CATERPILLAR®

G3600 Engine Basics

LEKQ9085

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CATERPILLAR®

G3600 Engine Basics

Engine Design Specifications

G3606

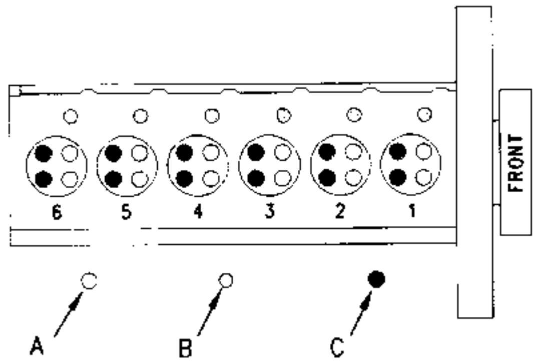


Illustration 1
G3606 Engine Design
(A) Inlet. (B) Gas admission. (C) Exhaust.

Number and arrangement of cylinders ....In-line 6

Valves per cylinder

- Inlet valves 2
- Exhaust valves 2
- Gas inlet valve 1

Displacement ....127.2 L (7762 cu in.)

Bore ....300 mm (11.8 in.)

Stroke ....300 mm (11.8 in.)

Compression ratio 9.2:1

Combustion ....Spark Ignited

Firing order

- Standard rotation CCW 1-5-3-6-2-4

Valve lash

- Inlet ....0.50 mm (.020 in.)
- Exhaust ....1.27 mm (.050 in.)
- Gas admission ....0.64 mm (.025 in.)

When the crankshaft is viewed from the flywheel end the crankshaft rotates in the following direction . ...Counterclockwise

Note: The front end of the engine is opposite the flywheel end of the engine. The left and the right side of the engine are determined from the flywheel end. The number 1 cylinder is the front cylinder.

G3608

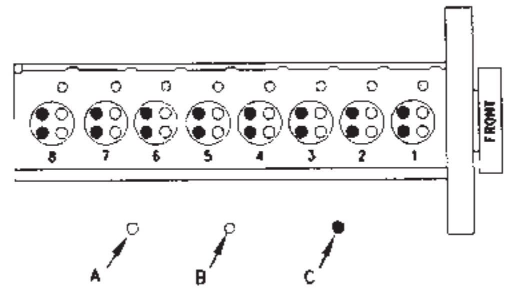


Illustration 2
G3608 Engine Design
(A) Inlet. (B) Gas admission. (C) Exhaust.

Number and arrangement of cylinders ....In-line 8

Valves per cylinder

- Inlet valves 2
- Exhaust valves 2
- Gas admission valve 1

Displacement ....170 L (10,352 cu in.)

Bore ....300 mm (11.8 in.)

Stroke ....300 mm (11.8 in.)

Compression ratio 9.2:1

Combustion ....Spark Ignited

Firing order

- Standard rotation CCW 1-6-2-5-8-3-7-4

Valve lash

- Inlet ....0.50 mm (.020 in.)
- Exhaust ....1.27 mm (.050 in.)
- Gas admission ....0.64 mm (.025 in.)

When the crankshaft is viewed from the flywheel end the crankshaft rotates in the following direction . ...Counterclockwise

Note: The front end of the engine is opposite the flywheel end of the engine. The left and the right side of the engine are determined from the flywheel end. The number 1 cylinder is the front cylinder.

G3612

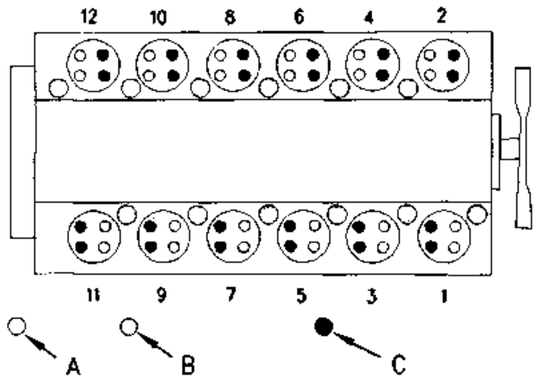


Illustration 3
G3612 Engine Design
(A) Inlet. (B) Gas admission. (C) Exhaust.

Number and arrangement of cylinders ....Vee 12

Valves per cylinder

Inlet valves 2
Exhaust valves 2
Gas admission valve 1

Displacement ....254.5 L (15,525 cu in.)

Bore ....300 mm (11.8 in.)

Stroke ....300 mm (11.8 in.)

Compression ratio 9.2:1

Compression ratio 10.5:1

Combustion ....Spark Ignited

Firing order

Standard rotation CCW 1- 12-9-4-5-8-11-2-3-10-7-6

Valve lash

Inlet ....0.50 mm (.020 in.)
Exhaust ....1.27 mm (.050 in.)
Gas admission ....0.64 mm (.025 in.)

When the crankshaft is viewed from the flywheel end the crankshaft rotates in the following direction . ...Counterclockwise

Note: The front end of the engine is opposite the flywheel end of the engine. The left and the right side of the engine are determined from the flywheel end. The number 1 cylinder is the front cylinder.

G3616

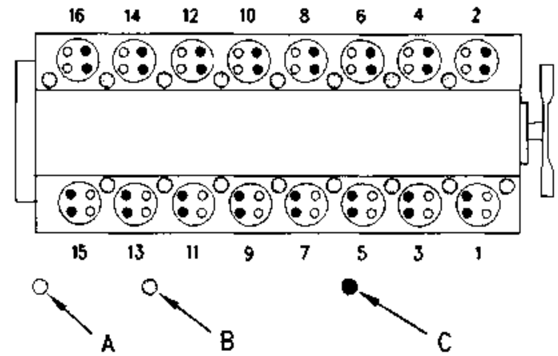


Illustration 4
G3616 Engine Design
(A) Inlet. (B) Gas admission. (C) Exhaust.

