM)
2. Glow Plug Relay
3. Manifold Absolute Pressure (MAP) Sensor
4. Injection Control Pressure (ICP) Sensor
5. Injection Pressure Regulator (IPR) Valve
6. Engine Oil Temperature (EOT) Sensor
7. Engine Oil Pressure (EOP) Sensor
8. Main Engine Wiring Harness

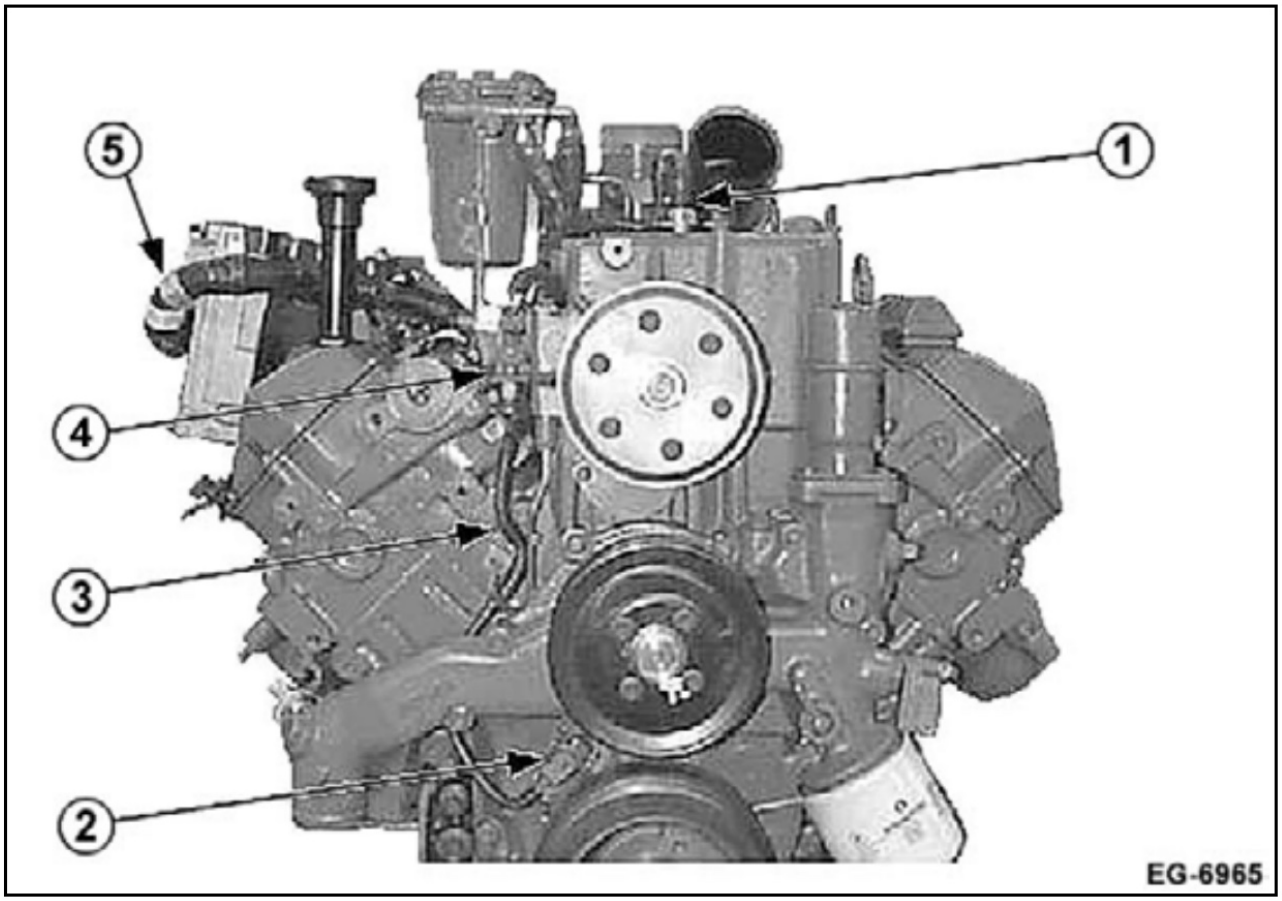

Figure 356 Engine Front View

1. Engine Oil Pressure (EOP) Sensor
2. Camshaft Position (CMP) Sensor
3. Engine Coolant Temperature (ECT) Sensor
4. Exhaust Back Pressure (EBP) Sensor
5. Main Engine Wiring Harness

Electronic Control Module (ECM)

Removal

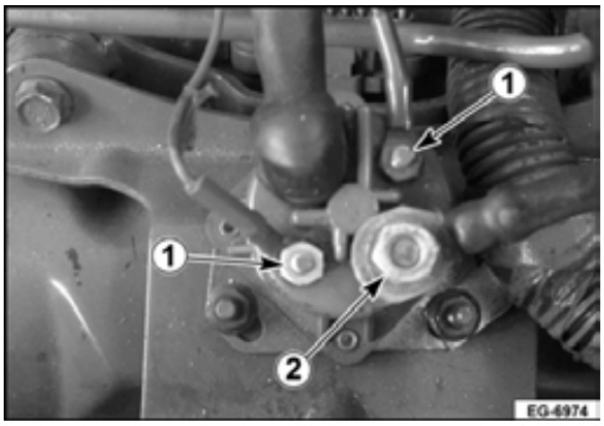

Figure 357 Glow Plug Relay

1. Glow Plug Connector Terminals
2. Battery Connection Terminal

1. Disconnect the battery and glow plug connectors from glow plug relay.

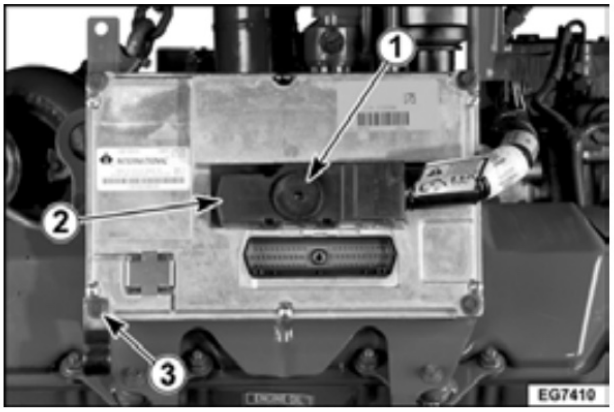

Figure 358 ECM Wiring Harnesses and Mounting Bolts

1. Connector Bolt
2. Engine Wiring Harness
3. ECM Mounting Bolt (4)

2. Use a square head driver to unscrew the connector bolt. Disconnect the engine wiring harness from the ECM.
3. To remove the ECM from the support assembly, remove the four mounting bolts and lift the ECM from the support bracket.
4. To remove the ECM and support assembly **as one unit**, perform the following steps:

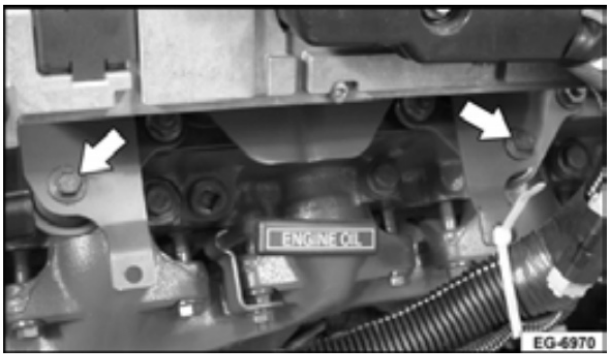

Figure 359 ECM Support Assembly Lower Mounting Bolts

a. Remove the two lower mounting bolts for the ECM support assembly.

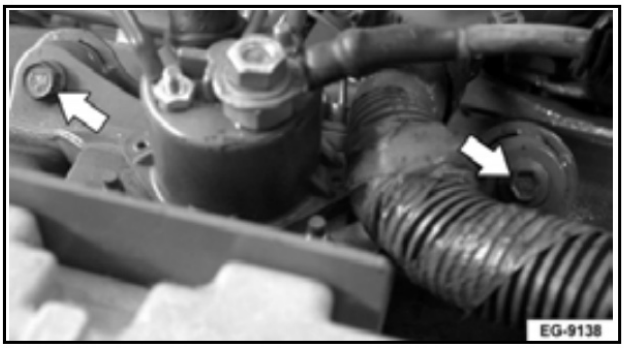

Figure 360 ECM Support Assembly Upper Mounting Bolts

b. Remove the two upper mounting bolts for the ECM support assembly.

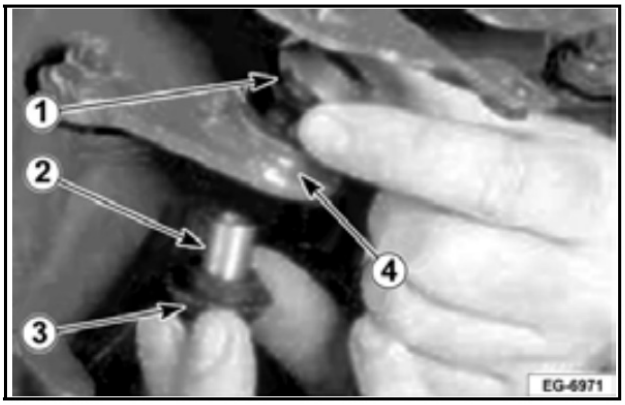

Figure 361 Bottom Mounting Bracket

1. Top Bushing
2. Bushing Pin
3. Bottom Bushing
4. Bottom Mounting Bracket

c. If necessary, remove the bushings and pins from the mounting brackets.

Inspection

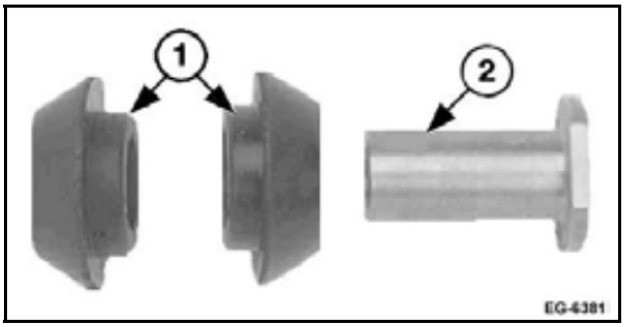

Figure 362 ECM Mounting Bushings and Pin

1. Bushings
2. Pin

1. Inspect ECM mounting bushings for wear and damage. Replace as necessary.
2. Inspect the wiring harnesses, covers, and cover shields for wear and damage. Replace as necessary.

Installation

1. To install the ECM and support assembly **as one unit**, perform the following steps:

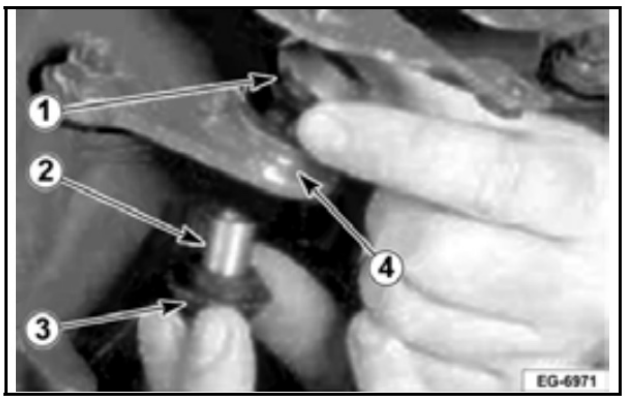

Figure 363 ECM Support Assembly Bushings and Pins

1. Top Bushing
2. Bushing Pin
3. Bottom Bushing
4. Bottom Mounting Bracket

a. If previously removed, install the bushings and pins in the bolt holes of the support assembly.

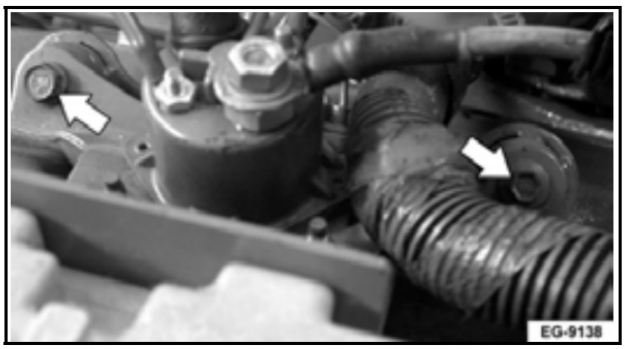

Figure 364 ECM Support Assembly Upper Mounting Bolts

b. Install the ECM and support assembly on the engine. Install and tighten the two upper mounting bolts to the special torque value.

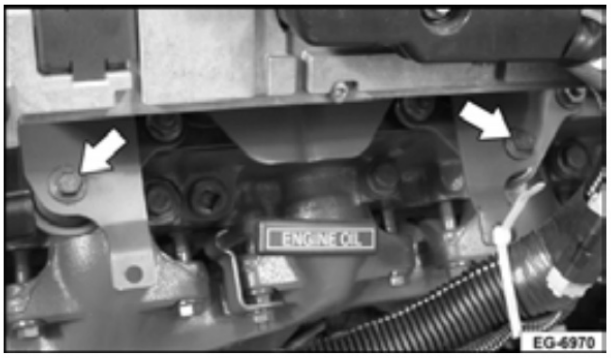

Figure 365 ECM Support Assembly Lower Mounting Bolts

c. Install and tighten the two lower mounting bolts to the special torque value.

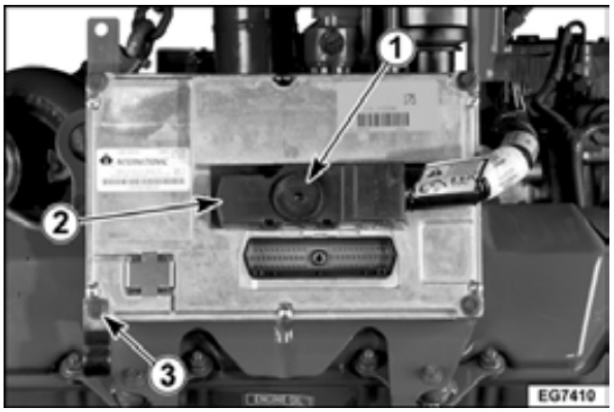

Figure 366 ECM Wiring Harnesses and Mounting Bolts

1. Connector Bolt
2. Engine Wiring Harness
3. ECM Mounting Bolt (4)

2. To install the support assembly and ECM **separately**, first perform the procedure in Step 1 for the support assembly only. Then install the ECM on the support assembly. Install and tighten the four mounting bolts to the special torque value.
3. Connect the engine wiring harness to the ECM. Tighten the connector bolt to the special torque value.

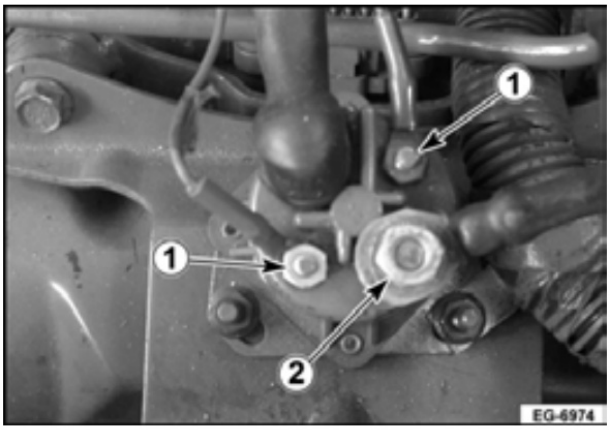

Figure 367 Glow Plug Relay

1. Glow Plug Connector Terminals
2. Battery Connection Terminal

4. Connect the battery and glow plug connectors to the glow plug relay terminals.

Main Engine Wiring Harness

Removal

1. Perform Steps 1 through 7 in the **Engine Control Module (ECM), Removal** procedure in this section.

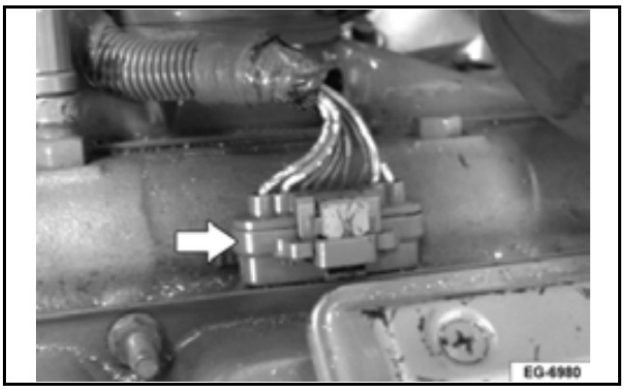

Figure 368 9–Pin Connector to the Valve Cover Gasket

2. Carefully unlatch and disconnect the 9–pin connectors from the valve cover gasket. There is one connector for each valve cover.

