CATERPILLAR®

SENR2374-04
July 2010

# Systems Operation
# Testing and Adjusting

## 3500 Marine Engines

**4MJ1-Up (Engine)**
**50Y1-Up (Engine)**
**96Y1-Up (Engine)**
**29Z1-Up (Engine)**
**66Z1-Up (Engine)**
**69Z1-Up (Engine)**
**72Z1-Up (Engine)**

i03991620

# Important Safety Information

Most accidents that involve product operation, maintenance and repair are caused by failure to observe basic safety rules or precautions. An accident can often be avoided by recognizing potentially hazardous situations before an accident occurs. A person must be alert to potential hazards. This person should also have the necessary training, skills and tools to perform these functions properly.

**Improper operation, lubrication, maintenance or repair of this product can be dangerous and could result in injury or death.**

**Do not operate or perform any lubrication, maintenance or repair on this product, until you have read and understood the operation, lubrication, maintenance and repair information.**

Safety precautions and warnings are provided in this manual and on the product. If these hazard warnings are not heeded, bodily injury or death could occur to you or to other persons.

The hazards are identified by the “Safety Alert Symbol” and followed by a “Signal Word” such as “DANGER”, “WARNING” or “CAUTION”. The Safety Alert “WARNING” label is shown below.

**⚠ WARNING**

The meaning of this safety alert symbol is as follows:

**Attention! Become Alert! Your Safety is Involved.**

The message that appears under the warning explains the hazard and can be either written or pictorially presented.

A non-exhaustive list of operations that may cause product damage are identified by “NOTICE” labels on the product and in this publication.

**Caterpillar cannot anticipate every possible circumstance that might involve a potential hazard. The warnings in this publication and on the product are, therefore, not all inclusive. You must not use this product in any manner different from that considered by this manual without first satisfying yourself that you have considered all safety rules and precautions applicable to the operation of the product in the location of use, including site-specific rules and precautions applicable to the worksite. If a tool, procedure, work method or operating technique that is not specifically recommended by Caterpillar is used, you must satisfy yourself that it is safe for you and for others. You should also ensure that the product will not be damaged or become unsafe by the operation, lubrication, maintenance or repair procedures that you intend to use.**

The information, specifications, and illustrations in this publication are on the basis of information that was available at the time that the publication was written. The specifications, torques, pressures, measurements, adjustments, illustrations, and other items can change at any time. These changes can affect the service that is given to the product. Obtain the complete and most current information before you start any job. Cat dealers have the most current information available.

**⚠ WARNING**

**When replacement parts are required for this product Caterpillar recommends using Cat replacement parts or parts with equivalent specifications including, but not limited to, physical dimensions, type, strength and material.**

**Failure to heed this warning can lead to premature failures, product damage, personal injury or death.**

**In the United States, the maintenance, replacement, or repair of the emission control devices and systems may be performed by any repair establishment or individual of the owner's choosing.**

# Table of Contents

# Systems Operation Section

# Fuel System

i01370666

## Fuel System Operation

**SMCS Code:** 1250

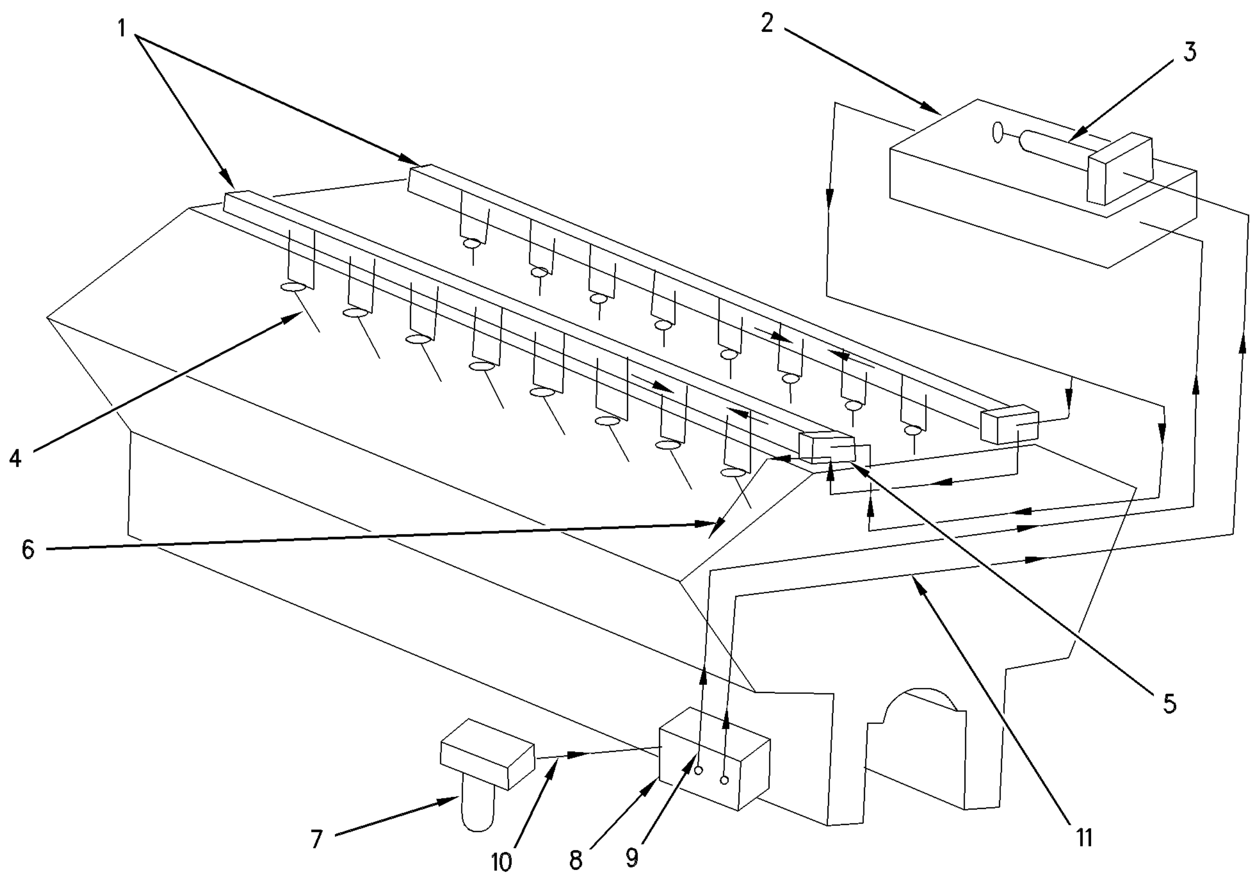


Illustration 1 g00322667

Fuel flow schematic (typical example)

(1) Fuel manifolds
(2) Fuel filter
(3) Fuel priming pump
(4) Fuel injectors
(5) Pressure regulating valve
(6) Fuel return to tank
(7) Primary fuel filter
(8) Fuel transfer pump
(9) Fuel line to filter
(10) Fuel supply line from the primary fuel filter
(11) Fuel line to priming pump

Fuel is pulled through primary fuel filter (7) by fuel transfer pump (8). Fuel transfer pump (8) delivers the fuel to fuel filter (2).

Fuel transfer pump (8) has a check valve and a bypass valve. The check valve is located in the pump head assembly. The pump head assembly is located behind the connection for fuel line (9). The check valve prevents fuel flow back through the fuel transfer pump when fuel priming pump (3) is used.

The bypass valve is located behind a cap (plug) in the drive end of the pump. The bypass valve limits the maximum pressure of the fuel. The bypass valve will open the outlet side of the pump to the pump inlet if the fuel pressure exceeds 860 kPa (125 psi). This process helps prevent damage to the fuel system components from too much pressure.

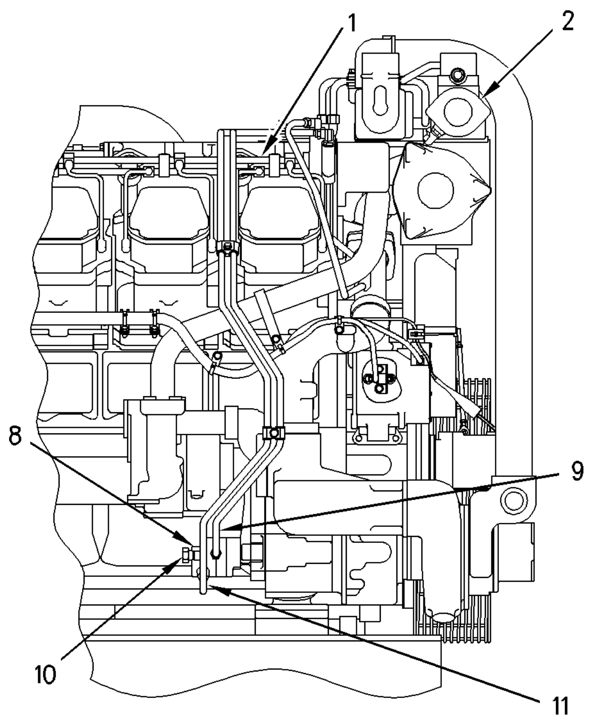


Illustration 2 g00735965

(1) Fuel manifold
(2) Fuel filter
(8) Fuel transfer pump
(9) Fuel line to filter
(10) Fuel supply line from the primary fuel filter
(11) Fuel line to priming pump

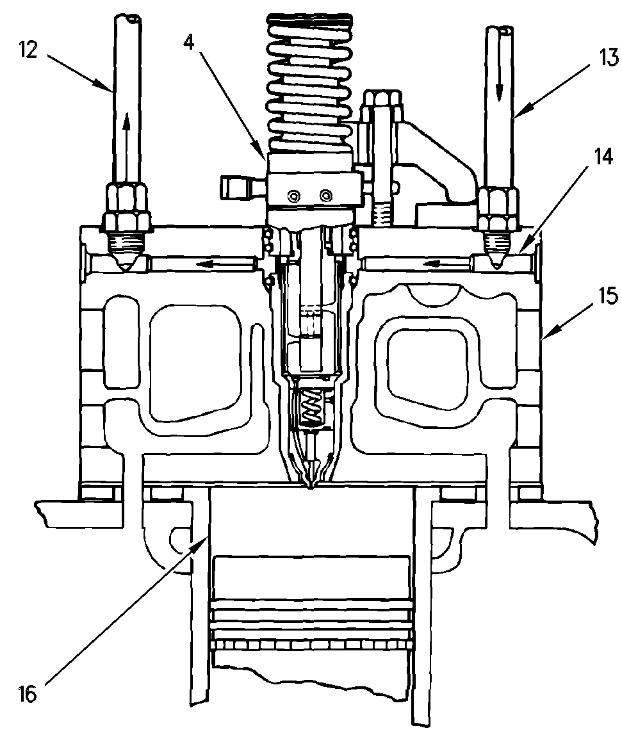


Illustration 3 g00322727

Fuel flow through injector

(4) Fuel injector
(12) Outlet fuel line
(13) Inlet fuel line
(14) Drilled passage
(15) Cylinder head
(16) Cylinder

The fuel transfer pump delivers fuel through fuel filter (2). The fuel transfer pump then delivers fuel to fuel manifolds (1). The fuel flows through fuel manifold (1) to inlet fuel line (13) which is connected to the right side of each cylinder head (15).

Filter screens are located in the ports of the fuel injector. Drilled passage (14) in the cylinder head delivers fuel to a circular chamber around fuel injector (4). The chamber is made by the O-rings on the outside diameter of the fuel injector and by the injector bore in the cylinder head.

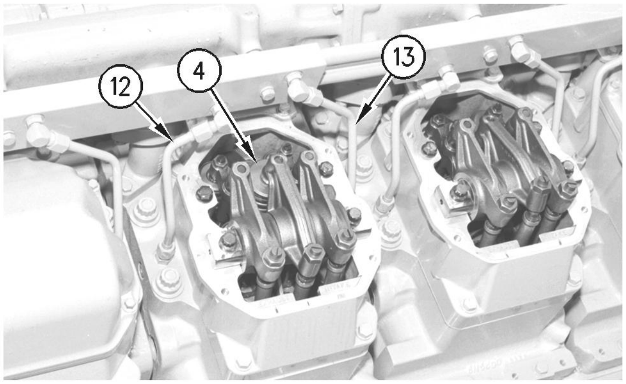


Illustration 4 g00322726

Cylinder heads

(4) Fuel injector
(12) Outlet fuel line
(13) Inlet fuel line

Only part of the fuel in the chamber is used for injection. Approximately three to five times the amount of fuel that is needed for normal combustion flows through the chamber. This fuel then flows to a drilled passage in the left side of the cylinder head. This passage is connected by outlet fuel line (12) to the bottom section of the fuel manifold. This constant flow of fuel around the injectors helps to cool the injectors.

The fuel flows back through fuel manifolds (1). The fuel flows to pressure regulating valve (5) on the front of the right fuel manifold. The fuel flows through this valve. Fuel then flows back to the tank.

Pressure regulating valve (5) consists of a spring and a plunger. This arrangement is between the bottom section of the fuel manifolds and the line that returns fuel to the tank. The valve keeps the pressure of the fuel between 415 to 450 kPa (60 to 65 psi).

i02451273

# Fuel Injection Control Linkage

**SMCS Code:** 1257

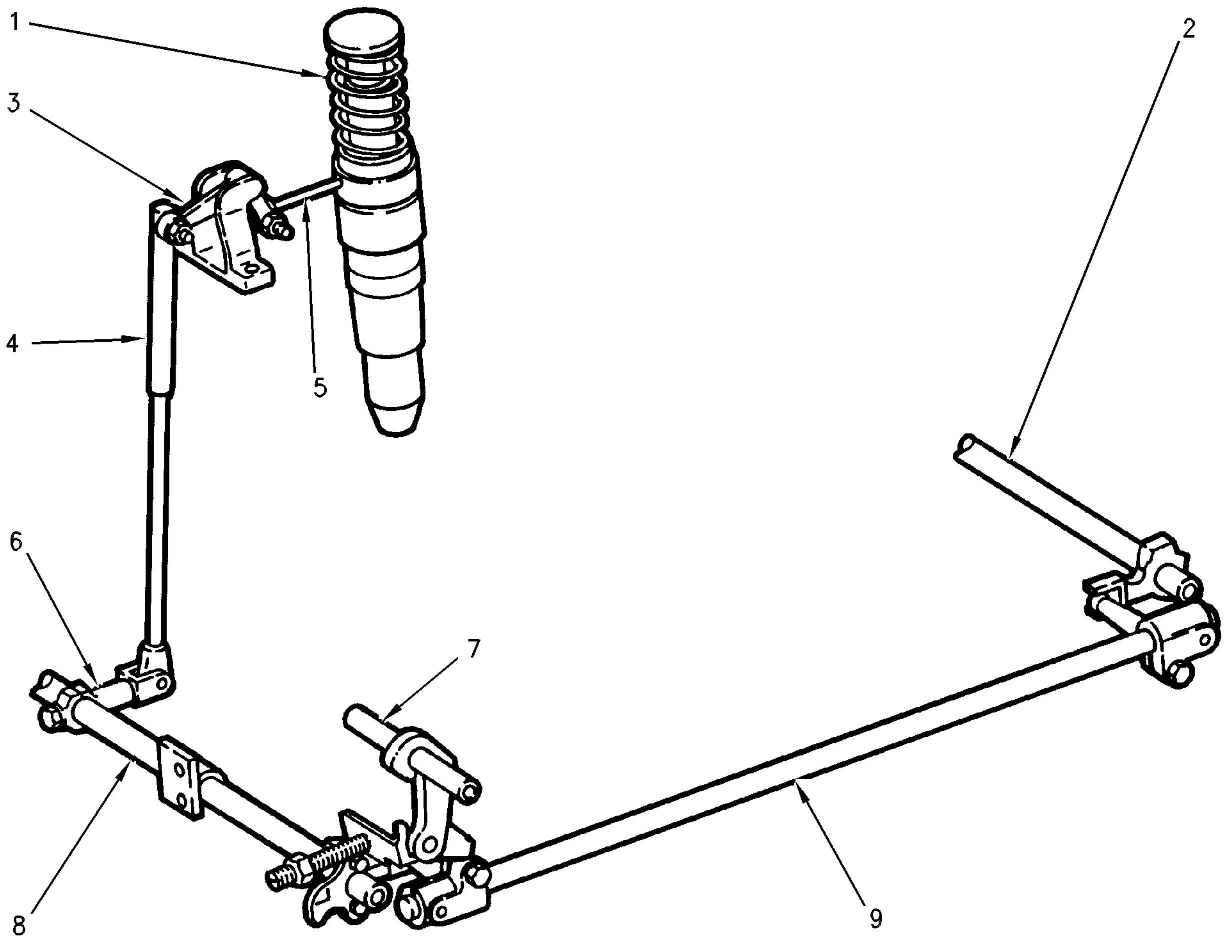


Illustration 5 g00322845

Fuel injector control linkage

(1) Fuel injector
(2) Left control shaft
(3) Bellcrank
(4) Control rod
(5) Rack
(6) Lever
(7) Governor shaft
(8) Right control shaft
(9) Cross shaft

Fuel injector (1) is located in each cylinder head. The position of rack (5) controls the amount of fuel that is injected into the cylinder. The rack is pulled out of the injector for more fuel. The rack is pushed in the injector for less fuel.

The rack position is changed by bellcrank (3). The bellcrank is moved by control rod (4). The control rods have an adjustment screw on the top. The adjustment screw is used to synchronize the injectors. The control rods are spring loaded. If the rack of one injector sticks, it will still be possible for the governor to control the other racks so the engine can be shutdown.

Each control rod on the right side of the engine is connected by lever (6) to right control shaft (8). When governor shaft (7) is viewed from the front of the engine and the governor shaft rotates in a clockwise direction, the action of the governor linkage moves the right control shaft in a counterclockwise direction. This counterclockwise direction is the “FUEL ON” position.

Right control shaft (8) and left control shaft (2) are connected by cross shaft (9). The linkage between the injectors on the left side of the engine and the left control shaft is similar to the linkage on the right side.

If the linkage becomes disconnected from the governor, the weight of the control linkage will move the fuel injector racks to the “FUEL OFF” position and the engine will stop.

i02200475

# Fuel Transfer Pump

**SMCS Code:** 1256

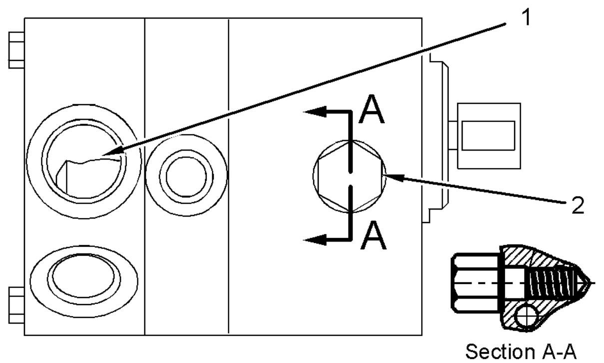


Illustration 6 g01111664

(1) Check valve
(2) Bypass valve

The fuel transfer pump is located on the right side of the engine. The lower shaft of the engine oil pump drives the gear type transfer pump. Fuel from the supply tank is pulled through the primary fuel filter by the fuel transfer pump. The fuel is sent to the fuel filter housing.

The fuel transfer pump has a check valve (1) and a bypass valve (2). The check valve (1) is located in the pump head assembly. The check valve prevents fuel flow back through the transfer pump when the fuel priming pump is used. The bypass valve (2) is located behind a cap (plug) in the drive end of the pump. The bypass valve limits the maximum pressure of the fuel. The bypass valve will open the outlet side of the pump to the pump inlet if the fuel pressure exceeds 860 kPa (125 psi). This process helps prevent damage to the fuel system components from too much pressure.

i02408960

# Fuel Injector

**SMCS Code:** 1290

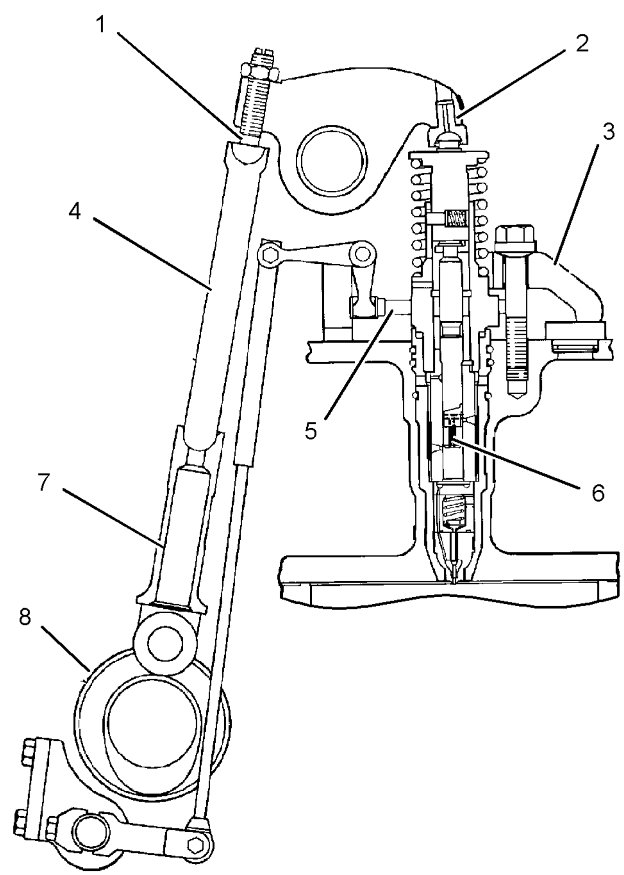


Illustration 7 g01203687

Fuel injector operation

(1) Screw
(2) Rocker arm
(3) Clamp
(4) Control rod
(5) Rack
(6) Plunger
(7) Lifter assembly
(8) Camshaft

The fuel injector is held in position by clamp (3). Fuel is injected when rocker arm (2) pushes the top of the fuel injector downward. The movement of the rocker arm is controlled by camshaft (8) through lifter assembly (7) and control rod (4). The amount of fuel that is injected is controlled by rack (5). Movement of the rack causes the rotation of a gear that is fastened to plunger (6). Rotation of the plunger changes the effective stroke of the plunger.

Injection timing is a product of two factors. The two factors include the angular location of the camshaft and the location of the plunger. The angular location of the camshaft is controlled by the camshaft drive gears at the rear of the engine. The location of the plunger can be adjusted with screw (1).

i02451432

# Fuel Injection Cycle

**SMCS Code:** 1290

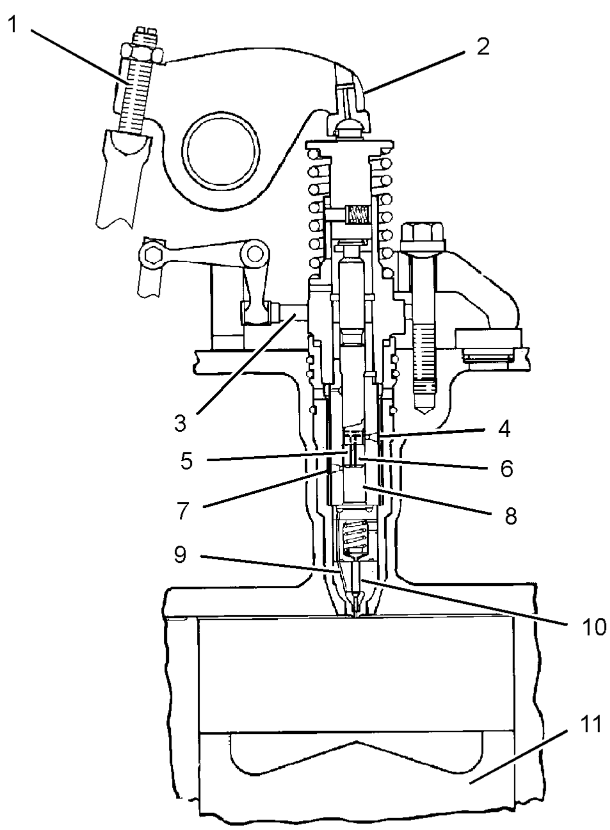


Illustration 8 g01203738

Fuel injection cycle

(1) Screw
(2) Rocker arm
(3) Rack
(4) Upper port
(5) Drilled passage
(6) Plunger
(7) Lower port
(8) Injector barrel
(9) Fuel passage
(10) Needle valve
(11) Piston

When plunger (6) is at the top of a stroke, fuel flows from the chamber for the fuel supply, around the injector, and through lower ports (7) and through upper ports (4) of injector barrel (8). As the plunger is moved downward by rocker arm (2), fuel is pushed back into the supply chamber through the lower port. Fuel can also go through drilled passage (5) in the center of the plunger, around the relief groove, and through the upper port of the injector barrel. As the lower port is closed by the bottom of the plunger, fuel can still flow through the upper port until the port is closed by the upper edge of the relief groove on the plunger. At this point, injection starts and the effective stroke of the plunger begins.

During the effective stroke, fuel is injected into the cylinder until the downward movement of the plunger allows the scroll (helix) to open the lower port. This downward movement of the plunger also releases the fuel pressure. The amount of fuel that is injected during the effective stroke is determined by the position of the scroll in relation to the lower port.

Fuel goes through the center passage of the plunger and fuel goes through the lower port during the remainder of the downstroke. As the lower port is opened, the sudden release of very high pressure causes the fuel to hit the deflector for spills with a high force. The deflector for spills gives protection to the injector housing from erosion because of the force of the released fuel. On the return stroke, the injector barrel is filled with fuel again from the fuel supply chamber.

The plunger can be turned by rack (3) while the plunger is moved upward and the plunger is moved downward by the rocker arm. The upper part of the plunger has a flat side that fits through the gear. The gear is engaged with the rack. The plunger slides upward and the plunger slides downward in the gear. As the rack moves, the gear and the plunger rotate together. This rotation of the plunger controls the fuel output of the injector. The rotation of the plunger changes the relation of the scroll to the lower port in the injector barrel. The rotation of the plunger also increases or the rotation decreases the length of the effective stroke for injection. The scroll can set the amount of fuel per injection stroke. Therefore, the fuel rate to the engine can be controlled in relation to different engine loads.

No injection takes place during the downstroke of the plunger when the rack is moved all the way against the fuel injector body. This is the “Fuel Off” position. Fuel injection begins when the rack is moved outward by a small distance. As the rack continues to move outward, the amount of fuel that is injected into the cylinder is increased until the maximum fuel position is reached.

During the fuel injection stroke, fuel passes from the injector barrel through a valve assembly. The valve assembly has a spring-loaded needle valve (10) and fuel flows through fuel passages (9) around the needle valve to the valve chamber. The fuel pressure lifts the needle valve off the seat. The fuel can now flow through the orifices in the tip into the combustion chamber.

If the needle valve is held open between injection cycles by small debris, then gases from combustion could enter the injector. The gases will cause damage. A flat check valve is used above the needle valve in order to keep these high pressure gases from combustion out of the injector. The injector operates with the flat check valve until the foreign particle has been washed away through the orifices by the fuel and normal operation again takes place.

The tip of the injector extends a short distance below the cylinder head into the combustion chamber. The tip has several small orifices that are evenly spaced around the outside diameter in order to spray fuel into the combustion chamber. The top surface of piston (11) is designed with a shaped crater that causes the air to swirl. The fuel is sprayed into the air that is swirling for more complete combustion.

i01676223

## Governor (3161)

**SMCS Code:** 1264

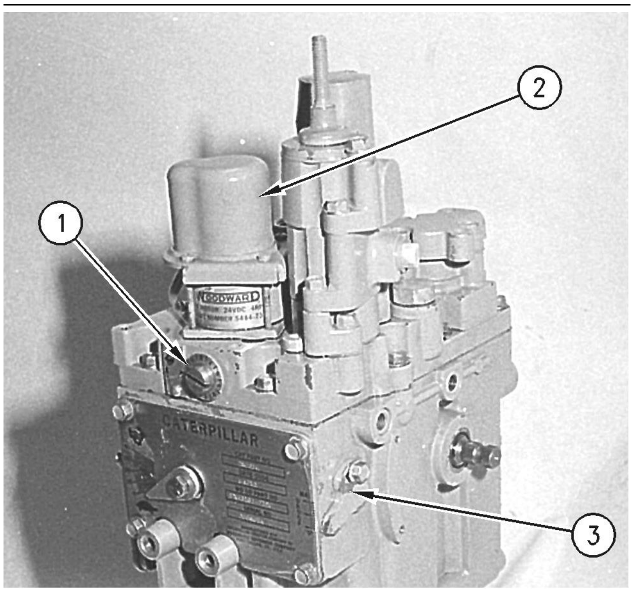


Illustration 9 g00868655

3161 Governor (typical example)

(1) Manual speed setting control
(2) Speed adjusting motor head
(3) External droop adjustment

The 3161 Governor is a hydromechanical governor. The 3161 Governor is connected to the engine fuel system by a mechanical linkage. The governor controls the rate of fuel that is injected into each of the engine cylinders in order to adjust for engine loads.

The speed adjusting motor is located on the governor cover and runs on 24 VDC power supply. When the motor is actuated, the motor rotates a speed adjusting screw in order to adjust the position of the governor speed adjusting lever.

The manual speed setting control (1) which is located on the front of the governor can be increased or decreased by the engine speed. Turn the manual speed setting control (1) clockwise in order to increase the speed setting. Turn the manual speed setting control (1) counterclockwise in order to decrease the speed setting. The high speed stops and the low speed stops will limit the adjustments.

The 3161 Governor has a maximum of 11 N·m (9 lb ft) of torque output over the full 42 degrees of terminal shaft rotation while the fuel is in the ON direction and the OFF directions. The governor terminal shafts are moved in both directions by hydraulic pressure. No return spring is used on the outside of the governor. The return spring is located on the inside of the governor. This spring will cause the terminal shafts to rotate to the full shutoff position when the governor is not in operation.

The recommended travel (rotation) of the terminal shafts is approximately 30 degrees from low idle to full load. The following results will take place:

- There will be extra play at each end of the terminal shafts.
- The governor will make a complete shutdown.
- The maximum amount of fuel will be provided.

The 3161 Governor is connected to the engine oil system. The pressurized engine oil supply is sent to the governor through an orifice and through internal passages. The governor maintains the correct oil level and the governor will drain excess oil back into the engine. This will give a constant flow of engine oil through the governor.

The governor must be filled with approximately 1.8 L (1.9 qt) of clean engine oil before engine start-up. Fill the governor with oil if the governor has been removed or if the governor has been overhauled. The oil fill cap on the 3161 Governor is located on the top cover.