Number and arrangement of cylinders ....Vee 16

Valves per cylinder

Inlet valves 2
Exhaust valves 2
Gas admission valve 1

Displacement ....339.3 L (20,700 cu in.)

Bore ....300 mm (11.8 in.)

Stroke ....300 mm (11.8 in.)

Compression ratio 9.2:1

Compression ratio 10.5:1

Combustion ....Spark Ignited

Firing order

Standard rotation CCW 1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8

Valve lash

Inlet ....0.50 mm (.020 inch)
Exhaust ....1.27 mm (.050 inch)
Gas admission ....0.64 mm (.025 inch)

When the crankshaft is viewed from the flywheel end the crankshaft rotates in the following direction . ...Counterclockwise

Note: The front end of the engine is opposite the flywheel end of the engine. The left and the right side of the engine are determined from the flywheel end. The number 1 cylinder is the front cylinder.

Engine Supervisory System

The Engine Supervisory System (ESS) is specifically designed for the Caterpillar G3600 Engines. The ESS integrates several control systems that are installed on the engine. With the ability to communicate with the various systems, the ESS optimizes each controlled parameter in order to ensure maximum engine performance.

The ESS communicates with the following systems:

- Start/Stop/Prelube Logic
- Engine Monitoring And Protection
- Governing
- Air/Fuel Ratio
- Ignition Control

The control panel for the ESS is the center of control for the systems. The control panel for the ESS contains the control modules of each system.

The Engine Supervisory System consists of the following components:

- Control Panel For The Engine Supervisory System (ESS)
- Engine Mounted Junction Box
- Engine Mounted Sensors And Actuators
- Relays, Solenoids And Switches
- Harness

The Engine Supervisory System (ESS) is divided into the following three interactive systems:

Start/Stop/Prelube System – This system controls the starting of the engine, the stopping of the engine, and the prelube pump.

Engine Monitoring And Protection System – This system provides a display of parameters of engine operation. The system generates warnings when one or more parameters are outside acceptable limits. The system can stop the engine if the engine operation reaches a setpoint that is programmed for shutdown. The system can prevent the engine from starting if certain parameters are outside of acceptable limits.

Engine Control System – This system governs the engine. This system controls the air/fuel ratio, the ignition timing, and the limiting of power.

Note: Some of the components within the ESS perform more than one function. For example, the Engine Control Module (ECM) is involved with starting the engine, stopping the engine, monitoring the engine, and controlling the engine.

Engine Mounted Sensors

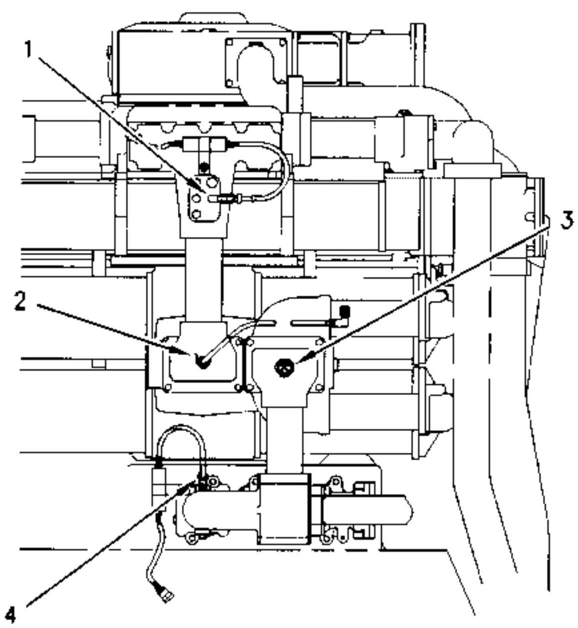


Illustration 5
Engine Mounted Sensors Front View
(1) CMS unfiltered engine oil pressure sensor. (2) SCM engine oil temperature sensor. (3) SCM filtered engine oil pressure sensor. (4) CMS filtered engine oil pressure sensor.

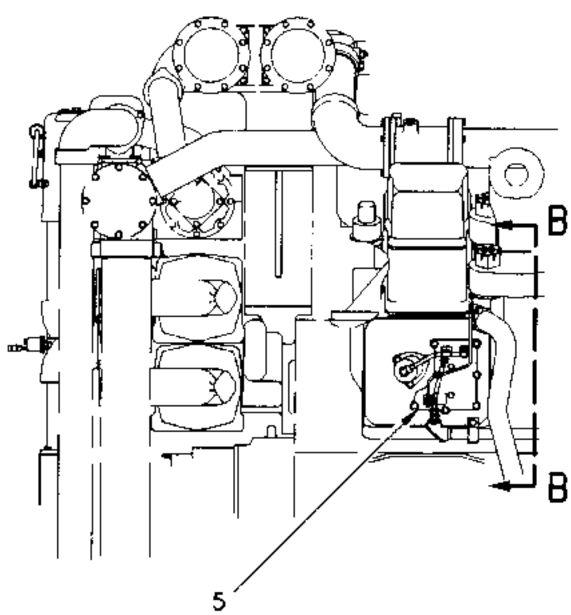


Illustration 6
Engine Mounted Sensors Left Side View
(5) Combustion buffer.

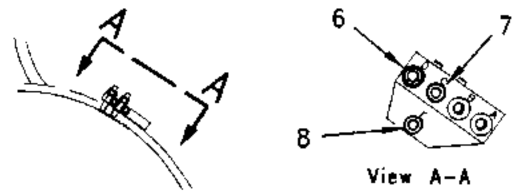


Illustration 7
Engine Mounted Sensors Rear View
(6) Timing control speed sensor. (7) Engine control speed sensor. (8) Timing control crank angle sensor.