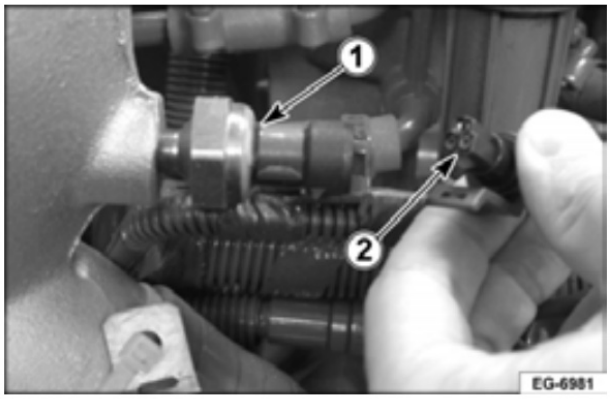

Figure 369 MAP Sensor Connector

1. MAP Sensor
2. Sensor Connector

3. Carefully unlatch and disconnect the sensor connector from the MAP sensor.

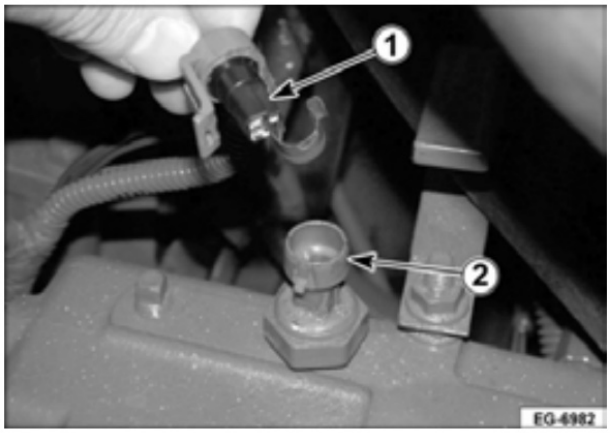

Figure 370 EOP Sensor Connector

1. Sensor Connector
2. EOP Sensor

4. Carefully unlatch and disconnect the sensor connector from the EOP sensor.

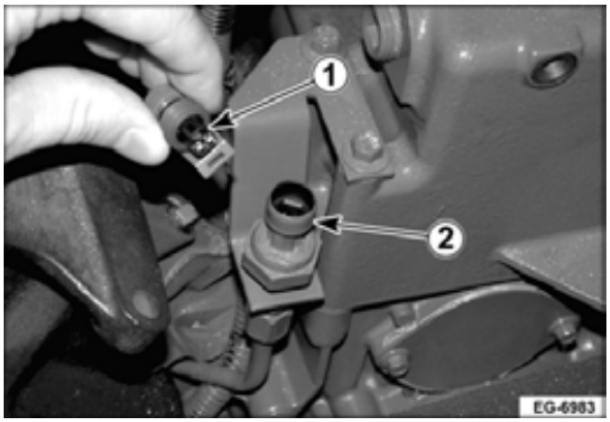

Figure 371 EBP Sensor Connector

1. Sensor Connector
2. EBP Sensor

5. Carefully unlatch and disconnect the sensor connector from the EBP sensor.

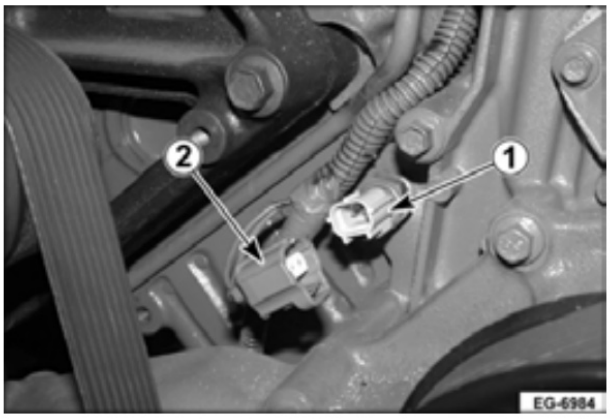

Figure 372 ECT Sensor Connector

1. ECT Sensor
2. Sensor Connector

6. Carefully unlatch and disconnect the sensor connector from the ECT sensor.

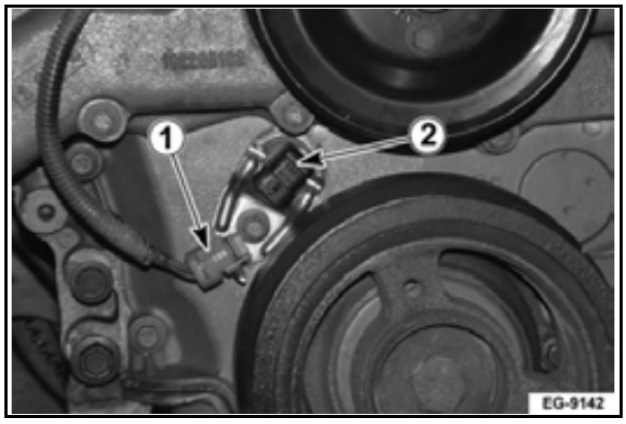

Figure 373 CMP Sensor Connector

1. Sensor Connector
2. CMP Sensor

7. Carefully unlatch and disconnect the sensor connector from the CMP sensor.

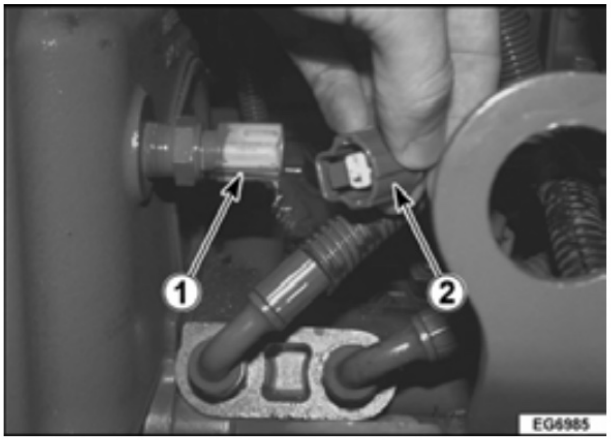

Figure 374 EOT Sensor Connector

1. EOT Sensor
2. Sensor Connector

8. Carefully unlatch and disconnect the sensor connector from the EOT sensor.

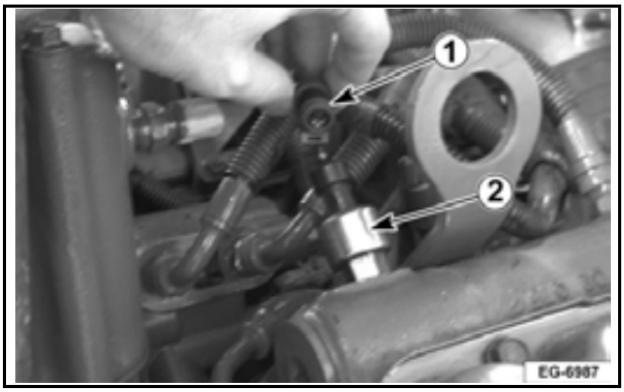

Figure 375 ICP Sensor Connector

1. Sensor Connector
2. ICP Sensor

9. Carefully unlatch and disconnect the sensor connector from the ICP sensor.

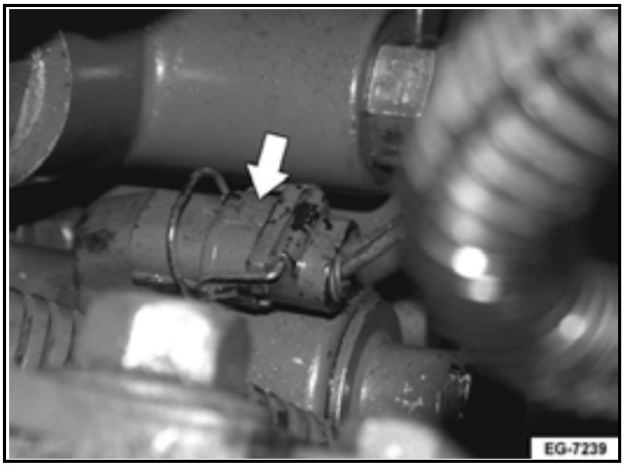

Figure 376 IPR Valve Connector

10. Carefully unlatch and disconnect the valve connector from the IPR valve.

    NOTE: For removal of the IPR valve, refer to the “HIGH-PRESSURE OIL PUMP” section.

11. Remove the wiring harness routing clips from the cylinder heads and front cover.

CAUTION: To avoid engine damage, if any resistance is felt during removal, DO NOT tug on the wiring harness to free it. This could damage the wiring harness. Investigate the source of resistance and free the wiring harness carefully before continuing with the removal.

12. Carefully lift the engine wiring harness from the engine.

Inspection

1. If any sensors are removed, clean off any thread locking compound from the sensor threads.
2. Check the connector pins on the sensors. If any pins are bent or corroded, replace the sensor.
3. Carefully inspect the wiring harness for worn conduit, frayed insulation, and heat damage. Repair as necessary.
4. Check each connector for:
   - corrosion (green or gray) or white deposits on metal terminals.
   - female connector sleeves that are spread open.
   - terminals that are incorrectly latched into the connector body or pushed back relative to other terminals in the same connector.
5. Check the wiring harness connectors, connector covers, foam inserts, and cover shields for cracks, cuts, or worn areas. Replace as necessary.

Installation

NOTE: For installation of the IPR valve, refer to the HIGH PRESSURE OIL PUMP section.

1. If removed, install the EOT, ECT, EBP, EOP, and MAP sensors in their proper locations (Removal, page 232).
2. If removed, install the CMP sensor as follows:
   a. If necessary, check the clearance of the CMP sensor. Refer to **Verify CMP Sensor Clearance (Air Gap)** in this section.

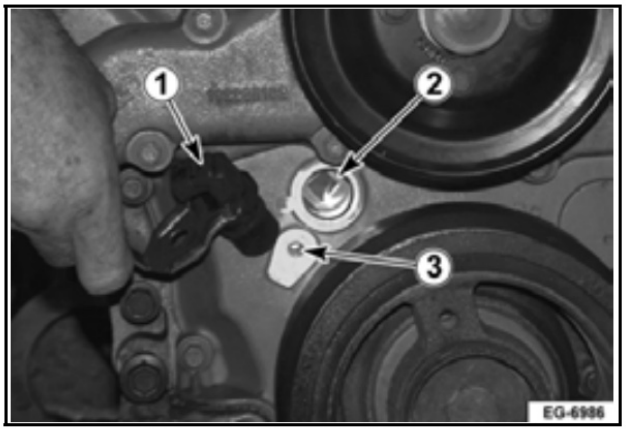

Figure 377 Installing the CMP Sensor

1. CMP Sensor
2. Sensor Port
3. Bolt Hole

   b. Put a new O-ring on the sensor and lubricate the O-ring with clean engine oil.
   c. Insert the sensor into the port. Secure the sensor with the mounting bolt.
3. If removed, install the ICP sensor as follows:

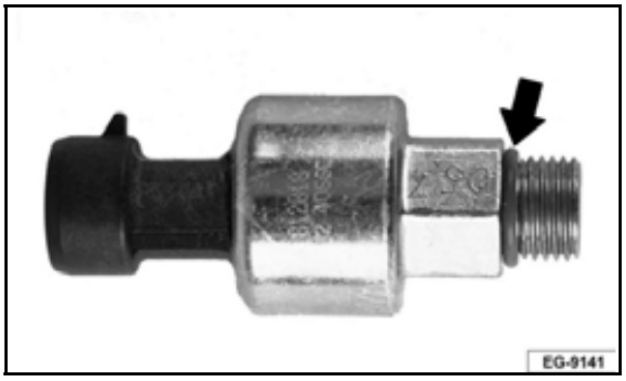

Figure 378 ICP Sensor O-Ring

   a. Put a new O-ring on the sensor.
   b. Apply Loctite® #277 to the threads of the sensor. Install the sensor in the front left cylinder head bank and tighten the sensor to the special torque value.

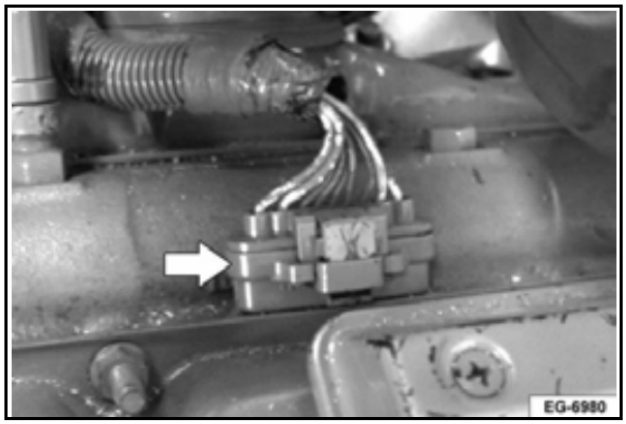

Figure 379 9–Pin Connector to the Valve Cover Gasket

NOTE: To ensure the electrical connection between the wiring harness and the valve cover gasket, install a new retainer clip from service kit P/N 1844193C91 on both wiring harness connectors.

4. Connect the two 9–pin connectors to the valve cover gaskets. There is one for each valve cover.

NOTE: Make sure that each connector has its ribbed seal in place before installation into sensor. In some cases, a ribbed seal may pull off its connector during removal and remain in the mating socket of a sensor or actuator. A connector that is installed without the appropriate ribbed seal may become contaminated with moisture and corrode the terminals, resulting in a poor electrical connection.

5. Install the wiring harness on the engine. Carefully align the connectors with the sensors. Push each connector into its mating socket until the locking tabs are fully latched.

6. Install the wiring harness routing clips.

Verifying CMP Sensor Clearance (Air Gap)

NOTE: It is only necessary to verify the sensor clearance if there has been erratic operation.

Engine misfiring may also be caused by a low diesel fuel cetane number. Verify the fuel being used has a cetane number of 42 or higher.

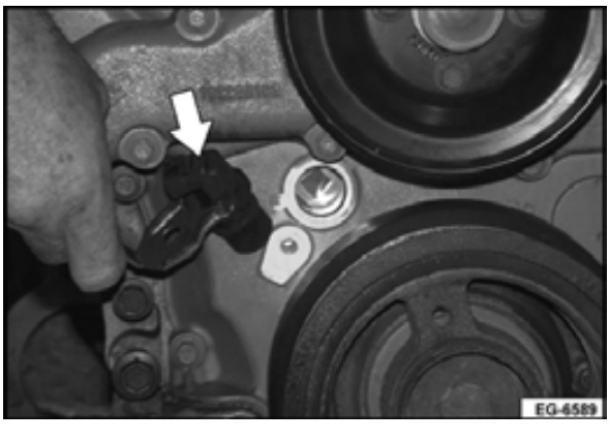

Figure 380 Removing CMP Sensor

1. Disconnect CMP sensor wiring harness connector.
2. Remove CMP sensor mounting bolt from engine front cover. Pull CMP sensor out.
3. Clean the sensor mounting surface.

Figure 381 Camshaft Sensor Air Gap Tool In CMP Sensor

4. Insert camshaft sensor air gap tool in calibration cup of CMP sensor. Hold firm downward pressure on tool and adjust indicator dial to zero. Tighten lock tab on dial ring of air gap tool. The tool is now calibrated for the length of the CMP sensor.
5. Install camshaft sensor air gap tool tip against the camshaft gear trigger wheel tooth. Secure tool to front cover by tightening mounting screw to 1.0 N•m (10 in•lbf).
6. Crank the engine with starter or bar engine over by hand. Turn over at least two complete revolutions prior to recording any readings.
7. Observe needle sweep on dial indicator. The range sweep is an indication of timing wheel run–out which should not exceed 0.20 mm (0.008 in).
8. Crank engine long enough to get an average reading of the camshaft sensor air gap tool dial indicator. If an interference condition is observed during cranking, the CMP sensor may have been damaged and must be replaced.
9. Perform the math using the CMP Sensor Clearance Worksheet. Select the appropriate combination of shims to achieve a measurement as close to 0.026 inch as possible. Refer to the International® Service Parts Dealer for the correct shim kit.
10. Install the CMP sensor with the shims required. Insure that the shims are centered on the CMP sensor flange. Use a small amount of grease to hold them in place.
11. Reconnect sensor wiring harness and test engine.

OPTIONAL METHOD

Figure 382 Measuring the Sensor Air Gap

12. Manually rotate the crankshaft clockwise at least two complete revolutions while facing the front of the engine. Then knock the crankshaft back gently. This ensures that the sensor air gap is at its maximum with the camshaft gear in contact with its rear thrust face.

NOTE: When taking the following measurement, measure up to the gear tooth on the trigger wheel. DO NOT measure into the window between the teeth.

13. Use a depth micrometer or a precision caliper to carefully measure the distance (to nearest one thousandth of an inch) from the sensor mounting surface to the camshaft gear tooth on the trigger wheel. Record the measurement (sensor air gap) on the worksheet.
14. Manually rotate the crankshaft 180° clockwise while facing the front of the engine. Repeat Steps 12 and 13. Continue this process two more times so the distance from the cover to the trigger wheel is measured at four different locations.

    Variations in these measurements determine the runout of the trigger wheel. The variation should not exceed 0.20 mm (0.008 in).

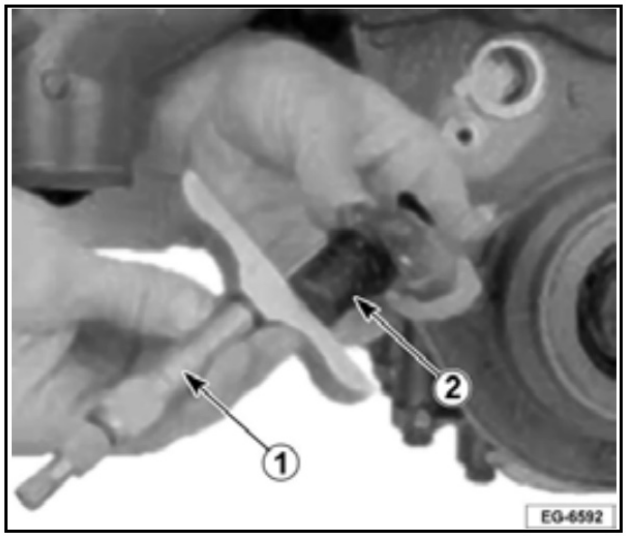

Figure 383 Measuring the CMP Sensor

1. CMP Sensor
2. Depth Micrometer

15. Use a depth micrometer or a precision caliper to carefully measure the CMP sensor from the tip to the surface of the mounting flange. Record the measurement on the worksheet.
16. Perform the math as directed on the worksheet. Then select the appropriate combination of shims to achieve a measurement as close to 0.026 inch as possible. Refer to your International® Service Parts Dealer for the correct shim kit.
17. Install the CMP sensor with the necessary shims. Ensure that the shims are centered on the sensor flange. If necessary, use a small amount of grease to hold them in place.
18. Connect the sensor wiring harness. Test the engine.

Table 24 CMP Sensor Clearance Worksheet

STEP	MEASUREMENT
1. Rotate crankshaft clockwise at least two revolutions. Measure distance from CMP sensor mounting surface to gear tooth on trigger wheel.	
2. Rotate crankshaft 180° clockwise. Repeat measurement.	**+**
3. Rotate crankshaft 180° clockwise. Repeat measurement.	**+**
4. Rotate crankshaft 180° clockwise. Repeat measurement.	**+**
5. Add measurements from Step 1 through Step 4.	**=**
6. Obtain average dimension by dividing Step 5 total by **4**.	**÷ 4**
7. Measure CMP sensor length from tip to surface of mounting flange.	**-**
8 Subtract Step 7 measurement from Step 6 average.	**=**
9. Desired air gap (inches)	**- 0.026**
10. Subtract Step 9 dimension from Step 8 total. This is the necessary shim thickness.	**=**

Glow Plug Relay

Removal

WARNING: To avoid engine damage, serious personal injury or possibly death, do not use a screwdriver or similar tool to pry off the terminal cover. Disconnect the batteries first due to the presence of battery voltage at the relay terminals. Disconnect the ground terminal first. Always wear eye protection when working around batteries.