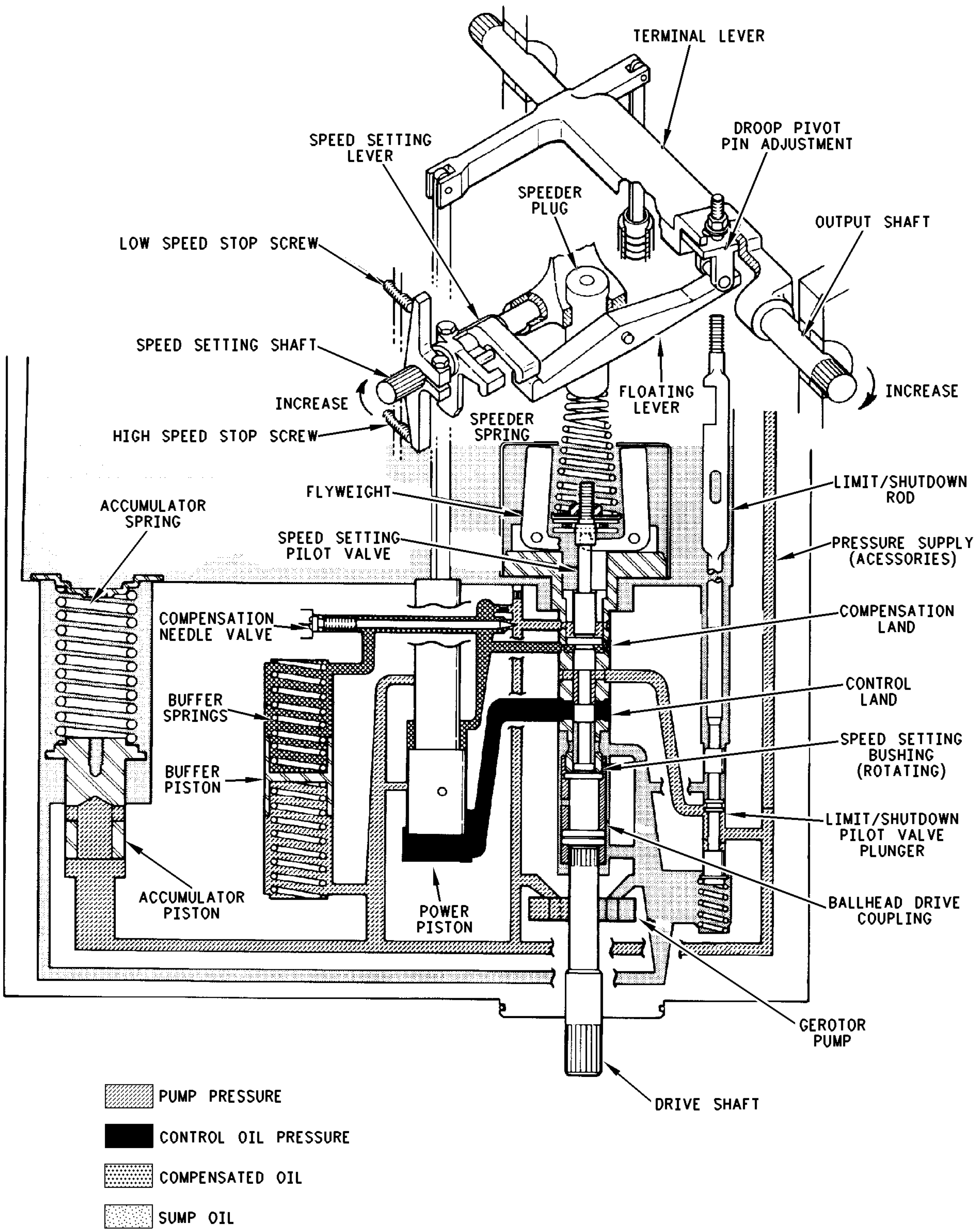


Illustration 10 g00868659

Schematic for 3161 Governor (typical example)

## Operation of the 3161 Governor

The 3161 Governor uses engine lubrication oil for the hydraulic system. The pressurized engine oil supply is sent to the governor oil reservoir through an orifice which can be removed from the governor housing for cleaning. First, the oil will travel through internal passages to the suction side of the gerotor pump. The oil will then travel to the pressure side of the gerotor pump as the drive shaft is turned by the engine. An accumulator spring and a piston will keep the pump pressure at approximately 690 kPa (100 psi). The accumulator piston moves upward in the piston cylinder until the pump pressure is 690 kPa (100 psi). The ports in the piston will open in order to control the pump pressure, after the established pump pressure is reached.

The pump pressure, which is set by the accumulator, controls the work output of the governor.

### Increase In Speed Setting

When the speed setting shaft is turned clockwise, the speed setting of the governor is increased. The high idle screw limits the high speed setting of the governor. As the speed setting shaft turns, the speed setting lever pushes down on the floating lever which is fastened to the speeder plug. The downward pressure on the speeder plug puts the speeder spring under compression. The force of the speeder spring will then become greater than the centrifugal force of the ballhead flyweights. The ballhead pilot valve plunger will move down. The governor speed setting is then increased.

When the pilot valve plunger is moved down the pressurized engine oil will move under the power piston. This process will push the piston upward. This will move the terminal lever upward. Turn the output shafts toward the increased fuel position in order to increase engine speed.

Before the engine reaches the new set speed, the compensation system will return the pilot valve plunger back to the center position. This will put the governor under stable control.

The oil above the power piston is connected to the upper side of the buffer piston and lower side of the pilot valve compensation land. As the power piston moves upward, the oil pressure will push the buffer piston downward. This will increase the compression of the lower buffer piston spring. The force of the spring works against the buffer piston movement and this results in a small increase in oil pressure on the upper side of the buffer piston. The increased pressure is directed to the lower side of the pilot valve compensation land. This will force the pilot valve plunger up to the center position. This stops the flow of pressurized engine oil to the lower side of the power piston and movement of the piston is stopped.

As the pilot valve plunger is returned to the center position and the power piston movement is stopped, there is oil leakage through the needle valve orifice. This will allow the oil pressure above the pilot valve compensation land and the oil pressure below the pilot valve compensation land to become equal. When this process is complete, the pilot valve plunger movement is stopped and the engine speed is returned to a stable condition. As the oil pressure above the pilot valve compensation land and the oil pressure below the pilot valve compensation land become equal, the buffer springs return the buffer piston to the center position.

### Decrease In Speed Settings

When the speed setting shaft is turned counterclockwise, the speed setting of the governor is decreased. The low idle screw limits the low speed setting of the governor with the exception of the D11N. As the speed setting shaft is turned counterclockwise, the force of the speed setting lever on the floating lever is removed. This lowers the compression of the speeder spring. Centrifugal force from the ballhead flyweights will lift the pilot valve plunger. This will open the control port that is inside of the rotating bushing. The control oil under the power piston will drain into the sump. This will permit the power piston to move down. Turn the output shafts toward the decreased fuel position in order to decrease engine speed.

Before the engine reaches the new set speed, the compensation system will return the pilot valve plunger back to the center position. This will put the governor under stable control.

When the pilot valve plunger is lifted, the oil that is under the power piston will drain back into the governor sump. The pump pressure oil on the bottom of the buffer piston will force the buffer piston upward. The oil above the buffer piston will put a force on the top of the power piston in order to move the power piston downward.

The upward movement of the buffer piston will increase the compression of the upper buffer piston spring. The force of the upper spring works against the movement of the buffer piston. This will result in a small increase to the pump oil pressure on the lower side of the buffer piston and on the top surface of the pilot valve plunger compensation land. The increase in the pump oil pressure is greater than the oil pressure that is in the pilot valve plunger. The difference in the pressure on both sides of the pilot valve plunger compensation land will create a force that will push the pilot valve back to the center position.

The force of the pressure difference on the pilot valve plunger compensation land will put the pilot valve plunger in the center position. This will occur when the new fuel setting and the setting for the output shafts are equal. The movement of the power piston and the output shaft is now stopped.

The continued decrease of engine speed to the steady state setting will result in a continued increase in downward force of the speeder spring on the pilot valve plunger as the ballhead flyweights move in. When the ballhead flyweights move in the pressure difference for the buffer piston and the pressure for the pilot valve plunger compensation land is released by the flow of oil through the needle valve orifice. This controlled discharge allows the buffer piston to return slowly to the normal position. The speeder spring will put a downward force on the pilot valve plunger until the spring force and the force of the ballhead flyweights become equal. The controlled reduction of the pressure difference on the two sides of the pilot valve plunger compensation land occur at the same rate. The pilot valve plunger remains centered until the engine is again at the on-engine speed condition at the new speed setting.

**Note:** An increase or a decrease in engine load will give the governor movement as an increase or a decrease in governor speed setting.

### Shutdown

The limit/shutdown pilot valve is located in the pump oil pressure supply line to the ballhead pilot valve. When the engine shutdown system is activated, the limit/shutdown rod pushes the limit/shutdown pilot valve plunger below the supply passage. This drains oil from the supply to the ballhead pilot valve plunger. The power piston will move downward as the output shafts turn in the decreased fuel direction. When engine speed is decreased, the ballhead flyweights move in. This will lower the ballhead pilot valve. The oil from the power piston will drain into the governor sump at a faster rate. As the power piston continues to move down, the output shaft is turned to the shutdown position until the engine is stopped.

i01379360

## Electronic Governors

**SMCS Code:** 1908

The 2301 Electric Governor Control System consists of the following components:

- 2301 Electric Governor Control (EGC)
- Actuator
- Engine Speed Sensor

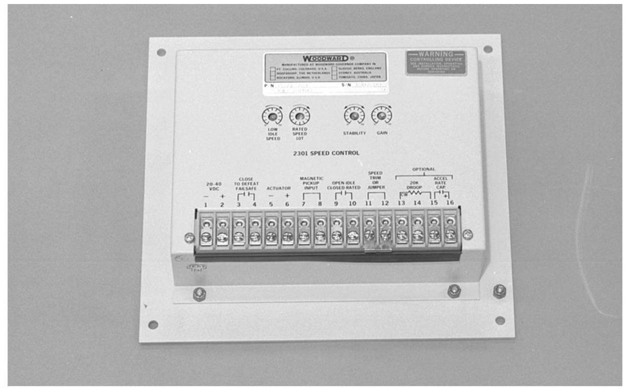

Illustration 11 g00322848

2301 Electric Governor Control (EGC)

The 2301 Electric Governor System gives precision engine speed control. The 2301 Control measures the engine speed constantly. The 2301 Control makes the necessary corrections to the engine fuel setting through an actuator. The actuator is connected to the fuel system.

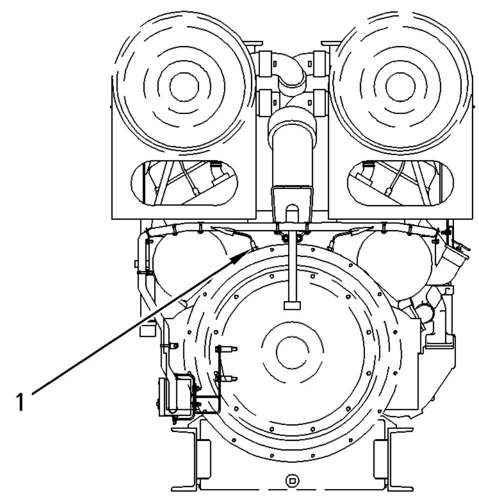


Illustration 12 g00316125

Engine speed sensor (typical example)

(1) Engine speed sensor

The engine speed is detected by an engine speed sensor. This sensor makes an AC voltage that is sent to the 2301 Control. The 2301 Control now sends a DC voltage signal to the actuator.

 

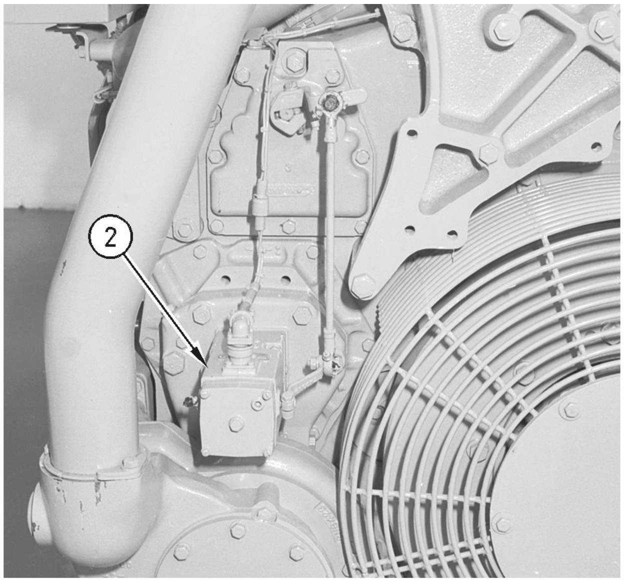


Illustration 13 g00322852

Front of engine (typical example)

(2) EG6P actuator

The actuator changes the electrical input from the 2301 Control to a mechanical output. The mechanical output is connected to the fuel system by a linkage. For example, if the engine speed is more than the speed setting, the 2301 Control will decrease the output. The actuator will now move the linkage in order to decrease the fuel to the engine.

# Air Inlet and Exhaust System

i01475083

## Air Inlet and Exhaust System Operation

**SMCS Code:** 1050

The components of the air inlet and exhaust system control the quality and the amount of air that is available for combustion. There are separate turbochargers and exhaust manifolds on each side of the engine. A common aftercooler is located between the cylinder heads in the center of the engine. The inlet manifold is a series of elbows that connect the aftercooler chamber to the inlet ports (passages) of the cylinder heads. There is one camshaft in each side of the block. The two camshafts control the movement of the valve system components.

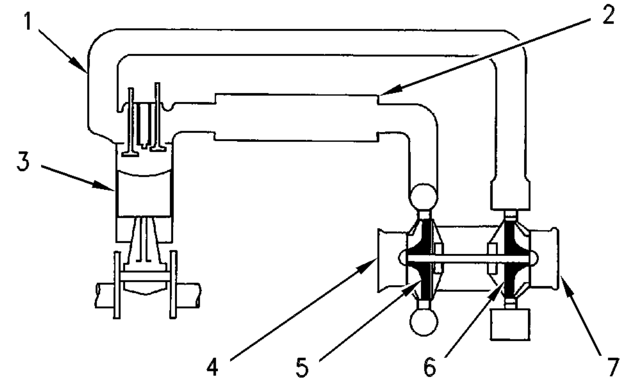


Illustration 14 g00281646

Air inlet and exhaust system

(1) Exhaust manifold
(2) Aftercooler
(3) Engine cylinder
(4) Air inlet
(5) Turbocharger compressor wheel
(6) Turbocharger turbine wheel
(7) Exhaust outlet

Clean inlet air from the air cleaners is pulled through air inlet (4) into the turbocharger compressor by turbocharger compressor wheel (5). The rotation of the turbocharger compressor wheel causes the air to compress. The rotation of the turbocharger compressor wheel then forces the air through a tube to aftercooler (2). The aftercooler lowers the temperature of the compressed air before the air gets into the inlet chambers in each cylinder head. This cooled and compressed air fills the inlet chambers in the cylinder heads. Air flow from the inlet chamber into the cylinder heads is controlled by the inlet valves.

There are two inlet valves and two exhaust valves for each cylinder. Refer to Systems Operation, “Valve System Components”. The inlet valves open when the piston moves down on the inlet stroke. The cooled, compressed air is pulled into the cylinder from the inlet chamber.

The inlet valves close and the piston starts to move up on the compression stroke. When the piston is near the top of the compression stroke, fuel is injected into the cylinder. The fuel mixes with the air and combustion starts. The force of the combustion pushes the piston downward on the power stroke. When the piston moves upward the piston is on the exhaust stroke. The exhaust valves open and the exhaust gases are pushed through the exhaust port into exhaust manifold (1). After the piston makes the exhaust stroke, the exhaust valves close and the cycle starts again.

Exhaust gases from the exhaust manifold go into the turbine side of the turbocharger. The exhaust gases cause turbocharger turbine wheel (6) to turn. The turbine wheel is connected to the shaft that drives the turbocharger compressor wheel. The exhaust gases exit through exhaust outlet (7).

i02329690

# Aftercooler

**SMCS Code:** 1063

The aftercooler is located at the center of the vee. The aftercooler has a core assembly that is charged with coolant. Coolant from the water pump flows through a pipe into the aftercooler. Coolant then flows through the core assembly (assemblies). Coolant flows back out the aftercooler through a different pipe.

There is a connector (tube) that connects the bottom rear of each core to the cylinder block. This connector is used in order to drain the aftercooler when the coolant is drained from the engine.

Inlet air from the compressor side of the turbochargers flows into the aftercooler through pipes. The air then passes through the fins of the core assembly which lowers the temperature. The cooler air flows out of the bottom of the aftercooler and into the inlet manifold. The air flows upward through the elbows to the inlet ports (passages) in the cylinder heads.

There are sensors for the aftercooler water temperature and for the inlet manifold air temperature.

i02200833

# Valve System Components

**SMCS Code:** 1108; 1109; 1121; 1123

The valve system components control the flow of the inlet air and the exhaust gases into the cylinders and out of the cylinders during engine operation.

The crankshaft gear drives the camshaft gears through idlers. Both camshafts must be timed to the crankshaft in order to get the correct relation between the piston and the valve movement.

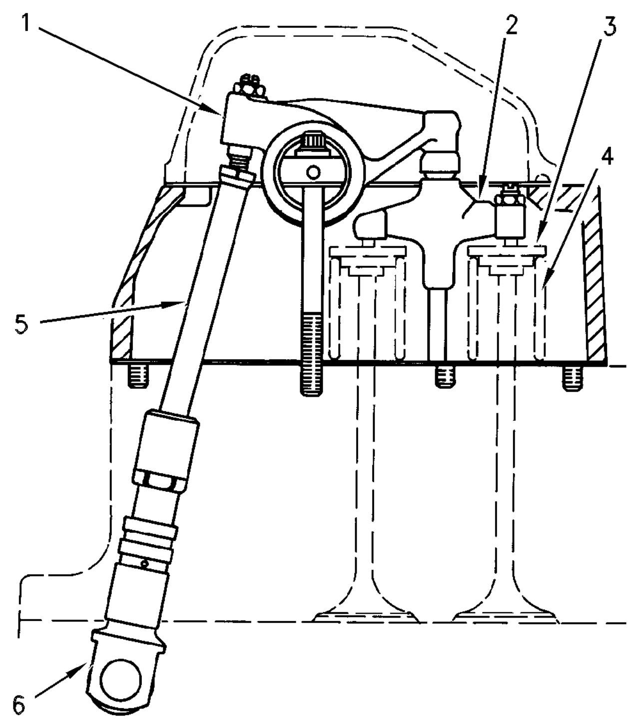


Illustration 15 g00322585

Valve system components that illustrate the adjustable valve bridge

(1) Rocker arm
(2) Bridge
(3) Rotocoil
(4) Valve spring
(5) Pushrod
(6) Lifter

 

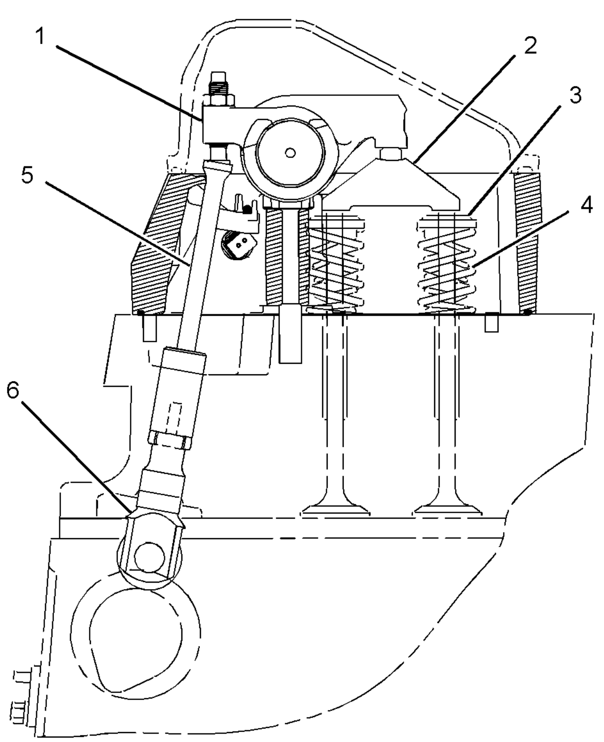


Illustration 16 g01042301

Valve system components that illustrate the nonadjustable valve bridge

(1) Rocker arm
(2) Bridge
(3) Rotocoil
(4) Valve spring
(5) Pushrod
(6) Lifter

The camshafts have three lobes for each cylinder. Two lobes operate the valves and the other lobe operates the fuel injector.

As each camshaft turns, the lobes on the camshaft cause lifters (6) to move up and down. This movement causes pushrods (5) to move rocker arms (1). The movement of the rocker arm causes bridges (2) to move up and down on the dowels in the cylinder head. The bridges allow one rocker arm to open two valves. When the lifters move downward the action of valve springs (4) closes the valves. The valves can be either inlet valves or exhaust valves. There are two inlet valves and two exhaust valves for each cylinder.

Rotocoils (3) cause the valves to turn while the engine is running. The rotation of the valves keeps the carbon deposits on the valves to a minimum which gives the valves a longer service life.

i02329337

# Turbocharger

**SMCS Code:** 1052

Two turbochargers are used on the top of the engine. A turbocharger is located on each side of the vee. The turbine side of each turbocharger is mounted to the respective exhaust manifold. The compressor side of each turbocharger is connected by pipes to the top of the aftercooler housing.

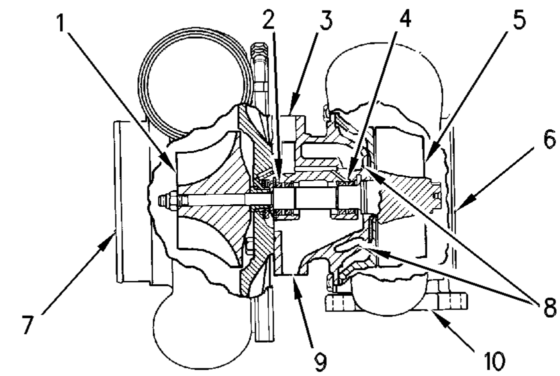


Illustration 17 g00281664

Turbocharger (Typical Example)

(1) Compressor wheel
(2) Bearing
(3) Oil inlet
(4) Bearing
(5) Turbine wheel
(6) Exhaust outlet
(7) Air inlet
(8) Coolant passages
(9) Oil outlet
() Exhaust inlet

The exhaust gases go into the exhaust inlet (10) of the turbine housing. The gases push the blades of turbine wheel (5). The turbine wheel and the compressor wheel turn at speeds up to 90,000 rpm.

Clean air from the air cleaners is pulled through the compressor housing air inlet (7) by the rotation of the compressor wheel (1). The action of the compressor wheel blades compress the inlet air. This compression gives the engine more power because the compression allows the engine to burn additional fuel with greater efficiency.

The maximum speed of the turbocharger is controlled by the engine's electronic control of fuel delivery. When the engine is operating, the height above the sea level also controls the maximum speed of the turbocharger.

Bearing (2) and bearing (4) in the turbocharger use engine oil under pressure for lubrication. The oil is sent through the oil inlet line to oil inlet (3) at the top. The oil then goes through passages in the center section for lubrication of the bearings. The oil goes out of oil outlet (9) at the bottom. The oil then goes back to the engine block through the drain line.

The bearing housing in the turbocharger is also cooled by the jacket water coolant. Coolant from the coolant inlet line enters the side of the center section. The coolant travels through coolant passages (8) in the bearing housing. The coolant then leaves the turbocharger at the other side of the center section. The coolant outlet lines return the coolant back to the jacket water radiator top tank.

# Lubrication System

i01489061

## Lubrication System Operation

**SMCS Code:** 1300

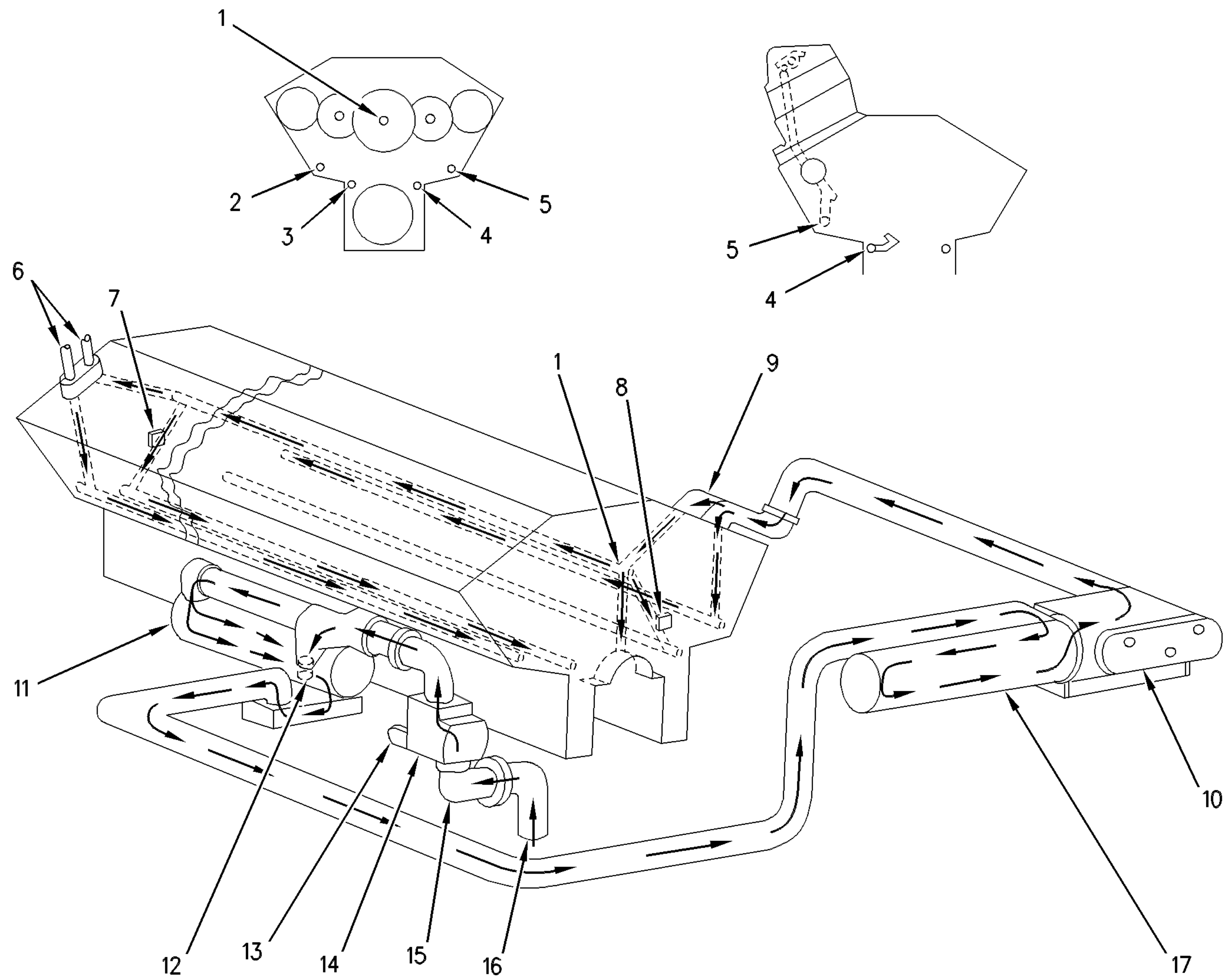


Illustration 18

g00322483

Main oil pump and lubrication system schematic (typical example)

(1) Main oil gallery
(2) Left camshaft oil gallery
(3) Piston cooling jet oil gallery
(4) Piston cooling jet oil gallery
(5) Right camshaft oil gallery
(6) Oil supply lines
(7) Sequence valve
(8) Sequence valve
(9) Adapter
(10) Engine oil filter bypass valve
(11) Engine oil cooler
(12) Engine oil cooler bypass valve
(13) Oil pump relief valve
(14) Engine oil pump
(15) Elbow
(16) Suction bell
(17) Engine oil filter housing

This system uses an engine oil pump (14) with three pump gears. The pump gears are driven by the front gear train. Engine oil is pulled from the pan through suction bell (16) and elbow (15) by engine oil pump (14). Suction bell (16) has a screen in order to clean the engine oil.

There is an oil pump relief valve (13) in the engine oil pump. The oil pump relief valve controls the pressure of the engine oil from the engine oil pump. This allows the engine oil that is not needed to go back to the inlet oil passage of the engine oil pump.

The engine oil pump pushes oil through engine oil cooler (11) and the engine oil filters to main oil gallery (1) and left camshaft oil gallery (2) in the cylinder block. Engine oil cooler (11) lowers the temperature of the engine oil before the engine oil is sent to the filters.

Engine oil cooler bypass valve (12) allows engine oil to flow directly to the filters if engine oil cooler (11) becomes plugged or if the engine oil becomes thick enough to increase the oil pressure differential by 180 ± 20 kPa (26 ± 3 psi).

Engine oil filters are located in engine oil filter housing (17) at the front of the engine. A single bypass valve is located in the engine oil filter housing.

Clean engine oil from the filters goes through adapter (9) into the cylinder block. Part of the engine oil goes to left camshaft oil gallery (2). The remainder of the engine oil goes to main oil gallery (1).

Left camshaft oil gallery (2) and right camshaft oil gallery (5) are connected to each camshaft bearing by a drilled hole. The engine oil goes around each camshaft journal. The engine oil then travels through the cylinder head and the rocker arm housing to the rocker arm shaft. A drilled hole connects the bores for the valve lifters to the oil hole for the rocker arm shaft. The valve lifters are lubricated at the top of each stroke.

The main oil gallery is connected to the main bearings by drilled holes. Drilled holes in the crankshaft connect the main bearing oil supply to the rod bearings. Engine oil from the rear of the main oil gallery goes to the rear of the right camshaft oil gallery.

Sequence valve (7) and sequence valve (8) allow engine oil from the main oil gallery to go to both piston cooling jet galleries (3) and (4). The sequence valves begin to open at approximately 130 kPa (19 psi). The sequence valves will not allow engine oil into the piston cooling jet galleries until there is pressure in the main oil gallery. This decreases the amount of time that is necessary for pressure buildup when the engine is started. This also helps hold pressure at idle speed.

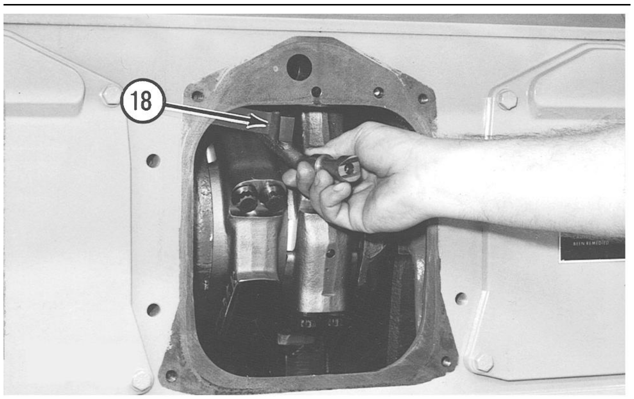


Illustration 19 g00281794

Piston cooling and lubrication (typical example)

(18) Piston cooling jet

There is a piston cooling jet (18) below each piston. Each cooling jet has two openings. One opening is in the direction of a passage in the bottom of the piston. This passage takes engine oil to a manifold behind the ring band of the piston. A slot (groove) is in the side of both piston pin bores. This slot connects with the manifold behind the ring band. The other opening is in the direction of the center of the piston. This helps cool the piston and this supplies lubrication to the piston pin.