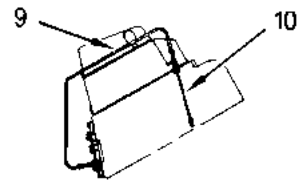


Illustration 8
Engine Mounted Sensors View B-B
(9) Combustion feedback cable. (10) Combustion feedback extension and probe.

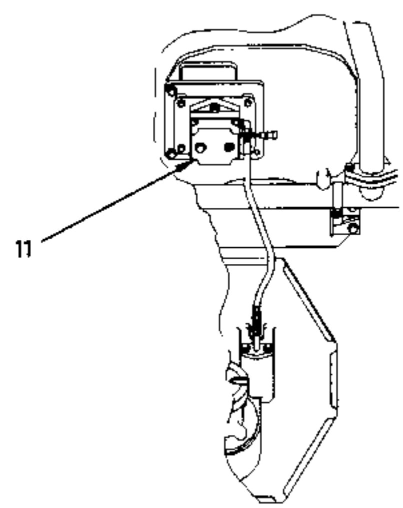


Illustration 9
Engine Mounted Sensors Right Side View
(11) Crankcase pressure sensor.

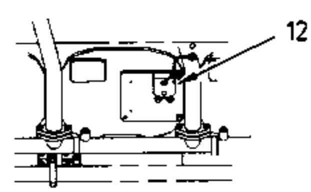


Illustration 10
Detonation Sensors
(12) Detonation sensors.

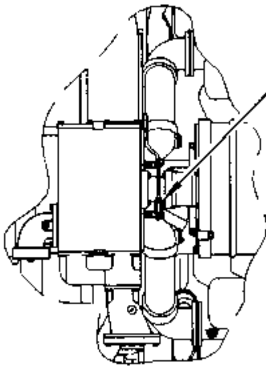


Illustration 11
Engine Mounted Sensors Top View
(13) Jacket water temperature sensor.

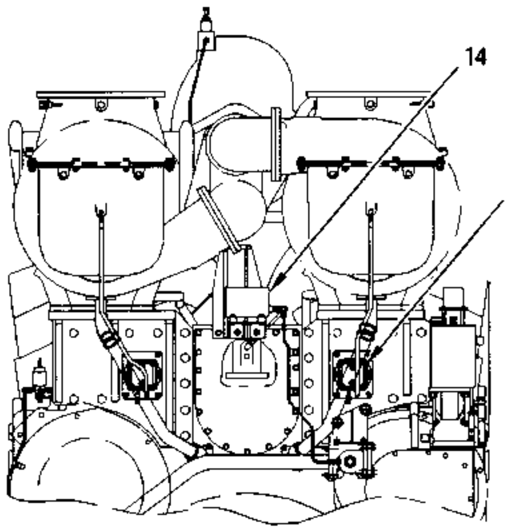


Illustration 12
Engine Mounted Sensors Rear View
(14) Fuel and air Pressure module. (15) Inlet air restriction.

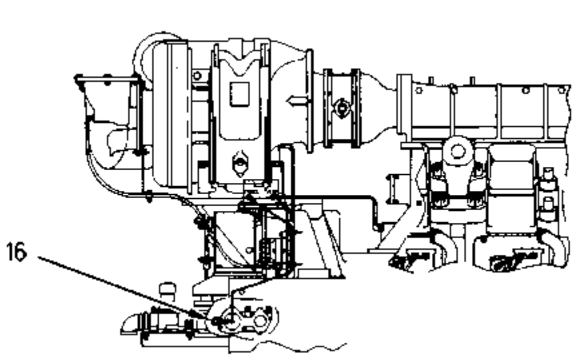


Illustration 13
Engine Mounted Sensors Right Side View
(16) Fuel temperature sensor.

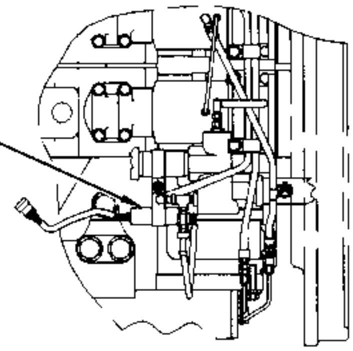


Illustration 14
Engine Mounted Sensors Left Side View
(17) Starting air pressure sensor.

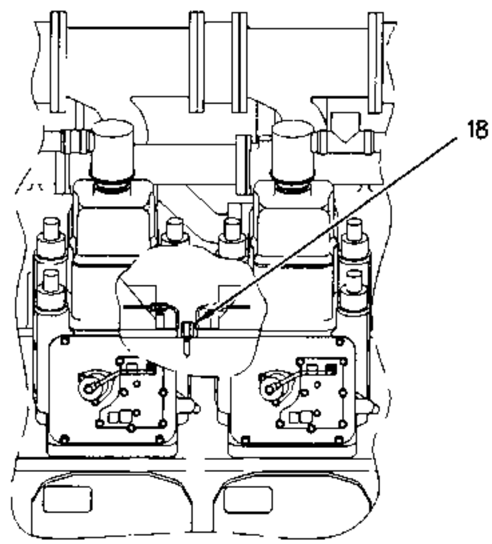


Illustration 15
Engine Mounted Sensors Right Side View
(18) Inlet air temperature sensor.