1. Disconnect the main negative cable from the batteries.
2. Remove the glow plug relay plastic terminal cover.

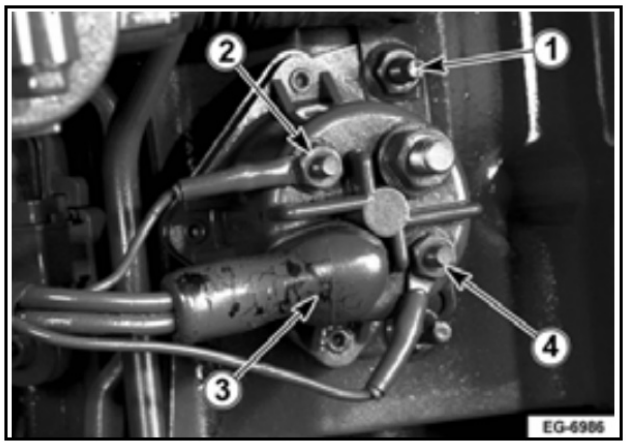

Figure 384 Glow Plug Relay Disconnection Points

1. Glow Plug Relay Mounting Bolt
2. Glow Plug Relay Terminal Stud
3. Relay Control Harness Connector
4. 12 Volt Power Wire Terminal Stud

3. Disconnect the 12V power wire, glow plug wire and relay control harness connector.
4. Remove the two mounting screws. Lift the glow plug relay from the engine.

Inspection

NOTE: The glow plug relay is not repairable beyond being certain that all electrical connections to it are clean and tight.

Inspect the base and relay housing for cracks. Replace if cracks are found.

Installation

1. Install the glow plug relay onto its bracket. Tighten the two mounting screws.
2. Connect the glow plug wire and 12V power wire to the top of the glow plug relay. Tighten the terminal nuts.
3. Connect the relay control harness connector to the glow plug relay.
4. Snap the glow plug relay cover into place.
5. Connect the main negative cable to the batteries.

SPECIFICATIONS

Table 25 Engine Electrical

Glow Plugs:		
Location		Cylinder Head
Quantity		8
Injection Pressure Regulator (IPR) Valve:		
Maximum Flow Rate	17.5 L/m (4.62 gpm)	
Maximum Operating Pressure		20.7 MPa (3000 psi)
Camshaft Position Sensor (CMP)		
Location		Front Cover
Operating Actuator Speed		15 to 2000 RPM
Operating Temperature Range	-40°C to +130°C (-40°F to +266°F)	
Operating Air Gap Range	0.10 to 0.86 mm (0.004 to 0.034 inch)	
Desired Air Gap Measurement	0.66 mm (0.026 inch)	

Special Torque

Table 26 Electrical System Special Torques

Glow Plug	19 N·m (14 lbf·ft)
Glow Plug Relay Stud Nuts	8 N·m (70 lbf·in)
Injection Control Pressure (ICP) Sensor	50 ± 5 N·m (37 ± 4 lbf·ft)
ECM Mounting Bolts	24 N·m (18 lbf·ft)
ECM Support Assembly Mounting Bolts	24 N·m (18 lbf·ft)
ECM Mounting Bracket Nuts	24 N·m (18 lbf·ft)
Wiring Harness Connector Mounting Bolt (Engine and Chassis)	3 – 5 N·m (30 – 45 lbf·in)

SPECIAL SERVICE TOOLS

Table 27 Special Service Tools

ZTSE 4414 Camshaft Sensor Air Gap
OEM 1013 Depth Gage Micrometer

Table of Contents

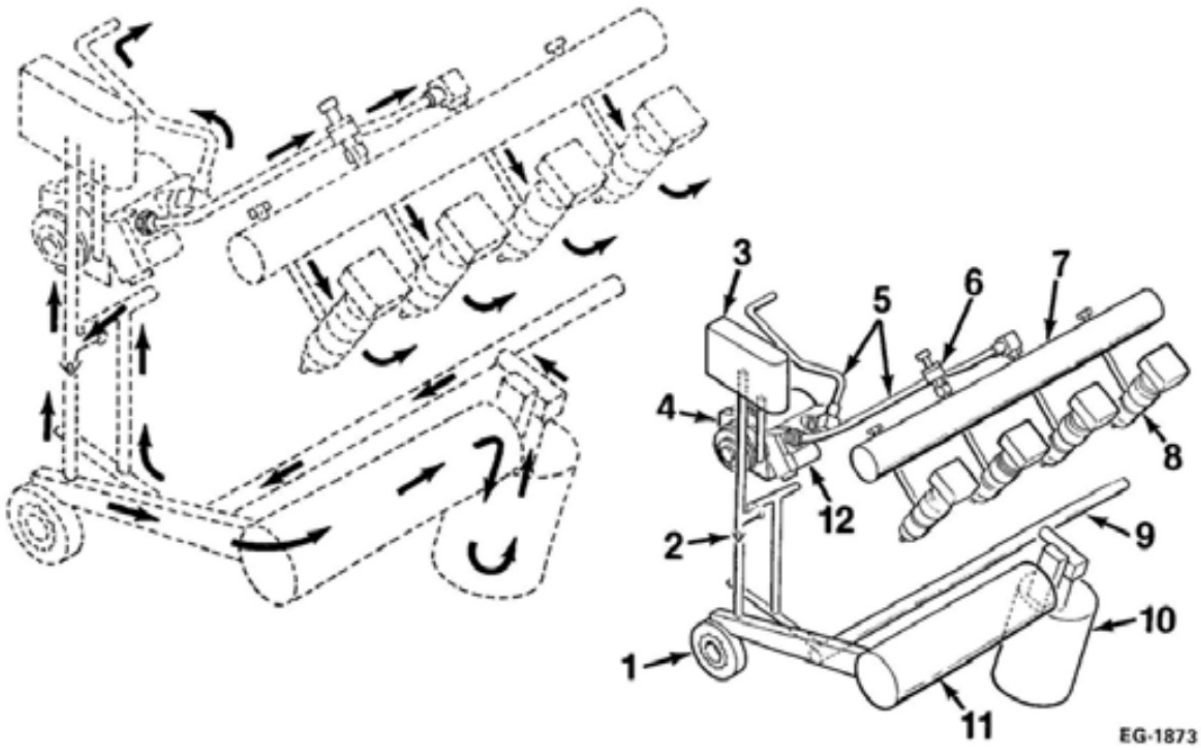

Figure 385 Injector Oil System Flow

1. Engine Lube Oil Pump
2. Check Valve
3. Reservoir (Located on the Top of Front Cover)
4. High-pressure Oil Pump
5. High-pressure Lines
6. Injection Control Pressure (ICP) Sensor
7. Cylinder Head High Pressure Oil Rail
8. Fuel Injector (8)
9. Gallery (Crankcase)
10. Oil Filter
11. Oil Cooler
12. Injection Pressure Regulator (IPR) Valve

Removal

High-pressure Oil Pump Reservoir

NOTE: A service kit for servicing the discharge fittings and rear plug is available for the high-pressure pump.

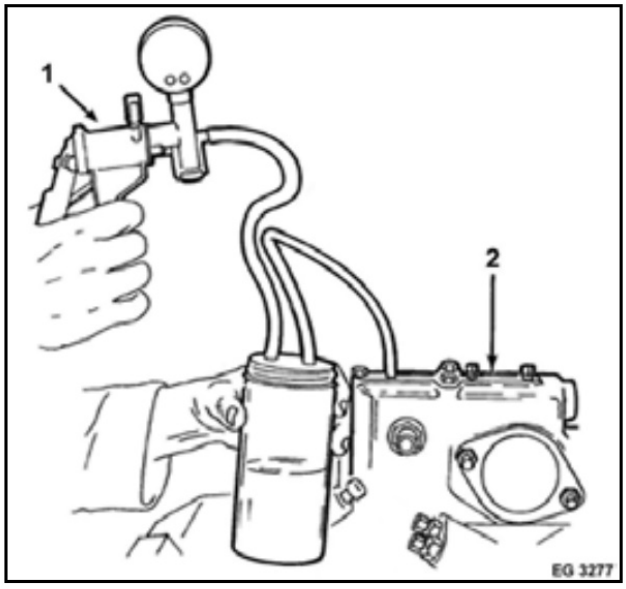

Figure 386 Removing Oil From High-pressure Oil Pump Reservoir

1. Hand Operated Vacuum Pump
2. High-pressure Oil Pump Reservoir

1. Remove pipe plug from top left side of high-pressure oil pump reservoir. Use a hand operated vacuum pump to extract oil from the reservoir.
2. Remove power steering pump.

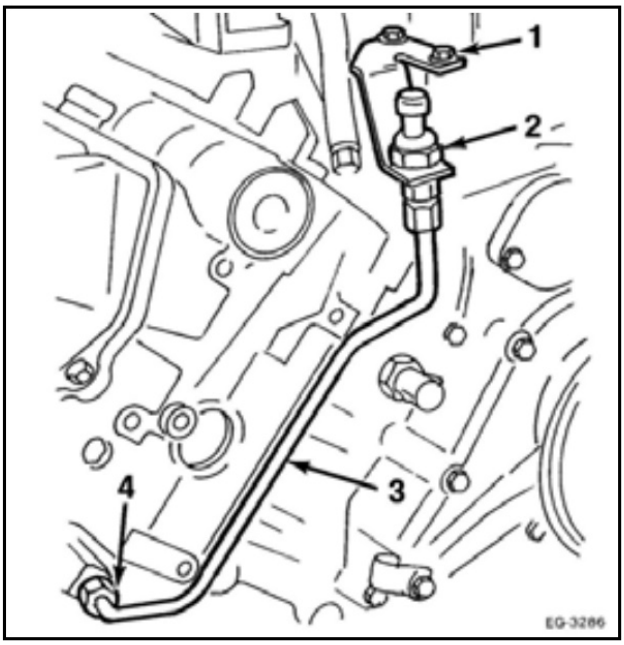

Figure 387 EBP Sensor Location

1. EBP Sensor Bracket Bolts (2)
2. EBP Sensor
3. EBP Sensor Tube
4. EBP Sensor Tube Nuts

3. Remove two bolts that secure the EBP sensor bracket to the right side of the high-pressure oil pump reservoir.
4. Disconnect the EBP sensor tube from the right exhaust manifold.

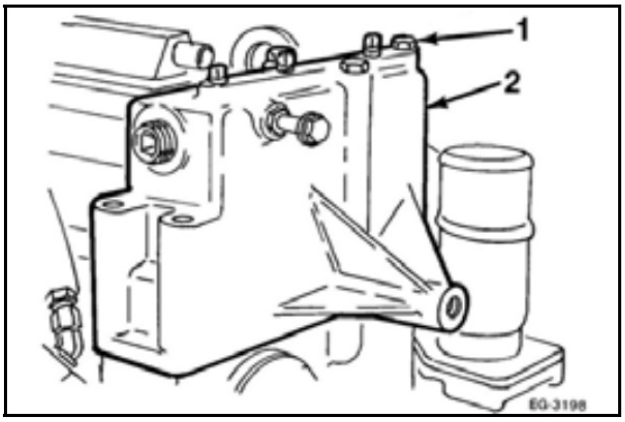

Figure 388 Removing Mounting Bolts From the High-pressure Oil Pump Reservoir

1. Mounting Bolts
2. High-pressure Oil Pump Reservoir

5. Remove the three remaining mounting bolts that secure the high-pressure oil pump reservoir to the front cover. Remove the high-pressure oil pump reservoir and gasket.

High-pressure Oil Pump and Drive Gear

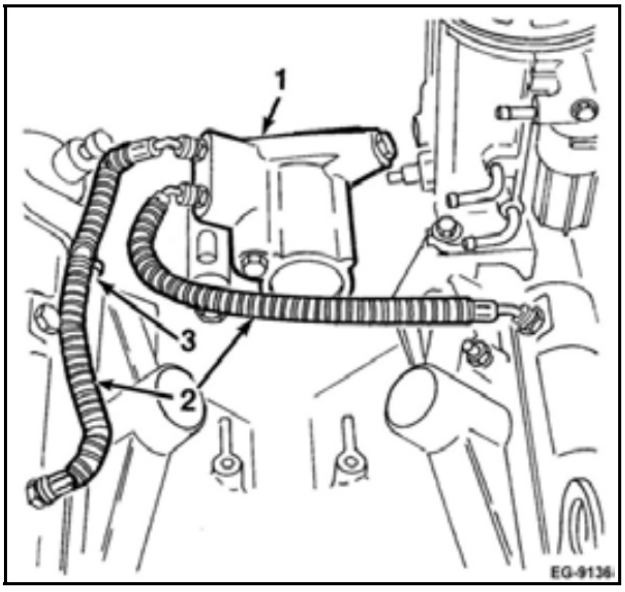

Figure 389 Removing High-pressure Oil Supply Hoses

1. High-pressure Oil Pump
2. Supply Hoses
3. Clamp

1. Use the special removal tool to disconnect the high-pressure oil supply hoses at the pump and at each cylinder head. Cap the fittings.
2. Disconnect the electrical harness from the IPR valve solenoid.

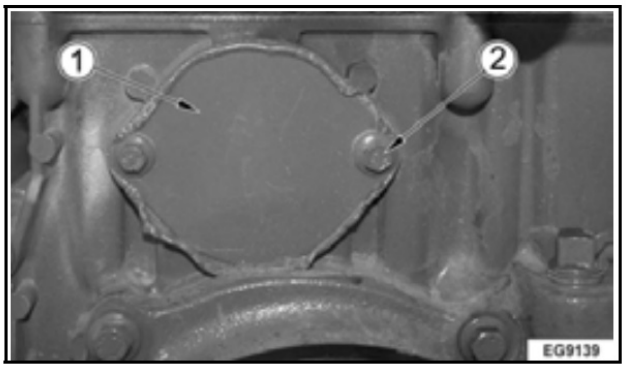

Figure 390 Removing Drive Gear Access Cover

1. Drive Gear Access Cover
2. Mounting Bolt (2)

3. Remove the two bolts and the drive gear access cover from the front cover. Clean all RTV sealant from the access cover and front cover mating surface.

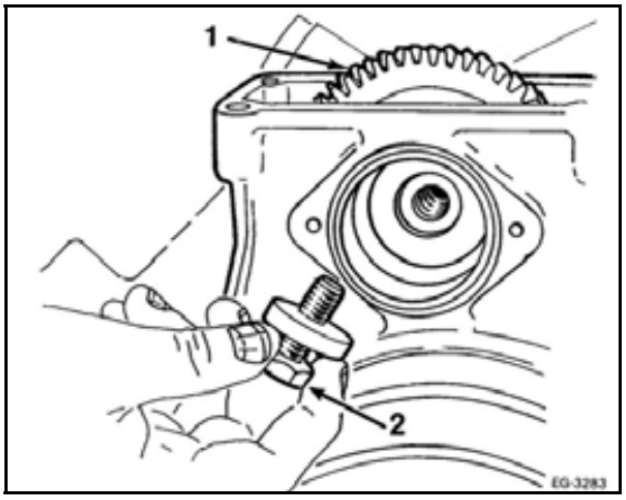

Figure 391 Removing Drive Gear Bolt

1. Drive Gear
2. Mounting Bolt and Washer

4. Remove bolt and washer that secure the drive gear to the high-pressure oil pump.

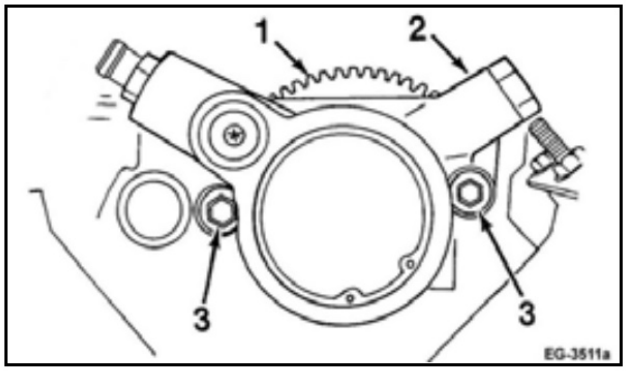

Figure 392 Removing High-pressure Oil Pump Mounting Bolts

1. Drive Gear
2. High-pressure Oil Pump
3. Mounting Bolts

5. Remove two capscrews that secure high-pressure oil pump to front cover. Remove pump and gasket from front cover.

NOTE: The gasket is reusable.

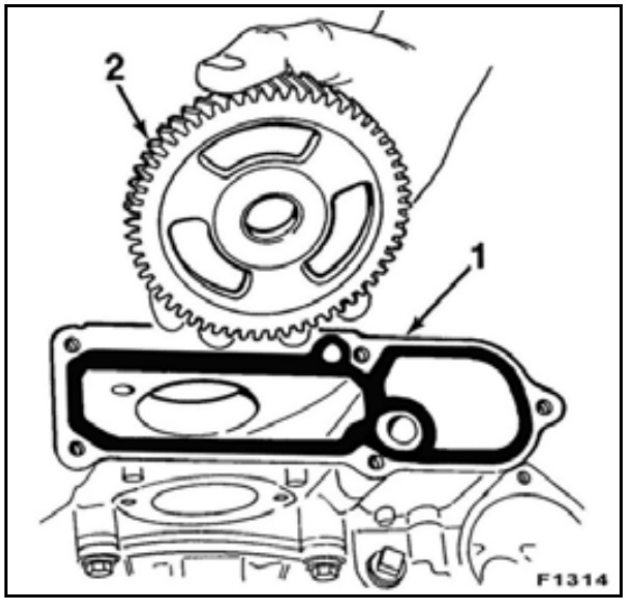

Figure 393 Removing Drive Gear

1. Front Cover
2. Drive Gear

6. Remove the drive gear through the top of the front cover.

Injection Pressure Regulator (IPR) Valve

NOTE: The IPR valve can be removed before or after the high-pressure oil pump is removed.