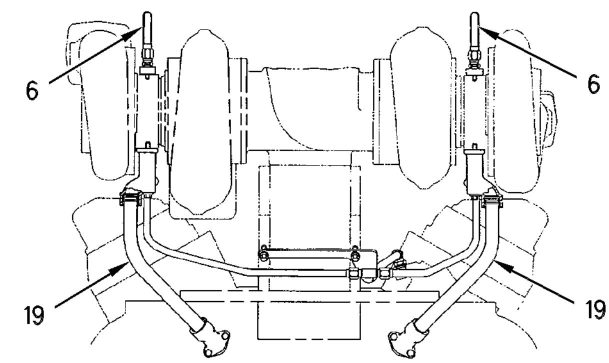


Illustration 20 g00322503

Turbochargers (typical example)

(6) Oil supply lines
(19) Oil drain lines

Oil supply lines (6) send oil from the rear adapter to the turbochargers. Oil drain lines (19) are connected to the flywheel housing on each side of the engine.

Engine oil is sent to the front and rear gear groups through drilled passages. The drilled passages are in the front housing, the rear housing, and the faces of the cylinder block. These passages are connected to left camshaft oil gallery (2) and right camshaft oil gallery (5).

After the engine oil flows through the lubrication system, the engine oil returns back to the engine oil pan.

i01908711

# Accumulator

**SMCS Code:** 1320

**S/N:** 29Z1-Up

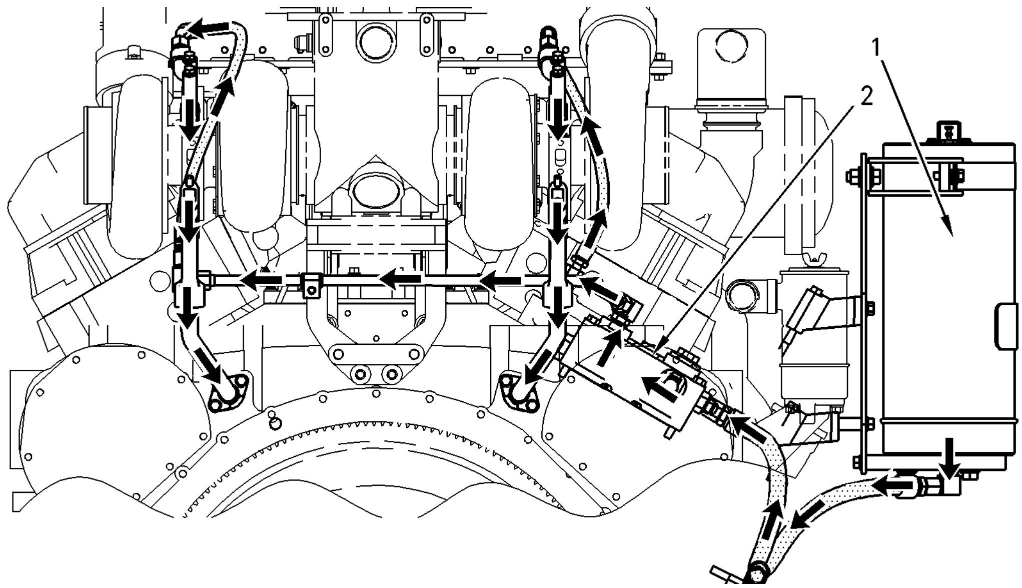


Illustration 21

g00994733

Flow of engine oil from the accumulator

(1) Accumulator (2) Adapter

Accumulator (1) provides lubrication to the turbochargers' bearings during shutdown when the engine oil pressure is reduced but the turbocharger's wheels are still rotating. This helps increase the service life of the turbochargers.

After start-up, engine oil pressure rises and pressurized oil from the engine block flows upward through adapter (2). Some of the oil flows through tubes and hoses to both turbochargers. The remainder of the oil flows through a hose to the accumulator.

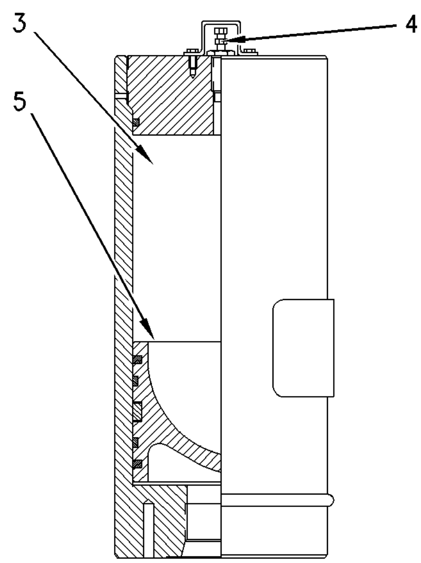


Illustration 22

g00998892

(3) Chamber
(4) Valve
(5) Piston

The accumulator has a chamber (3) that is filled with nitrogen gas. Valve (4) is used to fill the chamber and the valve is used to measure the pressure in the chamber.

Piston (5) is moved by differential pressures. Nitrogen gas in the upper part of the chamber pushes down on the piston. During engine operation, the engine oil pressure becomes greater than the nitrogen gas pressure. Pressurized engine oil pushes the piston upward. The lower portion of the chamber fills with oil until the pressure of the oil and the pressure of the nitrogen gas are equalized.

The piston's outer diameter is sealed in order to prevent the flow of gas or oil between the upper and lower portions of the chamber. The lower portion of the chamber remains filled with oil during engine operation.

When the engine shuts down, the pressure of the nitrogen gas becomes greater than the pressure of the engine oil. The piston is pushed downward and the oil is forced out of the chamber back through the adapter.

The adapter has a check valve that closes the oil passage from the cylinder block. This prevents the oil from draining into the cylinder block. The oil is directed to both turbochargers. After the turbocharger bearings are lubricated, the oil drains from the turbochargers into the rear housing.

Oil from the accumulator continues to lubricate the turbochargers until the nitrogen gas pushes the piston to the fully downward position and the supply of oil from the chamber is exhausted.

# Cooling System

i02389385

## Cooling System Operation (Jacket Water Aftercooled)

**SMCS Code:** 1350

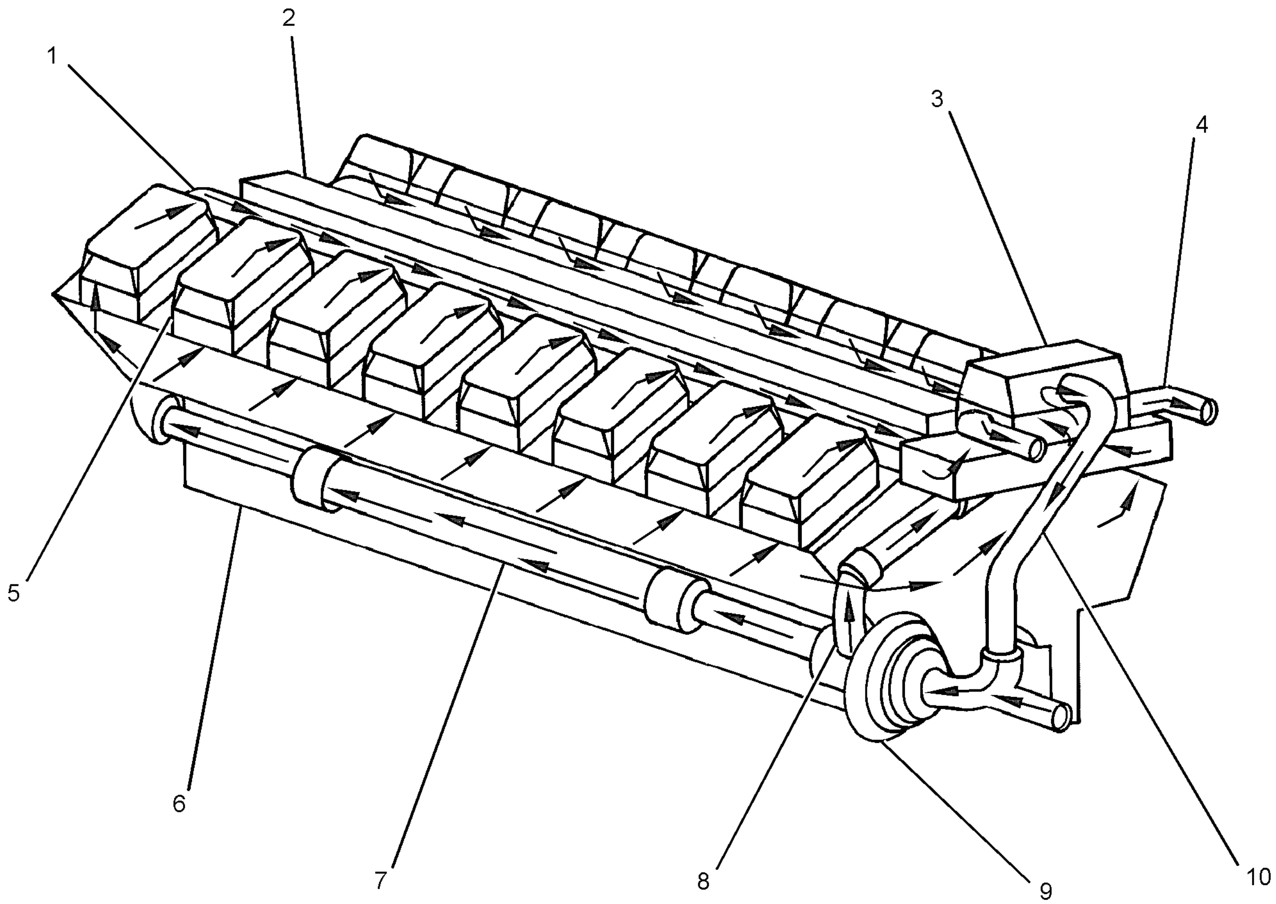


Illustration 23

g01193035

Schematic of cooling system (typical example)

(1) Water manifold
(2) Aftercooler
(3) Water temperature regulator housing
(4) Tube
(5) Cylinder head
(6) Cylinder block
(7) Engine oil cooler
(8) Tube
(9) Water pump
(10) Bypass tube

Coolant goes into water pump (9) through an elbow. The elbow connects to the radiator or to the heat exchanger. The coolant flow is divided at the outlet of the water pump. Part of the coolant flow is sent to aftercooler (2) through tube (8). The remainder of the coolant goes through engine oil cooler (7).

Coolant that is sent to the aftercooler goes through the aftercooler core. The coolant is sent by an elbow into a passage in cylinder block (6). The passage is near the center of the vee at the rear of the cylinder block.

The coolant flows through the engine oil cooler into the water jacket of the cylinder block at the right rear cylinder. The cooler coolant and the hotter coolant are then mixed. The coolant goes to both sides of the cylinder block through distribution manifolds. The distribution manifolds are connected to the water jacket of all the cylinders. The main distribution manifold is located just above the main bearing oil gallery.

The coolant flows upward through the water jackets. The coolant flows around the cylinder liners from the bottom to the top. The hottest temperature is near the top of the cylinder liners. The water jacket is smaller near the top of the cylinder liners. This shelf causes the coolant to flow faster for better liner cooling.

Coolant from the top of the liners goes into cylinder head (5). The cylinder head sends the coolant around the hottest parts. Coolant then goes to the top of the cylinder head. The coolant goes out through an elbow at each cylinder head and into water manifold (1) at each bank of cylinders. Coolant goes through the water manifold to temperature regulator housing (3).

The water temperature regulator housing has an upper flow section and a lower flow section. The housing uses four temperature regulators. The sensing bulbs of the four temperature regulators are in the lower section of the housing. Before the regulators open, cold coolant is sent through bypass tube (10) back to the inlet of water pump (9). As the temperature of the coolant increases and the regulators start to open, the coolant flow in the bypass tube is restricted. Some coolant is sent through the outlets to the radiator or to the heat exchanger.

The total system capacity will depend on the amount of coolant in the following components: cylinder block, radiator or the heat exchanger, and the coolant lines.

# Basic Engine

i02388283

## Cylinder Block, Liners and Heads

**SMCS Code:** 1100; 1200

The cylinders in the left side of the block form a 60 degree angle with the cylinders in the right side. The main bearing caps are fastened to the cylinder block with four bolts per cap.

The cylinder liners can be removed for replacement. The top surface of the cylinder block is the seat for the cylinder liner flange. Engine coolant flows around the cylinder liners in order to keep the cylinder liners cool. Three O-ring seals around the bottom of the cylinder liner make a seal between the cylinder liner and the cylinder block. A filler band goes under the cylinder liner flange. This makes a seal between the top of the cylinder liner and the cylinder block.

The engine has a separate cylinder head for each cylinder. Two inlet valves and two exhaust valves, which are controlled by a pushrod valve system, are used for each cylinder. Valve guides without shoulders are pressed into the cylinder heads. The opening for the unit injector is located between the four valves. A lobe on the camshaft moves the pushrod that operates the unit injector. Fuel is injected directly into the cylinder.

There is an aluminum spacer plate between each cylinder head and the cylinder block. Coolant goes out of the cylinder block through the spacer plate and into the cylinder head through eight openings in each cylinder head face. Water seals are used in each opening to prevent coolant leakage. Gaskets seal the engine oil drain line between the cylinder head, the spacer plate, and the cylinder block.

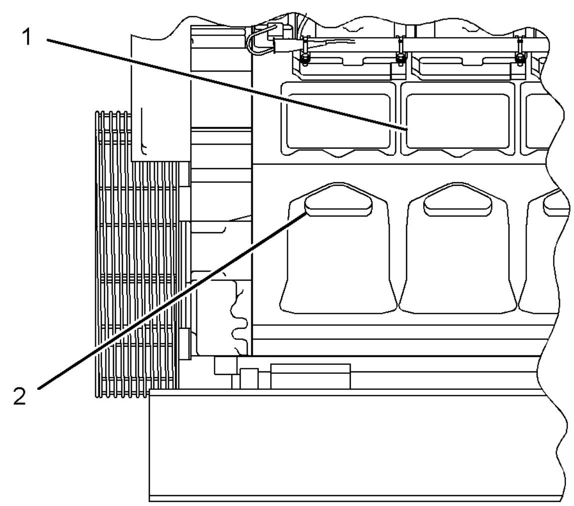


Illustration 24 g01192345

Left side of engine (typical example)

(1) Camshaft covers
(2) Crankcase covers

Camshaft covers (1) allow access to the camshaft and to the valve lifters. Crankcase covers (2) allow access to the crankshaft connecting rods, to the main bearings, and to the piston cooling jets. When the covers are removed, all the openings can be used for inspection and for service.

i01709872

# Pistons, Rings and Connecting Rods

**SMCS Code:** 1214; 1218

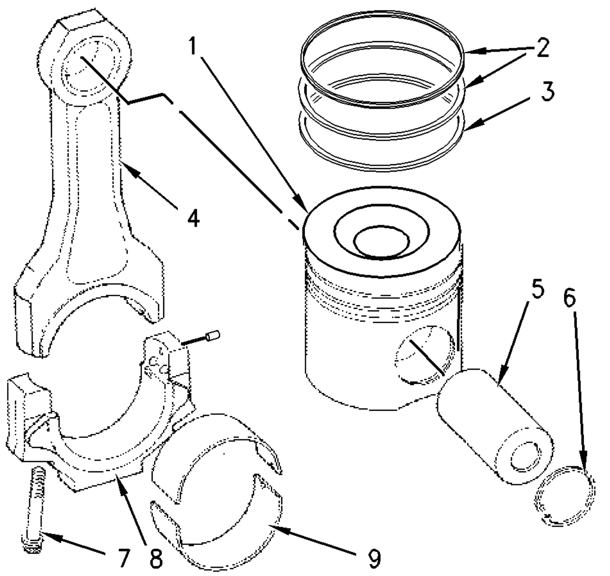


Illustration 25 g00807790

(1) Piston
(2) Compression rings
(3) Oil ring
(4) Connecting rod
(5) Piston pin
(6) Pin retainer
(7) Bolt
(8) Connecting rod cap
(9) Connecting rod bearing

Aluminum pistons (1) have three rings. The rings include two compression rings (2) and one oil ring (3). All the rings are located above the piston pin bore. The top two compression rings are rectangular. The oil ring is a two-piece ring. Engine oil returns to the crankcase through holes in the oil ring groove.

**Note:** Earlier designs of the pistons had a cast iron band for the top two rings in order to help reduce wear on the compression ring grooves. The newer design has a band for the top ring only.

The piston is attached to connecting rod (4) with piston pin (5) and with two pin retainers (6). The connecting rod has a taper on the pin bore end. This taper gives the connecting rod and the piston more strength in the areas with the most load. Four bolts (7), which are set at a small angle, hold connecting rod cap (8) to the connecting rod. This design keeps the connecting rod width to a minimum, so that a larger connecting rod bearing (9) can be used and the connecting rod can still be removed through the cylinder liner.

i04008992

# Pistons, Rings and Connecting Rods (Two-Piece Piston)

**SMCS Code:** 1214; 1218

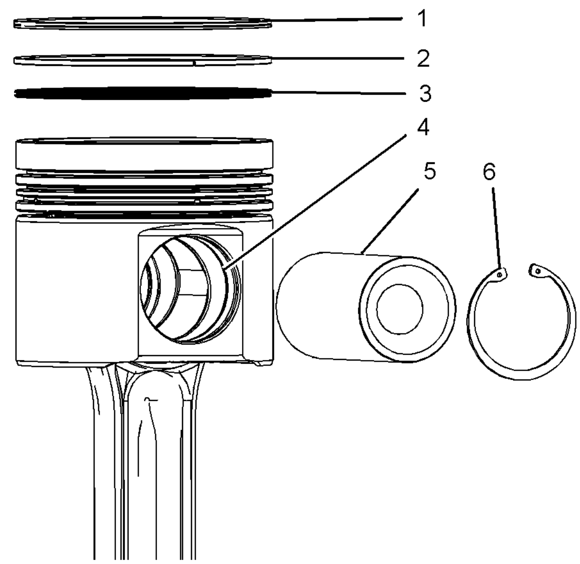


Illustration 26 g02182227

(1) Top ring
(2) Intermediate ring
(3) Oil control ring
(4) Piston pin bore
(5) Piston pin
(6) Piston pin retainer

The piston is a two-piece, articulated design. The piston consists of a forged, steel crown and a cast, aluminum skirt. The two pieces of the piston assembly are connected to the piston pin. The two pieces of the piston assembly pivot about the piston pin. The steel crown carries all three piston rings. Oil from the piston cooling jets flows through a chamber which is located directly behind the rings. The oil cools the piston which improves the life of the rings. The pistons have three rings which include two compression rings and one oil ring. All the rings are located above the piston pin bore. The oil ring is a standard ring. Oil returns to the crankcase through holes in the oil ring groove.

The connecting rod has a taper on the pin bore end. This taper gives the rod and the piston more strength in the areas with the most load. Four bolts, which are set at a small angle, hold the rod cap to the rod. The design keeps the rod width to a minimum. A larger rod bearing is used and the rod can still be removed through the liner.

i02410648

## Pistons, Rings and Connecting Rods

**SMCS Code:** 1214; 1218

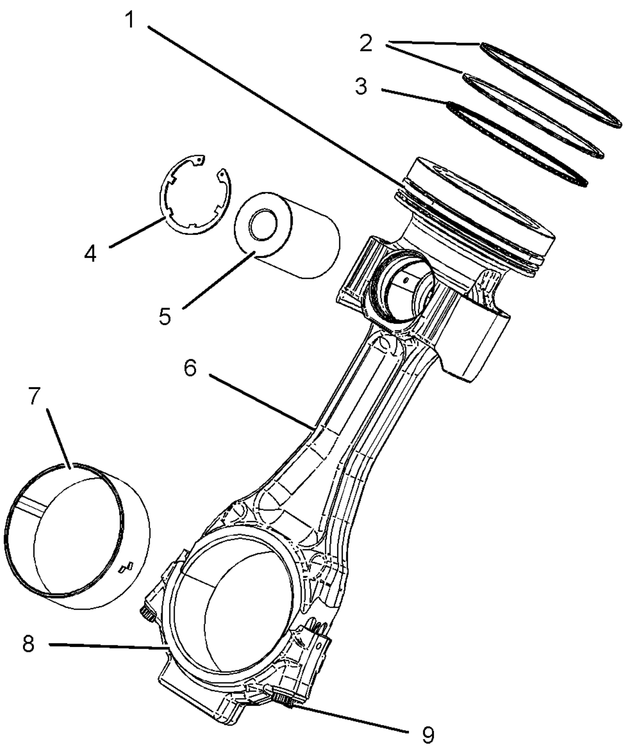


Illustration 27 g01204879

(1) Piston
(2) Compression rings
(3) Oil ring
(4) Pin retainer
(5) Piston pin
(6) Connecting rod
(7) Connecting rod bearing
(8) Connecting rod cap
(9) Bolt

Aluminum pistons (1) have three rings. The rings include two compression rings (2) and one oil ring (3). All the rings are located above the piston pin bore. The top two compression rings are rectangular. The oil ring is a two-piece ring. Engine oil returns to the crankcase through holes in the oil ring groove.

**Note:** Earlier designs of the pistons had a cast iron band for the top two rings in order to help reduce wear on the compression ring grooves. The newer design has a band for the top ring only.

The piston is attached to connecting rod (6) with piston pin (5) and with two pin retainers (4). The connecting rod has a taper on the pin bore end. This taper gives the connecting rod and the piston more strength in the areas with the most load. Four bolts (9), which are set at a small angle, hold connecting rod cap (8) to the connecting rod. This design keeps the connecting rod width to a minimum, so that a larger connecting rod bearing (7) can be used and the connecting rod can still be removed through the cylinder liner.

i02391905

## Crankshaft

**SMCS Code:** 1202

The crankshaft changes the combustion forces in the cylinder into usable rotating torque. A vibration damper is used at the front of the crankshaft in order to reduce torsional vibrations (twist) that can cause damage to the engine.

The crankshaft drives a group of gears that are on the front of the engine and on the rear of the engine. The gear group on the front of the engine drives the oil pump, the jacket water pump, the fuel transfer pump, and the accessory drives.

The rear gear group, which is also driven by the crankshaft, drives the camshafts and the accessory drives.

Seals and wear sleeves are used at both ends of the crankshaft. The seals and wear sleeves are replaceable. Pressure oil is supplied to all main bearings through drilled holes in the webs of the cylinder block. The oil then flows through drilled holes in the crankshaft in order to provide oil to the connecting rod bearings. The 3508 crankshaft is held in place by five main bearings. The 3512 crankshaft is held in place by seven main bearings. The 3516 crankshaft is held in place by nine main bearings. A thrust plate at either side of the center main bearing controls the end play of the crankshaft.

i01372180

## Camshaft

**SMCS Code:** 1210

There is one camshaft assembly per side. The 3508 camshaft is supported by five bearings. The 3512 camshaft is supported by seven bearings. The 3516 camshaft is supported by nine bearings. Each camshaft is driven by the rear gear group.

As the camshaft turns, each lobe moves a lifter. There are three lifters for each cylinder. Each outside lifter moves a pushrod and two valves. The valves can be inlet valves or exhaust valves. The center lifter moves a pushrod that operates the unit injector.

The camshafts must be in time with the crankshaft. The relation of the camshaft lobes to the crankshaft position causes the valves and unit injectors in each cylinder to operate at the correct time.

# Air Starting System

i02388307

## Air Starting System

**SMCS Code:** 1450

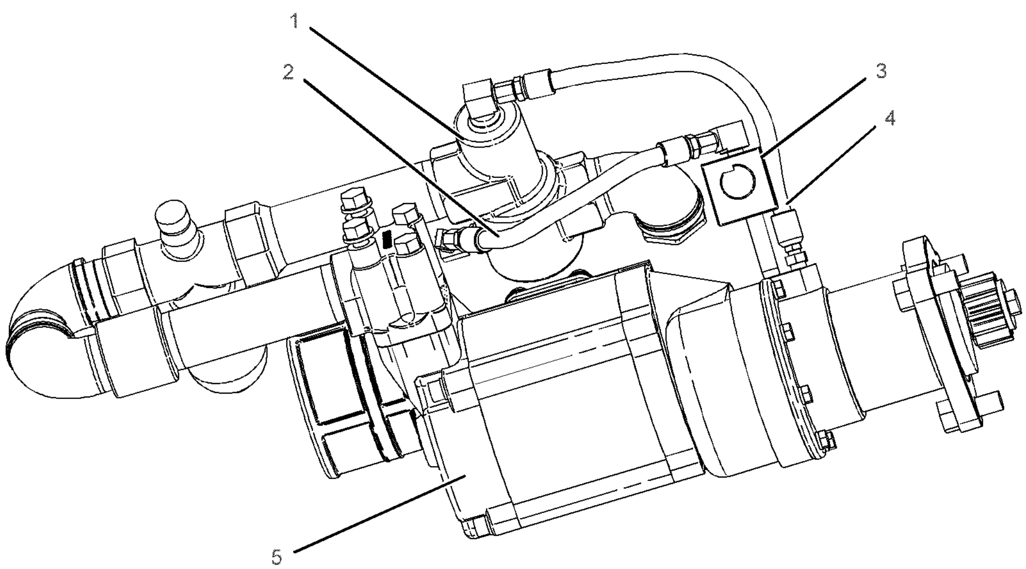


Illustration 28 g01013593

Air starting system (typical example)

(1) Relay valve
(2) Hose
(3) Starting motor solenoid
(4) Hose
(5) Air starting motor

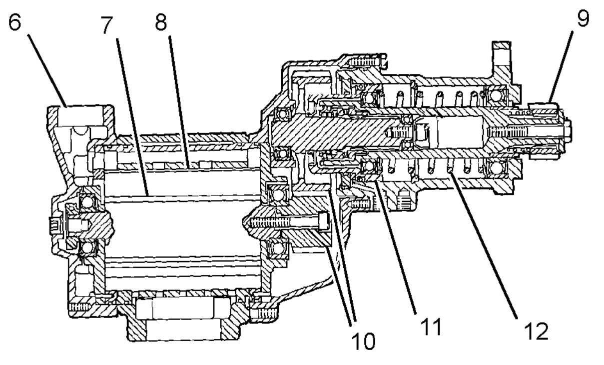


Illustration 29 g01192361

Air starting motor

(6) Air inlet
(7) Vanes
(8) Rotor
(9) Pinion
(10) Reduction gears
(11) Piston
(12) Piston spring

When the main supply of pressurized air is ON, pressurized air is provided to relay valve (1). The main supply of pressurized air is blocked by the relay valve. The relay valve allows some control air pressure to flow through hose (2) from the bottom of the relay valve to another valve that is connected to starting motor solenoid (3).

When the normally closed starting motor solenoid is activated for start-up, the solenoid opens the connected valve. The valve allows the control air pressure to flow behind piston (11) inside air starting motor (5).

The control air pressure pushes the piston. The piston compresses piston spring (12) and the piston moves the drive shaft for pinion (9) outward in order to engage the pinion with the flywheel ring gear. The starting motor does not crank the engine yet.

After the pinion is engaged with the flywheel ring gear, a port in the starting motor is opened in order to allow the control air pressure to flow through hose (4) to the top of relay valve (1). The relay valve opens in order to allow the main supply of pressurized air to flow through the starting motor's air inlet (6).

The pressurized air causes vanes (7) and rotor (8) to rotate. The rotor uses reduction gears (10) to rotate the drive shaft for the pinion and the pinion rotates the flywheel in order to crank the engine.

When the engine starts to run, the flywheel will begin to rotate faster than the pinion. The design of the drive shaft for the pinion allows the pinion to move away from the flywheel. This prevents damage to the air starting motor, to the pinion, and to the flywheel ring gear.

When the engine control senses the crank terminate speed, starting motor solenoid (3) is de-energized. The solenoid closes the attached valve and the control air pressure is removed from piston (11). Piston spring (12) retracts the piston, the drive shaft, and pinion (9).

The retraction of piston (11) closes the passage for the control air pressure to relay valve (1). The relay valve closes in order to shut off the main supply of pressurized air to the starting motor.

# Electrical System

i01372310

## Electrical System Operation

**SMCS Code:** 1400; 1450

The electrical system has three separate circuits. The circuits are the charging circuit, the starting circuit, and the low amperage circuit. Some of the electrical system components are used in more than one circuit. The following components are common in each of the circuits:

- Battery
- Circuit breaker
- Ammeter
- Cable
- Wires for the battery

The charging circuit is in operation when the engine is running. An alternator makes electricity for the charging circuit. A voltage regulator in the circuit controls the electrical output in order to keep the battery at full charge.

The starting circuit is in operation only when the start switch is activated.

The low amperage circuit is connected to the same side of the ammeter as the charging circuit. The starting circuit connects to the opposite side of the ammeter.

i01394904

# Alternator

**SMCS Code:** 1405

NOTICE

Never operate the alternator without the battery in the circuit. Making or breaking an alternator connection with heavy load on the circuit can cause damage to the regulator.

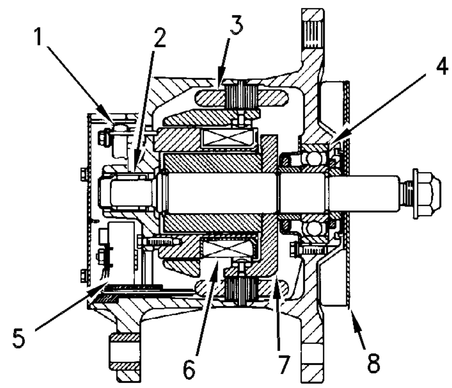


Illustration 30 g00285111

Alternator components (typical example)

(1) Regulator
(2) Roller bearing
(3) Stator winding
(4) Ball bearing
(5) Rectifier bridge
(6) Field winding
(7) Rotor assembly
(8) Fan

The alternator is driven by a belt from an auxiliary drive at the front right corner of the engine. This alternator is a three-phase, self-rectifying charging unit, and regulator (1) is part of the alternator.

This alternator design has no need for slip rings or brushes, and the only part that has movement is rotor assembly (7). All conductors that carry current are stationary. The conductors are field winding (6), stator windings (3), six rectifying diodes, and the regulator circuit components.

Rotor assembly (7) has many magnetic poles. Air space is between the opposite poles.

The poles have residual magnetism that produces a small amount of magnetic lines of force between the poles. As rotor assembly (7) begins to turn between field windings (6) and stator windings (3), a small amount of alternating current (AC) is produced in stator windings (3). This current is from the small, magnetic lines of force that are made by the residual magnetism of the poles. This alternating current (AC) is changed to a direct current (DC). The change occurs when the current passes through the diodes of rectifier bridge (5). Most of this current completes two functions. The functions are charging the battery and supplying the low amperage circuit. The remainder of the current is sent to field windings (6). The DC current flow through field windings (6) (wires around an iron core) now increases the strength of the magnetic lines of force. These stronger lines of force increase the amount of AC current that is produced in stator windings (3). The increased speed of rotor assembly (7) also increases the current and voltage output of the alternator.