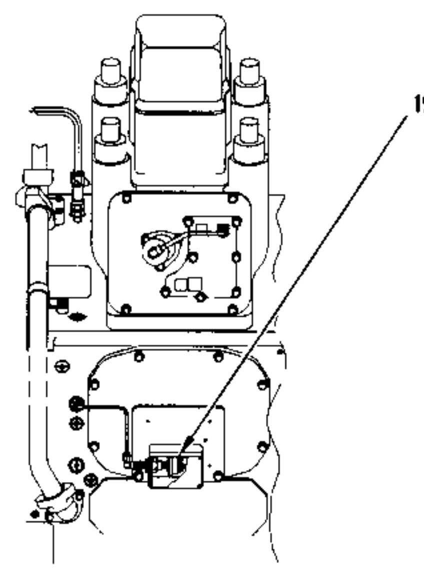


Illustration 16
Engine Mounted Sensors Right Side View
(19) Prelube pressure switch.

Control Panel For The Engine Supervisory System (ESS)

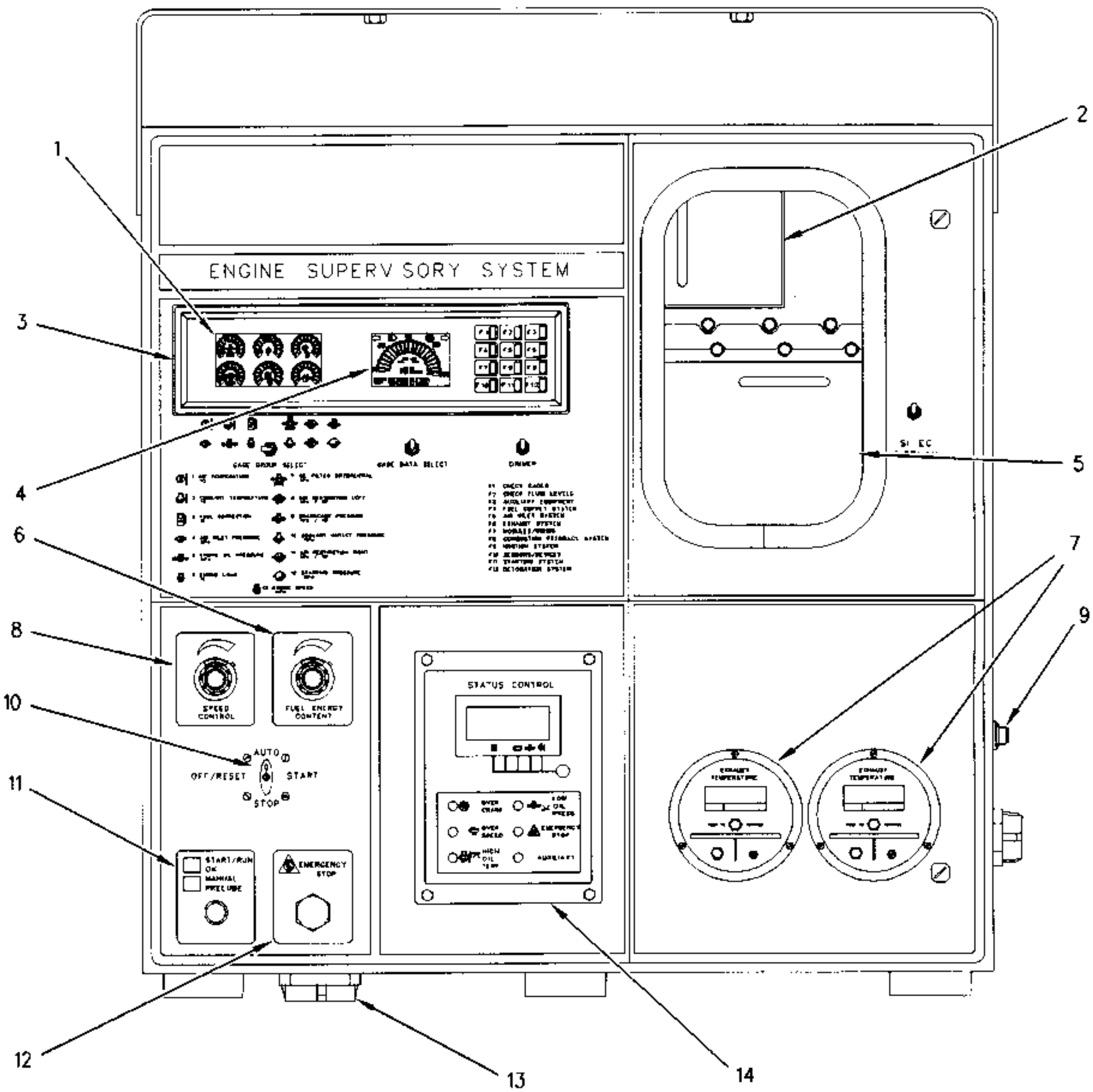


Illustration 17
(1) LED Dial gauges. (2) Timing Control Module (TCM). (3) CMS Gauge panel. (4) Digital gauge readout. (5) Engine Control Module (ECM). (6) Fuel energy adjustment dial. (7) Exhaust pyrometer. (8) Engine speed adjustment dial. (9) Digital Diagnostic Tool (DDT) connection. (10) Mode control switch. (11) Prelube switch. (12) Emergency stop push button. (13) Sensor wiring to the engine. (14) Status Control Module (SCM).

This panel contains the control modules, the switches, and the potentiometers that are associated with the system.

- Engine Control Module (ECM) (System Coordination, Governing, Air/Fuel Ratio Control)
- Timing Control Module (TCM) (Ignition System Control)
- Status Control Module (SCM) (Start/Stop Control)
- Computerized Monitoring System (CMS) (Gauge Panel Display of System Parameters)
- Pyrometer Module (Display of Exhaust Temperatures)
- Mode Control Switch (MCS)
- Prelube Switch/Start Run Okay Lamp
- Emergency Stop Switch
- Fuel Energy Adjustment Potentiometer
- Desired Speed Adjustment Potentiometer
- Gauge Group Select Switch
- Gauge Data Select Switch
- Display Select Switch
- Dimmer Switch Diagnostics

Diagnostics

The Engine Supervisory System is self-diagnostic. Through lights and fault codes, the ESS directs the service technician to the system or the component that requires maintenance.