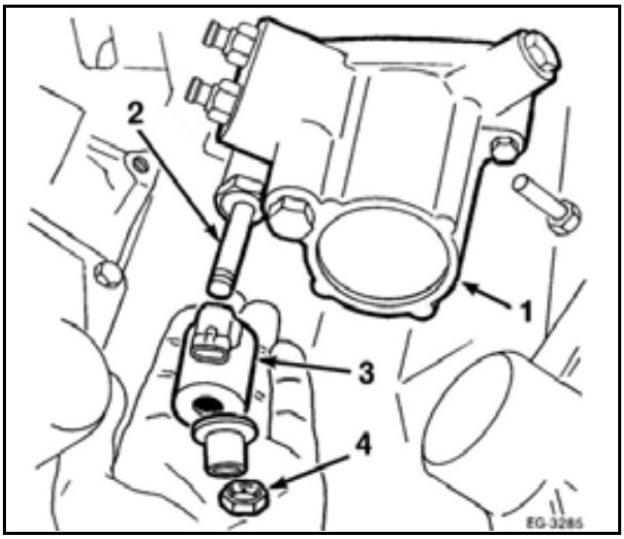

Figure 394 Removing the IPR Valve Solenoid

1. High-pressure Oil Pump
2. IPR Valve
3. Solenoid
4. Tinnermann Nut

1. Remove the tinnermann nut that secures the IPR valve solenoid. Remove the solenoid.

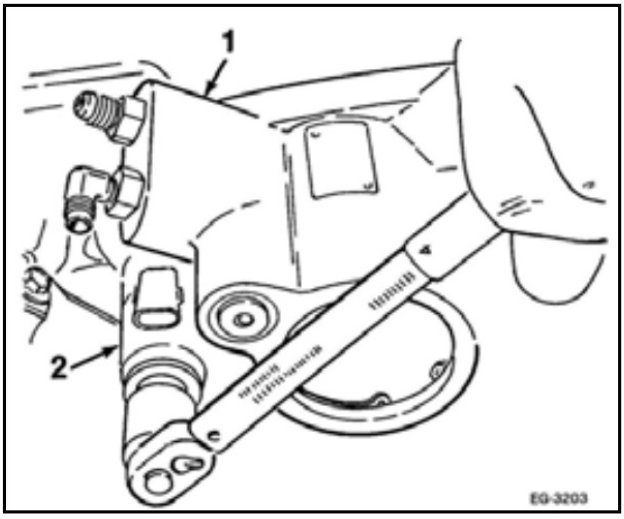

Figure 395 Removing the IPR Valve

2. Use a 28 mm (1-1/8 in) deep socket to unscrew the IPR valve from the high-pressure oil pump.

Installation

Injection Pressure Regulator (IPR) Valve

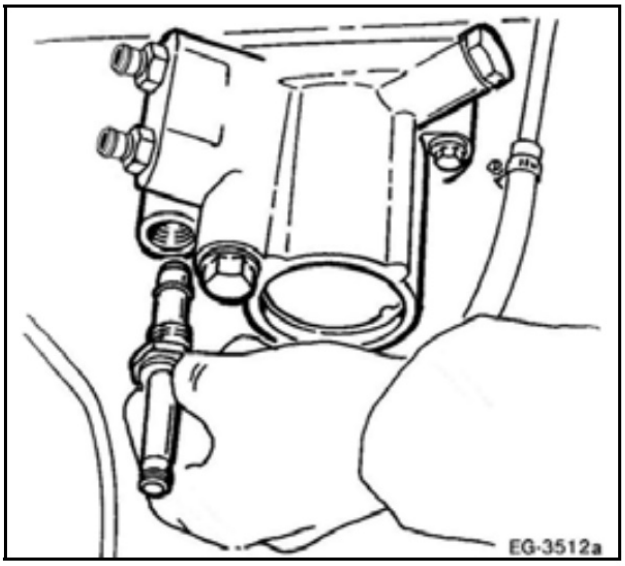

Figure 396 Installing the IPR Valve

1. Check the O-rings on the IPR valve. Replace the O-rings if damaged.
2. Install the IPR valve into the high-pressure oil pump. Tighten the IPR valve to the special torque value.
3. Install the solenoid and tinnermann nut. Tighten the tinnermann nut to the special torque value.

High-pressure Oil Pump and Drive Gear

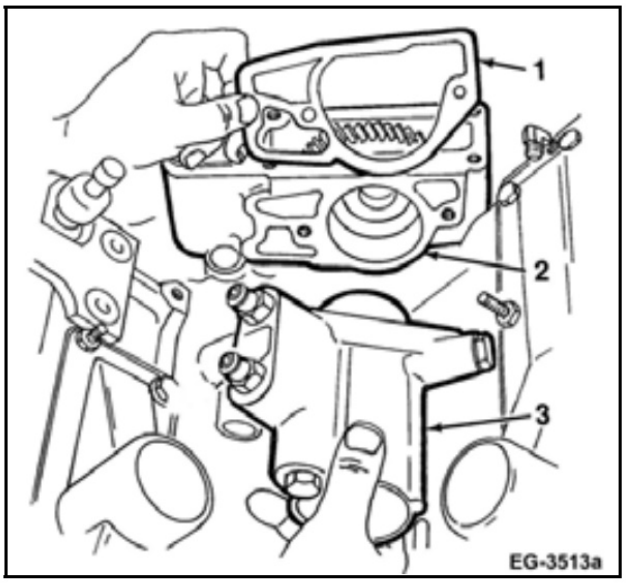

Figure 397 Installing High-pressure Oil Pump and Gasket

1. Gasket
2. Front Cover
3. High-pressure Oil Pump

1. Insert the high-pressure oil pump drive gear into the opening on top of the front cover.
2. Position the high-pressure oil pump with the gasket against the front cover.

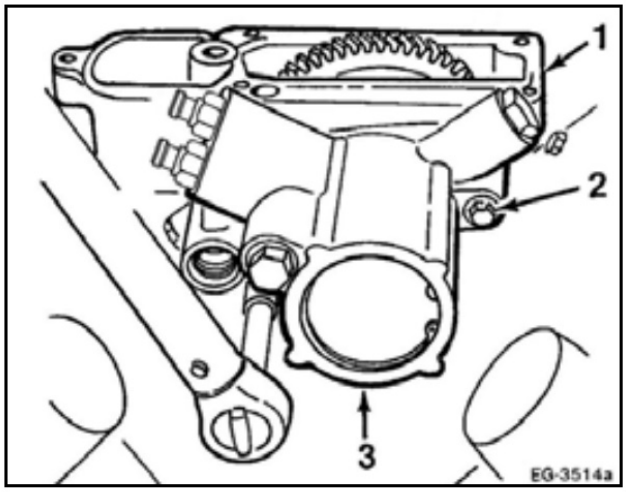

Figure 398 Installing High-pressure Oil Pump Mounting Bolts

1. Front Cover
2. Mounting Bolts (2)
3. High-pressure Oil Pump

3. Install and tighten the two mounting bolts to the special torque value.

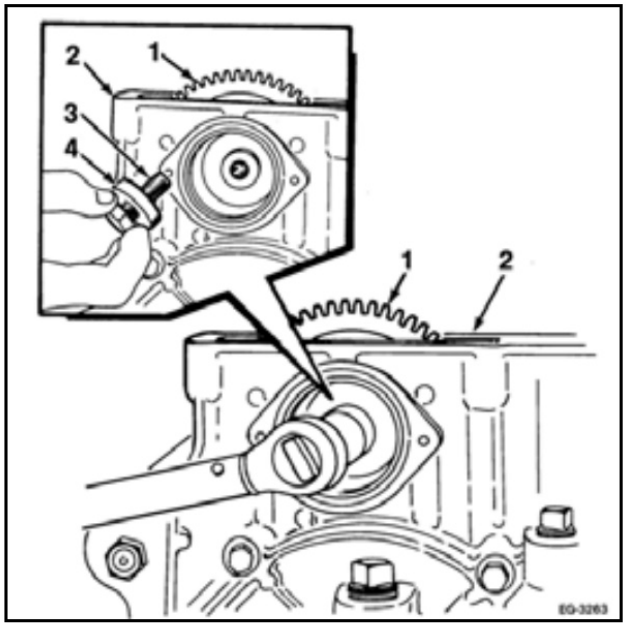

Figure 399 Installing the Drive Gear Bolt

1. Drive Gear
2. Front Cover
3. Drive Gear Mounting Bolt
4. Washer

4. Install the drive gear bolt and washer to secure the drive gear to the high-pressure oil pump. Tighten bolt to the special torque value.

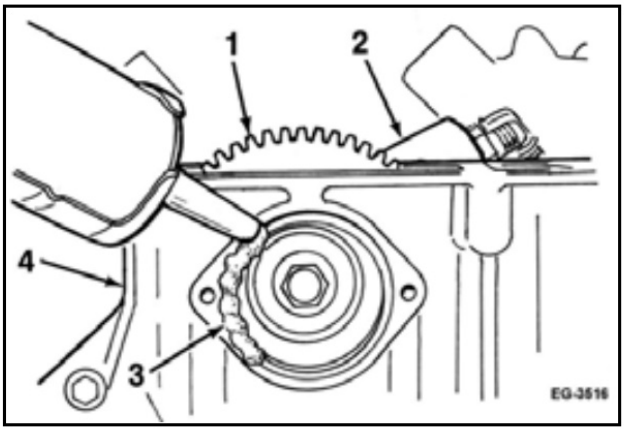

Figure 400 Applying RTV Sealant to the Drive Gear Access Cover

1. Drive Gear
2. High-pressure Oil Pump
3. RTV Bead
4. Front Cover

5. Apply RTV sealant to the drive gear access cover mounting surface.

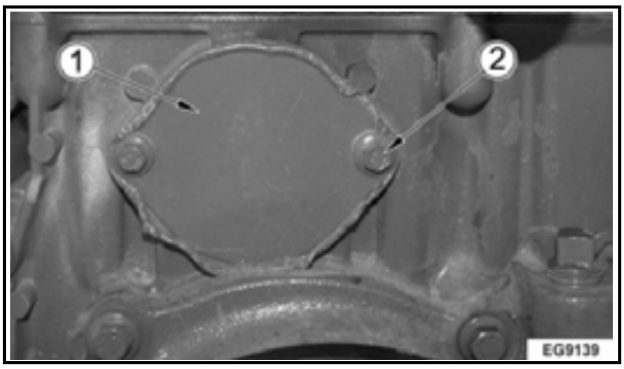

Figure 401 Install Drive Gear Access Cover

1. Drive Gear Access Cover
2. Mounting Bolt (2)

6. Install the access cover and two mounting bolts. Tighten the bolts to the standard torque value.
7. Connect the engine wiring harness connector to the IPR valve solenoid.

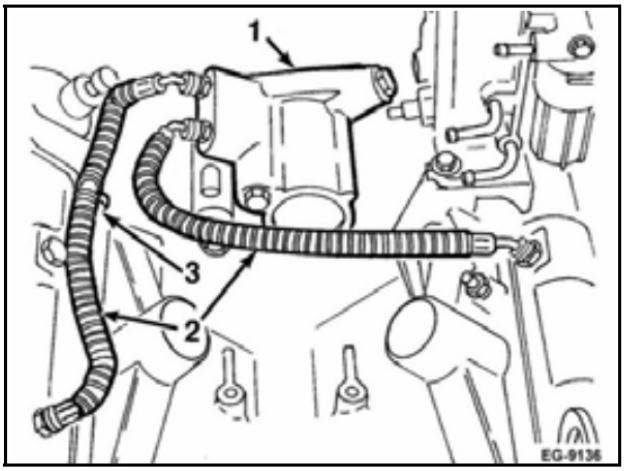

Figure 402 Installing High-pressure Oil Supply Hoses

1. High-pressure Oil Pump
2. High-pressure Oil Supply Hoses
3. Hose Clamp

8. Remove the protective caps from the fittings. Install both high-pressure oil supply hoses at the high-pressure oil pump and cylinder head. Make sure the hose fittings snap into place.

Check Drive Gear Backlash

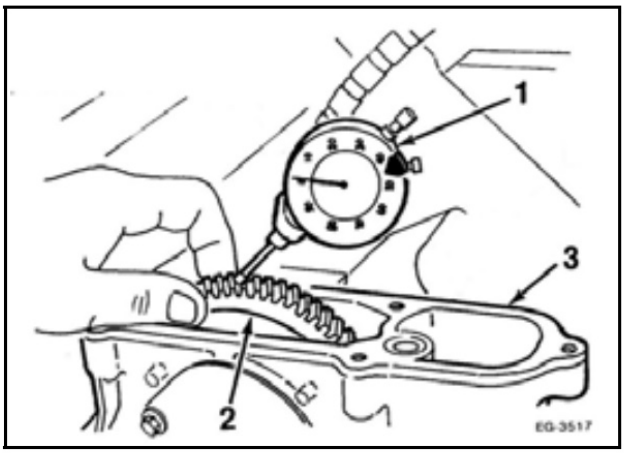

Figure 403 Measuring Drive Gear Backlash

1. Dial Indicator
2. Drive Gear
3. Front Cover

1. Mount the dial indicator.
2. Place the measuring tip of the dial indicator on the gear tooth, tangent to the gear tooth, if possible.
3. Move the gear in one direction and hold it in place.
4. Zero the dial indicator.
5. Move the drive gear by hand in the opposite direction. Record the backlash.
6. If the backlash exceeds specifications, replace the drive gear.

High-pressure Oil Pump Reservoir

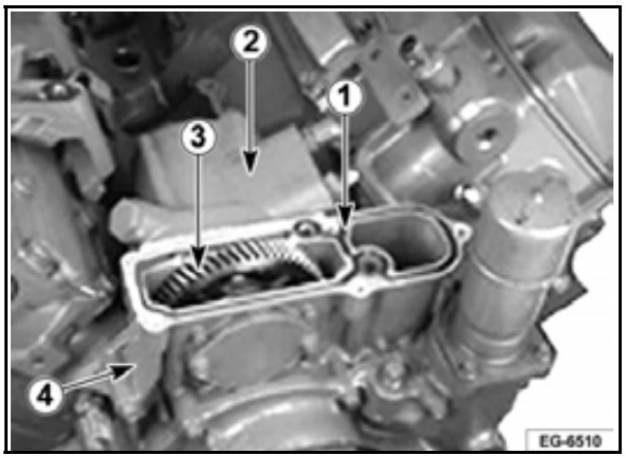

Figure 404 Installing a Gasket to the Reservoir Mating Surface

1. Reservoir Gasket
2. High-pressure Oil Pump
3. High-pressure Oil Pump Drive Gear
4. Front Cover

1. Install a new gasket onto the top of the reservoir mating surface.

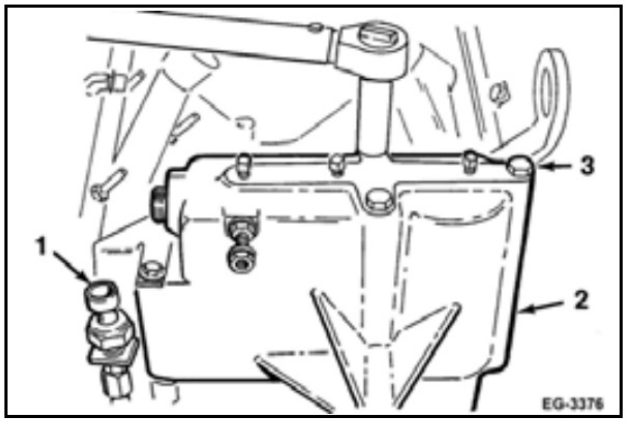

Figure 405 Install High-pressure Oil Pump Reservoir

1. Exhaust Back Pressure (EBP) Sensor
2. High-pressure Oil Pump Reservoir
3. Reservoir Mounting Bolts (3)

2. Install the reservoir to the front cover. Secure the reservoir with three mounting bolts.

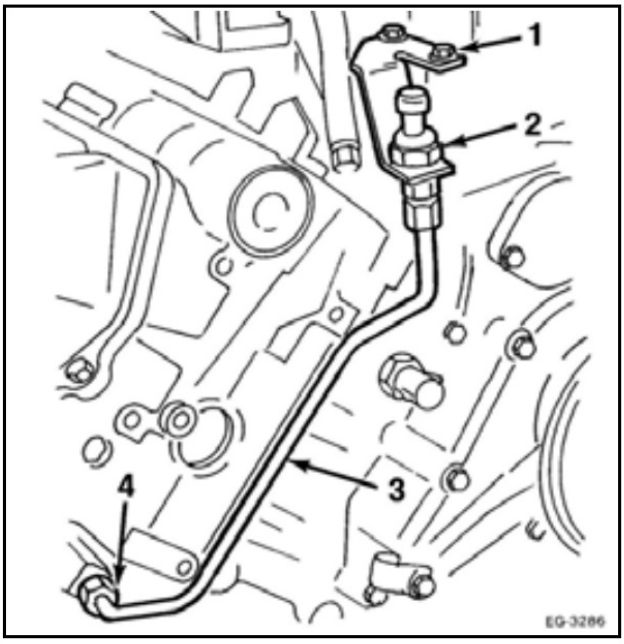

Figure 406 Installing EBP Sensor

1. EBP Sensor Bracket Bolts (2)
2. EBP Sensor
3. EBP Sensor Tube
4. EBP Sensor Tube Nuts

3. Use two bolts to secure the EBP sensor bracket onto the right side of the high-pressure oil pump reservoir.
4. Connect the EBP sensor tube to the right exhaust manifold. Tighten the tube nut.
5. Connect the EBP sensor to the wiring harness.
6. Fill the reservoir with clean engine oil.

