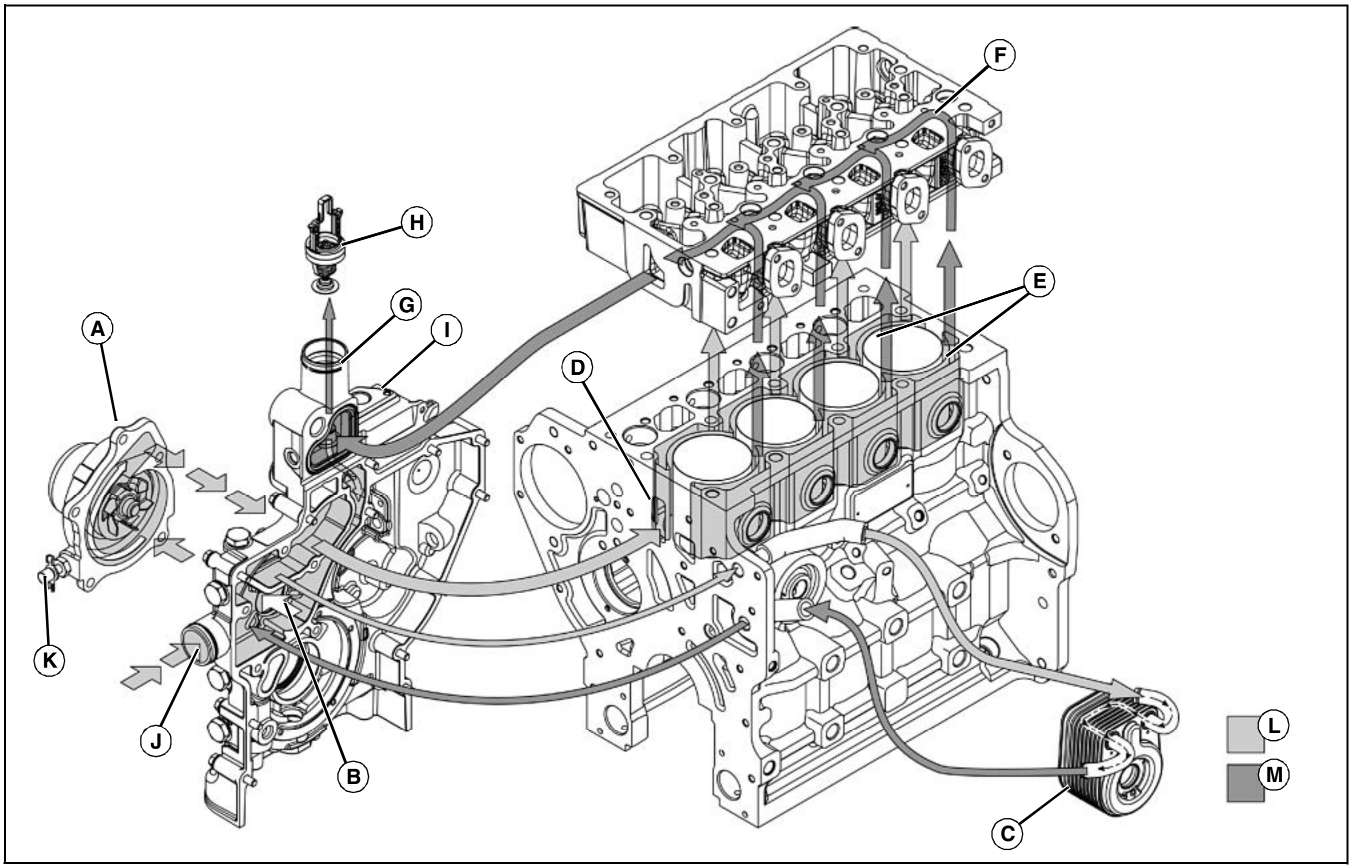
Coolant System Operation



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Picture Note: Coolant System (2.4 L Engine Shown)

- **A - Water Pump**
- **B - Coolant Flow to Water Pump (Suction Side)**
- **C - Oil Cooler**
- **D - Coolant Flow to Block**
- **E - Coolant Flow - Block to Cylinder Head**
- **F - Coolant Flow in Cylinder Head**
- **G - Thermostat Housing**
- **H - Thermostat**
- **I - Thermostat Bypass Port**
- **J - Coolant Return from Radiator**
- **K - Drain Valve**
- **L - Low Temperature Coolant**
- **M - High Temperature Coolant**

The coolant system includes the radiator, water pump, thermostat and housing, and coolant passages.