Mounting

The control panel for the ESS is a waterproof enclosure. The control panel is intended to be mounted at a remote location. The control panel can be mounted up to 30.5 m (100 ft) from the engine.

Hazardous Environments

The engine and the Engine Supervisory System have been Canadian Standards Association (CSA) certified for use in hazardous locations Class 1, Division 2, Group D.

Customer Interface Connections

Refer to Installation And Initial Start-up Procedures, SEHS9549, for information regarding customer input and output connection points.

RS232 Computer Interface

RS232 output of system data is available for customer monitoring and information systems. This output requires a ship loose converter module.

Start/Stop/Prelube System

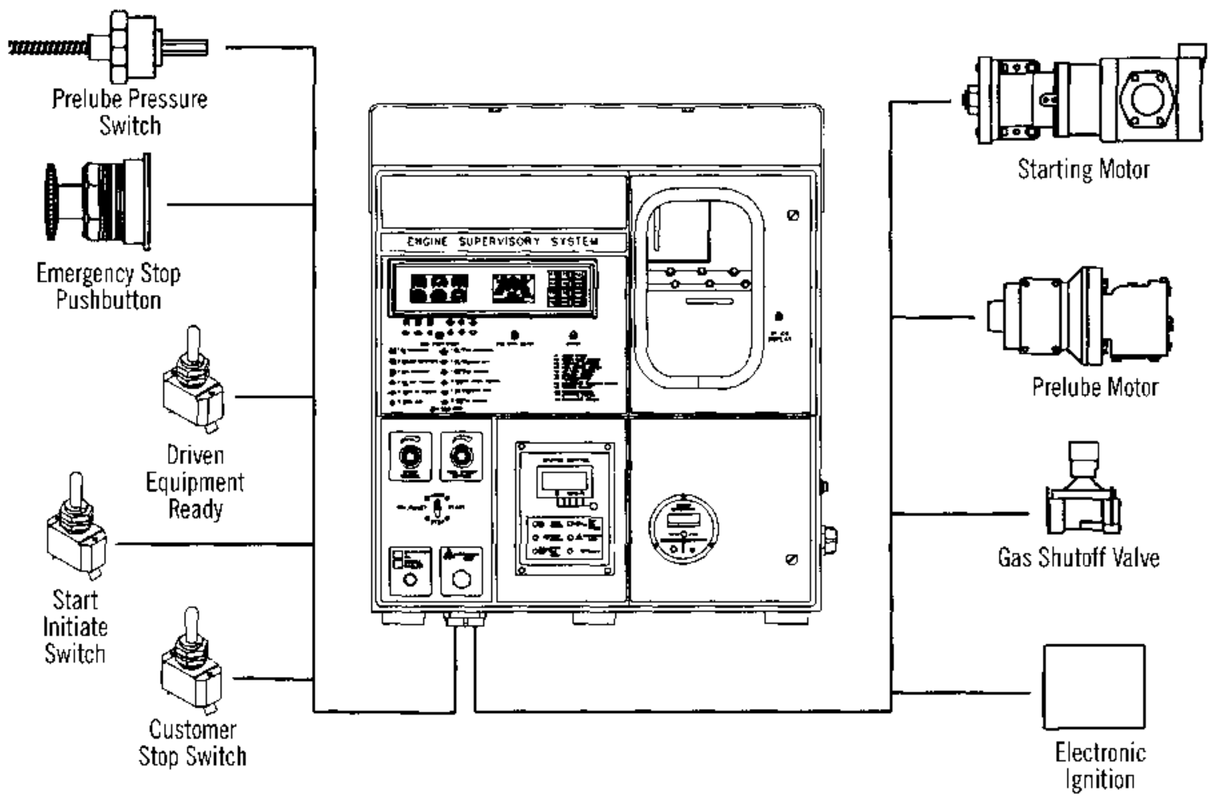


Illustration 18

The system consists of the following components:

1. The Control Panel For The Engine Supervisory System (ESS). The control panel consists of the following components:
   - Mode Control Switch (MCS)
   - Status Control Module (SCM)
   - Engine Control Module (ECM)
   - Prelube Switch/Lamp
   - Speed Control Dial
   - Fuel Energy Content Dial
   - Emergency Stop Push Button
2. Gas Shutoff Valve (GSOV)
3. Ignition System
4. Fuel Actuator
5. Prelube Pump System (Pump And Solenoid)
6. Engine Cranking System (Starting Motors And Solenoids)

The controls for the Start/Stop/Prelube and the Status Control Module perform the automatic start/ stop functions. The Status Control Module monitors certain engine functions that are required for operation. The Status Control Module monitors and provides an automatic shutdown of the engine under normal operating conditions.

The Speed Control Potentiometer will allow the operator the ability to select the engine speed that is needed for a particular application. Low idle speed is 550 rpm. Rated speed can be as high as 1000 rpm.

The Fuel Energy Content Potentiometer is used in order to adjust the setting for the Lower Heat Value of the fuel. The Fuel Energy Content Potentiometer setting should be adjusted in order to display a Btu value on the ECM that is equal to the Lower Heating Value of the fuel supply in terms of Btu/ft^3. The Lower Heating Value Btu is based on the data from a fuel analysis that is input into the Caterpillar Methane Number Program, 5.0, LEKQ6378-01.