SPECIFICATIONS

Table 28 High-pressure Lube Oil System

High-pressure Oil Pump	
Gear Backlash	0.140–0.256 mm (0.0055–0.0101 in)
End Play	0.45–1.22 mm (0.018–0.048 in)
Injection Pressure Regulator (IPR) Valve	
Operating Temperature Range	-40° to 125°C (-40° to 257°F)
Maximum Flow Rate	17.5 L/min (4.62 gpm)
Maximum Operating Pressure	20.7 MPa (3000 psi)

Special Torque

Table 29 High-pressure Lube Oil System Special Torques

High-pressure Oil Pump Drive Gear Bolt	129 N·m (95 lbf·ft)
IPR Valve Tinnermann Nut	5.5 ± 1.5 N·m (49 ± 13 lbf·in)
IPR Valve	50 ± 5 N·m (37 ± 4 lbf·ft)
High-pressure Hose Fitting (37° Flare)	26 N·m (19 lbf·ft)
45° and 90° Elbow Locknut	28 N·m (21 lbf·ft)

SPECIAL SERVICE TOOLS

Table 30 High-pressure Lube Oil System Special Service Tools

ZTSE2499	Hand Operated Vacuum Pump
ZTSE4295	High-pressure Oil System Cap Set
OEM1028	Magnetic Base Dial Indicator

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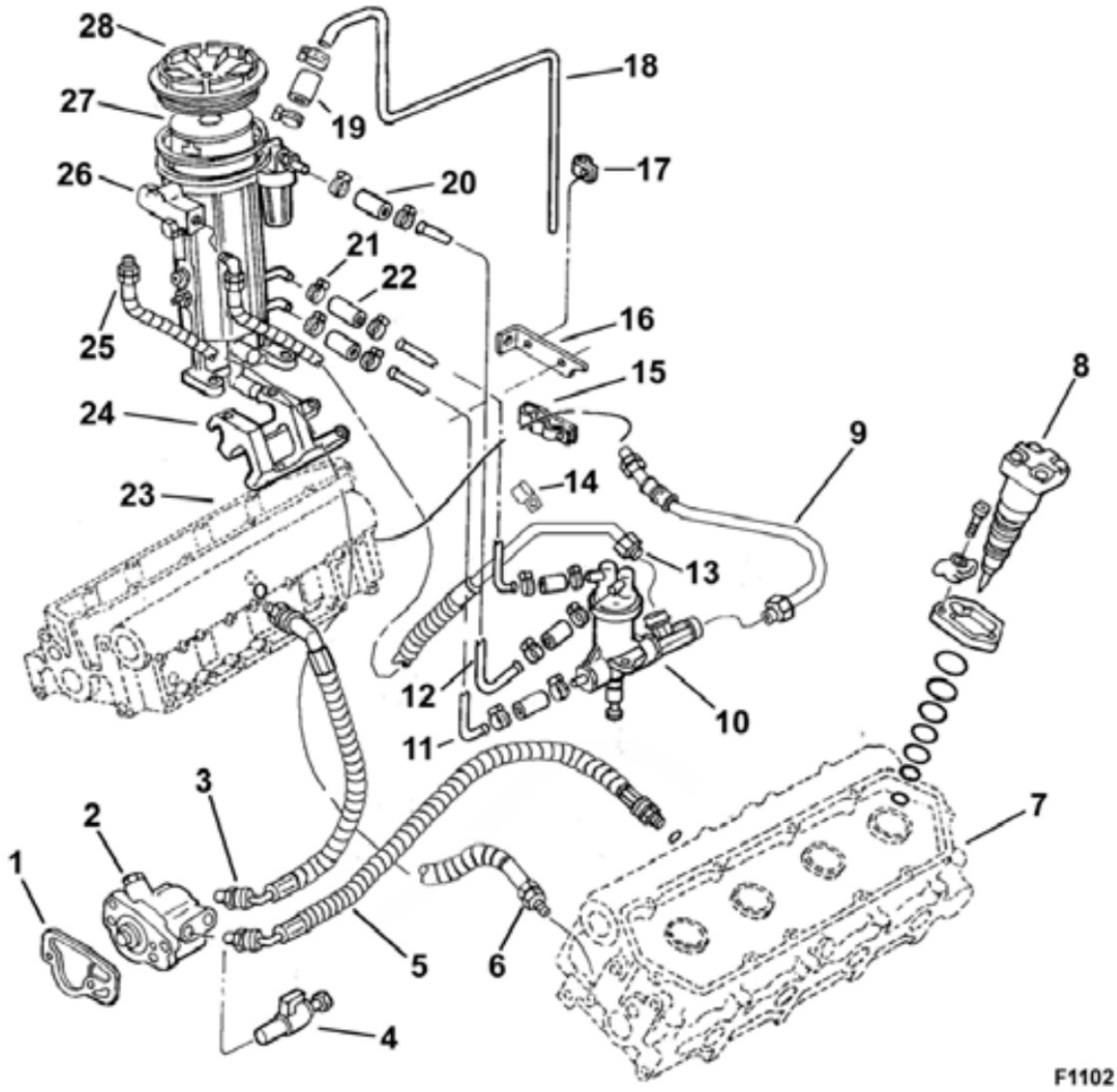

Figure 407 Fuel System Components

1. Pump Flange Gasket
2. High-pressure Oil Pump Assembly
3. High-pressure Manifold Hose (Right Side)
4. Fuel Injection Pressure Regulator
5. High-pressure Oil Pump Supply Hose (Left Side)
6. Fuel Supply Hose (Left Side) and Inlet Check Fittings
7. Cylinder Head (Left Side)
8. Fuel Injector Assembly
9. Fuel Supply Pipe (Right Side) and Inlet Check Fittings
10. Transfer Pump
11. Fuel Filter to Transfer Pump
12. Fuel Pump Supply Tube
13. Fuel Supply Hose from Pump to Regulator
14. Clamp
15. Fuel Pump Lines Retaining Clamp
16. Water Drain Tube Clamp Support
17. Clamp
18. Fuel Filter Water Drain Tube
19. Fuel Filter Water Drain Hose
20. Fuel Hose
21. Hose Clamp
22. Fuel Filter to Transfer Pump Tube
23. Cylinder Head (Right Side)
24. Fuel Filter Bracket
25. Fuel Supply Hose (Left Side)
26. Fuel Pressure Regulating Valve
27. Fuel Filter Element
28. Fuel Filter Lid (Part of Assembly)

Fuel Filter Tower, Bracket and Piping

Removal

WARNING: To avoid serious personal injury, possible death, or damage to the engine or vehicle, do not smoke or work near open flames and sparks when draining fuel.

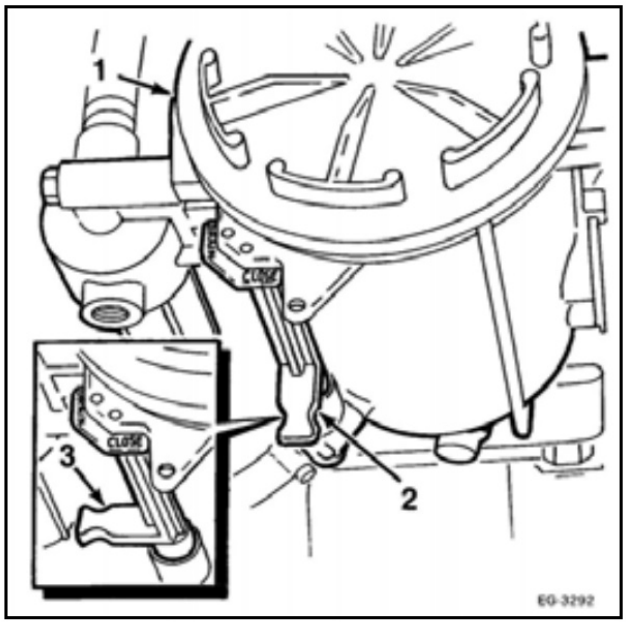

Figure 408 Fuel Filter Lever Locations

1. Fuel Filter Assembly
2. Fuel Filter Shutoff Lever, CLOSED Position
3. Fuel Filter Shutoff Lever, DRAIN Position

1. Place a suitable container at the end of the fuel filter drain line to catch the draining fuel. Move the fuel filter drain lever to the DRAIN position. When the fuel is done draining, return the lever to the CLOSED position.

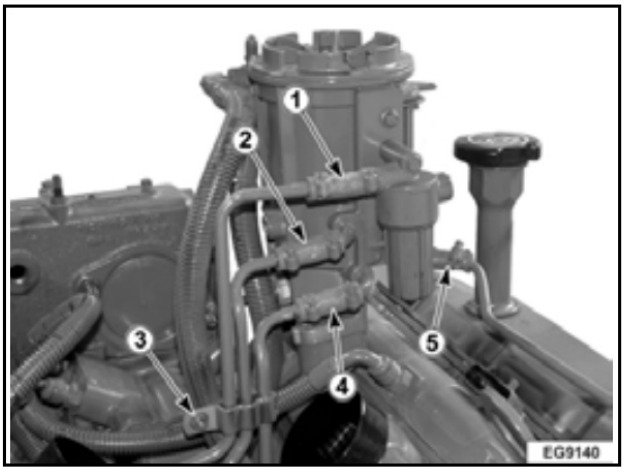

Figure 409 Removing the Fuel Lines

1. Fuel Supply to Fuel Transfer Pump Line
2. Fuel Transfer Pump to Fuel Filter Line
3. Retaining Clamp
4. Fuel Filter to Fuel Transfer Pump Line
5. Fuel Filter Drain Line

2. Remove the bolt for the retaining clamp that holds three of the fuel lines together.
3. Loosen the hose clamps and remove all four fuel lines.

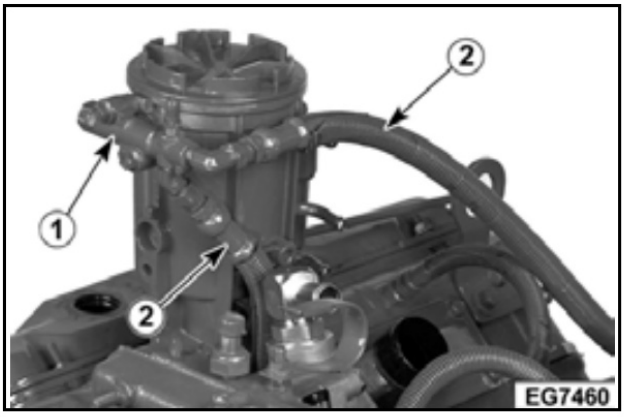

Figure 410 Removing Hoses from the Regulating Valve

1. Fuel Pressure Regulating Valve
2. Fuel Supply Hoses

4. Remove two fuel supply hoses from the fuel pressure regulating valve. Cap the fittings on the cylinder head.

5. Remove the bolts that secure the fuel pressure regulating valve to the fuel filter. Check for damage or corrosion.

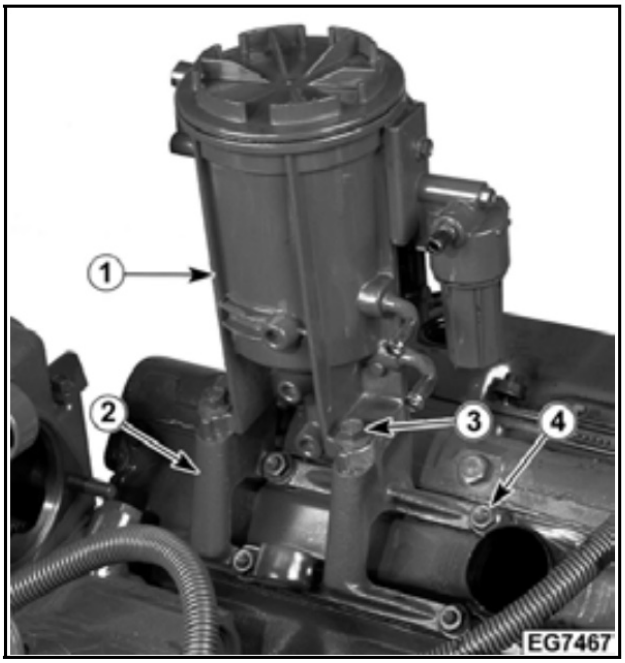

Figure 411 Removing the Fuel Filter Tower (Model Year 1997–1998)

1. Fuel Filter Tower
2. Fuel Filter Support Bracket
3. Fuel Filter Tower Mounting Bolts (2)
4. Support Bracket Mounting Nuts (4)

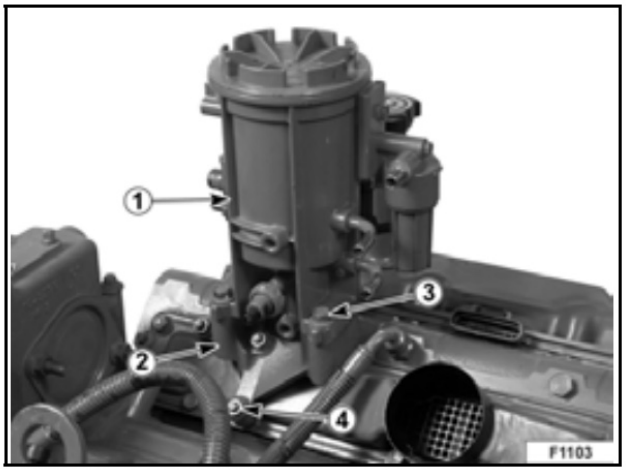

Figure 412 Removing the Fuel Filter Tower (Model Years 1999 and Up)

1. Fuel Filter Tower
2. Fuel Filter Support Bracket
3. Fuel Filter Tower Mounting Bolts (2)
4. Support Bracket Mounting Nuts (3)

6. Remove the two mounting bolts that secure the fuel filter tower to the fuel filter support bracket. Remove the fuel filter tower from the support bracket.
7. If necessary, remove the mounting nuts that secure the fuel filter support bracket to the cylinder head. Remove the support bracket.

Installation

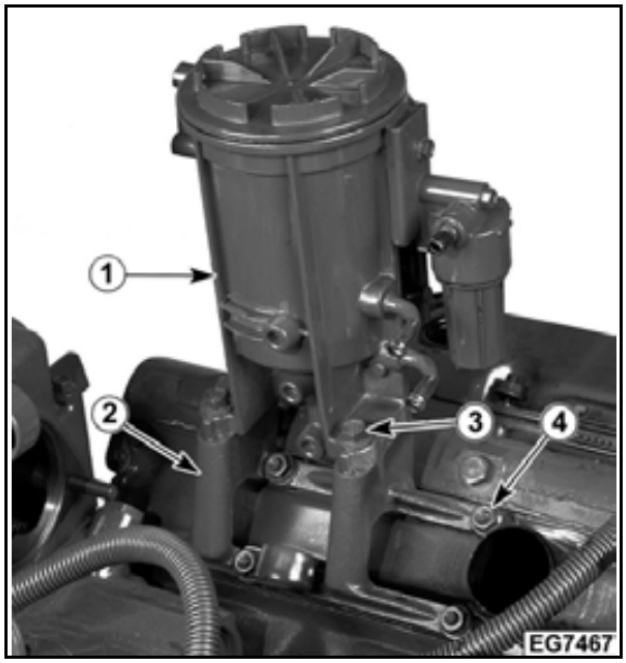

Figure 413 Installing the Fuel Filter Tower (Model Year 1997–1998)

1. Fuel Filter Tower
2. Fuel Filter Support Bracket
3. Fuel Filter Tower Mounting Bolts (2)
4. Support Bracket Mounting Nuts (4)

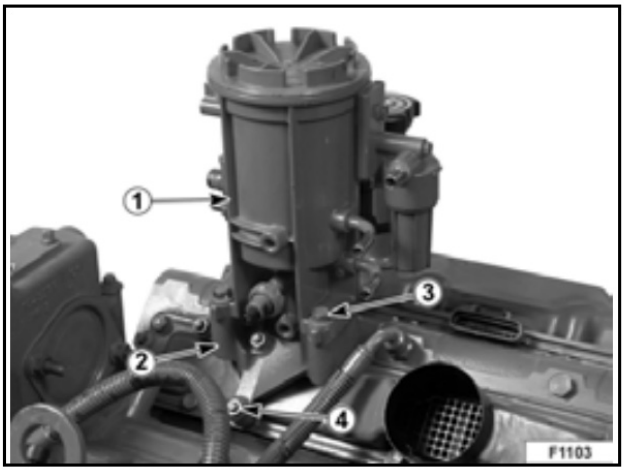

Figure 414 Removing the Fuel Filter Tower (Model Years 1999 and Up)

1. Fuel Filter Tower
2. Fuel Filter Support Bracket
3. Fuel Filter Tower Mounting Bolts (2)
4. Support Bracket Mounting Nuts (3)

1. If removed, install the support bracket on the cylinder head. Install the four mounting nuts and tighten them to the standard torque value.
2. Install the fuel filter tower on the support bracket. Install the two mounting bolts and tighten them to the standard torque value.

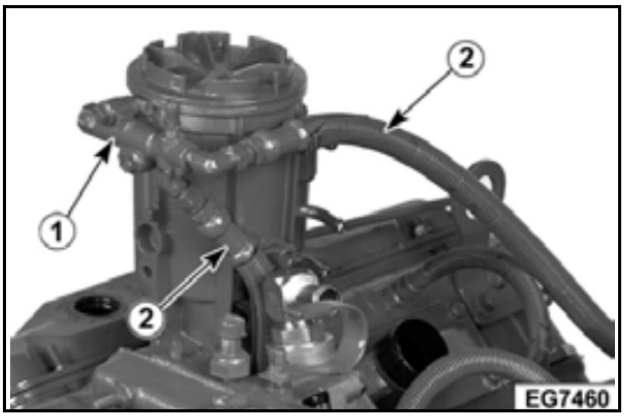

Figure 415 Installing Hoses to Regulating Valve

1. Fuel Pressure Regulating Valve
2. Fuel Hoses

3. Install a new O-ring onto the fuel pressure regulating valve.

4. Secure the regulating valve to the fuel filter with two mounting bolts. Tighten the bolts to the standard torque value.
5. Attach the fuel supply hoses to the fuel pressure regulating valve. Tighten the hose fittings.