When the engine is cold, the water pump (A) forces coolant through the engine block, around the cylinders (E), and into the cylinder head (F).

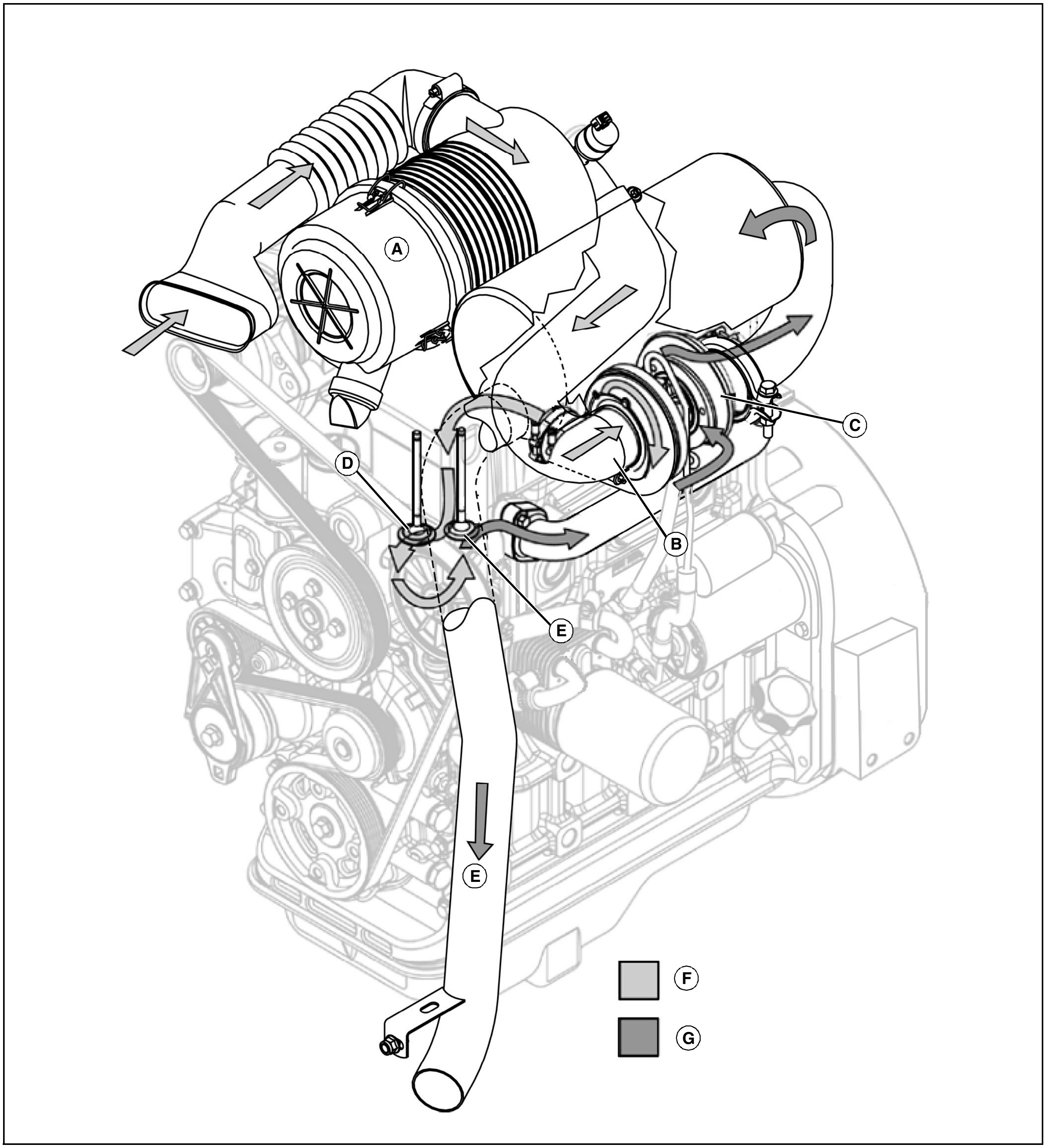
From the cylinder head, the coolant routes to the thermostat housing (G) and back to the bypass port (I). Regardless of engine temperature, the water pump also forces coolant through the oil cooler (C).

When the engine is warm, the coolant partially opens the thermostat (H) and the coolant is routed through the radiator and back to the coolant inlet, located in the front timing gear housing.