Voltage regulator (1) is a solid-state, electronic switch. The regulator feels the voltage in the system. The regulator will start and the regulator will stop many times in one second in order to control the field current to the alternator. The output voltage from the alternator will now supply the needs of the battery and the other components in the electrical system. No adjustment can be made in order to change the rate of charge on these alternator regulators.

i01394925

# Starting Solenoid

**SMCS Code:** 1467

A solenoid is an electromagnetic switch that does two basic operations.

- The solenoid closes the high current starting motor circuit with a low current start switch circuit.
- The solenoid engages the starter motor pinion with the ring gear.

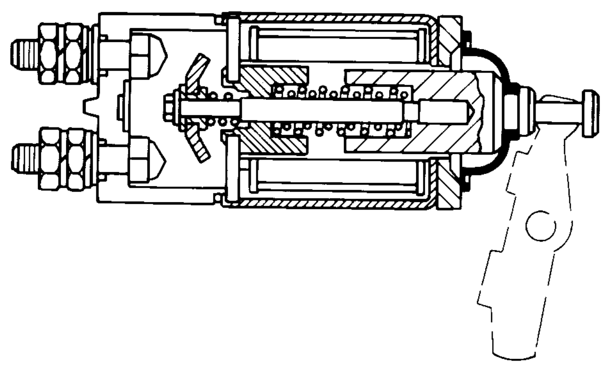

Illustration 31 g00285112

Typical solenoid schematic

The solenoid has windings (one or two sets) around a hollow cylinder. The cylinder contains a spring loaded plunger. The plunger can move forward and backward. When the start switch is closed and the electricity is sent through the windings, a magnetic field is made. The magnetic field pulls the plunger forward in the cylinder. This moves the shift lever in order to engage the pinion drive gear with the ring gear. The front end of the plunger makes contact across the battery and the motor terminals of the solenoid. The starting motor begins to turn the flywheel of the engine.

When the start switch is opened, current no longer flows through the windings. The spring pushes the plunger back to the original position. The spring simultaneously moves the pinion gear away from the flywheel.

When two sets of windings in the solenoid are used, the windings are called the hold-in windings and the pull-in windings. Both of the windings have the same number of turns around the cylinder. However, the pull-in winding uses a wire with a larger diameter in order to produce a greater magnetic field. When the start switch is closed, part of the current flows from the battery through the hold-in windings. The rest of the current flows through the pull-in windings to the motor terminal. The current then goes through the motor to the ground. When the solenoid is fully activated, current is shut off through the pull-in windings. Only the smaller hold-in windings are in operation for the extended period of time. This period of time is the amount of time that is needed for the engine to start. The solenoid will now take less current from the battery. The heat that is made by the solenoid will be kept at an acceptable level.

i01394933

# Starting Motor

**SMCS Code:** 1451

The starting motor is used to turn the engine flywheel in order to start the engine.

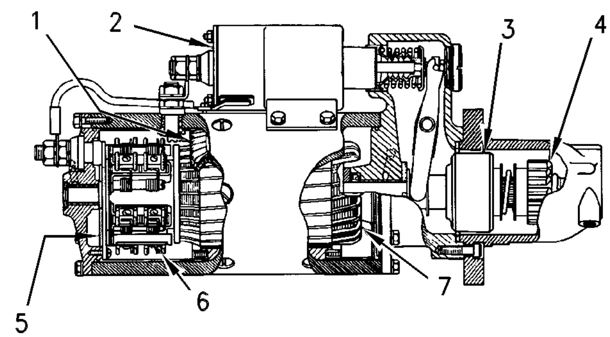


Illustration 32 g00285113

Cross section of the starting motor (typical example)

(1) Field winding
(2) Solenoid
(3) Clutch
(4) Pinion
(5) Commutator
(6) Brush assembly
(7) Armature

The starting motor has a solenoid (2). When the start switch is activated, electricity will flow through the windings of the solenoid. The solenoid core will move in order to push pinion (4) with a mechanical linkage. This will engage with the ring gear on the flywheel of the engine. Pinion (4) will engage with the ring gear before the electric contacts in solenoid (2) close the circuit between the battery and the starting motor. When the circuit between the battery and the starting motor is complete, pinion (4) will turn the engine flywheel. A clutch gives protection to the starting motor. The engine can not turn the starting motor too fast. When the start switch is released, pinion (4) will move away from the flywheel ring gear.

# Starting Motor Protection

The starting motor is protected from damage in two ways:

- The starting motor is protected from engagement with the engine when the engine is running. The control feature will not allow the starting motor to engage if the speed is above 0 rpm.

- The starting motor is protected from continuous starting. For example, if an operator is holding the key in the Start position after the engine starts, the starting motor solenoid will disengage after engine speed reaches 300 rpm.

i02388736

# Engine Speed Sensor

**SMCS Code:** 1907

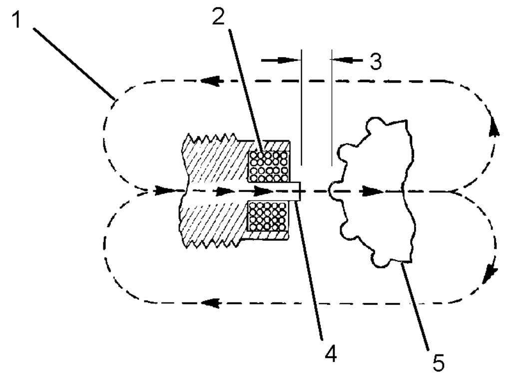


Illustration 33 g01192553

Schematic of engine speed sensor

(1) Magnetic lines of force
(2) Wire coils
(3) Gap
(4) Pole piece
(5) Flywheel ring gear

The engine speed sensor is a permanent magnet generator. This engine speed sensor has a single pole. The engine speed sensor is made of wire coils (2). The wire coils go around a permanent magnet pole piece (4).

As the teeth of flywheel ring gear (5) cut through magnetic lines of force (1) that are generated by the permanent magnet, an AC voltage is generated in wire coils (2). The frequency of this voltage is directly proportional to engine speed.

i01659570

# Coolant Temperature Switch

**SMCS Code:** 1435-TA

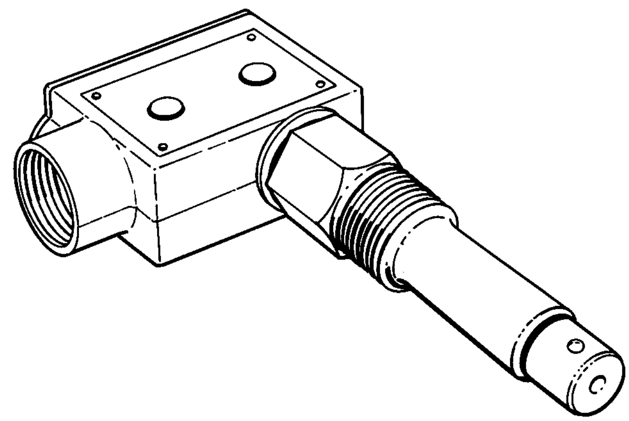

Illustration 34 g00322044

Coolant temperature switch

The coolant temperature switch is installed in the regulator housing. An adjustment to the temperature range of the contactor cannot be made. The element feels the temperature of the coolant. The element then operates the microswitch in the contactor when the coolant temperature is too high. The element must be in contact with the coolant in order to operate correctly. The coolant temperature switch will not operate if the engine is too hot due to low coolant level or no coolant level.

The coolant temperature switch is normally connected to the electric shutoff system in order to stop the engine. The switch can also be connected to an alarm system. As the coolant temperature lowers back to the operating range, the water temperature contactor switch opens automatically.

i01372425

# Magnetic Switch

**SMCS Code:** 1426

A magnetic switch is used in the circuit for the starting motor solenoid. The switch electrically operates in the same manner as the solenoid. The magnetic switch is used in order to reduce the low current load on the start switch. The magnetic switch also controls the low current to the starting solenoid.

i01259850

# Circuit Breaker

**SMCS Code:** 1420

The circuit breaker is a switch that opens the battery circuit if the current in the electrical system goes higher than the rating of the circuit breaker.

A heat-activated metal disc with a contact point completes the electric circuit through the circuit breaker. If the current in the electrical system gets too high the metal disc will get hot. This heat causes a distortion of metal disc. The disc opens the contacts. The disc breaks the circuit.

NOTICE

Find and correct the problem that causes the circuit breaker to open. This will help prevent damage to the circuit components from too much current.

# Testing and Adjusting Section

# Fuel System

i01938966

## General Information (Fuel System)

**SMCS Code:** 1250

Either too much fuel or not enough fuel for combustion can be the cause of a problem in the fuel system. Work is often done on the fuel system when the problem is really with some other part of the engine. It is difficult to find the cause of the problem, especially when smoke comes from the exhaust. Smoke that comes from the exhaust can be caused by a faulty fuel injector. Smoke can also be caused by one or more of the reasons that follow:

- Not enough air for good combustion
- Oil leakage into combustion chamber
- Air inlet and exhaust leaks
- Not enough compression

i02391941

## Fuel System Inspection

**SMCS Code:** 1250-040

A problem with the components that supply fuel to the engine can cause low fuel pressure. This can decrease engine performance.

1. Check the fuel level in the fuel tank. Look at the cap for the fuel tank. Make sure that the vent is not filled with debris.
2. Check the fuel lines for fuel leakage. Be sure that none of the fuel lines have a restriction or a faulty bend.
3. Install new main fuel filters. Clean the primary fuel filter.
4. Inspect the fuel pressure relief valve in the fuel transfer pump. Make sure that there is no restriction.

i02672579

## Checking Engine Cylinders

**SMCS Code:** 1290-535

When the engine is under load, the temperature of an exhaust manifold port can indicate the condition of a fuel injector. Low temperature at an exhaust manifold port is an indication of no fuel to the cylinder. This can possibly indicate an injector with a defect or a problem with the control system. An extra high temperature at an exhaust manifold port can indicate too much fuel to the cylinder. High temperatures may also be caused by an injector with a defect.

Refer to Testing And Adjusting, "Measuring Exhaust Temperature" for the procedure to check the exhaust manifold port temperatures.

i02388767

## Fuel Pressure

**SMCS Code:** 1250-081

The 1U-5470 Engine Pressure Group can be used in order to check the fuel pressure of an engine.

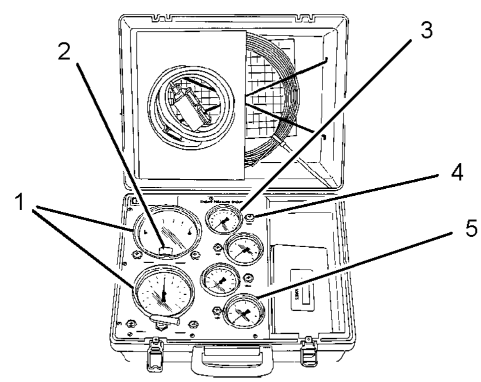


Illustration 35 g01192577

1U-5470 Engine Pressure Group

(1) Pressure indicators
(2) Zero adjustment screw
(3) Pressure indicator
(4) Pressure tap
(5) Pressure indicator

The Special Instruction, SEHS8907 is provided with the tool group.

The fuel pressure regulating valve keeps the pressure in fuel manifolds between 415 to 450 kPa (60 to 65 psi).

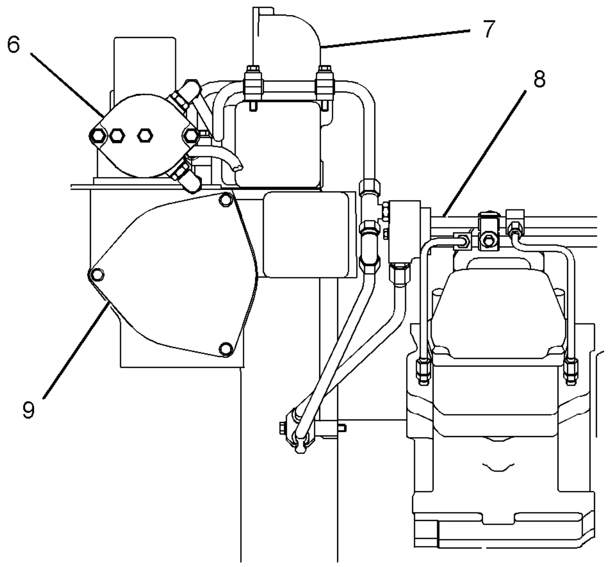


Illustration 36 g01192601

(6) Secondary fuel filter
(7) Regulator housing
(8) Fuel manifold
(9) Oil filter

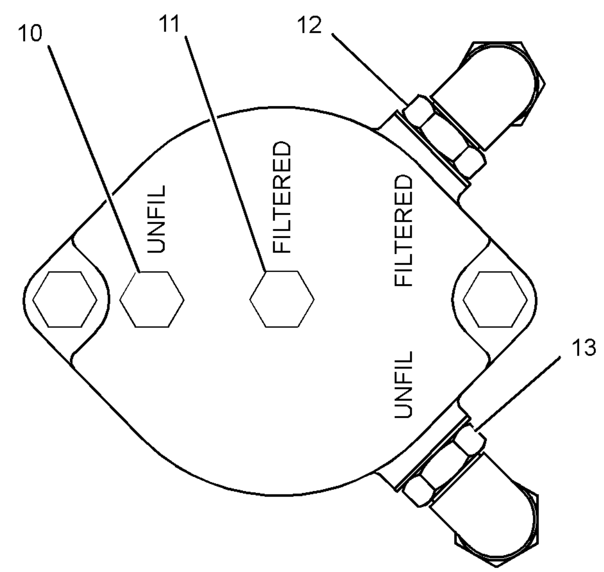


Illustration 37 g01192612

(10) Plug (port for unfiltered fuel pressure)
(11) Plug (port of filtered fuel pressure)
(12) Fuel outlet to the fuel manifolds (filtered fuel)
(13) Fuel inlet from the fuel transfer pump (unfiltered fuel)

Use the following procedure to connect the 1U-5470 Engine Pressure Group:

1. Remove plugs (10) and (11) from the secondary fuel filter housing cover.

2. Install 5P-5528 O-Ring Adapters at the location for the plugs.

3. Connect the 1U-5470 Engine Pressure Group to the O-Ring Adapters at the location of the plugs (10) and (11). Use the fittings and the nylon tubing that is provided with the Engine Pressure Group in order to connect to the O-Ring Adapters.

The fuel pressure from the fuel transfer pump can be checked at the location of plug (10). The fuel pressure to the fuel manifold can be checked at the location of plug (11). The fuel filter differential pressure can be checked from the difference in fuel pressure between the location of plug (10) and the location of plug (11).

i01255770

# Engine Rotation

**SMCS Code:** 1000

The SAE standard engine crankshaft rotation is counterclockwise from the flywheel end of the engine.

i02389395

# Finding the Top Center Position for the No. 1 Piston

**SMCS Code:** 1105-531

Table 1

| Tools Needed | Quantity |
|---|---|
| 9S-9082 Engine Turning Tool | 1 |

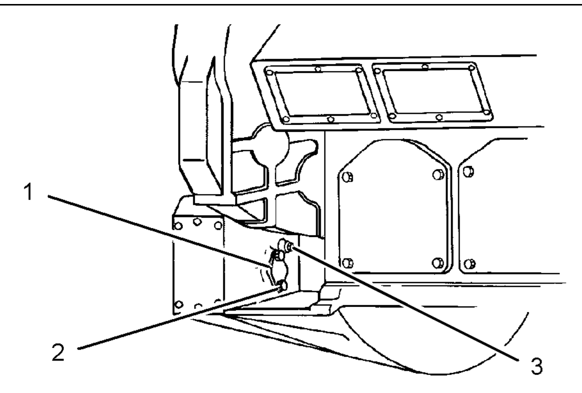


Illustration 38 g01193047

Timing bolt location (typical example)

(1) Cover
(2) Timing bolt
(3) Plug

1. Remove cover (1) and plug (3) from the right front side of the flywheel housing.

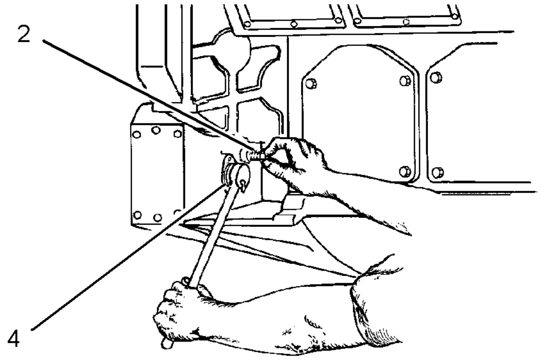


Illustration 39 g01193048

Timing bolt installation (typical example)

(2) Timing bolt
(4) 9S-9082 Engine Turning Tool

2. Put timing bolt (2) through the timing hole in the flywheel housing. Use the 9S-9082 Engine Turning Tool (4) and a ratchet wrench with a 1/2 inch drive in order to turn the flywheel in the direction of normal engine rotation. Turn the flywheel until the timing bolt engages with the hole in the flywheel.

**Note:** If the flywheel is turned beyond the point of engagement, the flywheel must be turned in the direction that is opposite of normal engine rotation. Turn the flywheel by approximately 30 degrees. Then turn the flywheel in the direction of normal engine rotation until the timing bolt engages with the threaded hole. This procedure will remove the play from the gears when the No. 1 piston is on the top center.

3. Remove the valve cover for the No. 1 cylinder head.

4. The inlet and exhaust valves for the No. 1 cylinder are fully closed if the No. 1 piston is on the compression stroke and the rocker arms can be moved by hand. If the rocker arms cannot be moved and the valves are slightly open, the No. 1 piston is on the exhaust stroke. Find the cylinders that need to be checked or adjusted for the stroke position of the crankshaft after the timing bolt has been installed in the flywheel. Refer to Testing and Adjusting, "Crankshaft Position for Fuel Injector Adjustment and Valve Lash Setting".

**Note:** When the actual stroke position is identified and the other stroke position is needed, remove the timing bolt from the flywheel. Turn the flywheel by 360 degrees in the direction of normal engine rotation.

i02492603

# Camshaft Timing

**SMCS Code:** 1210

## Timing Check

Table 2

| Tools Needed | Quantity |
|---|---|
| 9S-9082 Engine Turning Tool | 1 |

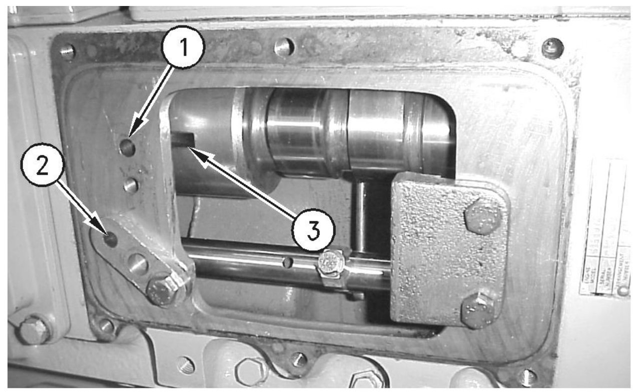


Illustration 40 g00769524

Location of timing pins (typical example)

(1) Timing hole
(2) Timing pin
(3) Slot in the camshaft for the timing pin

1. Remove rear camshaft covers from both sides of the engine.

2. Find the top center position for the number one piston. Refer to Testing and Adjusting, "Finding the Top Center Position for the No. 1 Piston" for the correct procedure.

**Note:** When the timing bolt is installed in the flywheel, it is not necessary to remove the No. 1 valve cover in order to find the compression stroke. Both rear camshaft covers must be removed in order to check the timing.

3. When the timing bolt is installed in the flywheel, look at the rear end of the camshaft. If the timing ring is visible, then the No. 1 piston is on the compression stroke. If the timing ring is not visible, feel the back of the camshaft for the groove. If the groove is at the back of the camshaft, the flywheel must be turned by 360 degrees in order to put the No. 1 piston on the compression stroke.

4. When the timing bolt is installed in the flywheel and the No. 1 piston is on the compression stroke, remove timing pins (2) from the storage positions.

5. Install the timing pins through timing holes (1) on each side of the engine. Install the timing pins into groove (3) in the camshaft on each side of the engine. In order to time the engine correctly, the timing pins must fit into the groove of each camshaft.

6. If the timing pins do not engage in the grooves of both camshafts, the engine is not in time, and one or both camshafts must be adjusted.

7. Both camshafts are adjusted in the same manner. Refer to "Timing Adjustment" for the procedure to put the camshafts in time with the crankshaft.

NOTICE
If a camshaft is out of time more than 18 degrees (approximately 1/2 the diameter of timing pin out of groove), the valves can make contact with the pistons. This will cause damage that will make engine repair necessary.

## Timing Adjustment

Table 3

| Tools Needed | Quantity |
|---|---|
| 9S-9082 Engine Turning Tool | 1 |
| 6V-3010 Puller Group | 1 |
| 8S-9089 Bolts | 2 |
| 5P-1076 Hard Washers | 2 |

**Note:** The timing must be checked before the timing adjustments are made. Refer to "Timing Check" for this procedure.

After the Timing Check procedure is complete, the timing bolt will be engaged in the flywheel. The No. 1 piston will be at the top center (TC) position.

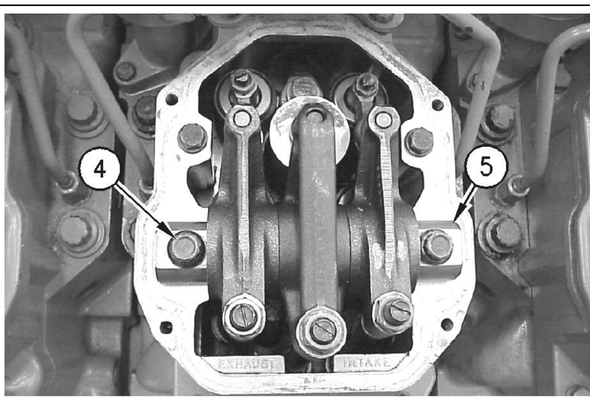


Illustration 41 g00769537

(4) Bolt
(5) Rocker shaft

1. Remove all of the valve covers on the side for the camshaft adjustment. Now, loosen bolts (4) that hold rocker shafts (5) to the valve cover bases until all rocker arms are free from the injectors and the valves.

**Note:** The above procedure must be done before camshaft drive gear (6) is pulled off the camshaft taper.

2. Remove the covers from the flywheel housing.

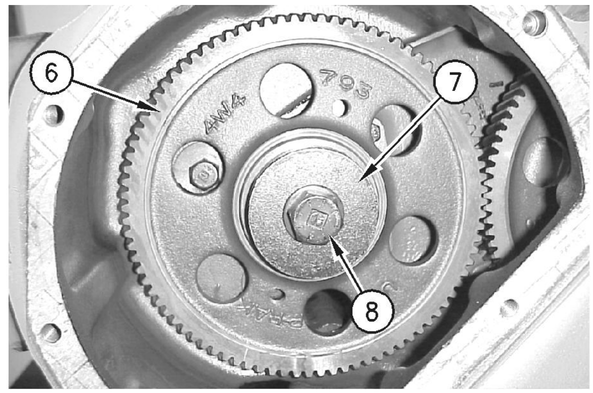


Illustration 42 g00769545

3. Remove bolt (8) and plate (7) from the end of the camshaft.

4. Install the 6V-3010 Puller Group, two 8S-9089 Bolts, and two 5P-1076 Hard Washers. Loosen drive gears (6) from the taper on the camshafts. Remove the tooling and the gears.

5. Remove timing pins (2) from the storage position on each side of the engine.

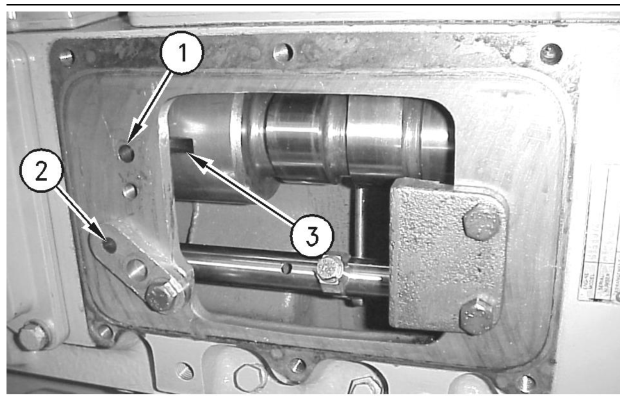


Illustration 43 g00769524

6. Turn the camshafts until the timing pins can be installed through the engine block and into grooves (3) (slots) in the camshafts.

7. Put camshaft drive gears (6) in position on the camshafts.

**8.** Use hand pressure to turn and hold the camshaft drive gears in the opposite direction of the rotation. This removes all gear clearance (backlash) between the camshaft drive gears and the idler gears.

**9.** Install plate (7) on the camshaft in order to hold the camshaft drive gears to each camshaft.

**10.** Tighten bolts (8).

Refer to the engine's Specifications manual.

**11.** Install the gaskets and covers on the flywheel housing.

**12.** Remove timing pins (2) from the camshafts. Install the timing pins in the storage positions. Install covers over the camshafts and timing pins.

**13.** Remove the timing bolt from the flywheel housing. Install the 8T-6765 Pipe Plug in the flywheel housing timing hole. Remove the engine turning tool. Install the cover and the gasket.

**14.** Be certain that the rocker arms are correctly engaged with the pushrods. Tighten the bolts in order to hold all of the rocker shafts in position.

**15.** Make valve lash adjustments to the unit injectors. Refer to Testing And Adjusting, “Valve Lash and Valve Bridge Adjustment” for the correct procedures.

i01493152

# Engine Speed Measurement

**SMCS Code:** 1901

Table 4

| Tools Needed | Quantity |
|---|---|
| 9U-7400 Multitach | 1 |

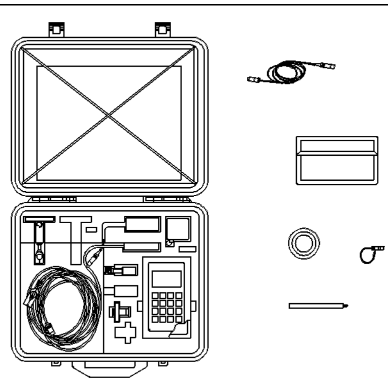

Illustration 44 g00286276

9U-7400 Multitach

The 9U-7400 Multitach can measure engine speed from an engine speed sensor on the flywheel housing. The 9U-7400 Multitach also has the ability to measure engine speed from visual engine parts in rotation.

The Operating Instructions, NEHS0605 are included with the 9U-7400 Multitach and these operating instructions contain instructions for the test procedure.

i02708199

# Crankshaft Position for Fuel Injector Adjustment and Valve Lash Setting

**SMCS Code:** 1202

Table 5

| Counterclockwise Rotation (Standard) from the Flywheel End of the Engine | | | | |
|---|---|---|---|---|
| Cylinders to Check/Adjust | | | | |
| Engine | Correct Stroke For No. 1 Piston At Top Center Position(1) | Inlet Valves | Exhaust Valves | Injectors |
| 3508 | Compression | 1-2-6-8 | 1-2-3-7 | 2-3-4-7 |
| | Exhaust | 3-4-5-7 | 4-5-6-8 | 1-5-6-8 |
| 3512 | Compression | 1-3-6-7-10-12 | 1-4-5-6-9-12 | 2-4-5-8-9-11 |
| | Exhaust | 2-4-5-8-9-11 | 2-3-7-8-10-11 | 1-3-6-7-10-12 |
| 3516 | Compression | 1-2-5-7-8-12-13-14 | 1-2-3-4-5-6-8-9 | 3-4-6-9-10-11-15-16 |
| | Exhaust | 3-4-6-9-10-11-15-16 | 7-10-11-12-13-14-15-16 | 1-2-5-7-8-12-13-14 |

(1) Put the No. 1 Piston at the top center (TC) position and identify the correct stroke. Refer to Testing and Adjusting, “Finding the Top Center Position for the No 1 Piston”. Find the top center position for a particular stroke and make the adjustment for the correct cylinders. Remove the timing bolt . Turn the flywheel by 360 degrees in the direction of normal engine rotation. This will put the No. 1 piston at the top center (TC) position on the other stroke. Install the timing bolt in the flywheel and complete the adjustments for the cylinders that remain.

Table 6

| Clockwise Rotation (Reverse) from the Flywheel End of the Engine | | | | |
|---|---|---|---|---|
| Cylinders To Check/Adjust | | | | |
| Engine | Correct Stroke For No. 1 Piston At Top Center Position(1) | Inlet Valves | Exhaust Valves | Injectors |
| 3508 | Compression | 1-3-4-8 | 1-2-7-8 | 2-6-7-8 |
| | Exhaust | 2-5-6-7 | 3-4-5-6 | 1-3-4-5 |
| 3512 | Compression | 1-3-4-6-7-12 | 1-4-5-8-9-12 | 2-5-8-9-10-11 |
| | Exhaust | 2-5-8-9-10-11 | 2-3-6-7-10-11 | 1-3-4-6-7-12 |
| 3516 | Compression | 1-2-5-6-7-8-13-14 | 1-2-3-4-5-6-9-10 | 3-4-9-10-11-12-15-16 |
| | Exhaust | 3-4-9-10-11-12-15-16 | 7-8-11-12-13-14-15-16 | 1-2-5-6-7-8-13-14 |

(1) Put the No. 1 Piston at the top center (TC) position and identify the correct stroke. Refer to Testing and Adjusting, “Finding the Top Center Position for the No 1 Piston”. Find the top center position for a particular stroke and make the adjustment for the correct cylinders. Remove the timing bolt . Turn the flywheel by 360 degrees in the direction of normal engine rotation. This will put the No. 1 piston at the top center (TC) position on the other stroke. Install the timing bolt in the flywheel and complete the adjustments for the cylinders that remain.

i01374151

# Fuel Injector Timing

**SMCS Code:** 1290-025

NOTICE

The camshafts must be correctly timed with the crankshaft before an adjustment of fuel timing is made. The timing pins must be removed from the camshafts before the crankshaft is turned or damage to the cylinder block will be the result.

**Note:** Ensure that the engine is in time. Refer to Testing And Adjusting, “Camshaft Timing”.

**Note:** Refer to Testing and Adjusting, “Crankshaft Position for Fuel Injector Adjustment and Valve Lash Setting”. All of the injectors can be checked or adjusted with the crankshaft positions that are given in the chart. This check will make sure that the pushrod lifters are off the lobes and on the base circles of the camshafts.

Refer to the TMI (Technical Marketing Information) for the correct fuel timing dimension to use.