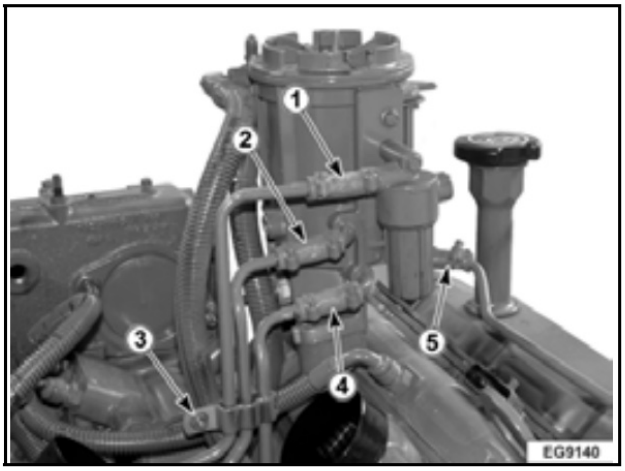

Figure 416 Attaching the Fuel Lines

1. Fuel Supply to Fuel Transfer Pump Line
2. Fuel Transfer Pump to Fuel Filter Line
3. Retaining Clamp
4. Fuel Filter to Fuel Transfer Pump Line
5. Fuel Filter Drain Line

6. Attach the three fuel lines between the fuel transfer pump and the fuel filter.
7. Install the retaining clip and bolt to hold the three fuel lines together.
8. Attach the fuel filter drain line. Secure it to the fuel filter with hose clamps.

Fuel Strainer

Removal

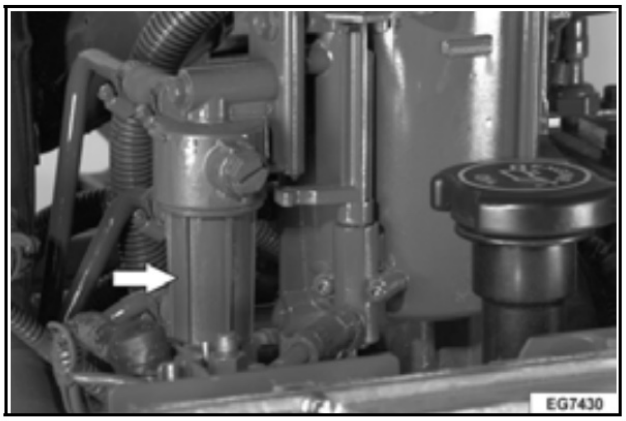

Figure 417 Removing the Fuel Strainer Assembly

1. Remove the fuel strainer assembly from the fuel filter housing.
2. Use a 29 mm or 1-1/8 inch socket to remove the plastic fuel strainer cover from the filter strainer assembly. Clean or replace the fuel strainer.

Installation

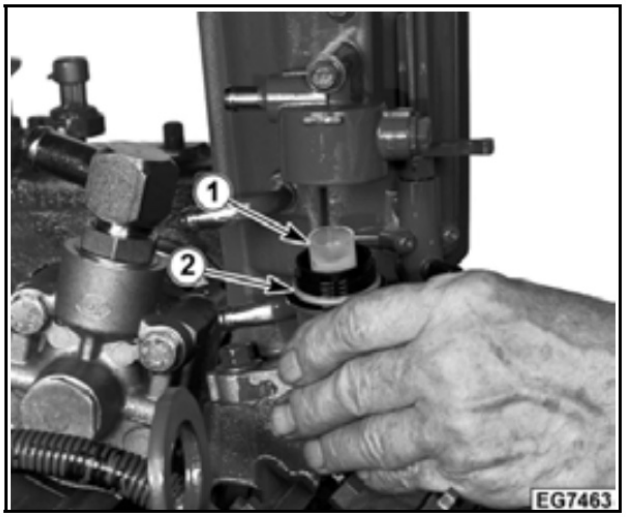

Figure 418 Installing the Fuel Strainer

1. Fuel Strainer
2. O-Ring

NOTE: Install the fuel strainer with the open end toward the top.

1. Install a new O-ring. Lubricate the threads of the fuel strainer cover and the O-ring with clean engine oil.
2. Install the new fuel strainer into the cover. Hand tighten the strainer into the fuel filter body.

Fuel Filter

Removal

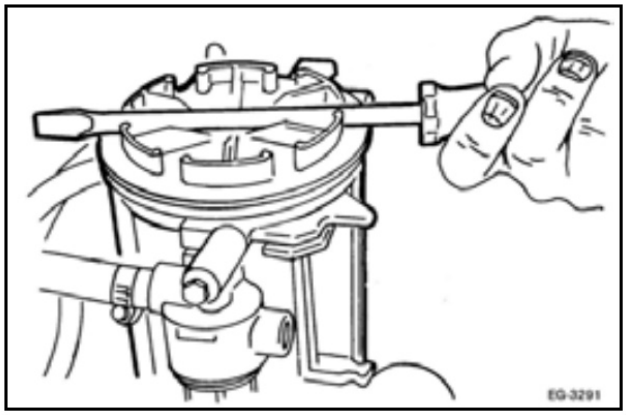

Figure 419 Removing the Fuel Filter Cap

1. Use a large screwdriver to remove the fuel filter cap. The filter element will come out with the cap.

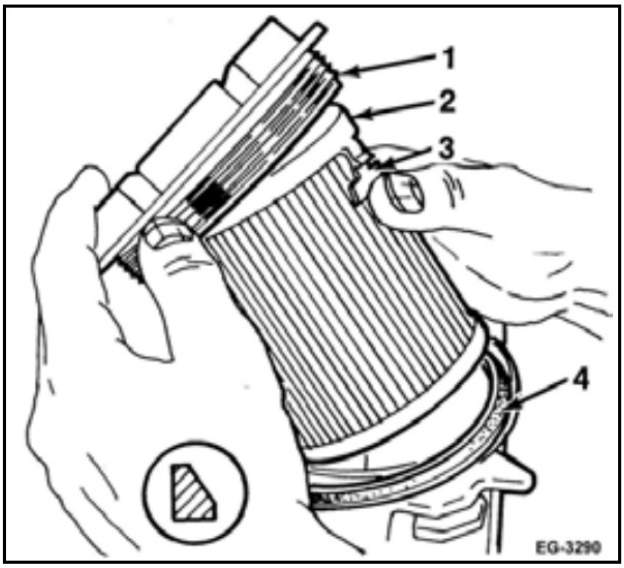

Figure 420 Removing the Fuel Filter Element Assembly

1. Fuel Filter Cap
2. Fuel Filter Element
3. Fuel Filter Locking Tab
4. Bevel-Cut Gasket

2. Remove and discard the bevel-cut gasket. Carefully clean all mating surfaces.
3. Press in on the fuel filter element locking tabs and separate the filter element from the cap.

Installation

CAUTION: The engine will not run without the filter element in place. Failure to secure the fuel cap to the fuel filter may result in engine damage because the filter element is required to open the valve in the center stand pipe. When the valve is open, fuel is allowed to flow into the filter. This feature protects the injectors from contaminants if the filter element is left out.

NOTE: If the fuel system has been drained, prime the fuel filter by filling the filter housing up to the cap threads with clean diesel fuel.

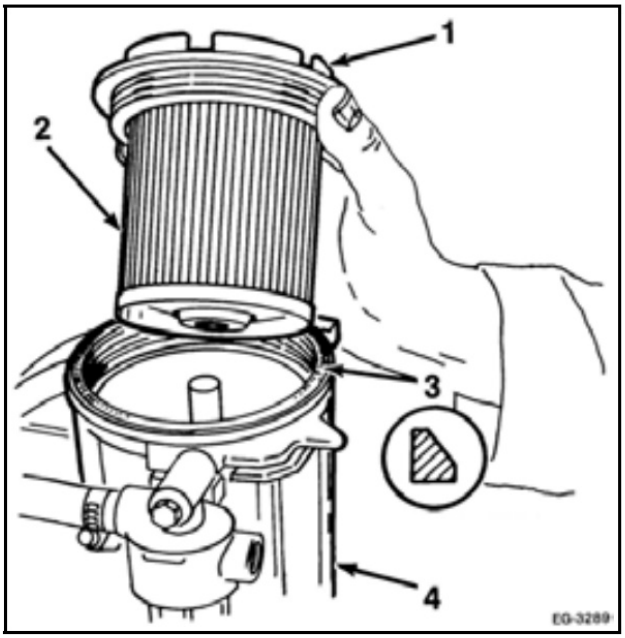

Figure 421 Installing a New Fuel Filter Element

1. Fuel Filter Cap
2. Fuel Filter Element
3. Bevel-Cut Gasket
4. Fuel Filter Housing

1. Apply a coating of diesel fuel to the new bevel-cut gasket and install it on the fuel filter housing gland.
2. Install a new fuel filter element on the cap. Place the new fuel filter element and cap into the fuel filter housing. Tighten the cap onto the fuel filter housing until the cap contracts the aluminum housing.

Fuel Transfer Pump

Removal

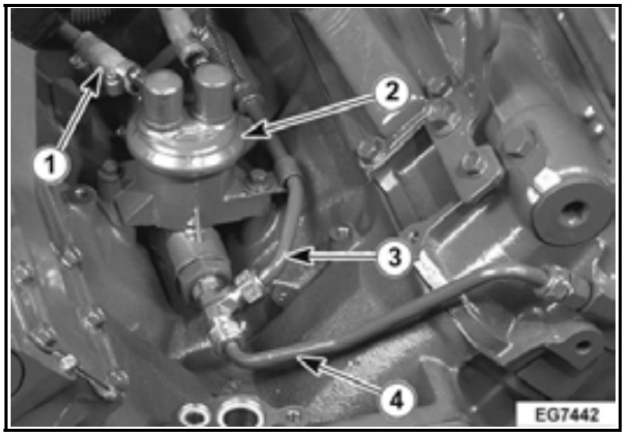

Figure 422 Removing the Fuel Transfer Pump

1. Lines from Pump to Filter
2. Fuel Transfer Pump
3. Fuel Supply Tube (to Regulating Valve)
4. Fuel Supply Tube (Right Side)

1. Disconnect the lines between the fuel transfer pump and the fuel filter. Plug the lines.
2. Disconnect both fuel supply tubes from the fuel transfer pump. Plug the tubes.
3. Remove the two mounting bolts that secure the fuel transfer pump to the base of the crankcase.
4. Rotate the engine by hand until the pump is pushed up approximately 1/2 inch. This places the cam lobe at the top. In this position, if the tappet falls out of the pump during removal, it will not enter the crankcase.
5. Remove the fuel transfer pump.
6. If required, retrieve the tappet from the fuel transfer pump bore located in the crankcase. Insert the tappet into the base of the fuel transfer pump.

Inspection

Inspect the fuel transfer pump tappet for wear.

Installation

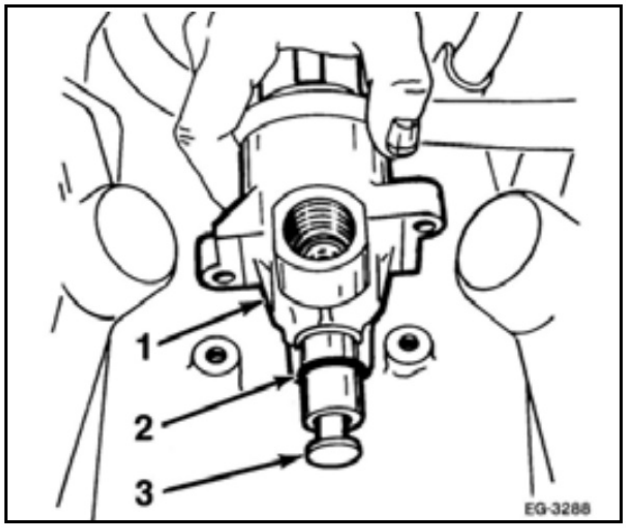

Figure 423 Installing a New O-Ring Onto the Fuel Transfer Pump

1. Fuel Transfer Pump
2. O-Ring
3. Tappet

1. Install a new O-ring onto the fuel transfer pump.
2. Rotate the engine by hand until the fuel transfer pump is pushed nearly flush with the crankcase. Install the mounting bolts to the standard torque value.
3. Remove the plugs from the fuel supply tubes. Place new O-rings onto the tube fittings. Connect the fuel supply tubes to the pump.
4. Connect the lines between the fuel transfer pump and the fuel filter.

Fuel Injectors

NOTE: Refer to the CYLINDER HEAD AND VALVES section, for fuel injector removal and installation instructions.

SPECIFICATIONS

Table 31 Fuel System Specifications

Fuel Filter	
Type	Spin-On with Fuel Strainer
Fuel Pressure Regulating Valve	
Valve open	496 kPa (72 psi)
Heater element activates	7° ± 14°C (45° ± 6.5°F)
Heater element deactivates	24° ± 13°C (75° ± 8.5°F)

Special Torque

Table 32 Fuel System Special Torques

Fuel Return Hose Fitting	16 N·m (12 lbf·ft)
Fuel Supply Tube Bolt (Lift Pump Banjo Fitting)	54 N·m (40 lbf·ft)

SPECIAL SERVICE TOOLS

Table 33 Fuel System Special Service Tools

ZTSE4294	Fuel System Cap Set

Table of Contents

NOTE: MOUNTING ENGINE ON STAND, and OIL COOLER AND FILTER sections, have no specifications that are necessary for service work.

SPECIFICATIONS

Table 34 Turbocharger

EBP Control Rod Spring Preload	13.5 ± 3 N·m (10 ± 2 lbf)
Turbine Shaft Axial End Play	0.02 - 0.10 mm (0.001 - 0.004 in.)
Turbine Shaft Radial Movement (Play)	0.08 - 0.15 mm (0.003 - 0.006 in)
Wastegate Actuator Movement (Standard Torque Model)	1.016 mm @ 101.35 ± 3.45 kPa (0.4 in @ 14.7 ± 0.5 psi)
Wastegate Actuator Movement (High Torque Model)	0.369 mm @ 131 kPa (0.015 in @ 19 psi)

Table 35 Manifolds

Maximum Allowable Warpage	**Between ports:** 0.13 mm (0.005 in) **Total:** 0.25 mm (0.010 in)
Maximum Allowable Removal of Material	0.25 mm (0.010 in)

Table 36 Cylinder Head

Exhaust Valves	
Stem Diameter	7.9210-7.9388 mm (0.31185-0.31255 in)
Stem To Guide Clearance (Max. Allowable Before Replacement)	0.140 mm (0.0055 in)
Face To Stem Runout (T.I.R. Max.)	0.05 mm (0.002 in)
Valve Face Angle	37.5°
Valve Face Margin (Min.)	1.37 mm (0.054 in)
Intake Valves	
Stem Diameter	7.9210-7.9388 mm (0.31185-0.31255 in)
Stem To Guide Clearance (Max. Allowable Before Replacement)	0.140 mm (0.0055 in)
Face To Stem Runout (T.I.R. Max.)	0.05 mm (0.002 in)
Valve Face Angle	30°
Valve Face Margin (Min.)	1.67 mm (0.066 in)
Cylinder Heads	
Inside Diameter Of Valve Guide	7.978-8.004 mm (0.3141-0.3151 in)
Valve Guide Taper (Max.)	0.10 mm (0.004 in)
Valve Seat Width (intake and exhaust)	1.65-2.41 mm (0.065-0.095 in)
Valve Seat Angle (intake)	30°
Valve Seat Angle (exhaust)	37.5°
Valve Seat Run Out (T.I.R. Max.)	0.05 mm (0.002 in)
Gasket Surface Flatness	0.025 mm in 0.5 mm (0.001 in. in 2 inches) 0.10 mm (0.004 in) overall
Gasket Surface Finish (Micro Inches)	63-125
Deck To Deck Dimension (Head Thickness Overall)	129.41-129.67 mm (5.095-5.105 in)
Valve Head Recession Relative To Deck (Head Gasket) Surface On Cylinder Head	
Intake	1.17-1.47 mm (0.046-0.058 in)
Exhaust	1.32-1.63 mm (0.052-0.064 in)
Valve Spring	
Free Length	52.70 ± 3.8 mm (2.075 ± 0.150 in)
Test Length	34.34 mm (1.352 in)
Load at Test Length	102-113 kg (225-249 lbf)
Push Rod Runout/Straightness (Max. T.I.R.)	0.518 mm (0.02 in)

Table 37 Vibration Damper, Lubricating Oil Pump, Oil Pan, Oil Pick-Up Tube and Front Cover

Lubricating Oil Pump	
Type	Gerotor
End Clearance - inner and outer rotor to housing	0.02-0.08 mm (0.001-0.003 in)
Radial clearance between outer rotor housing	0.71-0.81 mm (0.028-0.032 in)
Engine Lube Oil Pressure at Operating Temperature	
At low idle speed (700 rpm) minimum	69 kPa (10 psi)
At high idle speed	241-483 kPa (35-70 psi)
Engine Oil Capacity	
Without filter	17 liters (18 quarts)
With filter	18.5 liters (19.5 quarts)
Vibration Damper	
Vibration damper mounting area runout (maximum)	0.13 mm (0.005 in)

Table 38 Valve Train

Camshaft	
Bearing Journal Diameter (All Journals)	53.31-53.34 mm (2.099-2.100 in)
Bearing (Bushing) Inside Diameter	53.39-53.48 mm (2.102-2.105 in)
Journal/Bushing Running Clearance	0.051-0.165 mm (0.002-0.006 in)
Camshaft End Play	0.051-0.203 mm (0.002-0.008 in)
Timing Gear Backlash	0.140-0.2794 mm (0.0055-0.0110 in)
Maximum Permissible Cam Lobe Wear	0.51 mm (0.020 in)
Journal Surface Finish (microinches)	16 µin
Camshaft Thrust Plate Thickness	3.910-3.960 mm (0.154-0.156 in)
Camshaft Lobe Lift	
Intake	6.44 mm (0.2535 in) max.
Exhaust	6.43 mm (0.2531 in) max.
Valve Timing No. 1 Cylinder (Top of Ramp)	
Intake Open	17.2 ° BTDC
Closed	34.8 ° ABDC
Exhaust Open	51.2 ° BBDC
Closed	20.8 ° ATDC
Hydraulic Valve Lifters	
Diameter	23.391-23.411 mm (0.9209-0.9217 in)
Bore Diameter In Crankcase	23.439-23.477 mm (0.9228-0.9243 in)
Clearance In Bore	0.027-0.086 mm (0.0011-0.0034 in)
Bleed Down Rate – Time required for plunger to move 3.175 mm (0.125 in) under a 50 lb load using test fluid at room temperature	18-90 seconds

Table 39 Crankcase, Camshaft Bushing, Crankshaft and Main Bearing, Connecting Rod and Piston

CRANKSHAFT	
Main Bearing Journal Diameter	
Standard Size	79.3191 - 79.3394 mm (3.1228 - 3.1236 in)
0.254 mm (0.010 in) Undersize	79.0651 - 79.0854 mm (3.1128 - 3.1136 in)
0.508 mm (0.020 in) Undersize	78.8111 - 78.8314 mm (3.1028 - 3.1036 in)
0.762 mm (0.030 in) Undersize	78.5571 - 78.5774 mm (3.0928 - 3.0936 in)
Main Bearing Journal Maximum Out-of-Round	0.00559 mm (0.00022 in)
Main Bearing Thrust Face Runout (T.I.R. maximum)	0.0254 mm (0.001 in)
Main Bearing Journal Taper (max. per inch)	0.381 mm (0.0015 in)

Table 39 Crankcase, Camshaft Bushing, Crankshaft and Main Bearing, Connecting Rod and Piston (cont.)