When the engine is at operating temperature, the coolant fully opens the thermostat, increasing coolant flow through the radiator. Under operating temperature conditions, the bypass port (I) is closed. All of the coolant circulates through both the radiator and oil cooler assembly, and back to the water pump inlet (B).

Coolant continues flowing through the radiator circuit until the coolant temperature drops below the thermostat opening temperature.

Air Intake and Exhaust System Operation



Picture Note: Air Intake and Exhaust System

A - Air Cleaner

B - Clean Air Intake

C - Turbocharger Turbine Housing (exhaust side)

D - Intake Valve/Combustion Chambers

E - Exhaust Valve/Gases

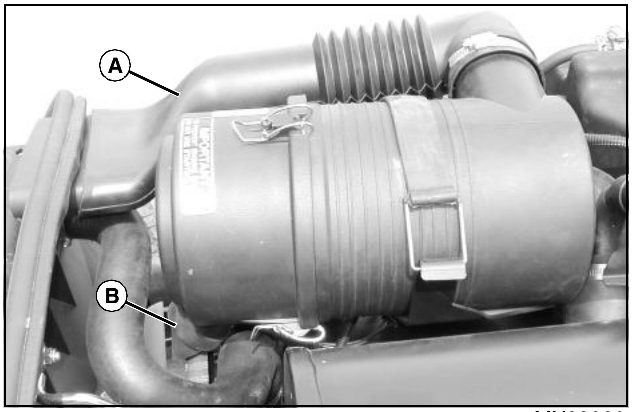
F - Intake Air

G - Exhaust Air

Engine suction draws dust laden outside air through an air inlet stack into the air cleaner (A). Air is filtered through dry type primary and secondary (safety) filter elements in the air cleaner canister. Clean air (F) travels through the air intake hose to the turbocharger and into the air intake side of the cylinder head (D).

Exhaust gases (E) drive the turbocharger turbine (A), which in turn drives the turbocharger compressor to compress the intake air and thus deliver a larger quantity of air to the combustion cylinders. The quantity of air delivered to an engine intake by a turbocharger is not possible with naturally aspirated, or non-turbocharged, applications.

Air Cleaner Operation



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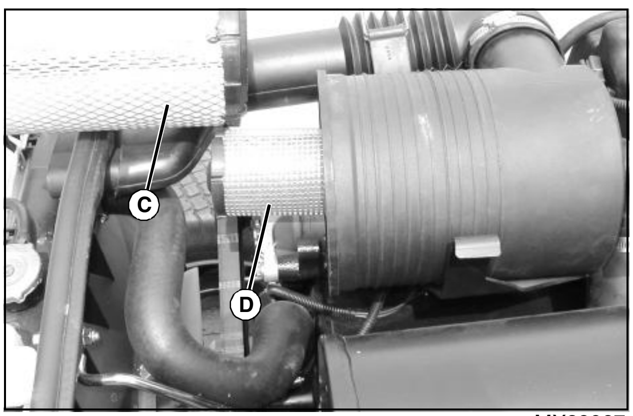
Picture Note: Air Cleaner Assembly



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Picture Note: Air Cleaner Primary and Secondary Elements

A - Air Inlet Tube

B - Dust Unloading Tube

C - Primary Air Filter Element

D - Secondary, or Safety, Filter Element

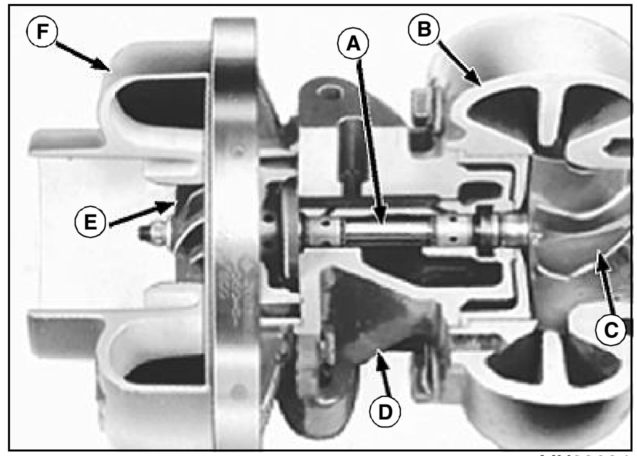
Under suction generated by the engine, unfiltered air flows through the air inlet tube (A) and is forced into a high speed centrifugal motion. By this circulating action, most of the dust and dirt particles are separated from the air and collected in the dust unloading tube (B).