The major functions of this system are controlled by the following components:

- Mode Control Switch (MCS)
- Prelube Push Button

The MCS has the following four positions and operations:

- AUTO
- START
- STOP
- OFF/RESET

AUTO – When the mode control switch is in the AUTO position, the system is configured for remote operation. When the remote start/stop initiate contact closes, the prelube system will operate and the engine will start. When the remote start/stop initiate contact opens, the engine will shut off. If the cool down cycle is programmed, the engine will operate for the cool down period before the engine stops. The cool down cycle can be programmed for a 0 to 30 minute period. A cool down period is not recommended for G3600 engines.

START – When the mode control switch is turned to the START position, the prelube system will operate. When the prelube pressure is sufficient, the engine will start. The engine will operate until the ESS receives a shut down signal.

STOP – When the mode control switch is turned to the STOP position, the engine will shut off. After the engine stops, a postlube cycle will operate. The power to the control panel is maintained when the mode control switch is in the STOP position. The “STOP” mode can be used to troubleshoot some problems without starting the engine.

OFF/RESET – When the mode control switch is turned to the OFF/RESET position, the engine is immediately shut off and the diagnostic lights of the status control module are reset. Power is removed from the control panel and the actuators after the engine completes the postlube cycle.

MANUAL PRELUBE button enables the operator to prelube the engine. All G3600 Family Engines should be lubricated before the crankshaft is rotated. This includes crankshaft rotation in order to service the engine. Rotating the crankshaft before prelube may cause damage to the crankshaft bearings if the surfaces of the bearings are dry.

All G3600 Family Engines require lubrication prior to start-up. The ESS will not permit the engine to start until sufficient prelube pressure has been achieved. The actuators will be powered up after the engine has been prelubed.

Note: The ECM is programmed to provide engine lubrication after the engine is shut off. The typical duration of the postlube is 60 seconds.

The EMERGENCY STOP push button immediately de-energizes the Gas Shutoff Valve and grounds the CIS in order to stop the engine (no cool down). The engine may not be restarted until the Status Control Module has been reset by turning the MCS to the OFF/RESET position. More than one EMERGENCY STOP push button may be used, depending on the engine installation.

NOTICE

The EMERGENCY STOP push button is not to be used for normal engine shutdown. To avoid possible engine damage, use the Mode Control Switch (or Start Initiate Contact for remote operation) for normal engine shutdown.

These engines require a prelube cycle prior to start-up. The engine will not start until the Status Control Module tells the Engine Supervisory System that the minimum requirement for oil lubrication has been reached.

The Engine Control Module is programmed to provide a period of engine lubrication (postlube) after shutdown. The time that is required for postlube is typically 60 seconds.

Sequence Of Operation

The Mode Control Switch (MCS) of the remote control panel has four positions: AUTO, START, STOP, OFF/RESET. If the MCS is in the AUTO position and a signal to run is received from a remote initiate contact (IC), or when the MCS is placed in the START position, the engine will prelube, crank, terminate cranking and run. The engine may cycle crank if the feature for cycle crank is utilized. The engine will run until the signal to run is removed by either turning the Mode Control Switch (MCS) to STOP, OFF/RESET, or opening the remote initiate contact with the MCS in the AUTO position. Once the MCS is moved to the STOP position, or if in the AUTO position and the remote initiate contact opens, the engine will run for a short period of time in the cool down mode, if the cool down feature was utilized, If the cool down feature was not utilized the engine will shut down immediately. The engine will then start the postlube cycle. The engine is then capable of immediate restart.

Sequence Of Operation (Normal Start/ Stop)

When the MCS is placed in the START position or the AUTO position and the remote initiate contact is closed:

1. A signal is sent to the prelube relay.
2. The prelube pump will run.
3. The prelube switch will close to indicate that 6.9 kPa (1 psi) of oil pressure is at the switch.
4. After a preprogrammed period of time (typically 30 seconds), the ECM will send a signal in order to energize the prelube pump switch relay The green prelube light will turn on. CMS Gauge No. 5 will stop flashing. A start signal is sent to the SCM.

Upon receipt of a signal to start, the SCM will check in order to ensure that the following conditions are met:

1. An emergency stop signal is not present.
2. All faults have been reset.
3. All sensors are connected and operating properly.
4. No abnormal mode control switch signals are present.
5. The engine is not already running.
6. The SCM microprocessor is functioning properly.
7. The SCM is not in the programming mode.

The SCM will not allow the start sequence to begin. The SCM will display the proper diagnostic code when applicable, if an above fault condition exists. However, once the SCM is satisfied that conditions are normal, the SCM will energize the Starting Motor Relay (SMR) and the Run Relay (RR). The SCM will also signal for fuel to be turned on by energizing the Fuel Control Relay (FCR) and the Run Relay (RR). The fuel actuator will begin to open at 50 rpm. The Ignition Shutoff Relay will be energized in order to begin the ignition system functioning.

If the feature for cycle crank is enabled, the SCM will automatically crank/rest/crank the engine for adjustable time periods. If the engine fails to start within the selected total crank time, the SCM will execute an overcrank fault. If a fault condition occurs while the engine is cranking, the SCM will terminate and lock out cranking. The SCM will display the applicable diagnostic code, or the SCM will light the appropriate LED.

After the engine starts and has achieved the crank termination speed (typically 250 rpm), the SCM will de-energize the starting motor by de-energizing the SMR. The SCM will energize the Crank Termination Relay (CTR). Once the correct low idle oil pressure is achieved, the SCM will signal for the ECM to accelerate the engine to rated speed.

The engine will run if the operating conditions remain normal and a signal to run is being received by the SCM. The SCM will sequentially display each of the following for a two second period: the engine oil pressure, the oil temperature, the rpm, the service hours, and the system DC volts. This is done via the digital display prior to or while the engine is operating. As well as monitor for any fault or abnormal conditions that may occur.