Main Journal Fillet Radius, Journal No. 1, 2, 3 and 4	3.302 mm (0.130 in)
Main Journal Fillet Radius, Journal No. 5	3.99 - 4.14 mm (0.157 - 0.163 in)
Rod Journal Fillet Radius	3.68 mm (0.145 in)
Oil Seal Journal Runout (maximum)	0.05 mm (0.002 in)
Flywheel Housing Bore Concentricity (maximum)	0.20 mm (.008 in)
Flywheel Housing Face Runout (maximum)	0.51 mm (0.020 in)
Flywheel Surface Runout (maximum)	0.05 mm (0.002 in)
Flywheel Thickness (minimum) (See flywheel reconditioning Figure 251.)	44.907 mm (1.768 in)
Thrust Taken By	No. 5 Main
Thrust Bearing Journal Length	31.509 - 31.585 mm (1.2405 - 1.2435 in)
Main Bearing Inner Diameter (Installed)	79.385 - 79.436 mm (3.1254 - 3.1274 in)
Main Bearing to Crankshaft Running Clearance	0.046 - 0.117 mm (0.0018 - 0.0046 in)
Connecting Rod Journal Diameter	
Standard Size	63.45 - 63.47 mm (2.498 - 2.499 in)
0.254 mm (0.010 in) Undersize	63.20 - 63.22 mm (2.488 - 2.489 in)
0.508 mm (0.020 in) Undersize	62.94 - 62.96 mm (2.478 - 2.479 in)
0.762 mm (0.030 in) Undersize	62.69 - 62.71 mm (2.468 - 2.469 in)
Connecting Rod Journal, Maximum Out-of-Round	0.0056 mm (0.00022 in)
Connecting Rod Journal Taper (max. per inch)	0.0066 mm (0.00026 in)
Connecting Rod Bearing to Crankshaft Running Clearance	0.038 - 0.114 mm (0.0015 - 0.0045 in)
Crankshaft Flange Outer Diameter	111.05 - 111.15 mm (4.372 - 4.376 in)
Crankshaft End Play	0.063 - 0.216 mm (0.0025 - 0.0085 in)
Crankshaft End Play Maximum Wear Limit	0.51 mm (0.020 in)
Rod to Crankshaft Side Clearance	0.30 - 0.61 mm (0.012 - 0.024 in)
Crankshaft Straightness (T.I.R. Maximum)	0.10 mm (0.004 in)
Crankshaft Gear Backlash	(0.1397 - 0.02794 mm (0.0055 - 0.0110 in)
CRANKCASE	
Crankcase Deck Flatness	0.025 mm per 50.8 mm, 0.10 mm Total (0.001 in. per 2 inches, 0.004 in Total)
Crankcase Main Bearing Bore Diameter	84.206 - 84.231 mm (3.3152 - 3.3162 in)
Crankcase Cam Bearing Bore Diameter	56.655 - 56.693 mm (2.2305 - 2.2320 in)
Valve Lifter Bore Diameter	23.439 - 23.477 mm (0.9228 - 0.9243 in)
Valve Lifter Outer Diameter	23.391 - 23.411 mm (0.9209 - 0.9217 in)

Table 39 Crankcase, Camshaft Bushing, Crankshaft and Main Bearing, Connecting Rod and Piston (cont.)

Oil Jet Tube Bore Diameter (Spray Hole Diameter)	0.91 - 1.32 mm (0.036 - 0.052 in)
Cylinder Bore Taper (Top to Bottom)	0.076 mm (0.003 in)
Cylinder Bore Diameter	104.384 - 104.402 mm (4.1096 - 4.1103 in)
Cylinder Bore Maximum Out-of-Round	0.05 m (0.002 in)
Centerline of Main Bearing Bore to Head Deck	287.73 - 287.83 mm (11.328 - 11.332 in)
Oil Seals (Front and Rear Seal Face Runout With Plates Installed On Engine)	0.38 mm (0.015 in) T.I.R. Max.
CONNECTING RODS	
Connecting Rod Length Center to Center	181.10 mm (7.130 in)
Bushing Bore Diameter (Pin End)	33.235 - 33.243 mm (1.3085 - 1.3088 in)
Piston Pin Bushing Inner Diameter	32.83 - 32.84 mm (1.2924 - 1.2929 in)
Bearing Bore Diameter (Crankshaft End)	68.339 - 68.364 mm (2.6905 - 2.6915 in)
Bearing Bore Maximum Out-of-Round	0.013 mm (0.0005 in)
Bearing Bore Maximum Taper / Inch	0.013 mm (0.0005 in)
Connecting Rod Bearing Inner Diameter	63.513 - 63.564 mm (2.5005 - 2.5025 in)
Connecting Rod Bearing Running Clearance	0.038 - 0.114 mm (0.0015 - 0.0045 in)
Connecting Rod Side Clearance	0.30 - 0.61 mm (0.012 - 0.024 in)
Twist	0.05 mm/in (0.002 in/in)
Bend	0.025 mm/in (0.001 in/in)
Weight - Complete Rod Without Bearing (Old Style)	1.058 - 1.446 kg (1058 - 1446 g)
Weight - Complete Rod Without Bearing (New Style)	1.202 - 1.216 kg (1201.5 - 1215.5 g)
Pin to Bushing Clearance	0.010 - 0.023 mm (0.0004 - 0.0009 in)
PISTONS	
Skirt Diameter — Measure 43 mm (1.684 in) below oil groove, at 90° angle to the piston pin. Measure only at room temperature of 19-21°C (66-70°F).	104.34 - 104.44 mm (4.108 - 4.112 in)
Service Piston	
Standard Size	104.25 - 104.27 mm (4.104 - 4.105 in)
0.254 mm (0.010 in) Oversize	104.50 - 104.52 mm (4.114 - 4.115 in)
0.508 mm (0.020 in) Oversize	104.75 - 104.77 mm (4.124 - 4.125 in)
0.762 mm (0.030 in) Oversize	105.02 - 105.03 mm (4.134 - 4.135 in)
Piston Protrusion Above Crankcase Deck	0.58 – 0.84 mm (0.023 – 0.033 in)
Clearance In Cylinder Bore No. 1 – 8	0.112 - 0.1491 mm (0.0044 - 0.00587 in)
Top compression ring groove width - Measure over 2.92 mm (0.1150 in) gauge pins:	

Table 39 Crankcase, Camshaft Bushing, Crankshaft and Main Bearing, Connecting Rod and Piston (cont.)

Upper Limit	104.85 mm (4.128 in)
Replacement Limit	104.06 mm (4.097 in)
Piston Pins	
Length	75.9 - 76.2 mm (2.99 - 3.00 in)
Diameter	33.220 - 33.226 mm (1.3079 - 1.3081 in)
Pin fit @ room temperature, 19-21°C (66-70°F):	
Clearance In Rod	0.010 - 0.023 mm (0.0004 - 0.0009 in)
Clearance In Piston	0.007 - 0.018 mm (0.0003 - 0.0007 in)
End Clearance	0.10 - 0.76 mm (0.004 - 0.030 in)
Piston Rings	
Ring Diameter (Standard)	
Compression Top (Full Keystone (Barrel Face) Plasma Coated)	104.4 mm (4.11 in)
Compression 2nd (Rectangular Negative Twist - Tapered Face)	104.4 mm (4.11 in)
Oil Control (One Piece Conformable with Chrome Expander Spring)	104.4 mm (4.11 in)
Fit in Groove (Side Clearance)	
2nd	0.05 - 0.10 mm (0.002 - 0.004 in)
Oil Control	0.023 - 0.074 mm (0.0009 - 0.0029 in)
Ring Gap in Bore	
Top	0.35 - 0.61 mm (0.014 - 0.024 in)
2nd	1.57 - 1.82 mm (0.062 - 0.072 in)
Oil Control	0.30 - 0.61 mm (0.012 - 0.024 in)

Table 40 Thermostat and Coolant Filter

Thermostat	
Type	Poppet Valve, Pellet Operated
Operating Start-to-Open Temperature	89 ± 2°C (192 ± 4°F)
Maximum Full-Open Temperature	104°C (219°F)
Sleeve Travel at Full-Open Temperature	8 mm (0.315 in)
Coolant Filter	
Type	Spin-On
Length of Filter	106 mm (4.18 in)

Table 41 Engine Electrical

Glow Plugs	
Location	Cylinder Head
Quantity	8
Injection Pressure Regulator (IPR) Valve	
Maximum Flow Rate	17.5 L/m (4.62 gpm)
Maximum Operating Pressure	20.7 MPa (3000 psi)
Camshaft Position Sensor (CMP)	
Location	Front Cover
Operating Actuator Speed	15 to 2000 RPM
Operating Temperature Range	-40°C to +130°C (-40°F to +266°F)

Table 42 High-pressure Lube Oil System

High-pressure Oil Pump	
Gear Backlash	0.140–0.256 mm (0.0055–0.0101 in)
End Play	0.45–1.22 mm (0.018–0.048 in)
Injection Pressure Regulator (IPR) Valve	
Operating Temperature Range	-40° to 125°C (-40° to 257°F)
Maximum Flow Rate	17.5 L/min (4.62 gpm)
Maximum Operating Pressure	20.7 MPa (3000 psi)

Table 43 Fuel System

Fuel Filter	
Type	Spin-on with fuel strainer
Fuel Pressure Regulating Valve	
Valve open	496 kPa (72 psi)
Heater element activates	7° ±14° C (45° ± 6.5° F)
Heater element deactivates	24° ± 13° C (75° ± 8.5° F)

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General Torque Guidelines

CAUTION: To avoid engine damage, do not substitute fasteners. Original equipment standard hardware is defined as Class 10.9 metric or Type 8 standard coarse thread bolts and nuts and hardened flat washers (Rockwell "C" 38-45), all phosphate coated.

The standard torque charts provide the tightening torque for general purpose applications using original equipment standard hardware as listed in the Parts Catalog for the application involved.

Table 44 Standard Torques – Pipe Thread

Thread Size	Torque[1]
1/8 in NPT	11 N·m (90 lbf·in)
1/4 in NPT	14 N·m (120 lbf·in)
3/8 in NPT	20 N·m (180 lbf·in)
1/2 in NPT	34 N·m (25 lbf·ft)
3/4 in NPT	41 N·m (30 lbf·ft)

[1] Tolerances are ±10% of nominal value.

Table 45 Standard Torques — Class 10.9 Metric Bolts and Studs

Thread Diameter	Thread Pitch (mm/thread)	Torque[1]
6 mm	1	13 N·m (115 lbf·in)
8 mm	1.25	31 N·m (23 lbf·ft)
10 mm	1.5	62 N·m (45 lbf·ft)
12 mm	1.75	107 N·m (79 lbf·ft)
14 mm	2	172 N·m (127 lbf·ft)
15 mm	2	216 N·m (159 lbf·ft)
16 mm	2	266 N·m (196 lbf·ft)
18 mm	2.5	368 N·m (272 lbf·ft)
20 mm	2.5	520 N·m (384 lbf·ft)

[1] Tolerances are ±10% of nominal value.

Table 46 Standard Torques — Class 12.9 Metric Bolts and Studs

Thread Diameter	Thread Pitch (mm/thread)	Torque[1]
6 mm	1	15 N·m (132 lbf·in)
8 mm	1.25	36 N·m (27 lbf·ft)
10 mm	1.5	72 N·m (53 lbf·ft)
12 mm	1.75	126 N·m (93 lbf·ft)
14 mm	2	201 N·m (148 lbf·ft)
15 mm	2	252 N·m (186 lbf·ft)
16 mm	2	311 N·m (230 lbf·ft)
18 mm	2.5	430 N·m (317 lbf·ft)
20 mm	2.5	608 N·m (448 lbf·ft)

[1] Tolerances are ±10% of nominal value.

DESIGNATION		MATERIAL TYPE	THERMAL TREATMENT	HEAD MARKING	
INTERNATIONAL CLASS	ISO R 898 I			PREFFERED	OPTIONAL
5.8	5.8	LOW OR MEDIUM CARBON STEEL	NON REQUIRED		
8.8	8.8	MEDIUM CARBON OR MEDIUM CARBON ALLOY STEEL OR LOW CARBON BORON STEEL	QUENCH AND TEMPERED		
9.8	--				
10.9	10.9				

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Figure 424 Classification and Identification – Metric Fasteners

INTERNATIONAL DESIGNATION	TYPE OF MATERIAL	THERMAL TREATMENT	HEAD MARKING	
			PREFERRED	OPTIONAL
CLASS	METRIC FASTENERS			
10.9R	MEDIUM CARBON, MEDIUM CARBON ALLOY STEEL	QUENCH AND TEMPERED, ROLL THREADED AFTER HEAT TREATMENT		
12.9	MEDIUM CARBON ALLOY STEEL	QUENCH AND TEMPERED		
12.9R		QUENCH AND TEMPERED ROLL THREADED AFTER HEAT TREATMENT		

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Figure 425 Classification and Identification – Special Use Fasteners

Many conditions affect torque and the results of torque applications. The major purpose in tightening a fastener to a specified torque is to obtain tension in the fastener (i.e., bolt, nut, etc.), which in turn develops a clamping load which exceeds any possible loading imposed on parts due to engine rpm or vibration.

New phosphate coated fasteners do not require oil lubrication during assembly and torque application. Reused fasteners (even if originally phosphate coated) do require oil lubrication to the threads and under head area for proper torque application.

Threads that are dry, excessively rough, battered or filled with dirt require considerable effort just to rotate. Then when the clamping load is developed or the bolt tension is applied, the torque reading mounts rapidly (due to thread friction) to the specified torque value. However, the desired bolt tension and maximum clamping effect is not achieved. This condition can lead to failure of the fastener to maintain component integrity. The proper bolt tension and clamping effect can never be attained if the fastener is dry. The fastener threads must have a film of clean lubricant (engine oil) to be considered lubricated.

Special Torque

NOTE: The THERMOSTAT AND COOLANT FILTER and OIL COOLER AND FILTER sections, have no special torques that are necessary for service work.

Table 47 Engine Mounting Special Torques

Oil Pan Drain Plug	41 N·m (30 lbf·ft)

Table 48 Turbocharger Special Torques

Air Inlet Hose Clamps	4 N·m (36 lbf·in)
Compressor Outlet Clamp	2 N·m (19 lbf·in)
Exhaust Back Pressure Valve to Turbine Housing Mounting Bolts	21-24 N·m (15-18 lbf·ft)
Exhaust Inlet Clamp	5.6 N·m (50 lbf·in)
Exhaust Tube to Exhaust Inlet Adapter Flange Bolts	28 N·m (21 lbf·ft)
Exhaust Tube to Exhaust Manifold Flange Bolts	26 N·m (19 lbf·ft)
Turbocharger Pedestal to Crankcase Mounting Bolts	24 N·m (18 lbf·ft)
Turbocharger to Pedestal Mounting Bolts (Standard Torque Model)	47–51 N·m (34–37 lbf·ft)
Turbocharger to Pedestal Mounting Bolts (High Torque Model)	49 N·m (36 lbf·ft)

Table 49 Manifolds Special Torques

Intake Manifold Cover Bolts	24 N·m (18 lbf·ft)
Exhaust Manifold Mounting Bolts	61 N·m (45 lbf·ft)
Exhaust Manifold Flanges	28 N·m (21 lbf·ft)

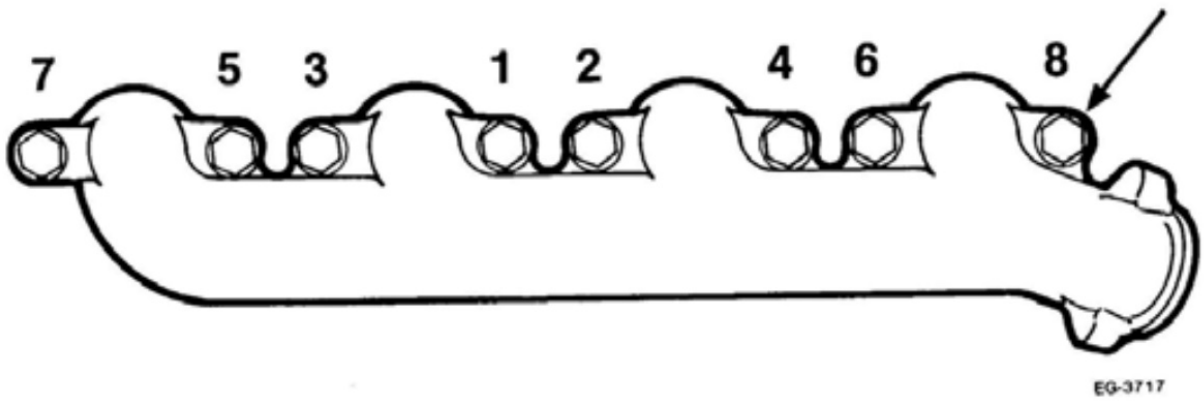

Figure 426 Exhaust Manifold Mounting Bolt Torque Sequence

1. Start all exhaust manifold mounting bolts into the holes by hand. Tighten all exhaust manifold mounting bolts to 61 N·m (45 lbf·ft) in the numerical sequence shown.
2. Tighten all exhaust manifold mounting bolts to 61 N·m (45 lbf·ft) again in an inline sequence from the rear to the front. Start at the arrow.