The remaining dirt is removed as the air flows through the primary element (C) and the secondary (safety) filter (D), before being drawn into the engine.

The secondary (safety) filter ensures that, should the primary element fail, no unfiltered air is drawn into the engine.

Under normal operating conditions, maximum air intake restriction is 6.25 kPa (0.06 bar) (1.0 psi) (25 in. water). However, a clogged air cleaner element will cause excessive intake restriction and a reduced air supply to the engine. An air restriction indicator aids the operator to know when an air cleaner needs servicing.

Turbocharger Operation



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Picture Note: Turbocharger Components

A - Shaft

B - Turbine Housing

C - Turbine Wheel

D - Center Housing

E - Compressor Wheel

F - Compressor Housing

The turbocharger, which is basically an air pump that is driven by exhaust gases, allows the engine to produce added power without increasing displacement. Turbochargers are specially matched to the engine for the power ratio requirements of each specific application.

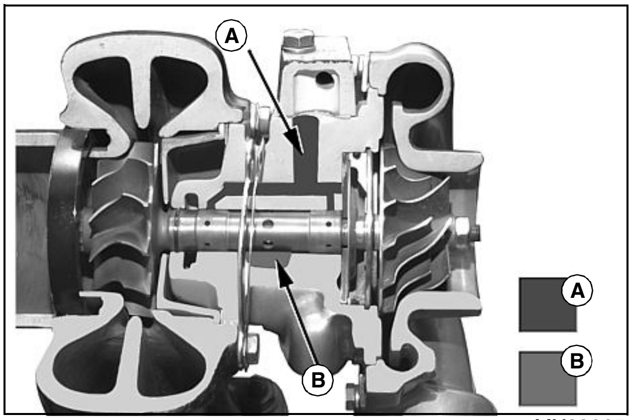
The turbine wheel (C) is driven by the hot engine exhaust gases. These gases flowing through the turbine housing (B) act on the turbine wheel, causing the shaft (A) to turn.

The compressor wheel (E) draws in filtered air and discharges the compressed air into the intake manifold, where it is then delivered to the engine combustion chambers.

Since exhaust gas pressure varies with engine speed and load, the power available to operate the turbocharger also varies.

Engine oil, under pressure from the engine lubricating system, is provided to the turbocharger center housing (D) to lubricate and cool the shaft and bearings.