Table 7

| Tools Needed | |
|---|---|
| 5P-4160 Indicator Contact Point | 1 |
| 1U-8869 Dial Indicator | 1 |
| 9U-5138 Setting Gauge | 1 |
| 9U-5233 Magnetic Fixture Group | 1 |
| 9S-9082 Engine Turning Tool | 1 |


Illustration 45 g00322956

1U-8869 Dial Indicator

**1.** The digital dial indicator needs to be programmed to read actual timing dimensions. Since the 9U-5138 Setting Gauge in the timing and fuel setting tool group is 87.00 mm, set the digital dial indicator for 87.00 mm. Use the following steps in order to program the indicator to read 87.00 mm.

**a.** Turn the indicator to the ON position by pushing the "on/off" button.

**b.** Push the "in/mm" button so the display shows "mm".

**c.** A negative "-" sign should be in the display window under "REV". If that space is blank, push the "+/−" button so the display shows a negative "-" sign. When this is done, the movement of the plunger into the indicator will be displayed. The display will be shown as a negative movement. The movement of the plunger out of the indicator will be displayed as a positive movement.

**d.** Push the preset button and hold the preset button down until there is a flashing "P" in the upper right corner of the display. Then release the button.

**e.** Push the preset button and hold the preset button down until the flashing "P" disappears and a flashing indicator bar is seen in the lower left corner of the display. Then release the button. Use the preset button so that this position is blank.

**f.** Push the preset button and hold the preset button down until the flashing indicator begins flashing under the first number position. The first number position is located in the fourth position to the left of the decimal. Then release the button. Momentarily pushing the preset will cause the display number in that position to change. Use the preset until this position reads zero (0).

**g.** Use the preset button to move the flashing indicator and change the display numbers until the display shows 0087.00 mm. Push the preset button and hold the preset button until the flashing "P" is shown in the upper right corner of the display. Release the preset button. Momentarily push the preset button so the flashing "P" and the zeroes to the left of 87.00 mm disappear.

**h.** The indicator can now be turned off. The indicator will retain the preset number in memory. To recall the preset number, repeat Steps 1.a through 1.d.

**2.** Install a 5P-4160 Indicator Contact Point in the indicator stem.

**3.** Install the indicator into the 9U-5233 Magnetic Fixture Group. Leave the collet loose.

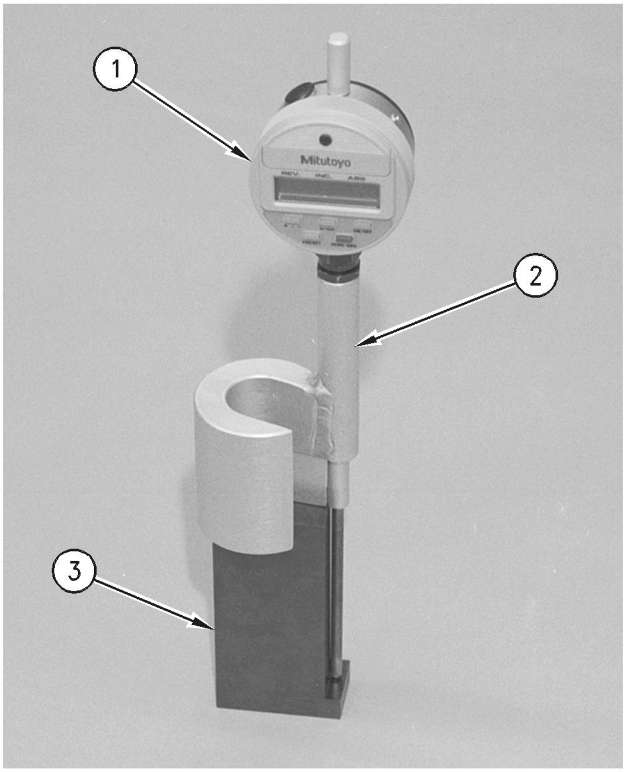


Illustration 46 g00323023

Adjustment of fuel timing tools

(1) 1U-8869 Dial Indicator
(2) 9U-5233 Magnetic Fixture Group
(3) 9U-5138 Setting Gauge

**4.** Place the fixture and the indicator on the 9U-5138 Setting Gauge with the extension rod of the bracket on the step of the gauge. Position the indicator in the bracket so that the indicator plunger can travel adequately. Tighten the collet.

**5.** Repeat Steps 1.a through 1.d.

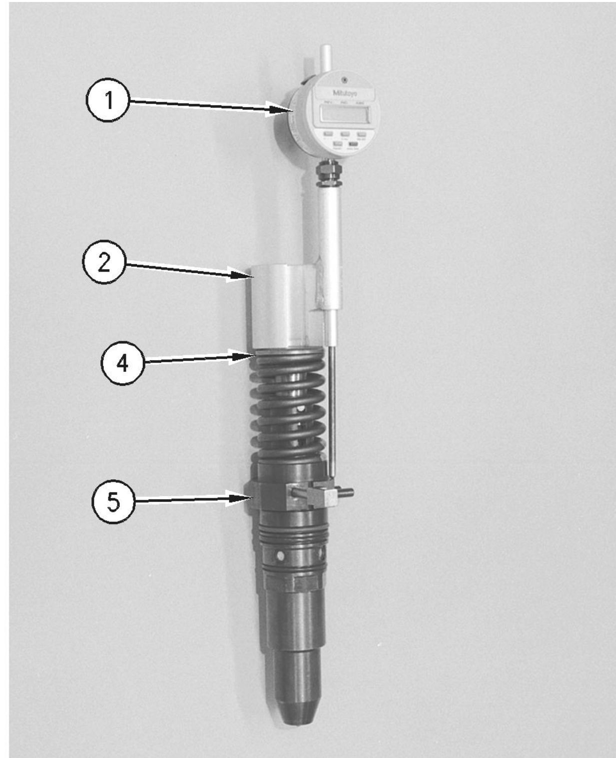


Illustration 47 g00323029

Fuel timing tools in position

(1) 1U-8869 Dial Indicator
(2) 9U-5233 Magnetic Fixture Group
(4) Injector follower
(5) Shoulder on fuel injector body

**6.** Momentarily push the preset button on the digital dial indicator in order to stop the “P” in the upper right hand corner from flashing. The display should show 87.00 mm. Place the 1U-8869 Dial Indicator and the 9U-5233 Magnetic Fixture Group in the correct position on the injector. Make sure that the magnetic base of the timing fixture is on the top surface of injector follower (4) and that the extension rod is on the top surface of shoulder on fuel injector body (5).

**Note:** In order to ensure an accurate fuel timing dimension, the top surfaces of injector follower (4) and shoulder on fuel injector body (5) must be clean and dry.

**7.** The digital dial indicator should now read the actual fuel timing dimension of the injector that is being checked.

**8.** No adjustment is necessary if the dial indicator reads the correct fuel timing dimension. Refer to the TMI (Technical Marketing Information) for the engine that is being checked. Proceed to Step 12.

**9.** If the dial indicator does not read the correct fuel timing dimension or the desired fuel timing dimension, proceed with Steps 10 through 13.

**10.** Ensure that the 1U-8869 Dial Indicator and the 9U-5233 Magnetic Fixture Group are in the correct position on the injector. Loosen the locknut for the pushrod adjustment screw.

**11.** Turn the adjustment screw until the desired fuel timing dimension is read on the digital dial indicator.

**Note:** Turning the adjustment screw clockwise will lower the fuel timing dimension. Turning the adjustment screw counterclockwise will increase the fuel timing dimension.

Tighten the adjustment screw locknut to a torque of 70 ± 15 N·m (50 ± 11 lb ft) and check adjustment again. If necessary, repeat the procedure until the adjustment is correct.

**12.** Remove the timing bolt from the flywheel when the fuel timing check is completed.

**13.** Turn the flywheel by 360 degrees in the direction of normal engine rotation. Install the timing bolt for the flywheel. Repeat the procedure for the other half of the engine.

i01374252

# Fuel Injector Synchronization

**SMCS Code:** 1290-025

Table 8

| Tools Needed | |
|---|---|
| 8T-2684 Rack Synchronization Gauge | 1 |

Injector synchronization is the setting of all fuel injector racks to a reference position so each injector gives the same amount of fuel to each cylinder. Injector synchronization is done by setting each fuel injector rack to the same position while the control linkage is in a fixed position. Use the following procedure for the adjustment of injector synchronization:

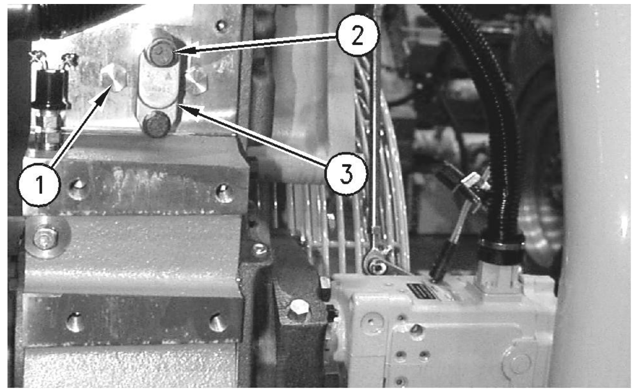


Illustration 48 g00323443

Location of fuel setting cover and synchronization pin (typical example)

(1) Plug
(2) Synchronization pin
(3) Cover

**1.** The top bolt that holds cover (3) in position is synchronization pin (2). Remove synchronization pin (2) and plug (1) from the front drive housing. DO NOT destroy the seal or remove cover (3).

**2.** Remove the washer from the synchronization pin. Remove the plug and install the synchronization pin into the threaded hole. Tighten the synchronization pin.

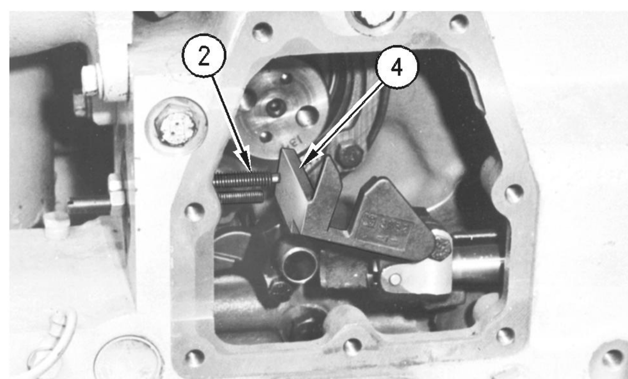


Illustration 49 g00323444

Position of the synchronization pin (typical example)

(2) Synchronization pin
(4) Fuel stop lever

**3.** Turn the governor or the actuator terminal shaft to the fuel ON position until the flat face of fuel stop lever (4) contacts synchronization pin (2). This is the synchronizing position or zero reference point. Hold the control linkage in this position when the injectors are adjusted.

**4.** Remove the valve covers.

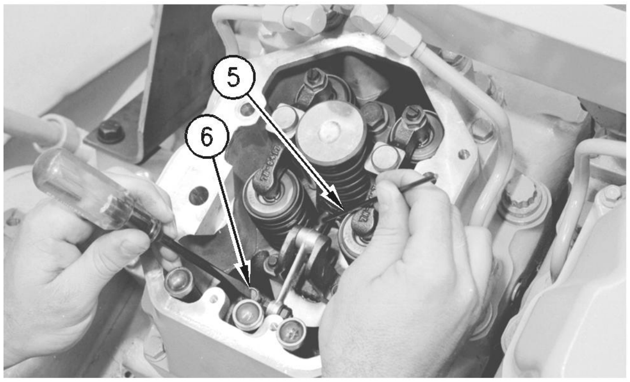


Illustration 50 g00323446

Location for gauge and control rod adjustment (typical example)

(5) 8T-2684 Rack Synchronization Gauge
(6) Control rod

**5.** With the fuel stop lever against the synchronization pin, put the 8T-2684 Rack Synchronization Gauge (5) on the round part of the fuel injector rack between the fuel injector body and the end of the rack. Use a screwdriver and make an adjustment of control rod (6). Turn the screw that is located on the control rod one click at a time until the 8T-2684 Rack Synchronization Gauge fits between the fuel injector body and the shoulder at the end of the rack. Remove the screwdriver from the control rod so that no pressure remains on the linkage. Check the setting with the rack synchronization gauge. Any pressure on the linkage with the screwdriver will not give a correct indication when the setting is checked with the rack synchronization gauge. Ensure that the linkage is free and that the linkage is giving an accurate setting by moving the linkage. Check the setting again. Put the box end of a combination wrench over the nut and the bolt. The nut and the bolt connect control rod (6) and the bellcrank. Pull upward on the control rod three times. Check the setting again.

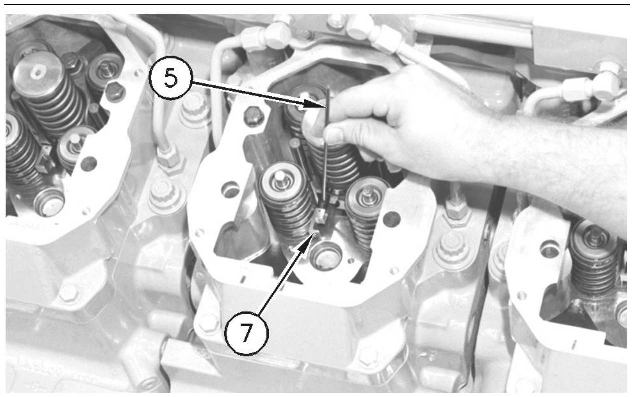


Illustration 51 g00323448

Gauge in place on the fuel injector rack (typical example)

(5) 8T-2684 Rack Synchronization Gauge
(7) Fuel injector rack

**6.** If the other injectors need to be adjusted, use rack synchronization gauge (5). When all adjustments have been made, release the actuator terminal shaft.

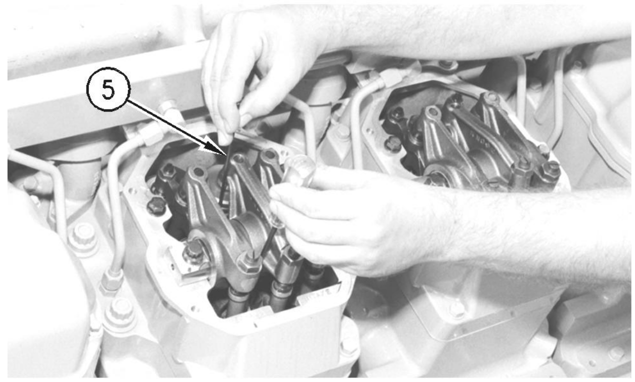


Illustration 52 g00323450

Adjustment of fuel control rod (typical example)

(5) 8T-2684 Rack Synchronization Gauge.

**7.** Install the valve covers.

**8.** Check the fuel setting and perform any necessary adjustments. Refer to Testing And Adjusting, "Fuel Setting" for this procedure.

i01549302

# Fuel Setting

**SMCS Code:** 1257-025

Table 9

| Tools Needed | |
|---|---|
| 9U-5132 Engine Timing Tool Group | 1 |
| 4C-8753 Extended Collet | 1 |
| 6V-3075 Dial Indicator | 1 |
| 5P-7263 Indicator Contact Point | 1 |
| 8T-2684 Rack Synchronization Gauge | 1 |

Refer to Special Instruction, SEHS9278 for the instructions on the use of the 4C-8753 Extended Collet.

Fuel setting is the adjustment of the fuel setting screw to a specified position. The fuel setting screw limits the power output of the engine by setting the maximum travel of all the fuel injector racks.

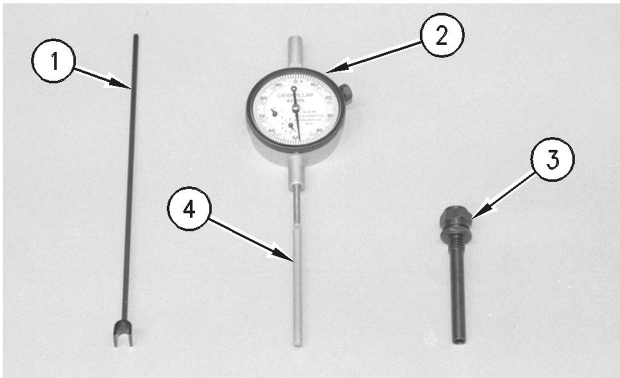


Illustration 53 g00323603

Synchronization and fuel setting tools

(1) 8T-2684 Rack Synchronization Gauge
(2) 6V-3075 Dial Indicator
(3) 4C-8753 Extended Collet
(4) 5P-7263 Indicator Contact Point

Before the fuel setting is checked, the injectors must be correctly synchronized. Refer to Testing And Adjusting, “Fuel Injector Synchronization”. After the injectors are synchronized correctly, leave the synchronization pin in place for the procedure that follows.

1. Put 6V-3075 Dial Indicator (2) with 5P-7263 Indicator Contact Point Contact Point (4) in 4C-8753 Extended Collet (3). Remove the plug from the right side of fuel setting cover (8).

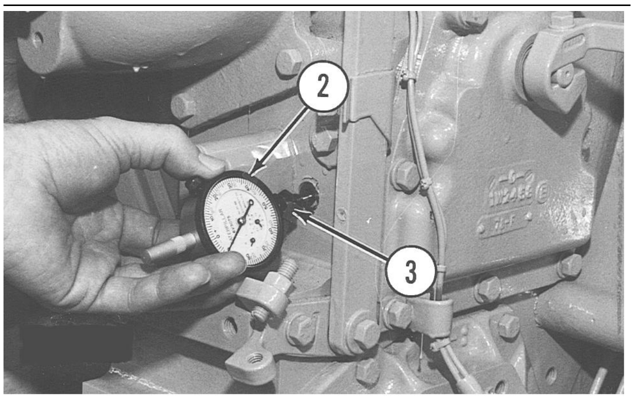


Illustration 54 g00323643

Installed dial indicator (typical example)

(2) 6V-3075 Dial Indicator with 5P-7263 Indicator Contact Point
(3) 4C-8753 Extended Collet

2. Move the governor or the actuator terminal shaft toward the ON position. The flat face of fuel stop lever (6) should make contact with synchronization pin (5). Hold the linkage in this position.

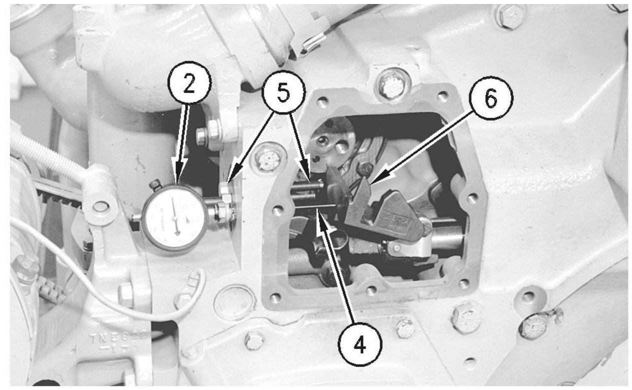


Illustration 55 g00323663

(2) 6V-3075 Dial Indicator
(4) 5P-7263 Indicator Contact Point
(5) Synchronization pin
(6) Fuel stop lever

3. Install dial indicator (2) and extended collet (3) in the threaded hole. After indicator contact point (4) touches fuel stop lever (6), slide dial indicator (2) until the indicator reads zero. Keep the dial indicator in this position by tightening collet (3).

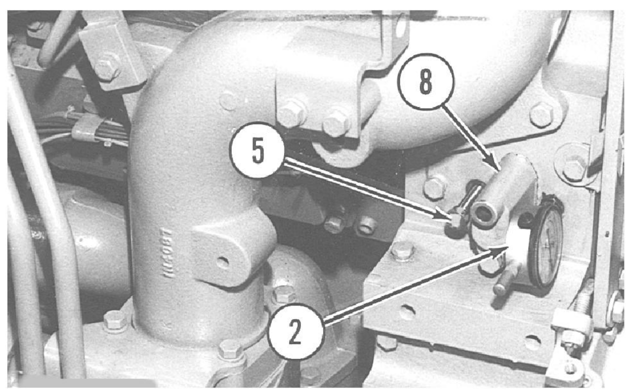


Illustration 56 g00805403

Checking fuel setting (typical example)

(2) 6V-3075 Dial Indicator
(5) Synchronization pin
(8) Fuel setting cover

4. Unscrew synchronization pin (5) by 25 mm (1 inch) or remove synchronization pin (5). Slowly move the governor or the actuator terminal shaft toward the fuel ON position until the flat face of the fuel stop lever is against the end of the fuel setting screw. The dial indicator reading will be the present fuel setting when the linkage is held in this position.

**Note:** Refer to the TMI (Technical Marketing Information) for the correct fuel setting.

5. If the fuel setting is correct, remove the dial indicator and the synchronization pin. Install the two plugs, and install the synchronization pin back into cover (8).

**6.** If the fuel setting needs adjustment, see "Fuel Setting Adjustment".

NOTICE

A mechanic with governor and fuel setting training is the ONLY one to make adjustments to the engine fuel setting.

## Fuel Setting Adjustment

**1.** Cut the seal wire and remove fuel setting cover (8) and the gasket. Loosen locknut (7). Hold the fuel stop lever against the end of the fuel setting screw. Turn the fuel setting screw clockwise or counterclockwise until the correct reading is on the dial indicator.

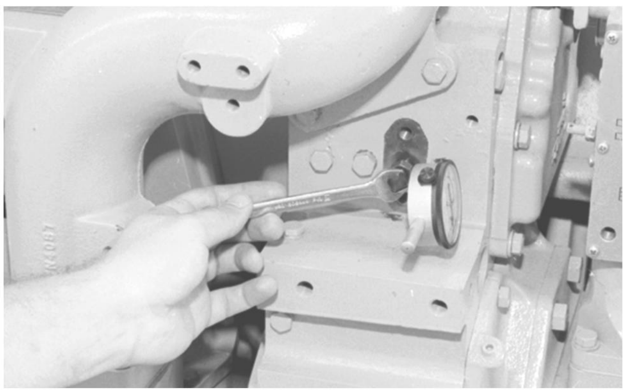

Illustration 57 g00323705

Adjustment of the fuel setting screw (typical example)

**2.** Now tighten locknut (7). Be sure that the fuel setting screw does not turn when the locknut is tightened. Release the fuel system linkage and move the linkage toward the fuel ON position. Check the dial indicator reading again in order to be sure that the fuel setting is still correct.

**3.** Remove dial indicator (2) and synchronization pin (5). Install the two plugs.

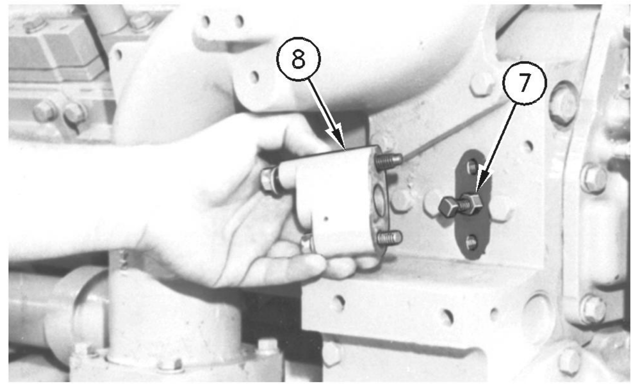


Illustration 58 g00323706

Installed cover (typical example)

(7) Locknut
(8) Fuel setting cover

**4.** Put fuel setting cover (8) and the gasket in position over the fuel setting screw. Install the bolt and synchronization pin (5) in the cover. Install a new seal wire.

# Air Inlet and Exhaust System

i01374804

## Restriction of Air Inlet and Exhaust

**SMCS Code:** 1050-040

There will be a reduction in the performance of the engine if there is a restriction in the air inlet system or the exhaust system.

The flow of air through the air cleaner may have a restriction. The pressure at the restriction of the flow of air must not exceed 6.25 kPa (25 inches of $H_2O$).

Back pressure is the difference in the pressure between the exhaust at the outlet elbow and the atmospheric air. Back pressure from the exhaust must not be more than 6.75 kPa (27 inches of $H_2O$).

i02371518

## Measuring Inlet Manifold Pressure

**SMCS Code:** 1058-082

The efficiency of an engine can be checked. Compare the pressure in the inlet manifold with the specifications that are given in the Fuel Setting and Related Information in the TMI (Technical Marketing Information). This test is performed when there is a decrease in the horsepower from the engine yet there is no real sign of a problem with the engine.

The correct pressure for the inlet manifold is given in the TMI. Development of this information is done with these conditions:

- 96 kPa (28.8 inches of Hg) dry barometric pressure
- 29 °C (84 °F) outside air temperature
- 35 API rated fuel

Any change from these conditions can change the pressure in the inlet manifold. The outside air may have a higher temperature and a lower barometric pressure than the values that are given above. This will cause a lower horsepower and a lower inlet manifold pressure measurement than the pressure that is given in the TMI (Technical Marketing Information). Outside air that has a lower temperature and a higher barometric pressure will cause a higher horsepower and a higher inlet manifold pressure measurement.

A difference in the fuel rating will change the horsepower in the inlet manifold and the pressure in the inlet manifold. If the fuel is rated above 35 API, the pressure in the inlet manifold can be less than the pressure that is given in the TMI. If the fuel is rated below 35 API, the pressure in the inlet manifold can be more than the pressure that is given in the TMI.

When you are checking the pressure in the inlet manifold, be sure that the air inlet or the exhaust is not restricted.

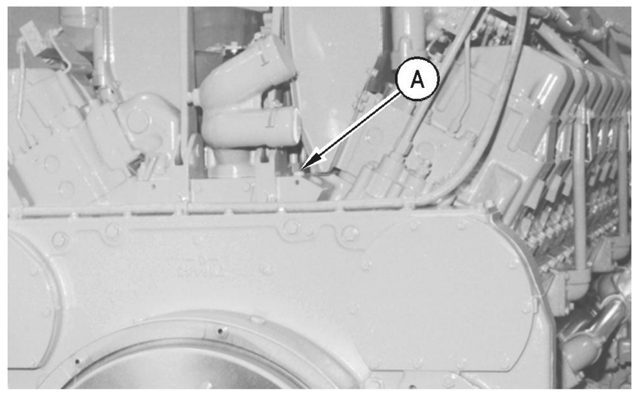


Illustration 59 g00322855

Pressure test location (typical example)

(A) Pipe plug

In order to check the inlet manifold pressure, remove the 1/2-14-NPTF pipe plug (A). Connect the 1U-5470 Engine Pressure Group to this opening in the inlet manifold.

This tool group has a gauge to read pressure in the inlet manifold. Refer to Special Instruction, SEHS8524 for further instructions.

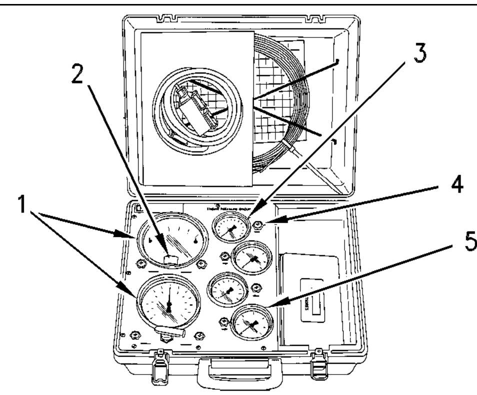


Illustration 60 g00284796

1U-5470 Engine Pressure Group

(1) Pressure indicators
(2) Zero adjustment screw
(3) Pressure indicator
(4) Pressure tap
(5) Pressure indicator

i02492616

# Measuring Exhaust Temperature

**SMCS Code:** 1088-082

Use the 164-3310 Infrared Thermometer in order to check the exhaust temperature. Refer to the instructions that are packaged with the tool for additional information.

Individual cylinder head exhaust temperatures can be checked with the 4C-6090 Temperature Selector Group, the 6V-9130 Temperature Adapter, and the 237-5130 Digital Multimeter. Refer to Operating Manual, NEHS0537 for the complete operating instructions for using the 4C-6090 Temperature Selector Group.

i01727329

# Crankcase Pressure

**SMCS Code:** 1215; 1317-082

Several conditions can cause high crankcase pressure:

- High engine oil level
- Plugged crankcase breather and/or ventilation
- Loose fuel injector
- Damaged oil seal in the turbocharger
- Internal engine problem

Damaged pistons and/or piston rings cause excessive pressure in the crankcase. This condition will cause the engine to run rough. Excessive fumes flow through the crankcase breather and the crankcase breather can be quickly restricted. Restriction of the crankcase breather and the corresponding increase in crankcase pressure can cause engine oil to leak from gaskets and seals.

Internal engine problems can cause a rapid increase of crankcase pressure. For this reason, the engine is shut down if the crankcase pressure exceeds the ambient air pressure by 7 kPa (1 psi).

i01219662

# Compression

**SMCS Code:** 1215-081

An engine that runs roughly can have a leak at the valves. An engine that runs roughly can also have valves that need an adjustment. Removing the head and inspecting the valves and valve seats is necessary in order to find the small defects. Repairs of these problems are normally done when you are reconditioning the engine.

i01665366

# Cylinder Heads

**SMCS Code:** 1100

The cylinder heads have valve seat inserts, valve guides, and bridge dowels that can be removed when the parts are worn or damaged. Refer to Disassembly And Assembly for the replacement of these components.

## Valves

The removal and the installation of the valves is easier with use of the 1P-3527 Valve Spring Compressor.

## Valve Seat Inserts

Use the 166-7441 Valve Seat Extractor Tool for the removal and the installation of the valve seat inserts. Lower the temperature of the insert before the insert is installed in the head.

## Valve Guides

The tools for the removal and for the installation of the valve guides are the 5P-1729 Valve Guide Bushing and the 7M-3975 Valve Guide Driver. The counterbore in the driver bushing installs the guide to the correct height.

## Checking Valve Guide Bores

Use the 5P-3536 Valve Guide Gauge Group in order to check the bore of the valve guides. Refer to Special Instruction, GMG02562 for the instructions for the use of this tool.

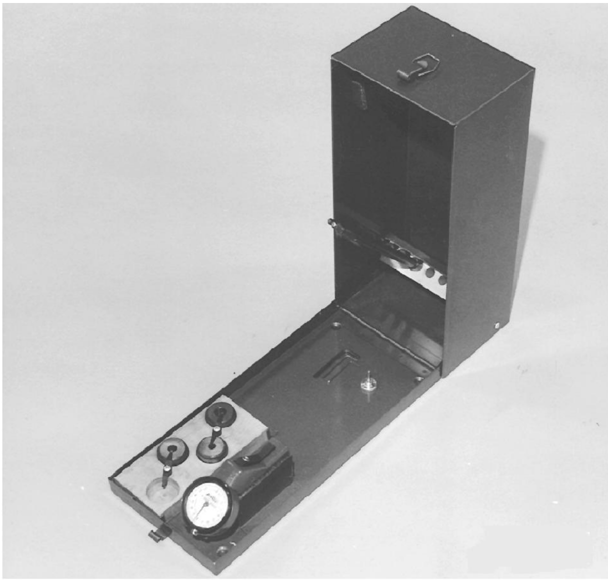

Illustration 61 g00285313

5P-3536 Valve Guide Gauge Group

## Bridge Dowels

Use a 5P-0944 Dowel Puller Group and a 5P-0942 Dowel Extractor. Remove the bridge dowels. Install a new bridge dowel with a 6V-4009 Dowel Driver. This dowel driver installs the bridge dowel to the correct height.

i02126811

# Valve Lash Check

**SMCS Code:** 1105-535

**⚠ WARNING**

**The Electronic Control Module produces high voltage. To prevent personal injury make sure the Electronic Control Module is not powered and do not come in contact with the fuel injector solenoid terminals while the engine is running.**

Valve lash is measured between the rocker arm and the bridge for the valves. All of the clearance measurements and the adjustments must be made with the engine stopped. **The valves must be fully closed.**

If the measurement of the valve lash is in the acceptable range, no adjustments are necessary. The range is given in Table 10.