Upon loss of the run signal, the engine will continue to run for an adjustable cool down period if the cool down feature is utilized. However, if the cool down feature is not used or if the SCM receives an off/reset signal, the SCM will immediately de-energize the Run Relay. The fuel circuitry will be de-energized. If the signal to run returns before the engine stops, the SCM will immediately go back to the running state. This means, the fuel will be turned back on, but the starting motor will not energize. However, if a restart does not occur and the rpm continues to drop, then the SCM will initiate cranking upon reaching zero rpm, Assuming that the run signal does not return and the engine speed continues to diminish until zero rpm is reached, then the Crank Termination Relay (CTR) will be de-energized and the SCM will be ready for an instant restart. The Fuel Control Relay will be ready for an instant restart. The Fuel Control Relay (FCR) of the SCM will de-energize in two seconds after zero rpm.

Sequence Of Operation (Fault Conditions)

If a fault condition occurs prior to starting the engine, the SCM will:

1. De-energize and lock out the starting motor circuit.

2. Ensure that fuel is shut off.

3. De-energize the Run Relay Circuit.

4. Energize the fault shutdown circuitry (Engine Failure Relay).

If a fault condition occurs while the engine is running, then the SCM will respond in the following manner:

1. Fuel control circuitry will be de-energized for energized to run engines.

2. Ignition Shutoff Relay will be de-energized, for an overspeed, emergency stop, or diagnostic codes 01, 04, 06 or if all six LEDs are on. The relay will also de-energize if the engine has not shut down within five seconds after the FCR commanded it to do so. This would be the result of a fault condition. The relay circuitry shall be re-energized for 10 to 15 seconds after the engine reaches zero rpm. The relay shuts off the ignition system.

3. The Starting Motor Relay (SMR) circuitry shall be locked in the de-energized state.

4. The Run Relay (RR) circuitry shall be de-energized.

5. The Fault Shutdown Circuitry shall be energized, including the Engine Failure Relay (ENFR).

If a fault occurs before or after the engine starts, then the appropriate fault indicating LED shall flash at two Hertz or a diagnostic code shall be displayed to indicate the nature of the problem. The indicators shall remain on. The SCM shall remain in the fault mode until it receives a reset signal.

Engine Monitoring And Protection System

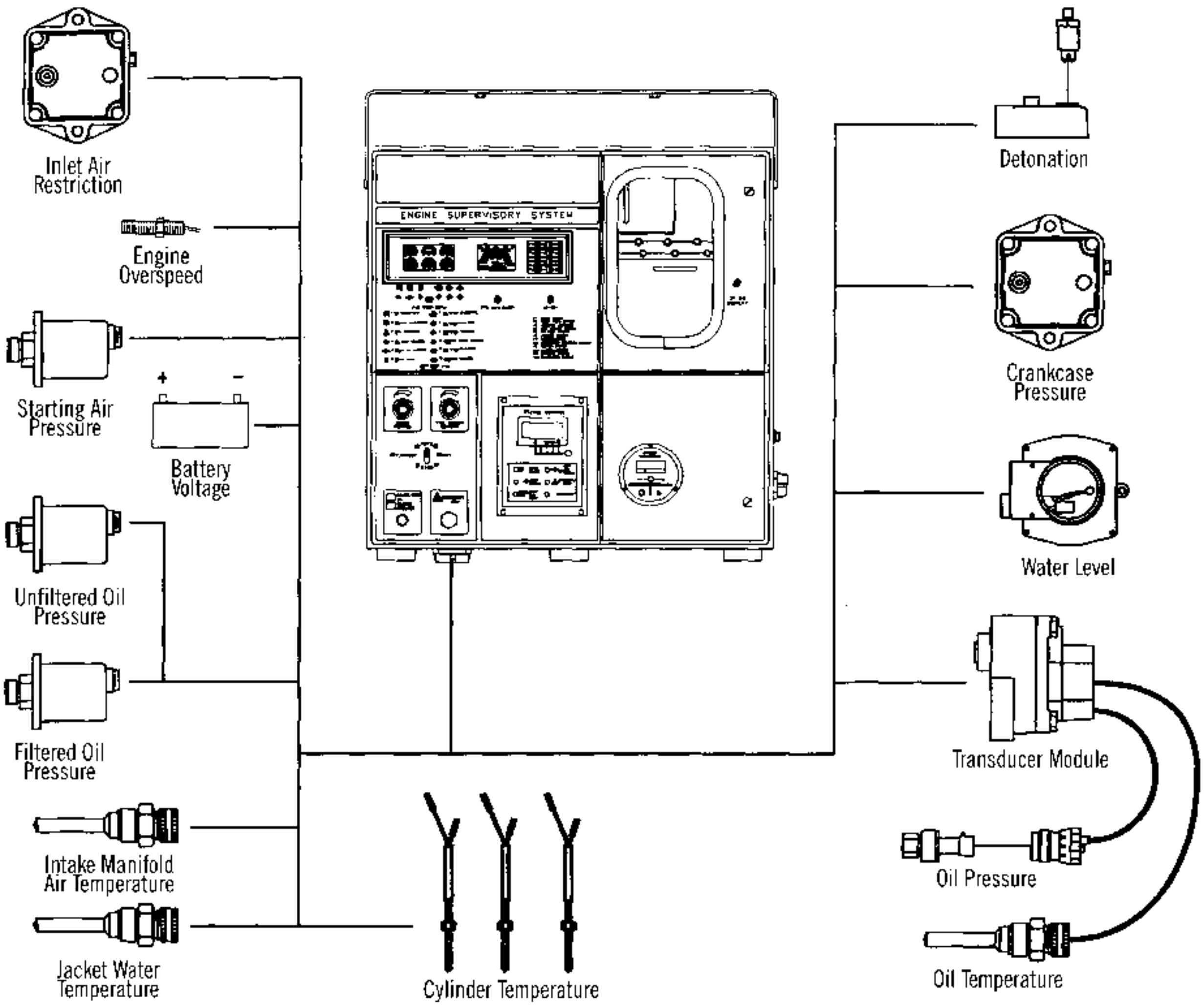


Illustration 19

The system provides engine protection and monitors engine systems for vital parameters. The system provides warnings and/or inhibits the engine from starting. The system shuts down the engine when the parameters are outside acceptable limits. Along with these features, the system provides display/ indication of the engine operating parameters.