Turbocharger Lubrication



Picture Note: Turbocharger Pressure and Discharge Oil

A - Pressure Oil

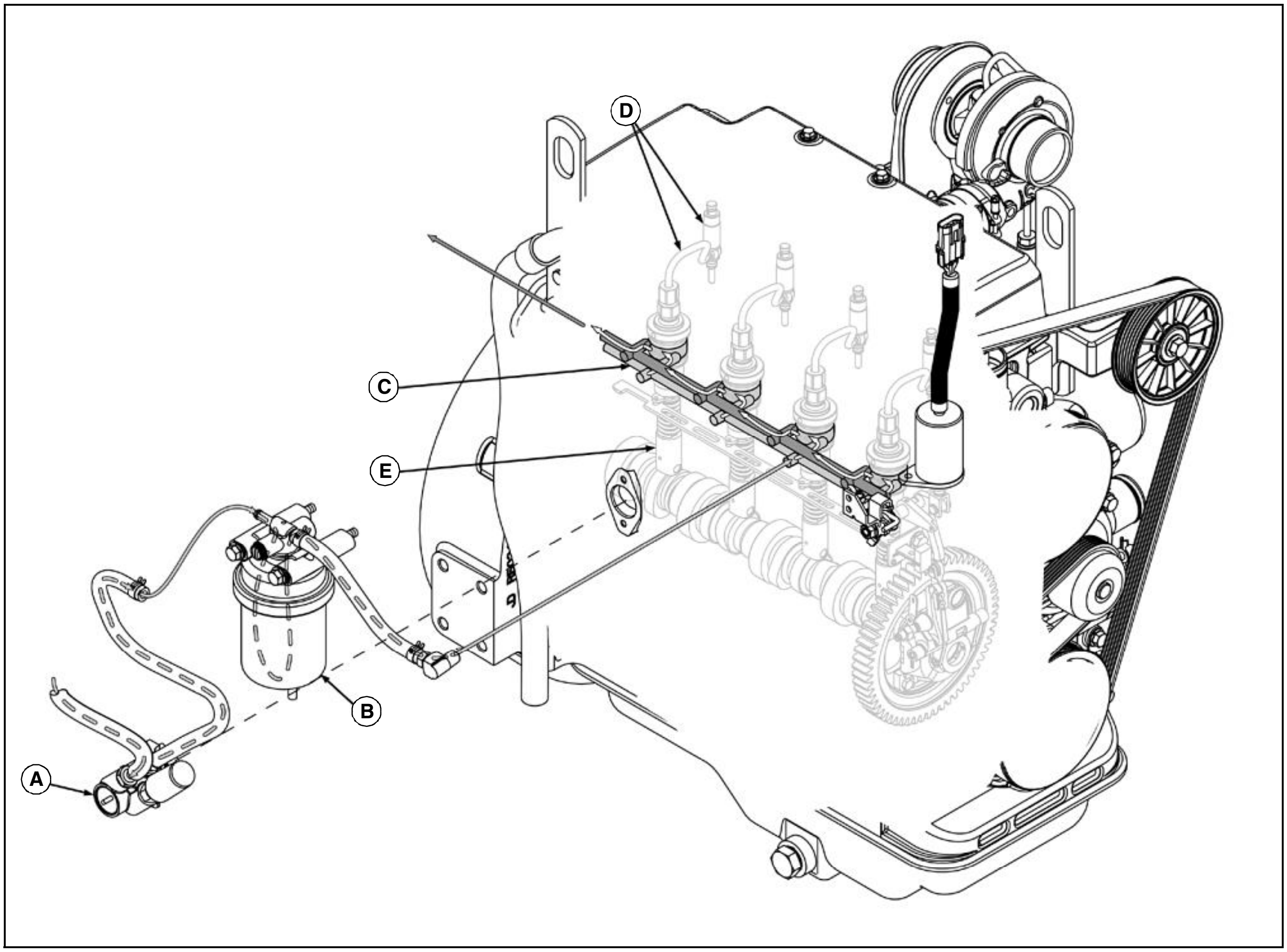
B - Discharge Oil

Engine oil, under pressure from the lubricating system, is pumped through a passage in the bearing housing and directed to the bearings, thrust plate, and thrust sleeve. Oil is sealed from the compressor and turbine by a piston ring at both ends of the bearing (center) housing.

The turbocharger contains two floating bearings. These bearings have clearance between the bearing OD and the housing bore, as well as clearance between the bearing ID and shaft OD. These clearances are lubricated by the oil supply pressure oil (A), and the bearings are protected by a cushion of oil. Discharge oil (B) drains by gravity from the bearing, or center, housing to the engine crankcase.

Theory of Operation (Air and Fuel)

Fuel System Operation



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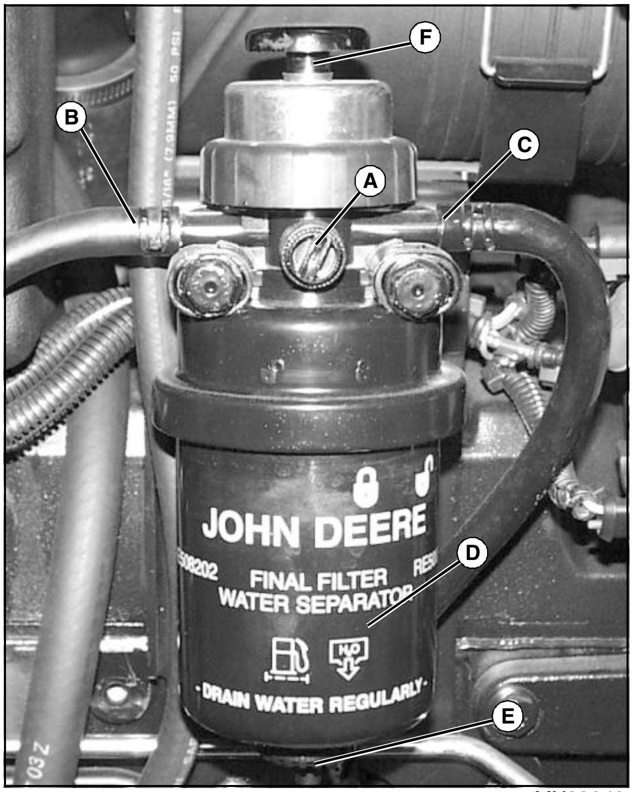
Picture Note: Fuel System

Direct fuel injection is provided by an integral pumping unit and compact nozzle assembly for each cylinder. A fuel transfer pump (A) draws fuel from the tank and provides pressure to and through the fuel filter (B) and cylinder block fuel galley (C). The fuel galley, integral with the cylinder block to avoid external fuel lines, supplies fuel to the pumping units and nozzles (D). The quantity of fuel delivered to each pumping unit is controlled by a mechanical governor and throttle assembly, located in the timing gear cover, and a rack assembly, located in the cylinder block. The fuel rack is located in the block and is parallel to the fuel galley. The pumping units, driven by hydraulic cam followers (E), pressurizes and delivers the fuel to the nozzle.