Table 10

| Valve Lash Check: Engine Stopped | |
|---|---|
| **Valves** | **Acceptable Valve Lash Range** |
| Inlet | 0.42 to 0.58 mm (0.017 to 0.023 inch) |
| Outlet | 0.92 to 1.08 mm (0.036 to 0.043 inch) |

If the measurement is not within this range, adjustment is necessary. Refer to Testing And Adjusting, "Valve Lash and Valve Bridge Adjustment".

i02013998

# Valve Lash and Valve Bridge Adjustment

**SMCS Code:** 1102-036

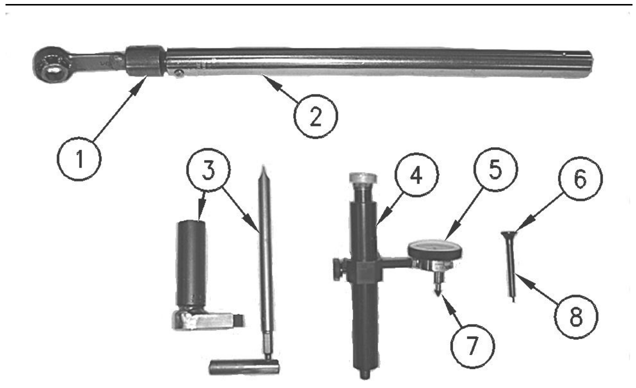


Illustration 62 g00286271

(1) 147-2060 Wrench
(2) 147-2059 Torque Wrench
(3) 148-7211 Bridge Nut Socket
(4) 145-5191 Gauge Support
(5) 147-2056 Dial Indicator
(6) 147-5536 Indicator Contact Point
(7) 147-2057 Indicator Contact Point
(8) 147-2058 Indicator Extension

Table 11

| Tools Needed | Quantity |
|---|---|
| 147-2060 Wrench | 1 |
| 147-2059 Torque Wrench | 1 |
| 148-7211 Bridge Nut Socket | 1 |
| 145-5191 Gauge Support | 1 |
| 147-2056 Dial Indicator | 1 |
| 147-5536 Indicator Contact Point | 1 |
| 147-2057 Indicator Contact Point | 1 |
| 147-2058 Indicator Extension | 1 |
| 147-5537 Dial Indicator (not shown) | 1 |

**Note:** The 145 - 5191 Gauge Support (4), the 147 - 2057 Indicator Contact Point (7), the 147 - 2058 Indicator Extension (8), and the 147 - 5536 Indicator Contact Point (6) are included in the 147 - 5482 Valve Lash Gauge Group.

**Note:** The 147 - 2056 Dial Indicator or the 147 - 5537 Dial Indicator (Metric, not shown) can be used with the 147 - 5482 Valve Lash Gauge Group.

There are two different design of valve bridges that are used. If the engine is equipped with an adjustable valve bridge (Illustration 63), proceed to the “Valve Bridge Adjustment”. If the engine is equipped with a nonadjustable valve bridge (Illustration 64), proceed to the “Valve Lash Adjustment”.

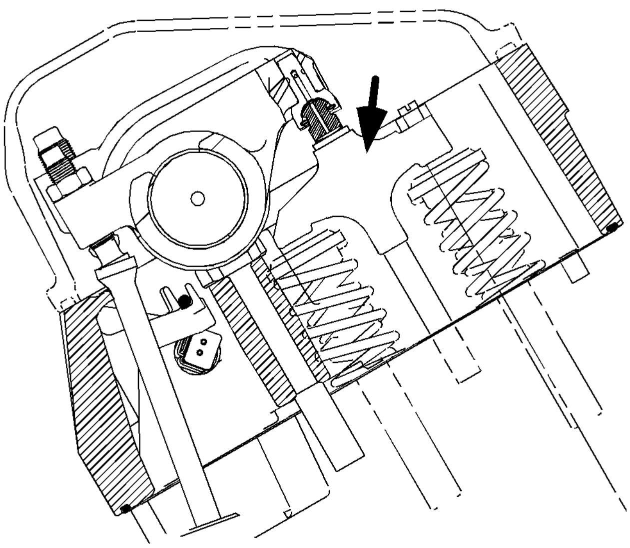

Illustration 63 g01034327

Adjustable valve bridge

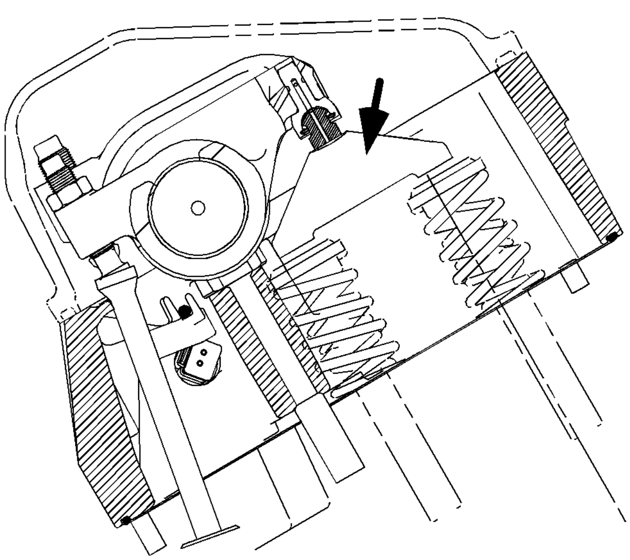

Illustration 64 g01034328

Nonadjustable valve bridge

## Valve Bridge Adjustment

**WARNING**

**The Electronic Control Module produces high voltage. To prevent personal injury make sure the Electronic Control Module is not powered and do not come in contact with the fuel injector solenoid terminals while the engine is running.**

**Note:** When the 147 - 5482 Valve Lash Gauge Group is used, it is not necessary for you to remove the rocker arm shaft assemblies. The valves must be fully closed when the adjustment is made. Refer to Testing and Adjusting, “Finding the Top Center Position for the No. 1 Piston”.

## Installation

1. Assemble the 147 - 2058 Indicator Extension and the 147 - 5536 Indicator Contact Point on the 147 - 2056 Dial Indicator or on the 147 - 5537 Dial Indicator.

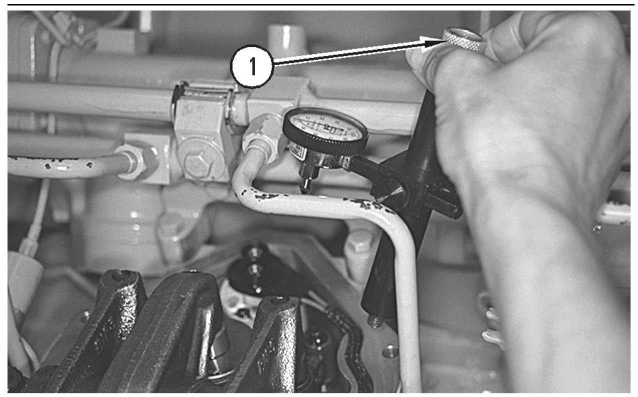


Illustration 65 g00286279

145 - 5191 Gauge Support

(1) Knurled knob

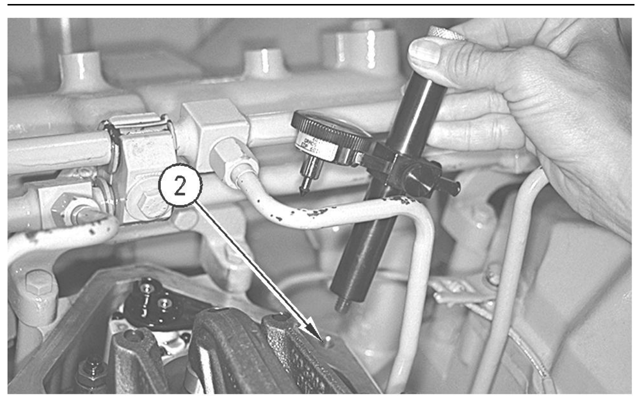


Illustration 66 g00286280

(2) Valve cover base rear bolt hole

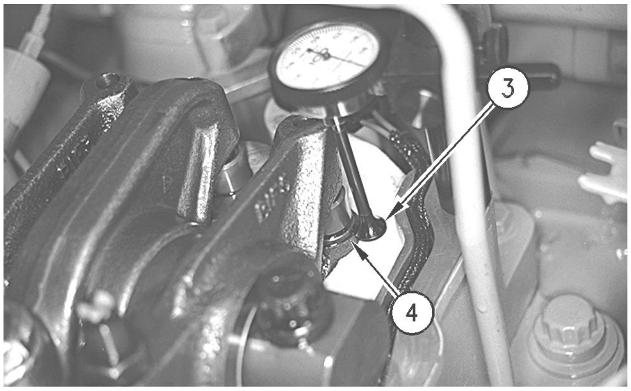


Illustration 67 g00286281

(3) 147-5536 Indicator Contact Point
(4) Top edge of the valve bridge

2. Install the 145-5191 Gauge Support in the rear bolt hole (2). The rear bolt hole is located in the valve cover base. Adjust contact point (3) on the top edge of valve bridge (4).

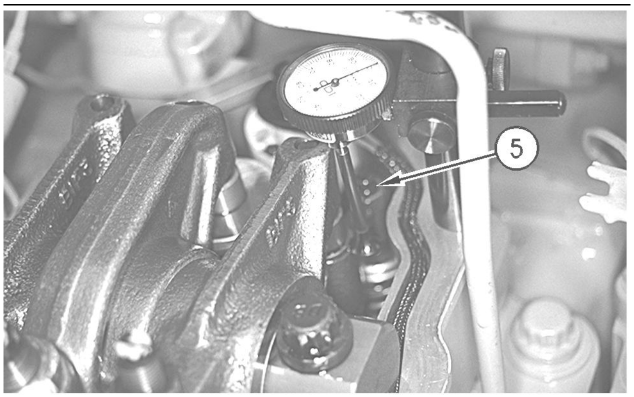


Illustration 68 g00286283

(5) Adjustment screw

3. Loosen the locknut for the adjustment screw. Loosen the adjustment screw (5) by several turns.

4. Apply a force of 5 N (1 lb) to 45 N (10 lb). Push down on the top contact surface of the valve bridge. Zero the indicator.

5. Turn adjustment screw (5) in the clockwise direction until the dial indicator reads 0.038 mm (0.0015 inch). This measurement is equal to turning the adjustment screw 20 to 30 degrees clockwise after the screw contacts the end of the valve.

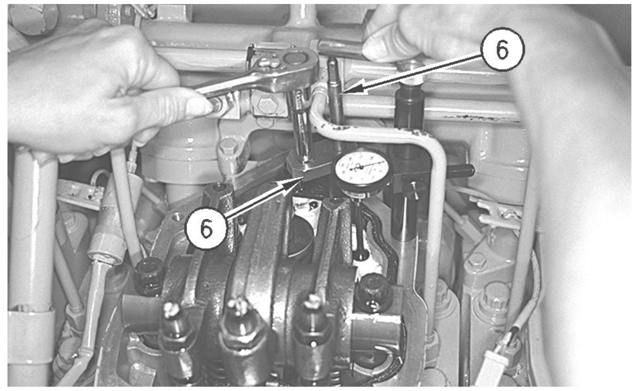


Illustration 69 g00286364

(6) 148-7211 Bridge Nut Socket

6. Hold the adjustment screw with the 148-7211 Bridge Nut Socket (6) in order to tighten the locknut to 30 ± 4 N·m (22 ± 3 lb ft). You may use a sliderule torque computer in order to determine the torque wrench dial reading for the different extensions. Refer to Special Instruction, SEHS7150, "Snap On Torque Computer".

## Valve Lash Adjustment

**WARNING**

**The Electronic Control Module produces high voltage. To prevent personal injury make sure the Electronic Control Module is not powered and do not come in contact with the fuel injector solenoid terminals while the engine is running.**

**Note:** Adjust the valve bridges before you make the valve lash adjustments.

Table 12

| Valve Lash Setting: Engine Stopped | |
|---|---|
| **Valves** | **Gauge Dimension** |
| Inlet | 0.50 mm (0.020 inch) |
| Exhaust | 1.00 mm (0.040 inch) |

1. Ensure that the number 1 piston is at the top center position. Refer to Testing and Adjusting , "Finding the Top Center Position for the No. 1 Piston".

2. The number 1 piston should be at the top center position of the correct stroke. Make adjustments to the valves according to the chart: Refer to Testing and Adjusting, "Crankshaft Positions for Fuel Injector Adjustment and Valve Lash Setting".

**Note:** Tap each rocker arm on the top of the adjustment screw before you make any adjustments. Use a soft hammer. Make sure that the lifter roller is seated against the base circle of the camshaft.

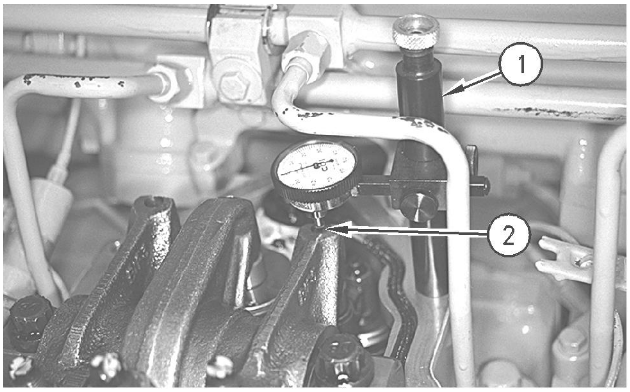


Illustration 70 g00286365

(1) 145-5191 Gauge Support
(2) 147-2057 Indicator Contact Point

3. Install the 145-5191 Gauge Support (1). Use the 147-2056 Dial Indicator or use the 147-5537 Dial Indicator. Use the 147-2057 Indicator Contact Point (2). Install the tool in the rear bolt hole. The rear bolt hole is located on the valve cover base.

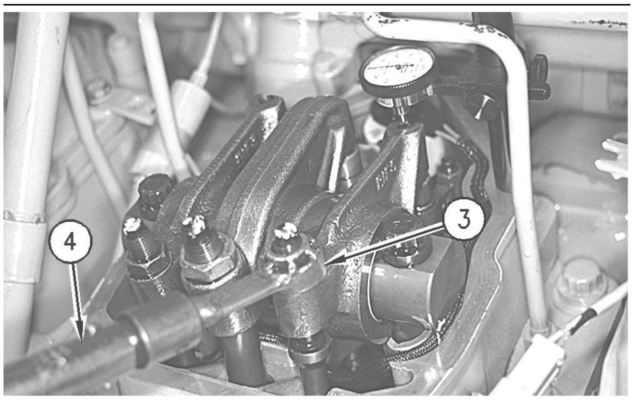


Illustration 71 g00286366

(3) 147-2060 Wrench
(4) 147-2059 Torque Wrench

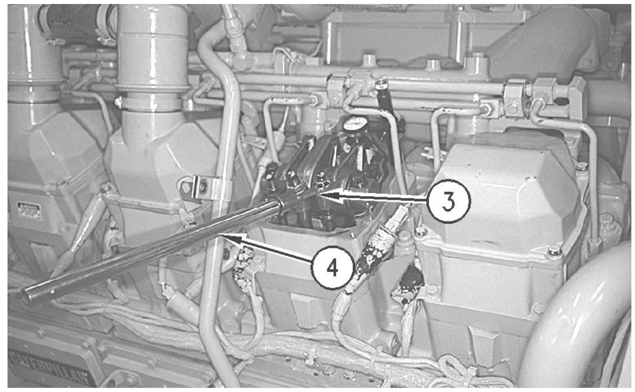


Illustration 72 g00286367

(3) 147-2060 Wrench
(4) 147-2059 Torque Wrench

4. Move the rocker assembly upward and move the rocker arm assembly downward. Move the rocker assembly several times. The oil film is removed in order to get a true zero reading on the dial indicator. Use the 147-2060 Wrench (3) and use the 147-2059 Torque Wrench (4). Install the socket wrench and install the torque wrench on the nut of the rocker arm. Apply upward pressure to the front of the rocker assembly. Set the dial indicator to zero. The weight of the torque wrench (4) allows the valve lash to be read. Do not apply any pressure on the torque wrench.

5. Loosen the locknut. The locknut is located on the adjustment screw of the pushrod. Turn the adjustment screw until the valve lash is set to specifications. Tighten the nut for the adjustment screw to 70 ± 15 N·m (50 ± 11 lb ft ). The 147-2059 Torque Wrench is preset to the torque that is required. Check the adjustment again.

# Lubrication System

i01574160

## General Information (Lubrication System)

**SMCS Code:** 1300

The following problems generally indicate a problem in the engine's lubrication system.

- Excessive consumption of engine oil
- Low engine oil pressure
- High engine oil pressure
- Excessive bearing wear
- Increased engine oil temperature

i01910919

## Accumulator Pressure - Test

**SMCS Code:** 1320-081

**S/N:** 29Z1-Up

Table 13

| Tools Needed | Qty |
|---|---|
| 175-5507 Nitrogen Charging Group | 1 |
| 8T-0862 Pressure Gauge (−100 to 500 kPa (−15 to 72 psi)) (1) | 1 |
| 8T-0863 Pressure Gauge (0 to 250 kPa (0 to 36 psi)) (1) | 1 |

(1) The procedure does not require two pressure gauges. Either pressure gauge may be used.

**Note:** Because the accumulator operates with a low pressure, a low pressure gauge is needed for this procedure.

Periodic measuring of the accumulator's pressure can help detect wear of the accumulator's seals.

If oil leaks past the piston's O-ring seal into the upper portion of the accumulator, the pressure in the upper portion will increase.

If nitrogen gas leaks past the piston's O-ring seal into the lower portion of the accumulator, the pressure in the lower portion will decrease. Low pressure can also be caused by nitrogen gas that leaks from the seals for the gas valve and/or for the end caps.

### Checking the Pressure

**Note:** The Tool Operating Manual, NEHS0742 is provided with the tool.

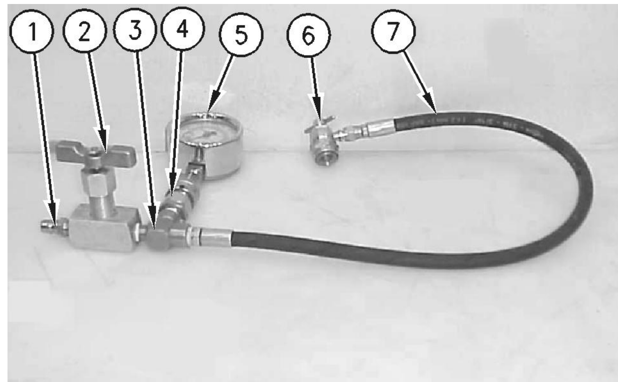


Illustration 73 g00995703

1. Assemble the following parts according to Tool Operating Manual, NEHS0742: nipple (1), needle valve (2), pipe tee (3), coupling (4), low pressure gauge (5), chuck (6), and hose (7). Make sure that needle valve (2) is closed.

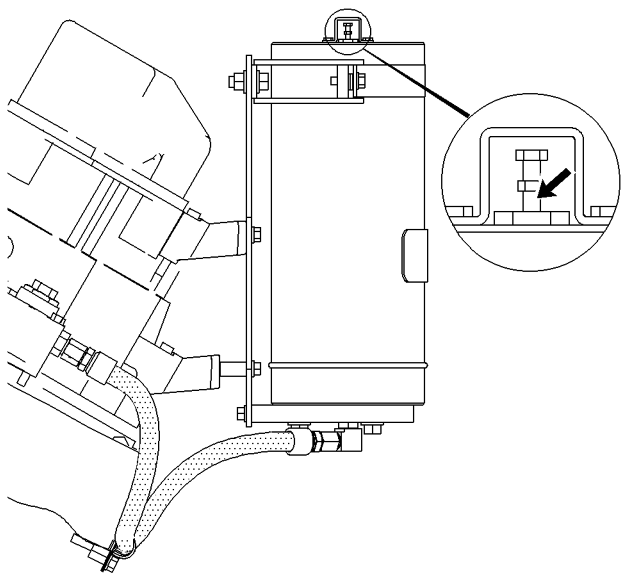

Illustration 74 g00995678

Gas valve

2. Remove the guard and the cap in order to access the gas valve.

3. Connect chuck (6) to the gas valve. Turn the chuck's handle in order to open the gas valve.

4. Wait until the low pressure gauge stabilizes. Read the gauge.

   For the correct pressure, refer to the engine's Specifications manual.

If the pressure is correct, proceed to Step 5.

If the pressure is too low, proceed to "Charging the Accumulator".

5. Turn the chuck's handle in order to close the gas valve. Open needle valve (2) in order to purge the nitrogen gas from the tooling.

6. Remove the tooling from the gas valve. Install the cap and the guard over the gas valve.

## Charging the Accumulator

**Note:** Only use dry nitrogen gas to fill the accumulator.

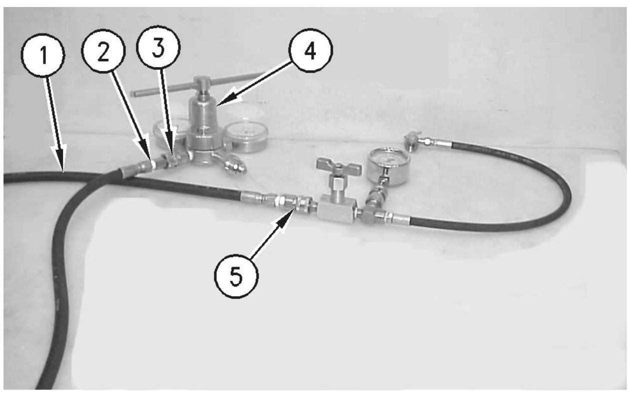


Illustration 75 g00995724

1. Assemble the following parts according to Tool Operating Manual, NEHS0742: hose (1), nipple (2), coupling (3), regulator (4), and coupling (5). Connect coupling (5) to the nipple that is on the needle valve.

2. Crack the nitrogen bottle's valve in order to purge any debris from the valve.

3. Make sure that regulator (4) is closed. Make sure that the nitrogen bottle's valve is closed and connect the regulator to the nitrogen bottle.

4. Open the needle valve. Open the nitrogen bottle's valve. Observe the pressure gauge on regulator (4) and open the regulator's valve until some pressure is indicated on the regulator's gauge. Then close the regulator's valve.

5. Wait for 10 to 15 minutes in order to allow the temperature of the nitrogen gas to stabilize. Read the low pressure gauge.

   For the correct pressure, refer to the engine's Specifications manual.

   If the pressure is too low, repeat Steps 4 and 5 until the correct pressure is achieved.

   If the pressure is too high, perform Step 5.a through Step 5.c.

   a. Close the needle valve and disconnect coupling (5).

   b. Open the needle valve and then close the needle valve in order to purge some of the nitrogen gas from the accumulator.

   c. Wait until the low pressure gauge stabilizes. Read the gauge.

      Repeat Step 5.a through Step 5.c until the correct pressure is achieved.

6. Turn the chuck's handle in order to close the gas valve. Open the needle valve in order to purge the nitrogen gas from the tooling.

7. Remove the tooling from the gas valve.

8. Close the nitrogen bottle's valve. Remove the tooling from the nitrogen bottle.

9. Install the cap and the guard over the gas valve.

i01473950

# Engine Oil Pressure - Test

**SMCS Code:** 1304-081

**⚠ WARNING**

**Work carefully around an engine that is running. Engine parts that are hot, or parts that are moving, can cause personal injury.**

NOTICE

Keep all parts clean from contaminants.

Contaminants may cause rapid wear and shortened component life.

NOTICE

Care must be taken to ensure that fluids are contained during performance of inspection, maintenance, testing, adjusting and repair of the product. Be prepared to collect the fluid with suitable containers before opening any compartment or disassembling any component containing fluids.

Refer to Special Publication, NENG2500, "Caterpillar Tools and Shop Products Guide" for tools and supplies suitable to collect and contain fluids on Caterpillar products.

Dispose of all fluids according to local regulations and mandates.

 

Table 14

| Tools Needed | | |
|---|---|---|
| **Part Number** | **Part Name** | **Quantity** |
| 1U-5470 | Engine Pressure Group | 1 |

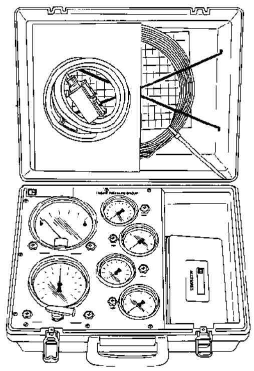

Illustration 76 g00296486

1U-5470 Engine Pressure Group

The 1U-5470 Engine Pressure Group measures the engine oil pressure in the system. This engine tool group can read the engine oil pressure inside the oil manifold.

**Note:** Refer to Special Instruction, SEHS8907, "Using the 1U-5470 Engine Pressure Group" for more information on using the 1U-5470 Engine Pressure Group.

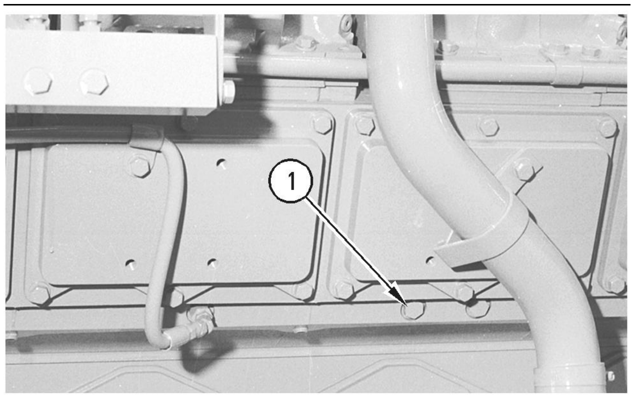


Illustration 77 g00751796

Location of the oil gallery plug

Typical example

(1) Plug

1. Install the 1U-5470 Engine Pressure Group into oil gallery plug (1).

**Note:** Engine oil pressure to the camshaft and main bearings should be checked on each side of the cylinder block at oil gallery plug (1).

2. Start the engine. Run the engine with SAE 10W30 or SAE 15W40 oil. The information in the engine oil pressure graph is invalid for other oil viscosities. Refer to Operation and Maintenance Manual, "Engine Oil" for the recommendations of engine oil.

**Note:** Allow the engine to reach operating temperature before you perform the pressure test.

**Note:** The engine oil temperature should not exceed 115 °C (239 °F).

3. Record the value of the engine oil pressure when the engine has reached operating temperature.

4. Locate the point that intersects the lines for the engine rpm and for the engine oil pressure on the engine oil pressure graph.

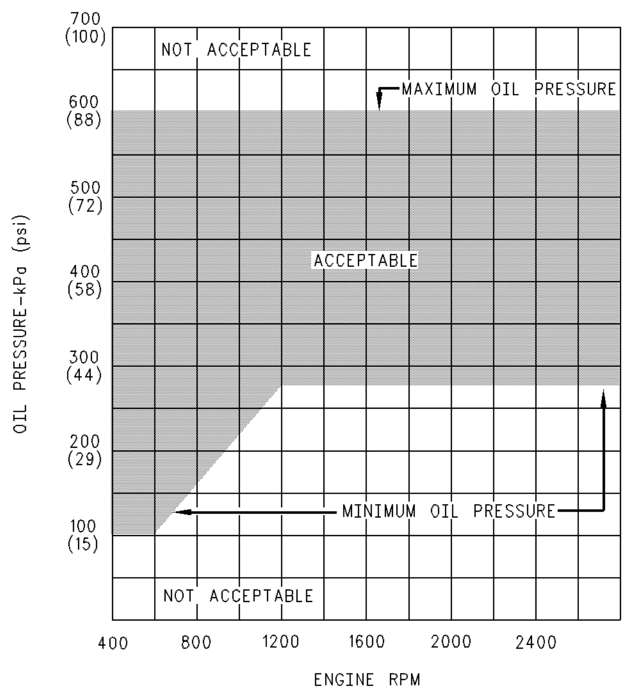


Illustration 78 g00293198

Engine oil pressure graph

5. The results must fall within the "ACCEPTABLE" range on the chart. A problem exists when the results fall within the "NOT ACCEPTABLE" range on the chart. The problem needs to be corrected. Engine failure or a reduction in engine life can be the result if engine operation is continued with oil manifold pressure outside this range.

**Note:** A record of engine oil pressure can be used as an indication of possible engine problems or damage. A possible problem could exist if the engine oil pressure suddenly increases or decreases 70 kPa (10 psi) and the engine oil pressure is in the “ACCEPTABLE” range. The engine should be inspected and the problem should be corrected.

6. Compare the recorded engine oil pressure with the engine oil pressure indicators on the instrument panel.

7. An engine oil pressure indicator that has a defect or an engine oil pressure sensor that has a defect can give a false indication of a low engine oil pressure or a high engine oil pressure. If there is a notable difference between the engine oil pressure readings make necessary repairs.

8. If the engine oil pressure is low, refer to Testing and Adjusting, “Engine Oil Pressure is Low” for the possible causes of low engine oil pressure.

9. If the engine oil pressure is high, refer to Testing and Adjusting, “Engine Oil Pressure is High” for the possible causes of high engine oil pressure.

i01563191

# Excessive Bearing Wear - Inspect

**SMCS Code:** 1203-040; 1211-040; 1219-040

When some components of the engine show bearing wear in a short time, the cause can be a restriction in a passage for engine oil.

An indicator for the engine oil pressure may show that there is enough engine oil pressure, but a component is worn due to a lack of lubrication. In such a case, look at the passage for the engine oil supply to the component. A restriction in an engine oil supply passage will not allow enough lubrication to reach a component. This will result in early wear.

i03993149

# Excessive Engine Oil Consumption - Inspect

**SMCS Code:** 1348-040

## Engine Oil Leaks on the Outside of the Engine

Check for leakage at the seals at each end of the crankshaft. Look for leakage at the gasket for the engine oil pan and all lubrication system connections. Look for any engine oil that may be leaking from the crankcase breather. This can be caused by combustion gas leakage around the pistons. A dirty crankcase breather will cause high pressure in the crankcase. A dirty crankcase breather will cause the gaskets and the seals to leak.