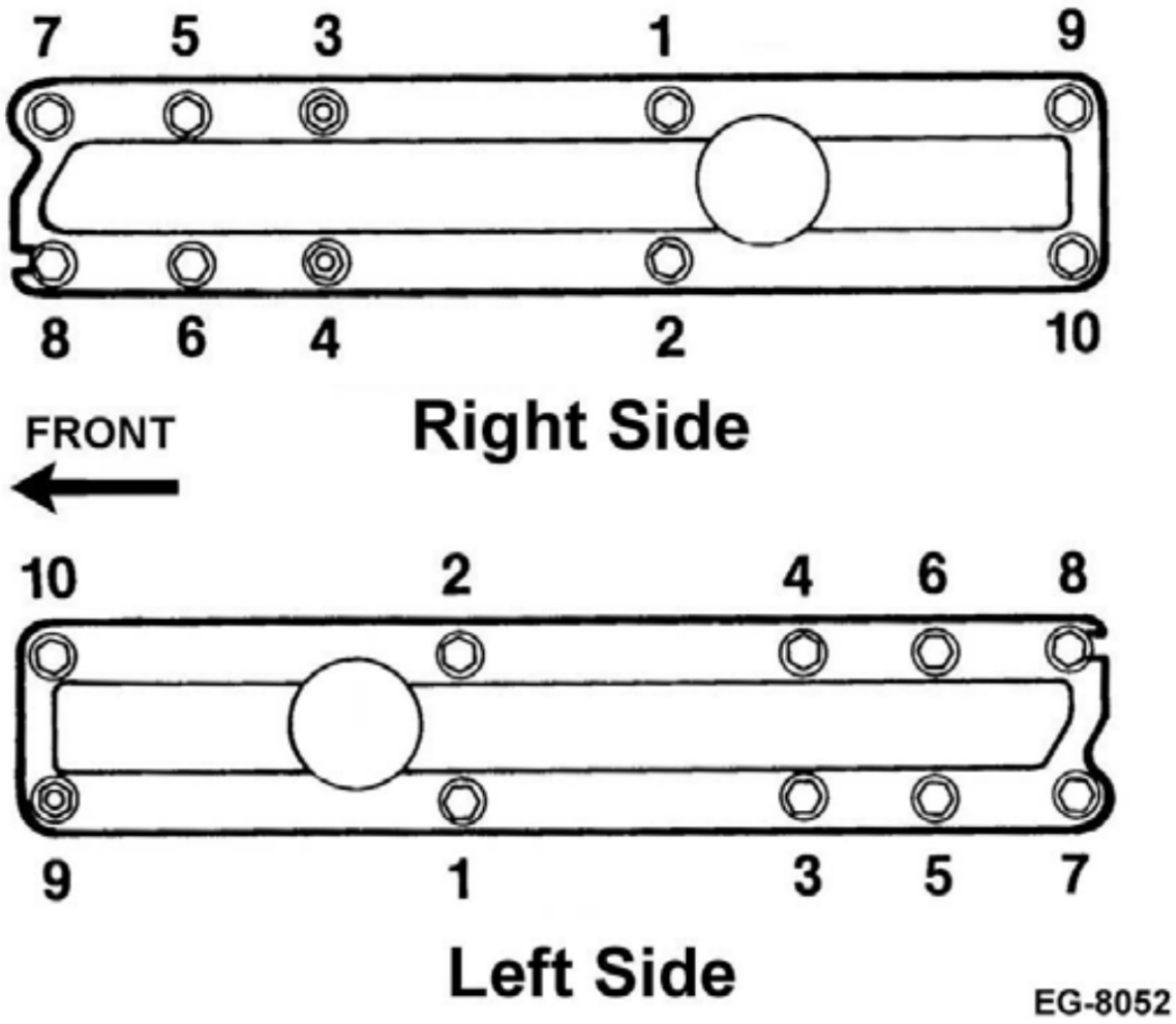

Figure 427 Intake Manifold Mounting Bolt Torque Sequence

Start all intake manifold mounting bolts into the holes by hand. Tighten the mounting bolts to 24 N·m (18 lbf·ft) in the numerical sequence shown.

Table 50 Cylinder Head Special Torques

Crankcase Breather Screws	2 N·m (18 lbf·in)
Cylinder Head Mounting Bolts (special torque sequences)	**Initial:** 54 N·m (40 lbf·ft) **Second:** 95 N·m (70 lbf·ft) **Final:** 129 N·m (95 lbf·ft)
Fuel Injector Hold Down Clamp Mounting Bolt	14 N·m (120 lbf·in)
Fuel Injector Shoulder Bolt	14 N·m (120 lbf·in)
Fuel Rail End Plugs	16.3 N·m (12 lbf·ft)
Glow Plugs	19 N·m (14 lbf·ft)
ICP Sensor	29 ± 2 N·m (21.5 ± 1.5 lbf·ft)
Oil Deflector Mounting Bolt	12 N·m (106 lbf·in)
Oil Rail Drain Plugs	6.8 ± 1 N·m (60 ± 10 lbf·in)
Oil Rail End Plugs	81 N·m (60 lbf·ft)
Oil Rail Plugs	29 ± 2 N·m (21.5 ± 1.5 lbf·ft)
Valve Cover Bolts (special torque sequence)	11 N·m (8 lbf·ft)
Valve Lever Mounting Bolt	27 N·m (20 lbf·ft)

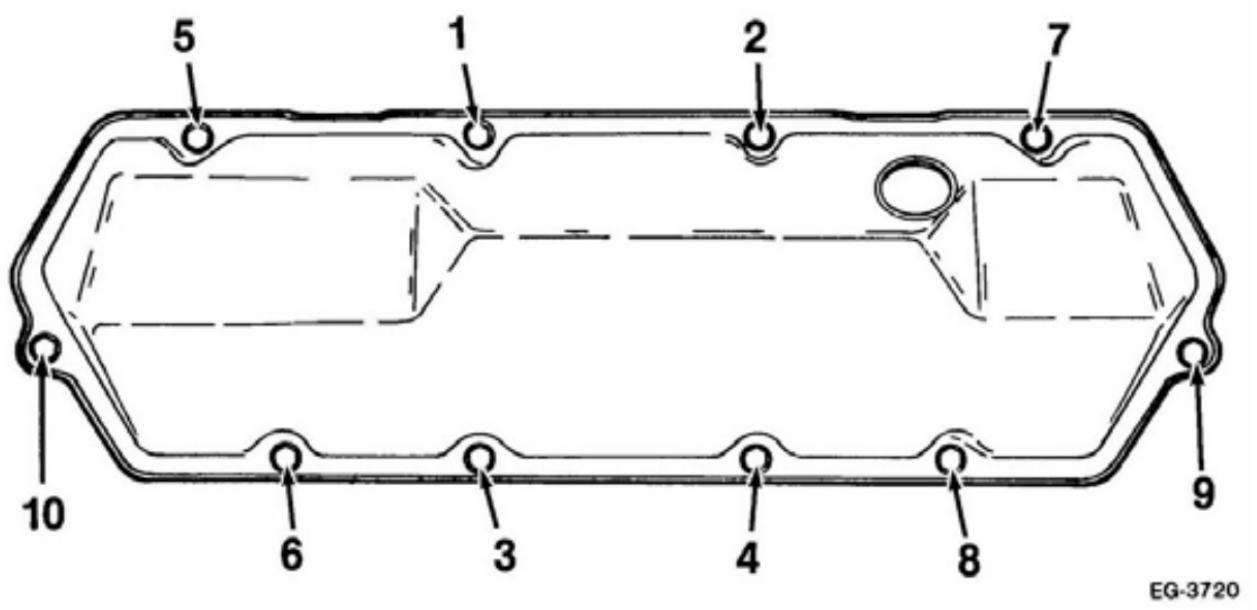

Figure 428 Valve Cover Bolt Special Torque Sequence

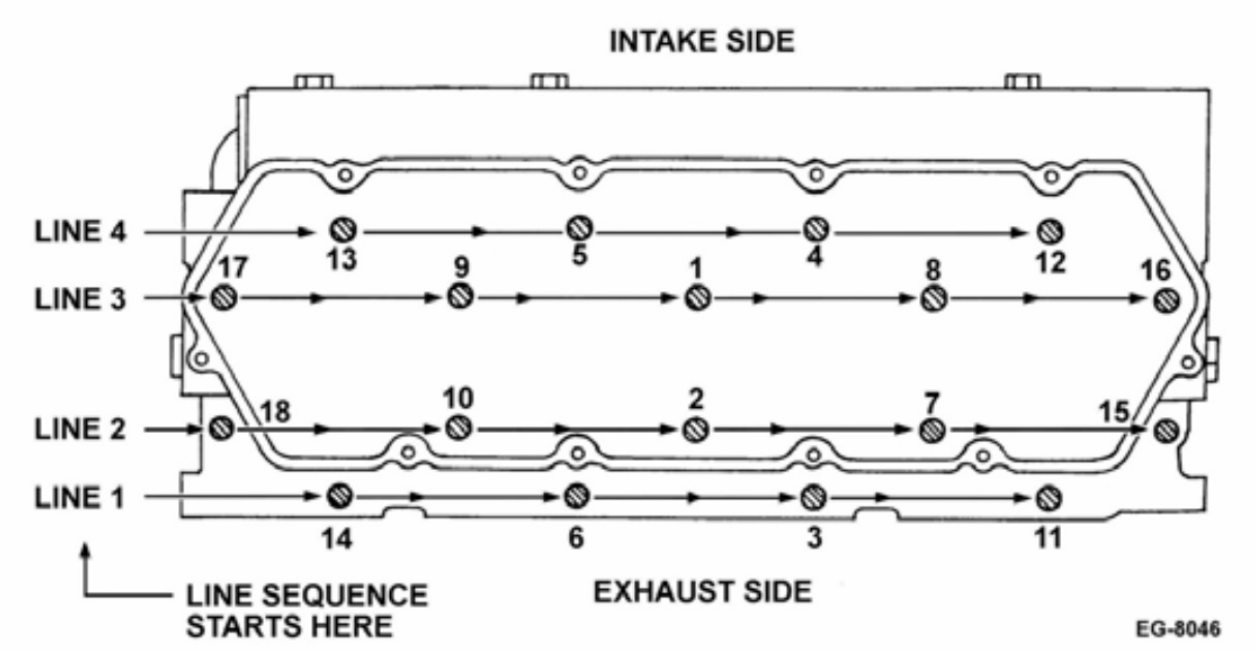

Figure 429 Cylinder Head Mounting Bolt Special Torque Sequence

1. Tighten to 54 N·m (40 lbf·ft) in numbered sequence.
2. Tighten to 95 N·m (70 lbf·ft) in numbered sequence.
3. Tighten to 129 N·m (95 lbf·ft) in line sequence.
4. Tighten to 129 N·m (95 lbf·ft) again in line sequence.

Table 51 Vibration Damper, Lubricating Oil Pump, Oil Pan, Oil Pick-Up Tube and Front Cover Special Torques

Oil Pan Drain Plug	41 N·m (30 lbf·ft)
Oil Pan Mounting Bolts	34 N·m (25 lbf·ft)
Oil Pick-Up Tube Flange Mounting Bolts	24 N·m (18 lbf·ft)
Oil Level Gauge Tube Adapter Nut	34 N·m (25 lbf·ft)
Vibration Damper Mounting Bolt	287 N·m (212 lbf·ft)
Water Pump Pulley Mounting Screw	41 ± 7 N·m (30 ± 5 lbf·ft)

Table 52 Valve Train Special Torques

Cam Follower Guide Mounting Bolt	20 N·m (15 lbf·ft)

Table 53 Crankcase, Crankshaft, Connecting Rods and Piston Special Torques

Connecting (4 lbf-ft) Rod Mounting Nuts (Old Style)	**First Step:** 71 N·m (52 lbf·ft) **Final Step:** 108 N·m (80 lbf·ft)
Connecting Rod Bearing Bolts (New Style)	**First Step:** 71 N·m (52 lbf·ft) **Final Step:** 122 N·m (90 lbf·ft)
Flywheel gear access cover bolts	5 N·m (4 lbf-ft)
Flywheel Mounting Bolts	121 N·m (89 lbf·ft)
Main Bearing Cap Mounting Bolts	**First Step:** 102 N·m (75 lbf·ft) **Final Step:** 129 N·m (95 lbf·ft)
Oil Pick up Tube Flange Bolts	24 N·m (18 lbf·ft)
Piston Cooling Jet Mounting Bolts	11 N·m (100 lbf·in)

Table 54 Electrical System Special Torques

Glow Plug	19 N·m (14 lbf·ft)
Glow Plug Relay Stud Nuts	8 N·m (70 lbf·in)
Injection Control Pressure (ICP) Sensor	50 ± 5 N·m (37 ± 4 lbf·ft)
ECM Mounting Bolts	24 N·m (18 lbf·ft)
ECM Support Assembly Mounting Bolts	24 N·m (18 lbf·ft)
ECM Mounting Bracket Nuts	24 N·m (18 lbf·ft)
Wiring Harness Connector Mounting Bolt (Engine and Chassis)	3 – 5 N·m (30 – 45 lbf·in)

Table 55 High-pressure Lube Oil System Special Torques

High-pressure Oil Pump Drive Gear Bolt	129 N·m (95 lbf·ft)
IPR Valve Tinnermann Nut	5.5 ± 1.5 N·m (49 ± 13 lbf·in)
IPR Valve	50 ± 5 N·m (37 ± 4 lbf·ft)
High-pressure Hose Fitting (37° Flare)	26 N·m (19 lbf·ft)
45° and 90° Elbow Locknut	28 N·m (21 lbf·ft)

Table 56 Fuel System Special Torques

Fuel Return Hose Fitting	16 N·m (12 lbf·ft)
Fuel Supply Tube Bolt (Lift Pump Banjo Fitting)	54 N·m (40 lbf·ft)

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NOTE: The MANIFOLDS, OIL COOLER AND FILTER, and ELECTRICAL SYSTEM sections have no special service tools that are necessary for service work.

SPECIAL SERVICE TOOLS

Table 57 Engine Mounting Special Service Tools

ZTSE4151A	Rear Mounted Engine Bracket (Keine Stand) (Not shown)
ZTSE4348	Side Mounted Engine Bracket (OTC Stand)
OEM4137	Engine Turn-Over Stand

Table 58 Turbocharger Special Service Tools

OEM1028	Dial Indicator with Magnetic Base
ZTSE4293	Turbocharger Intake Shield
ZTSE4296	Turbocharger Intake Cap Set
ZTSE4230	Spring Tension Scale 0–34 N·m (0-25 lbf)

Table 59 Cylinder Head Special Service Tools

OEM1004	Outside Micrometer (5–6 inch)
OEM1014	Dial Caliper
OEM1023	Small Hole Gauge Set
OEM1272	Defect Detection Kit (Dye Penetrant)
OEM1293	Straightedge
OEM6343	Cleaning Brush
OEM6459	Surface Height Gauge Tool
ZTSE1631A	Eccentric Valve Seat Grinder
ZTSE1846	Valve Spring Compressor
ZTSE1879	Slide Hammer Puller Kit
ZTSE2241	Valve and Clutch Spring Tester
ZTSE4296	Turbocharger Intake Cap Set
ZTSE4297	Cylinder Head Lifting Bracket
ZTSE4298	Valve Spring Compressor
ZTSE4299	Fuel Injector Holder Rack
ZTSE4300	Fuel Injector Removal Tool
ZTSE4301	Fuel Injector Tip Cleaning Brush
ZTSE4302A	Fuel Injector Sleeve Removal Tool
ZTSE4303	Fuel Injector Sleeve (Adapter) Replacer
ZTSE4304	Fuel Injector Sleeve Cleaning Brush Set
ZTSE43042	Injector Sleeve Bottom Brush
ZTSE4308	Cylinder Head Pressure Test Plate
ZTSE4320	Oil and Fuel Gallery Brush Cleaning Set (Consists of 4 brushes)
ZTSE4353	Fuel Injector Installation Tool
ZTSE4354	Fuel Injector Removal Tool
ZTSE43862	Hand Tap (Bottoming M12 X 1.75)
ZTSE43021A	Injector Sleeve Tap

Table 60 Vibration Damper, Lubricating Oil Pump, Oil Pan, Oil Pick-Up Tube and Front Cover Special Service Tools

OEM1028	Magnetic Base Dial Indicator
OEM1293	Straightedge
ZTSE229569	Vibration Damper Removal Tool
ZTSE4300	Fuel Injector/Front Oil Seal Removal Tool
ZTSE4310	Front Oil Seal/Vibration Damper Installation Tool
ZTSE4314	Vibration Damper Wear Ring Removal Tool
ZTSE4315	Vibration Damper Wear Ring Installation Tool
ZTSE4385	Oil Pan Removal Tool

Table 61 Valve Train Special Service Tools

OEM1000	Micrometer
OEM1028	Magnetic Base Dial Indicator
ZTSE1893	Hydraulic Valve Lifter Tester

Table 62 Crankcase, Crankshaft, Connecting Rods and Piston Special Service Tools

D81L6002B	Plastigage®
OEM1000	Micrometer
OEM1022	Telescoping Gauge Set
OEM1023	Telescoping Gauge
OEM1028	Magnetic Base Dial Indicator
OEM1032	Dial Bore Gauge
OEM1293	Straight Edge
OEM6270	120 Grit Glaze Breaker Brush
OEM6453	Piston Retaining Ring Pliers
ZTSE1897E	Camshaft Bushing Removal/Installation Set
ZTSE1942A	Crankshaft Rear Oil Seal Installation Tool
ZTSE3020	Piston Groove Wear Measuring Tool Set
ZTSE4155A	Expansion Plug Replacement Tool
ZTSE4220	Piston Ring Expander
ZTSE4311	Connecting Rod Installation/Remover Guide Pins
ZTSE4317	Crankshaft Wear Ring Removal Tool
ZTSE4318	Rear Oil Seal Installation Tool
ZTSE4375	Flywheel Installation/Removal Guide Studs
ZTSE4385	Oil Pan/Rear Oil Seal Cutting Tool
ZTSE4389	Oil Galley Cleaning Brush

Table 63 Thermostat and Coolant Filter Special Service Tools

OEM6413	Strap Wrench

Table 64 High-pressure Lube Oil System Special Service Tools

ZTSE2499	Hand Operated Vacuum Pump
ZTSE4295	High-pressure Oil System Cap Set
OEM1028	Magnetic Base Dial Indicator

Table 65 Fuel System Special Service Tools

ZTSE4294	Fuel System Cap Set

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