Fuel Supply Pump

The fuel supply pump (A) is a mechanical pump, driven off a lobe on the camshaft. The pump draws fuel from the vented fuel tank and directs and maintains pressurized flow through the fuel filter and the fuel galley within the cylinder block. It also contains an optional plunger for bleeding air from and priming the fuel system.

Fuel Filter/Water Separator Operation



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Picture Note: Fuel Filter

A - Bleed Screw
B - Fuel Inlet
C - Fuel Outlet
D - Filter
E - Drain Valve
F - Primer Pump

Fuels enters the filter at the inlet (B), then flows through the five micron filter element (D) and exits through the outlet (C) to the fuel galley of the cylinder block.

Since water and other contaminants settle at the bottom of the filter, a drain plug (E) is provided to drain water from the filter between scheduled filter changes.

The priming pump (F) draws fuel from the fuel tank to fill the filter after the fuel filter element has been changed or the machine has been run out of fuel. Air in the fuel system can be bled through the air vent when the bleed screw (A) is loosened and the primer pump is operated.

Governor Operation

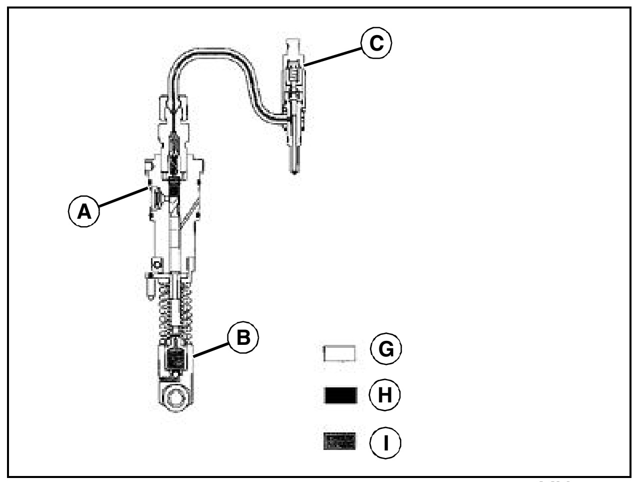
The purpose of the governor is to maintain and limit maximum engine speed. The governor system is located as part if the camshaft gear assembly. Flyweights and springs are mounted to the camshaft gear and are used to detect the speed of the engine.

To maintain engine speed, the flyweights are positioned in a manner that holds the fuel rack in a constant position. This holds the throttle control lever (plunger) of each pumping unit in the same position so that fuel delivery is neither increased, nor decreased.

As the engine load increases, engine speed decreases. Fuel delivery must increase to maintain engine speed. As engine speed decreases, the flyweights move inward and the rack rotates the throttle control lever (plunger) to increase fuel delivery.

As the engine load decreases, engine speed increases. Fuel delivery must decrease to maintain engine speed. As engine speed increases, the flyweights move out and the rack rotates the pump plunger control lever to decrease fuel delivery.

Integrated Fuel System (IFS) Operation



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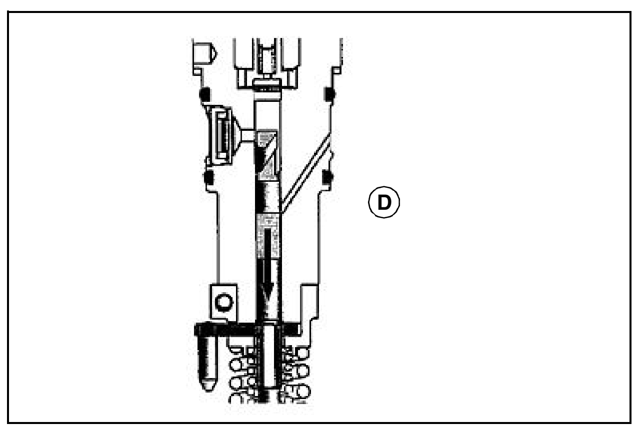
Picture Note: Integrated Fuel System (IFS)