## Engine Oil Leaks into the Combustion Area of the Cylinders

Engine oil that is leaking into the combustion area of the cylinders can be the cause of blue smoke. There are several possible ways for engine oil to leak into the combustion area of the cylinders:

- Leaks between worn valve guides and valve stems
- Worn components or damaged components (pistons, piston rings, or dirty return holes for the engine oil)
- Incorrect installation of the compression ring and/or the intermediate ring
- Leaks past the seal rings in the turbocharger shaft
- Overfilling of the crankcase
- Wrong oil level gauge or guide tube
- Sustained operation at light loads

Excessive consumption of engine oil can also result if engine oil with the wrong viscosity is used. Engine oil with a thin viscosity can be caused by increased engine temperature.

i01727302

# Increased Engine Oil Temperature - Inspect

**SMCS Code:** 1348-040

If the engine oil temperature is higher than normal, the engine oil cooler may have a restriction. Look for a restriction in the passages for engine oil in the engine oil cooler. The engine oil pressure will not necessarily decrease due to a restriction in the engine oil cooler.

Determine if the engine oil cooler bypass valve is held in the open position. This condition will allow the engine oil to flow through the valve rather than through the engine oil cooler. The engine oil temperature will increase.

Make sure that the cooling system is operating properly. A high coolant temperature in the engine oil cooler will cause high engine oil temperature.

i01662620

# Engine Oil Pressure is Low

**SMCS Code:** 1304-081

The following conditions can cause an indication of low engine oil pressure:

- Low engine oil level
- Problem with the engine oil pressure gauge
- Contaminated engine oil
- Improper circulation of the engine oil
- Worn components

## Low Engine Oil Level

Check the engine oil level. If the engine oil level is too far below the suction tube, the engine oil pump cannot supply enough lubrication for the engine components. If the engine oil level is low, add engine oil in order to obtain the correct level. For the correct engine oil to use, refer to Operation and Maintenance Manual, “Engine Oil”.

## Engine Oil Pressure Gauge

Refer to Testing and Adjusting, “Engine Oil Pressure - Test”. If the engine oil pressure gauge is incorrect, install a new gauge.

## Contaminated Engine Oil

Engine oil that is contaminated with another liquid will cause low engine oil pressure. High engine oil level can be an indication of contamination. Determine the reason for contamination of the engine oil and make the necessary repairs. Change the engine oil and the engine oil filter. For the correct engine oil to use, refer to Operation and Maintenance Manual, “Engine Oil”.

## Improper Circulation of the Engine Oil

Several factors could cause improper circulation of the engine oil:

- The engine oil filter is clogged. Replace the engine oil filter.
- A line or a passage for the engine oil is disconnected or broken. Replace the line or clear the passage.
- The engine oil cooler is clogged. Thoroughly clean the engine oil cooler.
- There is a problem with a piston cooling jet. The piston cooling jets direct engine oil toward the bottom of the pistons in order to cool the pistons. This also provides lubrication for the piston pin. Breakage, a restriction, or incorrect installation of a piston cooling jet will cause seizure of the piston.
- The inlet screen of the suction tube for the engine oil pump can have a restriction. This restriction can cause cavitation and a loss of engine oil pressure. Check the inlet screen on the suction tube and remove any material that may be restricting engine oil flow.
- The suction tube is drawing in air. Check the joints of the suction tube for cracks or a damaged O-ring seal.
- There is a problem with the engine oil pump. Check the gears of the engine oil pump for excessive wear. Engine oil pressure is reduced when gears in the engine oil pump have too much wear.

## Worn Components

Excessive clearance at the crankshaft or camshaft bearings will cause low engine oil pressure. Also, inspect the clearance between the rocker arm shafts and the rocker arms. Check the engine components for excessive clearance.

i01563187

## Engine Oil Pressure is High

**SMCS Code:** 1314

The following conditions can cause high engine oil pressure:

- The engine oil level is too high. Drain the excess engine oil.
- The engine oil temperature is too low. Low engine oil temperature increases the viscosity of the engine oil.
- The engine oil filter bypass valve is stuck in the closed position. Thoroughly clean the valve. Replace the engine oil filters.
- A line or a passage for the engine oil is restricted. Clean the component.

i01377229

## Indicators for Engine Oil Pressure

**SMCS Code:** 7485

An oil pressure indicator that has a defect or a sender that has a defect can give an indication of a low oil pressure or a high oil pressure.

 

# Cooling System

i02225295

## General Information (Cooling System)

**SMCS Code:** 1350

This engine has a pressure type cooling system. A pressure type cooling system has two advantages.

- The pressure helps prevent cavitation.
- The risk of boiling is reduced.

Cavitation occurs when mechanical forces cause the formation of air bubbles in the coolant. The bubbles can form on the cylinder liners. Collapsing bubbles can remove the oxide film from the cylinder liner. This allows corrosion and pitting to occur. If the pressure of the cooling system is low, the concentration of bubbles increases. The concentration of bubbles is reduced in a pressure type cooling system.

The boiling point is affected by three factors: pressure, altitude, and concentration of glycol in the coolant. The boiling point of a liquid is increased by pressure. The boiling point of a liquid is decreased by a higher altitude. Illustration 79 shows the effects of pressure and altitude on the boiling point of water.

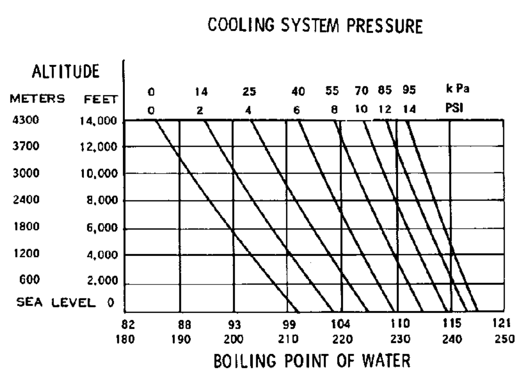


Illustration 79 g00286266

The boiling point of the coolant also depends on the type of coolant and the concentration of glycol. A greater concentration of glycol has a higher boiling temperature. However, glycol transfers heat less effectively than water. Because of the boiling point and the efficiency of heat transfer, the concentration of glycol is important.

Three basic problems can be associated with the cooling system:

- Overheating
- Coolant loss
- Overcooling

If the cooling system is not properly maintained, solids such as scale and deposits reduce the ability of the cooling system to transfer heat. The engine operating temperature will increase.

When the engine is overloaded, the engine will run in the lug condition. When the engine is running in the lug condition, the engine is operating at a lower engine rpm that reduces the coolant flow. Decreased coolant flow during high load will cause overheating.

Coolant can be lost by leaks. Overheated coolant can be lost through the cooling system's pressure relief valve. Lower coolant levels contribute to additional overheating. Overheating can result in conditions such as cracking of the cylinder head and piston seizure.

A cracked cylinder head or cylinder liner will force exhaust gas into the cooling system. The additional pressure causes coolant loss, cavitation of the water pump, less circulation of coolant, and further overheating.

Overcooling is the result of coolant that bypasses the water temperature regulators and flows directly to the radiator or to the heat exchanger. Low load operation in low ambient temperatures can cause overcooling. Overcooling is caused by water temperature regulators that remain open. Overcooling reduces the efficiency of operation. Overcooling enables more rapid contamination of the engine oil. This results in the formation of sludge in the crankcase and carbon deposits on the valves.

Cycles of rapid heating and cooling can result in cracked cylinder heads, gasket failure, accelerated wear, and excessive fuel consumption.

If a problem with the cooling system is suspected, perform a visual inspection before you perform any tests on the system.

i02826209

## Visual Inspection

**SMCS Code:** 1350-535

Perform a visual inspection of the cooling system before a test is made with test equipment.

**⚠ WARNING**

**Personal injury can result from escaping fluid under pressure.**

**If a pressure indication is shown on the indicator, push the release valve in order to relieve pressure before removing any hose from the radiator.**

---

1. Check the coolant level in the cooling system. Add coolant, if necessary.

   If the coolant level is too low, air will get into the cooling system. Air in the cooling system reduces coolant flow. Air creates bubbles that contribute to cavitation. Bubbles in the coolant also reduce the cooling capability.

2. Check the quality of the coolant. The coolant should have the following properties:

   - Color that is similar to new coolant
   - Odor that is similar to new coolant
   - Free from contamination
   - Properties that are recommended by the engine's Operation and Maintenance Manual

   If the coolant does not have these properties, drain the system and flush the system. Refill the cooling system according to the engine's Operation and Maintenance Manual.

3. Check for air in the cooling system. Air can enter the cooling system in different ways. The following conditions cause air in the cooling system:

   - Filling the cooling system incorrectly
   - Combustion gas leakage into the cooling system

   Combustion gas can get into the system through the following conditions: internal cracks, damaged cylinder head, and damaged cylinder head gasket.

4. Inspect the radiator (if equipped) and the air-to-air aftercooler (if equipped). Make sure that the air flow is not restricted. Look for the following conditions. Make corrections, if necessary:

   - Bent fins
   - Debris between the folded cores
   - Damaged fan blades

5. Check the heat exchanger (if equipped) for internal blockage. Make sure that the filters for the water are not clogged.

   The condition of the water that is circulated through the heat exchanger can decrease the effectiveness of the heat exchanger. Operating with water that contains the following types of debris will adversely affect the heat exchanger system: silt, sediment, salt, and algae. In addition, intermittent use of the engine will adversely affect the heat exchanger system.

6. Check the pressure cap.

   If the pressure cap does not maintain the correct pressure on the cooling system, the engine could overheat. A decrease in cooling system pressure reduces the temperature of the water's boiling point.

7. Inspect the cooling system hoses and clamps.

   Damaged hoses with leaks can normally be seen. Hoses that have no visual leaks can soften during operation. The soft areas of the hose can become kinked or crushed during operation. These areas of the hose restrict the coolant flow. Hoses can crack after a period of time. The inside of a hose can deteriorate and the loose particles of the hose can restrict the coolant flow.

8. Check the water temperature regulators.

   A water temperature regulator that does not open or a water temperature regulator that only opens part of the way can cause overheating.

   A water temperature regulator that does not close enables overcooling.

9. Check the engine water pump and check the auxiliary pump.

   Check for a fluid leak from the pump's weep hole during engine operation and check for a leak when the engine is stopped. If either coolant or oil is leaking from the weep hole, replace the pump.

   A water pump with a damaged impeller does not pump enough coolant for correct coolant flow. This affects the engine's operating temperature. Remove the water pump and check for damage to the impeller. Also inspect the inside of the pump's housing for scratches from the impeller.

10. Check the aftercooler.

    A restriction of water flow through the aftercooler can cause overheating. Check for debris or deposits which restrict the free flow of water through the aftercooler.

 

i02605557

# Test Tools for the Cooling System

**SMCS Code:** 0781; 1350

Table 15

| Tools Needed | | Quantity |
|---|---|---|
| 4C-6500 | Digital Thermometer | 1 |
| 285-0901 | Blowby Tool Gp | 1 |
| 285-0910 | Multi-Tool Gp | 1 |
| 9U-7400 | Multitach Tool Gp | 1 |
| 9S-8140 | Pressurizing Pump | 1 |

**WARNING**

**Making contact with a running engine can cause burns from hot parts and can cause injury from rotating parts.**

**When working on an engine that is running, avoid contact with hot parts and rotating parts.**

Illustration 80 g00286267

4C-6500 Digital Thermometer

The 4C-6500 Digital Thermometer is used in the diagnosis of overheating conditions or overcooling problems. This group can be used to check temperatures in several different parts of the cooling system. Refer to the testing procedure in the Operating Manual, NEHS0554.

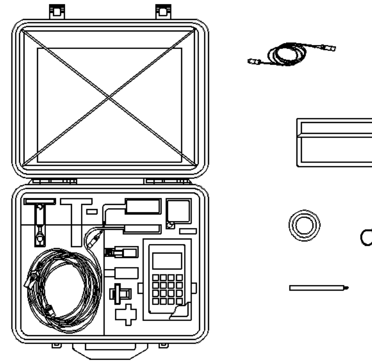

Illustration 81 g00286276

9U-7400 Multitach

The 9U-7400 Multitach is used to check the fan speed. Refer to the testing procedure in Operator Manual, NEHS0605.

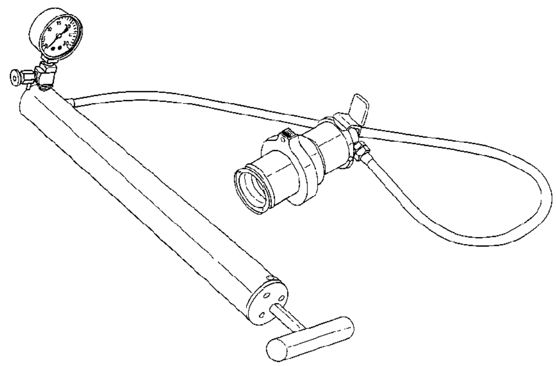

Illustration 82 g00286369

9S-8140 Pressurizing Pump

The 9S-8140 Pressurizing Pump is used to test pressure caps. The 9S-8140 Pressurizing Pump is used to pressure check the cooling system for leaks.

**WARNING**

**Steam or hot coolant can cause severe burns.**

**Do not loosen the filler cap or the pressure cap on a hot engine.**

**Allow the engine to cool before removing the filler cap or the pressure cap.**

i02406792

# Cooling System Pressure Cap - Test

**SMCS Code:** 1382-081

**⚠ WARNING**

**Pressurized System: Hot coolant can cause serious burns. To open the cooling system filler cap, stop the engine and wait until the cooling system components are cool. Loosen the cooling system pressure cap slowly in order to relieve the pressure.**

Table 16

| Tools Needed | |
|---|---|
| 9S-8140 | Pressurizing Pump |

One cause for a pressure loss in the cooling system can be inadequate sealing of the pressure cap.

After the engine is cool, loosen the pressure cap and allow the pressure out of the cooling system. Then remove the pressure cap.

Inspect the pressure cap carefully. Look for damage to the seal or to the sealing surface. Any foreign material or foreign deposits that accumulate on the following parts must be removed: cap, seal, and sealing surface.

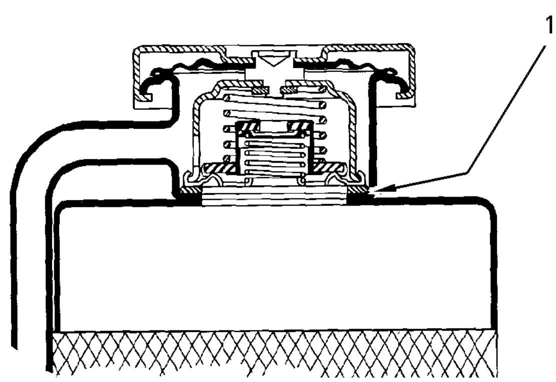


Illustration 83 g00296067

Typical schematic of filler cap

(1) Sealing surface of both filler cap and radiator

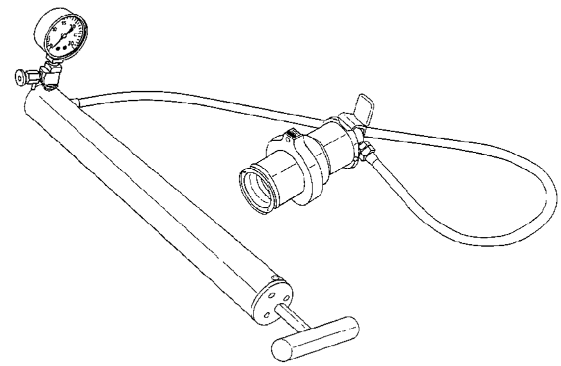

Illustration 84 g00286369

9S-8140 Pressurizing Pump

The 9S-8140 Pressurizing Pump is used to pressure test the caps and the cooling system for leaks.

To check the pressure cap opening pressure, use the procedure that follows:

1. Remove the pressure cap from the radiator.
2. Put the pressure cap on the 9S-8140 Pressurizing Pump.
3. Look at the gauge for the exact pressure that makes the pressure cap open.
4. Compare the reading on the gauge with the correct opening pressure that is labelled on the cap.
5. The pressure cap must open within ± 1 psi. Otherwise, install a new pressure cap.

i01930189

# Radiator and Cooling System - Test

**SMCS Code:** 1350-034; 1353-034

Table 17

| Tools Needed | Quantity |
|---|---|
| 9S-8140 Pressurizing Pump | 1 |

 

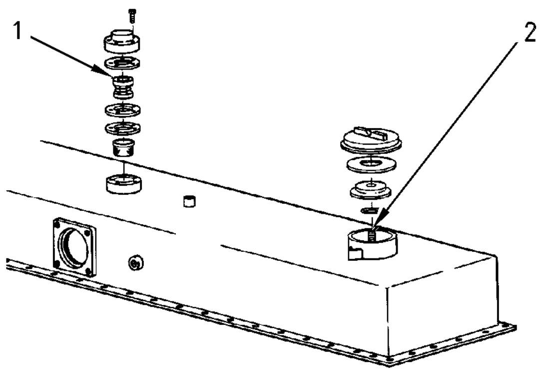


Illustration 85 g00286371

Typical pressure relief valve system

(1) Pressure relief valve
(2) Stud for filler cap

**⚠ WARNING**

**Steam or hot coolant can cause severe burns.**

**Do not loosen the filler cap or the pressure cap on a hot engine.**

**Allow the engine to cool before removing the filler cap or the pressure cap.**

Use the following procedure to check the pressure in the cooling system:

1. After the engine is cool, loosen the filler cap slowly and allow pressure out of the cooling system. Then remove the filler cap from the radiator.
2. Inspect the filler cap carefully. Look for damage to the seal or to the surface that seals. Any foreign material or deposits on the cap must be removed. Any foreign material or deposits on the seal must be removed. Any foreign material or deposits on the surface that seals must be removed.
3. Make sure that the coolant level is above the top of the radiator core.
4. Install the filler cap. Tighten the filler cap.

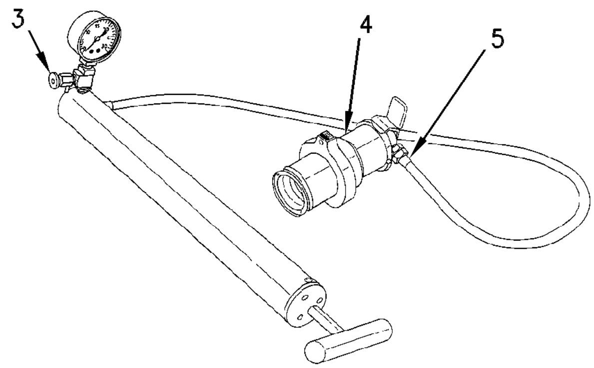


Illustration 86 g00286374

9S-8140 Pressurizing Pump

(3) Release valve
(4) Adapter
(5) Hose

5. Remove hose (5) from adapter (4).
6. Remove the pressure test plug for the radiator top tank.

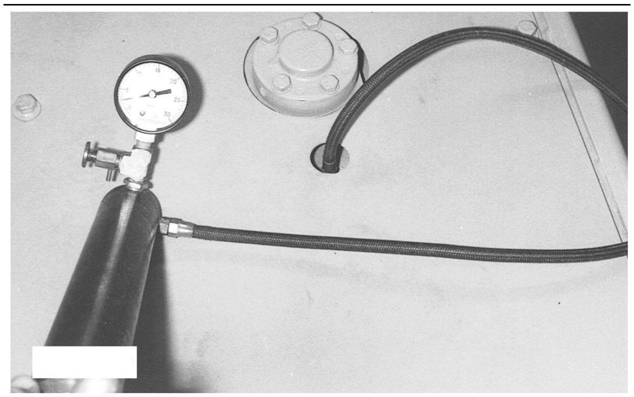

Illustration 87 g00286375

7. Install the end of the hose (5) in the hole for the pressure test plug.
8. Operate the pump until the pointer on the pressure indicator does not increase. The highest pressure indication on the pressure indicator is the point that opens the relief valve. The correct pressure that makes the relief valve open is stamped on the cap.
9. If the relief valve does not open within the pressure specification, replacement of the relief valve is necessary.
10. If the relief valve is within specifications, check the radiator for outside leakage.
11. Check all connections and hoses of the cooling system for outside leakage.

**12.** The radiator and the cooling system does not have leakage if the following conditions exist. There is no outside leakage. The pressure reading on the pressure indicator stays same after a five minute period. If the reading on the pressure indicators goes down and you do not see any outside leakage, there is leakage on the inside of the cooling system. Make the necessary repairs.

**WARNING**

**Personal injury can result from escaping fluid under pressure.**

**If a pressure indication is shown on the indicator, push the release valve in order to relieve pressure before removing any hose from the radiator.**

**13.** Remove hose (5) from the pressure test location on the radiator.

**14.** Install the plug in the pressure test location.

i01666401

# Water Temperature Regulator - Test

**SMCS Code:** 1355-081; 1355-081-ON

**WARNING**

**Personal injury can result from escaping fluid under pressure.**

**If a pressure indication is shown on the indicator, push the release valve in order to relieve pressure before removing any hose from the radiator.**

**1.** Remove the water temperature regulator from the engine.

**2.** Heat water in a pan until the temperature of the water is equal to the fully open temperature of the water temperature regulator. Refer to Specifications, “Water Temperature Regulator” for the fully open temperature of the water temperature regulator. Stir the water in the pan. This will distribute the temperature throughout the pan.

**3.** Hang the water temperature regulator in the pan of water. The water temperature regulator must be below the surface of the water. The water temperature regulator must be away from the sides and the bottom of the pan.

**4.** Keep the water at the correct temperature for ten minutes.

**5.** After ten minutes, remove the water temperature regulator. Immediately measure the opening of the water temperature regulator. Refer to Specifications, “Water Temperature Regulator” for the minimum opening distance of the water temperature regulator at the fully open temperature.

If the distance is less than the amount listed in the manual, replace the water temperature regulator.

# Basic Engine

i01220459

## Connecting Rod Bearings

**SMCS Code:** 1219-040

The connecting rod bearings fit tightly in the bore in the rod. If the bearing joints are fretted, check the bore size. This can be an indication of wear because of a loose fit.

Connecting rod bearings are available with 0.63 mm (0.025 inch) and 1.27 mm (0.050 inch) smaller inside diameter than the original size bearing. These bearings are for crankshafts that have been reground.

i01258188

## Main Bearings

**SMCS Code:** 1203-040

Main bearings are available with a larger outside diameter than the original size bearings. These bearings are available for the cylinder blocks with the main bearing bore that is made larger than the bores' original size. The size that is available has a 0.63 mm (0.025 inch) outside diameter that is larger than the original size bearings.

i01491831

## Cylinder Block

**SMCS Code:** 1201-040

If the main bearing caps are installed without bearings, the bore in the block for the main bearings can be checked. Tighten the nuts that hold the caps to the torque that is shown in the Specifications. Alignment error in the bores must not be more than 0.08 mm (0.003 inch). Refer to Special Instruction, SMHS7606 for the use of the 1P-4000 Line Boring Tool Group for the alignment of the main bearing bores. The 1P-3537 Dial Bore Gauge Group can be used to check the size of the bores. The Special Instruction, GMG00981 is with the group.

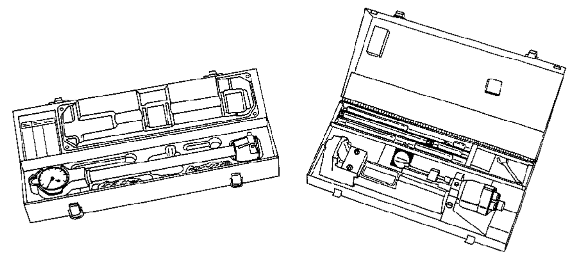

Illustration 88 g00285686

1P-3537 Dial Bore Gauge Group

i03875096

## Cylinder Liner Projection

**SMCS Code:** 1216-082

Table 18

| Tools Needed | Quantity |
|---|---|
| 1U-9895 Crossblock | 1 |
| 3H-0465 Push-Puller Plate | 2 |
| 8F-6123 Bolt (3/4-16 thread, 139.7 mm (5.5.50 inch) long | 2 |
| 3B-1925 Washer (COPPER) | 4 |
| 1A-0075 Bolt (3/4-16 thread, 44.45 mm (1.750 inch) long | 4 |
| 8T-0455 Liner Projection Tool Group | 1 |

1. Make sure that the top surface of the cylinder block, the cylinder liner bores, the cylinder liner flanges, and the spacer plates are clean and dry.

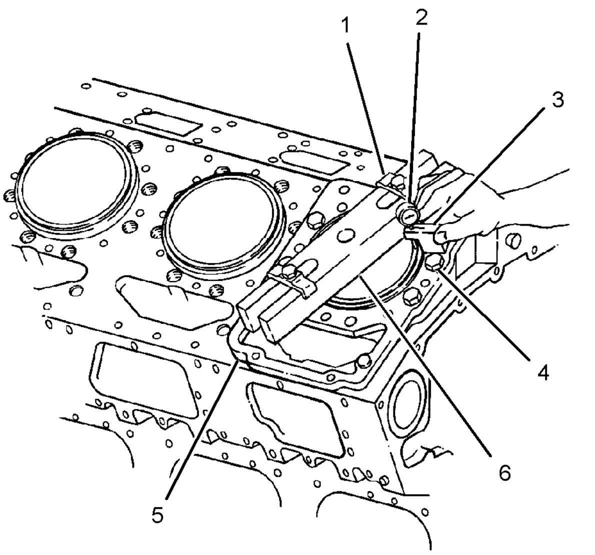


Illustration 89 g01192749

Measuring the cylinder liner projection

(1) 3H-0465 Push-Puller Plate
(2) 1P-2403 Dial Indicator
(3) 1P-2402 Gauge Body
(4) 1A-0075 Bolt and 3B-1925 Washer (COPPER)
(5) Spacer plate
(6) 1U-9895 Crossblock

2. Install a new gasket and spacer plate (5) on the cylinder block.

3. Install the cylinder liner in the cylinder block without seals or bands.

4. Hold spacer plate (5) and the cylinder liner in position according to the following procedure:

   a. Install four 3B-1925 Washers (COPPER) and four 1A-0075 Bolts(4) around spacer plate (5). Tighten the bolts evenly to a torque of 95 N·m (70 lb ft).

   b. Install the following components: 1U-9895 Crossblock (6), two 3H-0465 Push-Puller Plates (1), and two 8F-6123 Bolts. Ensure that 1U-9895 Crossblock (6) is in position at the center of the cylinder liner. Ensure that the surface of the cylinder liner is clean. Tighten the bolts evenly to a torque of 70 N·m (50 lb ft).

   c. Check the distance from the bottom edge of 1U-9895 Crossblock (6) to the top edge of spacer plate (5). The vertical distance from both ends of the 1U-9895 Crossblock must be equal.

5. Use 8T-0455 Liner Projection Tool Group (6) to measure the cylinder liner projection.

6. Mount 1P-2403 Dial Indicator (2) in 1P-2402 Gauge Body (3). Use the back of the 1P-5507 Gauge Block to zero dial indicator (2).

7. The cylinder liner projection must be between 0.06 to 0.20 mm (0.0024 to 0.0079 inch). Read the measurement on the outer flange of the cylinder liner at four equally distant positions. Do not read the measurement on the inner flange. The maximum allowable difference between the high measurements and the low measurements at four positions around each cylinder liner is 0.05 mm (0.002 inch). The maximum allowable difference between the four measurements must not exceed 0.05 mm (0.002 inch) on the same cylinder liner.

**Note:** If the cylinder liner projection is not within specifications, turn the cylinder liner to a different position within the bore. Measure the projection again. If the cylinder liner projection is not within specifications, move the cylinder liner to a different bore. Inspect the top face of the cylinder block.

**Note:** When the cylinder liner projection is correct, put a temporary mark on the cylinder liner and the spacer plate. Be sure to identify the particular cylinder liner with the corresponding cylinder. When the seals and the filler band are installed, install the cylinder liner in the marked position.

i02391235

# Flywheel - Inspect

**SMCS Code:** 1156-040

Table 19

| Tools Needed | | |
|---|---|---|
| Part Number | Part Name | Quantity |
| 8T-5096 | Dial Indicator Gp | 1 |

## Face Runout (Axial Eccentricity) of the Flywheel

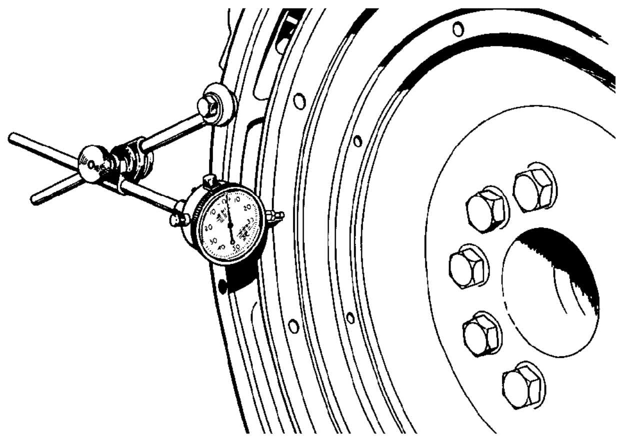

Illustration 90 g00286049

Checking face runout of the flywheel

1. Refer to illustration 90 and install the dial indicator. Always put a force on the crankshaft in the same direction before the dial indicator is read. This will remove any crankshaft end clearance.

2. Set the dial indicator to read 0.0 mm (0.00 inch).

3. Turn the flywheel at intervals of 90 degrees and read the dial indicator.

4. Take the measurements at all four points. Find the difference between the lower measurements and the higher measurements. This value is the runout. The maximum permissible face runout (axial eccentricity) of the flywheel must not exceed 0.15 mm (0.006 inch).

## Bore Runout (Radial Eccentricity) of the Flywheel

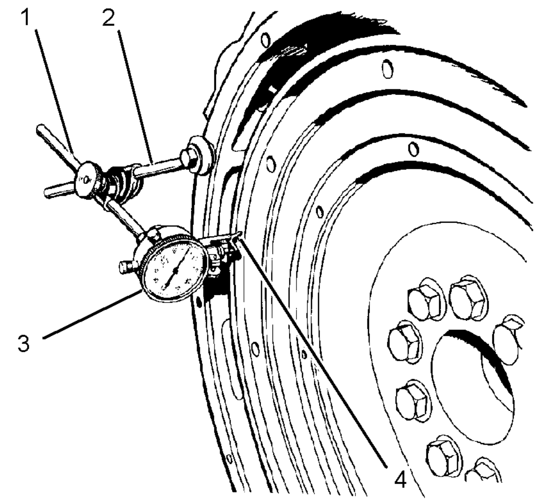


Illustration 91 g01193057

Checking bore runout of the flywheel

(1) 7H-1945 Holding Rod
(2) 7H-1645 Holding Rod
(3) 7H-1942 Dial Indicator
(4) 7H-1940 Universal Attachment

1. Install the 7H-1942 Dial Indicator (3). Make an adjustment of the 7H-1940 Universal Attachment (4) so that the dial indicator makes contact on the flywheel.