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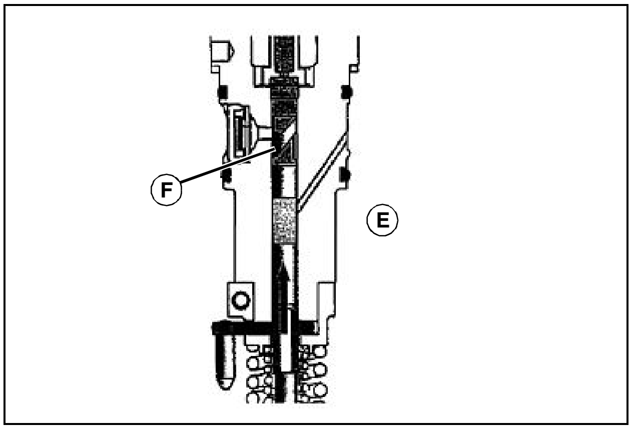
Picture Note: Charging Cycle



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Picture Note: Pumping Cycle

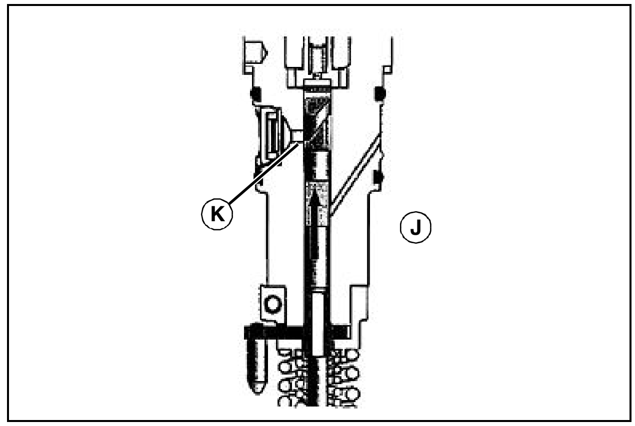
A - Unit Pump
B - Camshaft follower
C - Injector
D - Charging Cycle
E - Pump Body
F - Inlet Port
G - Inlet Pressure
H - Injection Pressure
I - Oil Pressure

The integrated fuel system, or IFS, consists of a unit pump (A) with a hydraulic roller camshaft follower (B), and an injector (C). The unit pump is capable of pressures of 1200 bar (17,400 psi), with a maximum fuel delivery of 100 mm3/ stroke at 3,600 engine rpm. The injector is a compact pencil nozzle (CPN) designed to operate at pressures up to 1,500 bar (21,750 psi). Since the injector is designed with a no leak-off feature, the entire system can be installed under the engine rocker arm cover.

At the pumping end of the plunger, a precision ground helix covers and uncovers, depending on the plunger position; the charging port in the unit pump body.

During the charging cycle (D), the camshaft follower follows the back side of the cam lobe, allowing the spring loaded plunger to move downward. As the plunger moves downward, the top edge of the helix uncovers the inlet port, filling the pumping chamber.

As the cam follower is forced to rise, due to the rotation of the engine, it forces the plunger upward and into the pump body (E). The helix on the plunger closes off the inlet port (F). The fuel trapped in the pumping chamber will be highly pressurized and pumped to the nozzle for injection.



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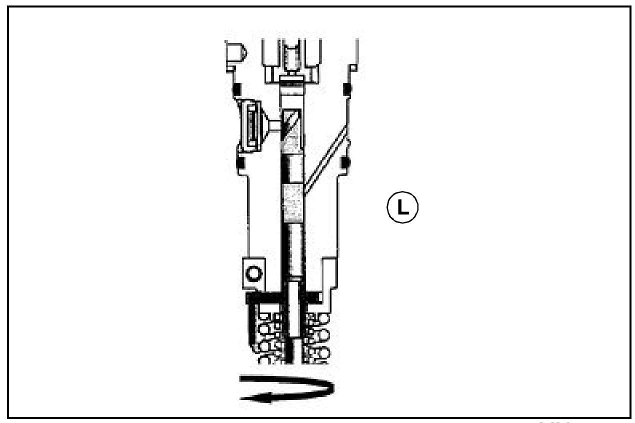
Picture Note: End of Pumping Event



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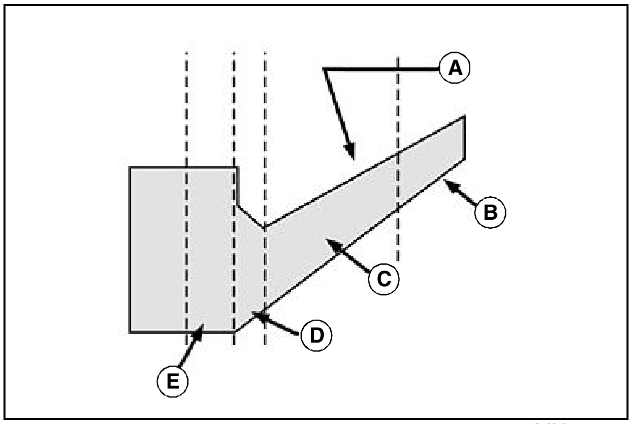
Picture Note: Plunger Rotation

The plunger continues to be lifted by the cam lobe and follower (J). The bottom edge of the helix uncovers the inlet port (K). As the port is uncovered, pressurized fuel from injection, plus any excess fuel in the pumping chamber spills back to the supply galley. The lowering of pressure in the pumping chamber ends the injection cycle.

A 100 kpa (15 psi) fuel outlet check valve, located at the rear of the cylinder block, maintains fuel pressure within the supply gallery. Excess fuel flows back to the fuel tank through the return line.

An engine driven governor in the camshaft assembly, through linkage to the unit pumps, controls the rotational position of the pumping plunger (L) (see “Governor Operation” on page 42). Varying the helix in relation to the inlet port achieves injection quantity and timing.

Light Load and Speed Advance Operation



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Picture Note: Plunger Helix

A - Upper Ramp

B - Lower Ramp

C - Starting (Cranking) Zone

D - Full Load Zone

E - Light Load Zone

The upper edge of the helix (A) controls start of pumping (timing). The lower ramp (B) controls fuel quantity delivered. The starting, or cranking zone (C) of the helix produces an advance in timing and a delivery of a large quantity of fuel, both of which aid starting.

The full load zone (D) provides less advance timing (lower upper ramp location), and less fuel, than the starting zone of the helix.

When the engine is run at no, to light load conditions, the governor rotates the plunger so that the light load zone of the helix (E) controls the covering and uncovering of the charging port as follows: With a decrease in load, engine speed increases, causing the governor to turn the plunger which in turn will cause a decrease in fuel with a corresponding increase in timing. As load increases, engine speed drops. The governor moves the plunger in the opposite direction, increasing fuel and decreasing timing advance.

IMPORTANT: Avoid damage! The helix is specially designed to advance fuel timing under light engine loads to improve combustion efficiency, especially during warm-up.

Cold Start Advance Operation

IMPORTANT: Avoid damage! By slightly advancing the injection event (pump timing), the injected fuel is provided more time to heat during the compression stroke and burn more cleanly in the combustion chamber when ignited. Without cold start advance (CSA), fuel injected into a cool or cold combustion chamber at cold startup takes longer to heat up and ignite. If this delay in ignition is too great, it results in unburned fuel (white smoke and "slobber") and rough running or misfire until the combustion chamber warms.

The cold start advance is controlled by oil pressure in the hydraulic roller cam followers, or lifters, for the unit pumps. During cold starting, engine oil is sent by the cold advance thermostat to the cold advance piston in the cam follower via the cold advance oil gallery. The oil pressure lifts the piston 1.5 mm, thus increasing the overall travel length, or stroke, of the unit pump plunger. This advances the pump timing. The increase in stroke of the plunger causes the cam to raise the plunger sooner. This change results in the injection timing to be advanced approximately ten degrees. The oil pressure needed to provide full cold start advance is about 35 psi. A ball check at the base of the piston prevents pumping forces from collapsing the advance.

The cold start advance thermostat begins to block the oil flow when oil temperatures reach approximately 80°C (176°F). When the oil supply port to the roller cam followers is fully blocked, residual oil in the piston cup bleeds out through a drain orifice located in the cup end of the follower. At approximately 15 psi oil pressure, the cold start advance is fully disabled. The follower piston returns to the lower position, returning timing advance to the optimum performance level for an engine at normal operating temperatures.

Glow Plug Cold Start Aid Operation

Glow plugs aid cold weather starting when the ambient temperature falls below 0°C (32°F). When the ignition switch is pushed in to the "AID" position, the indicator light will illuminate and the glow plugs will be activated. See "Glow Plug and Indicator Light Circuit Operation" on page 265 in the Electrical section.

The combustion chamber may be preheated by pushing in the key, with the switch in the run position, for up to 3 seconds before turning the key to the start position.

The engine preheat indicator light in the display panel provides a visual indication that the key is in the AID position and the glow plugs are being energized.