2. Set the dial indicator to read 0.0 mm (0.00 inch).

3. Turn the flywheel at intervals of 90 degrees and read the dial indicator.

4. Take the measurements at all four points. Find the difference between the lower measurements and the higher measurements. This value is the runout. The maximum permissible bore runout (radial eccentricity) of the flywheel must not exceed 0.15 mm (0.006 inch).

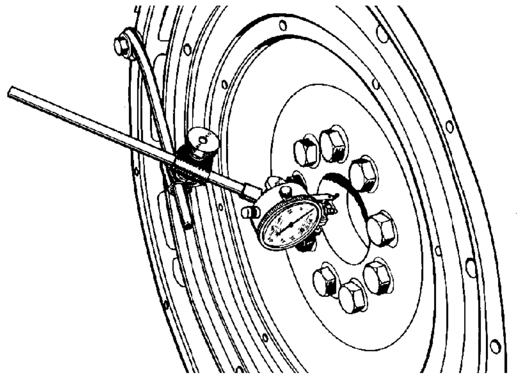

Illustration 92 g00286058

Flywheel clutch pilot bearing bore

5. Take the measurements at all four points. Find the difference between the lower measurements and the higher measurements. This value is the runout. The maximum permissible pilot bore runout of the flywheel must not exceed 0.13 mm (0.005 inch).

i02391240

# Flywheel Housing - Inspect

**SMCS Code:** 1157-040

Table 20

| Tools Needed | | Quantity |
|---|---|---|
| 8T-5096 | Dial Indicator Gp | 1 |

## Face Runout (Axial Eccentricity) of the Flywheel Housing

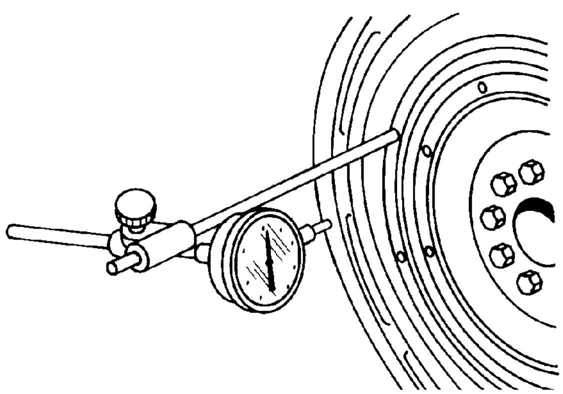

Illustration 93 g00285931

Checking face runout of the flywheel housing

If you use any other method except the method that is given here, always remember that the bearing clearance must be removed in order to receive the correct measurements.

1. Fasten a dial indicator to the flywheel so the anvil of the dial indicator will contact the face of the flywheel housing.

2. Put a force on the crankshaft toward the rear before the dial indicator is read at each point.

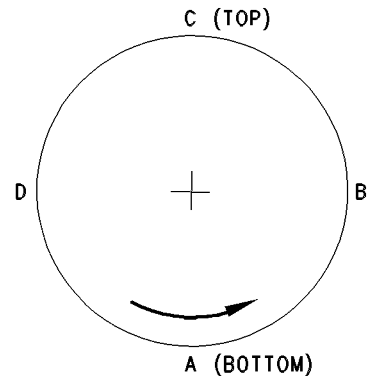


Illustration 94 g00285932

Checking face runout of the flywheel housing

3. Turn the flywheel while the dial indicator is set at 0.0 mm (0.00 inch) at location (A). Read the dial indicator at locations (B), (C) and (D).

4. The difference between the lower measurements and the higher measurements that are performed at all four points must not be more than 0.38 mm (0.015 inch), which is the maximum permissible face runout (axial eccentricity) of the flywheel housing.

## Bore Runout (Radial Eccentricity) of the Flywheel Housing

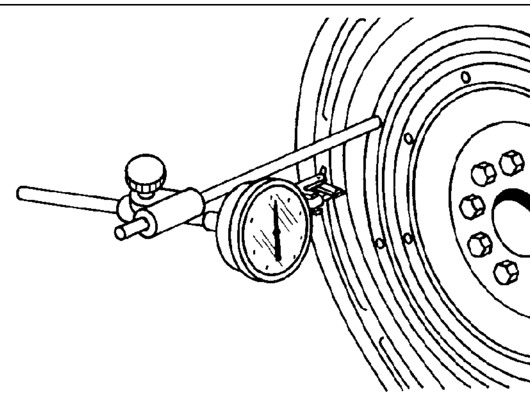

Illustration 95 g00285934

Checking bore runout of the flywheel housing

1. Fasten a dial indicator to the flywheel so the anvil of the dial indicator will contact the bore of the flywheel housing.

| CHART FOR DIAL INDICATOR MEASUREMENTS | | | | | |
|---|---|---|---|---|---|
| | Position of dial indicator | | | | |
| | Line No. | A | B | C | D |
| Correction for bearing clearance | I | 0 | | | |
| Dial Indicator Reading | II | 0 | | | |
| Total of Line 1 & 2 | III | 0 | ** | * | ** |

*Total Vertical eccentricity (out of round).
**Subtract the smaller No. from the larger No. The difference is the total horizontal eccentricity.

Illustration 96 g00285936

2. While the dial indicator is in the position at location (C) adjust the dial indicator to 0.0 mm (0.00 inch). Push the crankshaft upward against the top of the bearing. Refer to the illustration 96. Write the measurement for bearing clearance on line 1 in column (C).

**Note:** Write the measurements for the dial indicator with the correct notations. This notation is necessary for making the calculations in the chart correctly.

3. Divide the measurement from Step 2 by two. Write this number on line 1 in columns (B) and (D).

4. Turn the flywheel in order to put the dial indicator at position (A). Adjust the dial indicator to 0.0 mm (0.00 inch).

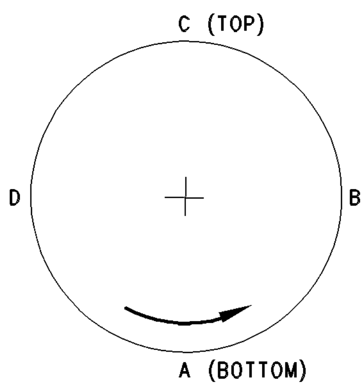


Illustration 97 g00285932

Checking bore runout of the flywheel housing

5. Turn the flywheel counterclockwise in order to put the dial indicator at position (B). Write the measurements in the chart.

6. Turn the flywheel counterclockwise in order to put the dial indicator at position (C). Write the measurement in the chart.

7. Turn the flywheel counterclockwise in order to put the dial indicator at position (D). Write the measurement in the chart.

8. Add the lines together in each column.

9. Subtract the smaller number from the larger number in column B and column D. Place this number on line III. The result is the horizontal eccentricity (out of round). Line III in column C is the vertical eccentricity.

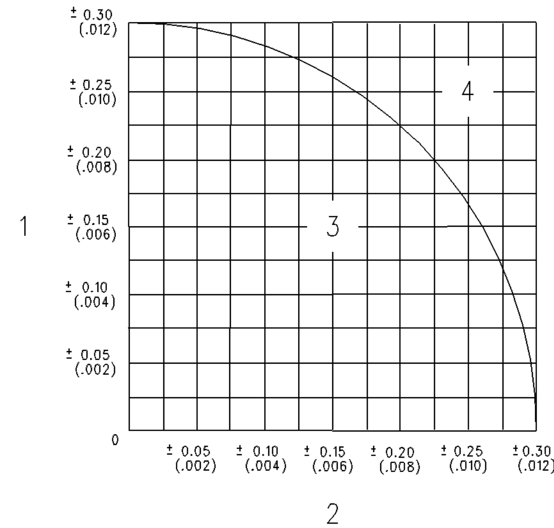


Illustration 98 g00286046

Graph for total eccentricity

(1) Total vertical eccentricity
(2) Total horizontal eccentricity
(3) Acceptable value
(4) Unacceptable value

10. On the graph for total eccentricity, find the point of intersection of the lines for vertical eccentricity and horizontal eccentricity.

11. The bore is in alignment, if the point of intersection is in the range that is marked “Acceptable”. If the point of intersection is in the range that is marked “Not acceptable”, the flywheel housing must be changed.

i01220768

# Vibration Damper

**SMCS Code:** 1205-535

Damage to the damper or failure of the damper will increase vibrations. This will result in damage to the crankshaft.

Replace the damper if the damper is bent or damaged. Replace the damper if the bolt holes are oversize. Replacement of the damper is also needed at the time of a crankshaft failure due to torsional forces.

# Air/Electric Starting System

i01433812

## General Information (Air/Electric Starting System)

**SMCS Code:** 1450; 1451; 1462

This starting system uses an electric solenoid to position an air valve in order to activate the air starting motor. If the starting motor does not function, do the procedure that follows:

1. Check the indicator reading for the air pressure.

2. If the reading is not acceptable then use a remote source to charge the system.

3. If the reading is acceptable then open the main tank drain valve for a moment. Verify the pressure that is shown on the pressure indicator. Listen for the sound of the high pressure from the discharge.

### Electrical Side Of The Air System

1. Move the start control switch in order to activate the starting solenoids. Listen for the sound of the engagement of the air starter motor pinion with the flywheel gear.

   a. If the sound of the engagement can be heard, the problem is with the Air Side Of The Air System. Proceed to the Air Side Of The Air System.

   b. If no sound of the engagement can be heard, the problem could be with the Electrical Side Of The Air System.

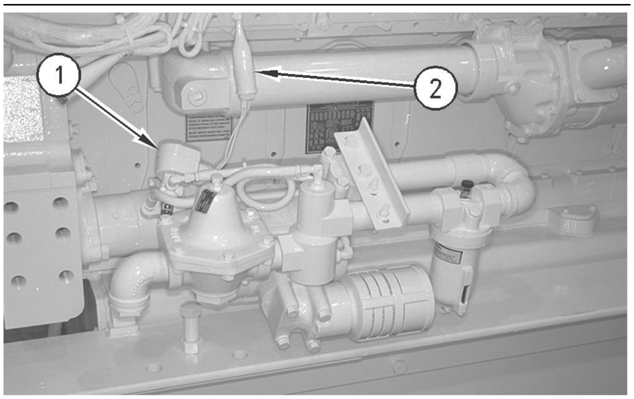


Illustration 99 g00286936

Control valve (typical example)

(1) Control valve
(2) Connector

2. Check the electrical system by disconnecting the leads from the control valve (1) at connector (2). Set the multimeter in the "DCV" range. Measure voltage across the disconnected leads that connect to the starting switch.

   a. A voltage reading shows that the problem is in the control valve (2) or the air starting motor. Go to Step 2 of Air Side Of The Air System.

   b. A "ZERO" reading shows that the problem is in the control switch or the problem is in the wires for the control switch.

3. Fasten the multimeter lead to the start switch at the terminal for the wire from the battery. Fasten the other lead to a good ground.

   a. A "ZERO" reading indicates a broken circuit from the battery. With this condition, check the circuit breaker and wiring.

   b. The problem is in the control switch if either a voltage reading is found at the control switch or if a voltage reading is found in the wires from the control switch to the control valve.

### Air Side Of The Air System

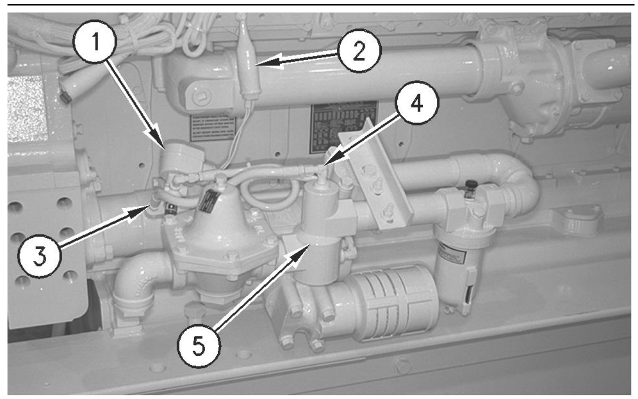


Illustration 100 g00286937

Air starting system (typical example)

(1) Control valve
(2) Connector
(3) Connection
(4) Air hose
(5) Relay valve

1. Activate the control switch. If the engagement of the air starter motor pinion with the flywheel ring gear can be heard then remove the small air hose (4) from the top of the relay valve (5).

   a. Full air pressure comes from the end of the air hose (4) when the control switch is activated. The relay valve (5) is worn or the air starting motor is damaged.

**b.** If no air pressure comes from the end of the air hose (4), then the problem is in the pinion nose housing for the air starting motor.

**2.** The sound of the air starter motor pinion is not heard when the control switch is activated. Voltage was measured at the control valve. Remove the other small air hose from the connection (3).

**a.** If no air comes from the end of the removed air hose, the control valve (1) is worn.

**b.** If the air comes from the end of the removed hose, then the problem is in the pinion nose housing for the air starting motor.

# Air Starting System

i01602995

## Pressure Regulating Valve

**SMCS Code:** 1462-025

Each engine installation must be inspected in order to determine the most advantageous starting conditions. The setting of the pressure regulating valve is affected by the following factors:

- Loads from attachments that are pulled by the engine during the start-up
- Ambient temperature conditions
- Viscosity of the lubricant for the air starting motor
- Capacity of the air reservoir
- Condition of the engine

Higher pressures provide increased torque for the starting motor and faster rotation of the engine. Lower pressures prolong the supply of pressurized air.

Use the following procedure to check and adjust the pressure regulating valve:

**1.** Purge the pressurized air from the system.

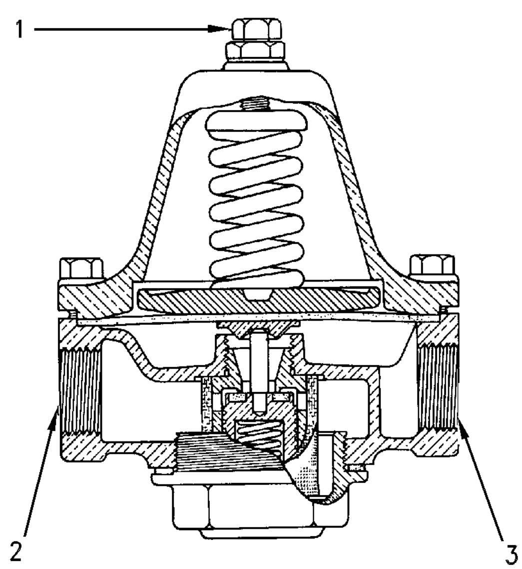


Illustration 101 g00281476

Pressure regulating valve

(1) Adjusting screw
(2) Regulator inlet
(3) Regulator outlet

**2.** Disconnect the air line from regulator outlet (3).

**3.** Connect an 8T-0849 Pressure Gauge to regulator outlet (3).

**4.** Apply air pressure to the gauge and check the pressure.

**5.** Use adjusting screw (1) to adjust the air pressure to 620 to 1030 kPa (90 to 150 psi).

**6.** After the pressure is correct, purge the pressurized air from the system.

**7.** Remove the 8T-0849 Pressure Gauge Group from the regulator outlet. Reconnect the air line.

i01305076

## Lubrication

**SMCS Code:** 1450

Always use an air line lubricator with the air starting motors that have vanes.

For temperatures above 0 °C (32 °F), use a SAE 10W nondetergent oil of high quality.

For temperatures below 0 °C (32 °F), use air tool oil.

To maintain the efficiency of the starting motor, flush the starting motor at regular intervals. Pour approximately 0.5 L (0.53 qt) of diesel fuel into the air inlet of the starting motor and operate the starting motor. This procedure will remove the dirt, the water and the mixture of oil from the vanes of the air starting motor.

# Electrical System

i03439502

## Test Tools for the Electrical System

**SMCS Code:** 0785

Table 21

| Tools Needed | | Quantity |
|---|---|---|
| 4C-4911 | Battery Load Tester | 1 |
| 271-8590 | Starting/Charging Analyzer Gp | 1 |
| 225-8266 | Ammeter Tool Gp | 1 |
| 146-4080 or 257-9140 | Digital Multimeter Gp | 1 |

Most of the tests for the electrical system can be done on the engine. First, check that the insulation for the wiring is in good condition. Ensure that the wire connections and cable connections are clean and tight. Check that the battery is fully charged. If the on-engine test shows that a component is not functioning properly, remove the component from the engine for more testing.

Refer to Testing And Adjusting Electrical Components, REG00636 for complete specifications and test procedures for the components of the starting circuit and the charging circuit.

### 4C-4911 Battery Load Tester

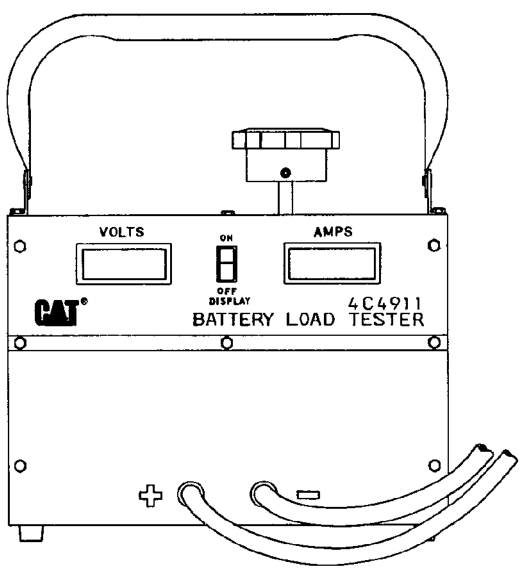


Illustration 102 g00283565

4C-4911 Battery Load Tester

The 4C-4911 Battery Load Tester is a portable unit in a metal case. The 4C-4911 Battery Load Tester can be used under field conditions and under high temperatures. The tester can be used to load test all 6, 8, and 12 Volt batteries. This tester has two heavy-duty load cables that can easily be fastened to the battery terminals. A load adjustment knob is located on the top of the tester. The load adjustment knob permits the current that is being drawn from the battery to be adjusted to a maximum of 1000 amperes. The tester is cooled by an internal fan that is automatically activated when a load is applied.

The tester has two built-in Liquid Crystal Displays (LCD). During testing, one LCD displays the battery voltage at the battery. This measurement is taken through tracer wires that are buried inside the load cables. The other LCD accurately displays the current that is being drawn from the battery which is being tested.

**Note:** Refer to Operating Manual, SEHS9249 for more complete information for the use of the 4C-4911 Battery Load Tester.

### 271-8590 Starting/Charging Analyzer Gp

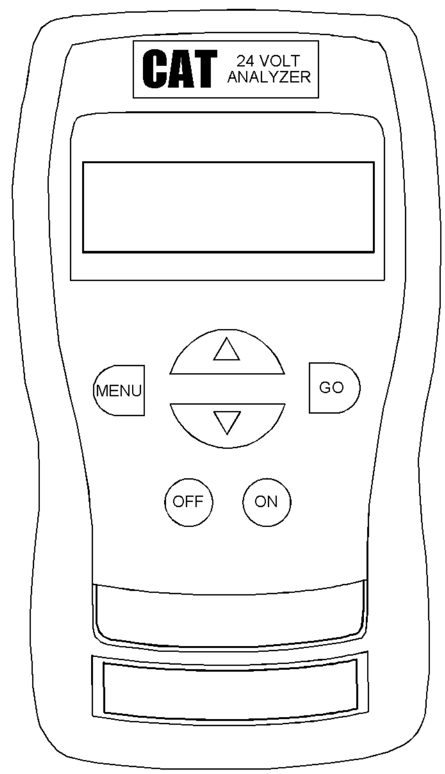


Illustration 103 g01789234

271-8590 Starting/Charging Analyzer Gp

The 271 - 8590 Starting/Charging Analyzer Gp is a portable, hand-held tool that is used to test the condition of all 6, 8, and 12 Volt batteries, as well as 6, 8, 12 and 24 Volt battery packs. The tester can also be used to test the starting and the charging system. The analyzer has a multifunction input for use with multimeter probes that are an optional purchase. The analyzer also has a print function that is used with a printer that is an optional purchase.

**Note:** Refer to Operating Manual, NEHS0973 for more complete information for the use of the 271 - 8590 Starting/Charging Analyzer Gp.

## 225 - 8266 Ammeter Tool Gp

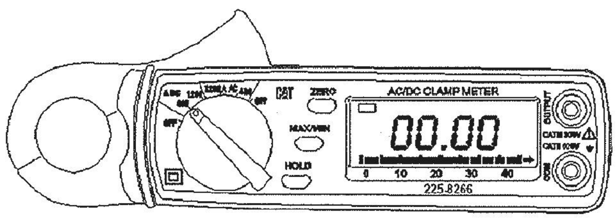


Illustration 104 g01012117

225 - 8266 Ammeter Tool Gp

The 225 - 8266 Ammeter Tool Gp is a completely portable, self-contained instrument that allows electrical current measurements to be made without breaking the circuit or without disturbing the insulation of a conductor. A digital display is located on the ammeter for displaying current measurements in a range from 1 to 1200 amperes. A 6V - 6014 Cable can be connected between the ammeter and a digital multimeter in order to measure a current of less than 1 ampere.

A lever is used to open a jaw on the meter that clamps on any conductor up to 23 mm (0.90 inch) in diameter. The jaw of the meter closes around the conductor for the current measurement. A dial is used to set the appropriate range for the amperage reading. A “HOLD” button on the meter allows the latest reading to be sustained on the display. If a measurement is taken in a limited access area, the meter will retain the measurement data that is on the display until the user clears the data. Batteries are used to power the ammeter.

**Note:** Refer to the ammeter's User's Guide for complete information that is related to the use of the ammeter. This guide is packaged with the unit.

## 146 - 4080 Digital Multimeter Gp

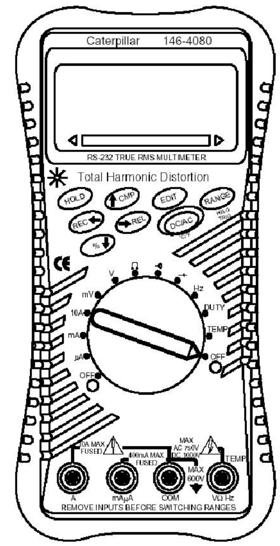


Illustration 105 g01015638

146 - 4080 Digital Multimeter Gp

The 146 - 4080 Digital Multimeter Gp is a portable instrument that has a digital display. This multimeter is case hardened with a rubber protector cover that provides extra protection against damage in field applications. The 146 - 4080 Digital Multimeter Gp can be used to perform the following measurements:

- Amperage
- Capacitance
- Frequency
- Pulse Width Modulation (PWM)
- Resistance
- Temperature
- Voltage

The multimeter has an instant ohms indicator that permits the checking of continuity for fast circuit inspection. Temperature measurements can be taken by using the adapter for type K thermocouples. An RS-232 interface adaptor can be used to interface with other electronic tools and displays.

**Note:** Refer to multimeter's Operator's Manual for complete information that is related to the use of the multimeter. The operator's manual is packaged with the unit.

i01305428

## Battery

**SMCS Code:** 1401-081

**WARNING**

**Never disconnect any charging unit circuit or battery circuit cable from the battery when the charging unit is operated. A spark can cause an explosion from the flammable vapor mixture of hydrogen and oxygen that is released from the electrolyte through the battery outlets. Injury to personnel can be the result.**

The battery circuit is an electrical load on the charging unit. The load is variable because of the condition of the charge in the battery.

NOTICE

The charging unit will be damaged if the connections between the battery and the charging unit are broken while in operation. Damage occurs because the load from the battery is lost and because there is an increase in charging voltage. High voltage will damage the charging unit, the regulator, and other electrical components.

Use the 4C-4911 Battery Load Tester in order to test a battery that does not maintain a charge when the battery is active. Refer to Operating Manual, SEHS9249 for detailed instruction on the use of the 4C-4911 Battery Load Tester. See Special Instruction, SEHS7633 for the correct procedure and for the specifications to use when you test the batteries.

i01487719

## Charging System

**SMCS Code:** 1406-081

The condition of charge in the battery at each regular inspection will indicate whether the charging system operates correctly. An adjustment is necessary when the battery is constantly in a low condition of charge or a large amount of water is needed. A large amount of water would be more than one ounce of water per cell per week or per every 100 service hours.

When it is possible, test the charging unit and the voltage regulator on the engine. Use wiring and components that are a permanent part of the system. This testing will give an indication of needed repair. After repairs are made, perform a test in order to prove that the units have been repaired to the original condition of operation.

To check for correct output of the alternator, see the Specifications module.

For complete service information, refer to Service Manual Module, SENR7503, “Delco-Remy Bulletin 1G-255”. This module is part of Service Manual, REG00636.

Before the start of on-engine testing, the charging system and the battery must be checked according to the following steps.

1. The battery must be at least 75 percent (1.225 Sp Gr) of the full charge. The battery must be held tightly in place. The battery holder must not put too much stress on the battery.

2. Cables between the battery, the starter, and the engine ground must be the correct size. Wires and cables must be free of corrosion. Wires and cables must have cable support clamps in order to prevent stress on battery connections (terminals).

3. Leads, junctions, switches, and panel instruments that have direct relation to the charging circuit provide correct circuit control.

4. Inspect the drive components for the charging unit in order to be sure that the components are free of grease and oil. Be sure that the drive components have the ability to operate the charging unit.

i02388966

## Alternator Regulator

**SMCS Code:** 1405-081

The charging rate of the alternator should be checked when an alternator is charging the battery too much. The charging rate of the alternator should be checked when an alternator is not charging the battery enough. Make reference to the Specifications module in order to find all testing specifications for the alternators and regulators.

No adjustment can be made in order to change the rate of charge on the alternator regulators. If the rate of charge is not correct, a replacement of the regulator is necessary.

## Tightening The Alternator Pulley Nut

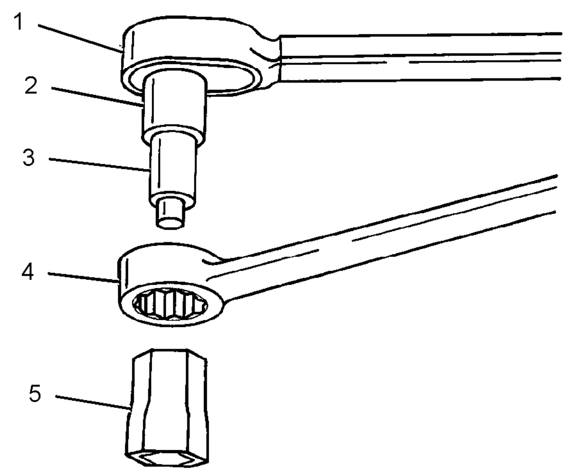


Illustration 106 g01192754

Tools for tightening the alternator pulley nut

(1) 8T-9293 Torque Wrench
(2) 8S-1588 Adapter (1/2 inch female to 3/8 inch male)
(3) 2P-8267 Socket Assembly
(4) 8H-8517 Combination Wrench (1-1/8 inch)
(5) 8T-5314 Socket

Tighten the nut that holds the pulley with the tools shown. Refer to the Specifications module for the torque.

i01487748

# Electric Starting System

**SMCS Code:** 1450-081

Use the multimeter in the DCV range to find the starting system components which do not function.

Move the start control switch in order to activate the starting solenoids. The starting solenoid's operation can be heard as the pinions of the starting motors are engaged with the ring gear on the engine flywheel.

If a solenoid for a starting motor will not operate, it is possible that the current from the battery did not reach the solenoid. Fasten one lead of the multimeter to the connection (terminal) for the battery cable on the solenoid. Put the other lead to a good ground. A zero reading indicates that there is a broken circuit from the battery. More testing is necessary when there is a voltage reading on the multimeter.

The solenoid operation also closes the electric circuit to the motor. Connect one lead of the multimeter to the solenoid connection (terminal) that is fastened to the motor. Fasten the other lead to a good ground. Activate the starting solenoid and look at the multimeter. A reading of the battery voltage shows that the problem is in the motor. The motor must be removed for further testing. A zero reading on the multimeter shows that the solenoid contacts do not close. Repair the solenoid if the contacts do not close. The clearance for the starter motor pinion gear may also need adjusting.

Perform a test. Fasten one multimeter lead to the connecting (terminal) for the small wire to the solenoid and fasten the other lead to the ground. Look at the multimeter and activate the starting solenoid. A voltage reading shows that the problem is in the solenoid. A zero reading indicates that the problem is in the start switch or in the wires for the start switch.

Fasten one multimeter lead to the start switch at the connection (terminal) for the wire from the battery. Fasten the other lead to a good ground. A zero reading indicates a broken circuit from the battery. Check the circuit breaker and wiring. If there is a voltage reading, the problem is in the start switch or in the wires for the start switch.

Starting motors that operate too slowly can have an overload because of too much friction in the engine that is being started. Slow operation of the starting motors can also be caused by the following conditions:

- A short circuit
- Loose connections
- Dirt in the motors

i02388967

# Pinion Clearance Adjustment

**SMCS Code:** 1454-025

When the solenoid is installed, make an adjustment of the pinion clearance. The adjustment can be made with the starting motor removed.

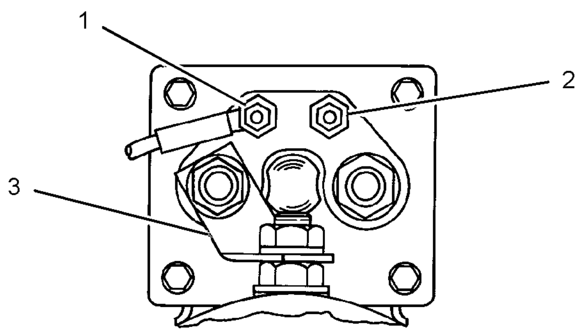


Illustration 107 g01192756

Connection for checking pinion clearance

(1) Ground terminal
(2) SW terminal
(3) Connector

1. Install the solenoid without connector (3) from the MOTOR connections (terminal) on the solenoid to the motor.

2. Connect a battery, that has the same voltage as the solenoid, to "SW" terminal (2).

3. Connect the other side of the battery to connector (3).

4. For a moment, connect a wire from the solenoid connection (terminal), which is marked "MOTOR", to the ground connection (terminal). The pinion will shift to the crank position and the pinion will stay there until the battery is disconnected.

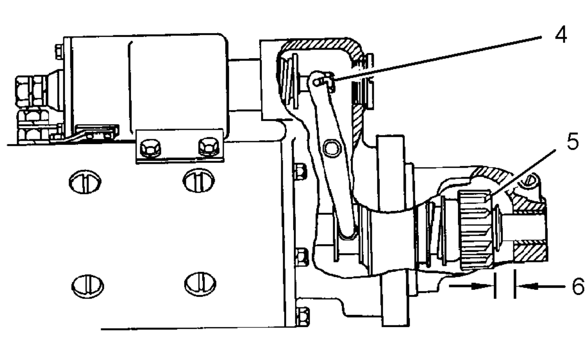


Illustration 108 g01192757

Pinion clearance adjustment

(4) Shaft nut
(5) Pinion
(6) Pinion Clearance

5. Push the pinion toward the end with the commutator in order to remove free movement.

6. Pinion clearance (6) must be 9.1 mm (0.36 inch).

7. In order to adjust the pinion clearance, remove the plug and turn shaft nut (4).

# Index