Engine Shutdown And Start Inhibiting Functions

The engine shutdown features provide engine protection by shutting down the engine when certain operating parameters are beyond acceptable limits. The engine shutdown features provide engine protection when the driven equipment sense a shutdown signal to the control panel for the ESS.

The start inhibiting features provide protection to the engine and the driven equipment by preventing the engine from cranking when the engine parameters are not within acceptable limits or the driven equipment has indicated that the driven equipment is not ready to start.

Engine shutdown and start inhibiting problems will be indicated by the CMS panel display, the Engine Control Module (ECM) or the Status Control Module (SCM). The CMS panel display will provide a diagnostic indication when the lights are ON. The ECM will display a FLASHING diagnostic code to indicate that engine shutdown due to a specific problem that was encountered. The ECM will display a SOLID diagnostic code in order to indicate that a warning condition has occurred due to a specific problem that was encountered. For additional information on troubleshooting the displayed information, refer to Troubleshooting, SENR6510, for G3600 Engines.

Computerized Monitoring System (CMS)

The display consists of six small gauges (left side) and one larger gauge (center). The information that is displayed on the gauges is controlled by the GAUGE GROUP SELECT switch and the GAUGE DATA SELECT switch. The GAUGE GROUP SELECT switch selects between two sets of parameters that are available for display on the six small gauges.

The GAUGE GROUP SELECT switch allows the data that is provided on each of the gauges to be viewed on the digital readout. The digital readout is located below the large center gauge. The upper number in the gauge display will indicate which parameter is being viewed. Each time that the GAUGE DATA SELECT switch is toggled, the next gauge is selected. This is within the range of gauges currently selected by the GAUGE GROUP SELECT switch.

If the GAUGE GROUP SELECT switch is switched, then the digital gauge will change to the gauge for the corresponding gauge position, If gauge 2 coolant temperature was selected and the GAUGE GROUP SELECT switch is moved the gauge data will switch to gauge 8, AIR RESTRICTION LEFT.

CMS Gauge Display

The film on the control panel for the ESS is either in English Units or Metric Units. Depending on the application, the readouts will be in either English Units or Metric Units. By setting the “GAUGE GROUP SELECT” switch to the left, the following engine functions are displayed on the gauge and the digital readout.

Gauge 1 AIR TEMPERATURE – The temperature of the air inlet manifold is displayed in °C or °F. The temperature is displayed within one degree.

Gauge 2 COOLANT TEMPERATURE – Temperature is displayed in °C or °F. The temperature is displayed within one degree.

Gauge 3 FUEL CORRECTION – The display shows a percent value. This is a ratio of the difference between the adjusted setting of the fuel energy content Btu potentiometer and the Btu energy content of the fuel that the engine is burning.

Note: When the red limit bars on this gauge are turned off, the air/fuel ratio is not being automatically controlled and the fuel correction factor is fixed at 100%. When the red bars are present, the air/fuel ratio control is based on the in cylinder measured combustion burn time.

Gauge 4 AIR INLET PRESSURE – Air inlet manifold pressure (absolute) is displayed in kPa or psi/10.

Gauge 5 ENGINE OIL PRESSURE – Pressure is displayed (gauge) in kPa or psi.

Note: Prelube oil pressure is indicated by a bar around the display for the oil pressure gauge. A solid bar indicates that the prelube pressure is OKAY. A flashing bar indicates that the prelube pressure is NOT OKAY.

Gauge 6 ENGINE LOAD – Load is displayed as a percentage of the full rated power output of the engine. The calculation of the percentage is based on the following factors: flow of fuel, engine rpm, and fuel energy content.

By setting the “GAUGE GROUP SELECT” switch to the right, the following engine functions are displayed on the gauge and the digital readout.

Gauge 7 OIL FILTER DIFFERENTIAL – The amount of pressure drop between the inlet and the outlet of the oil filter housing is displayed in kPa or psi.

Gauge 8 AIR RESTRICTION LEFT – The amount of pressure drop between the inlet (unfiltered) and outlet (filtered) sides of the air cleaner, displayed in kPa/10 or inches of $H_20/10$.

Gauge 9 CRANKCASE PRESSURE – This gauge indicates the pressure that is inside the crankcase. This is displayed in kPa/10 or inches of $H_20/10$

Gauge 10 COOLANT OUTLET PRESSURE – This gauge is not used.

Gauge 11 AIR RESTRICTION RIGHT – This gauge is not used with the G3600 engines.

Gauge 12 STARTING PRESSURE – This gauge indicates the air pressure that is available for starting the engine. This is displayed in kPa or psi.

The large gauge (center) always indicates the engine speed.

Gauge 13 ENGINE SPEED – This gauge displays engine speed in rpm (within 10 rpm).

CMS Fault Indicator Lights

The CMS has 12 lights that indicate a fault condition has occurred. A fault is either a measured parameter outside a safe limit or a malfunctioning device. Each light indicates the system to look for in determining the exact problem.

F1 CHECK GAUGES – One or more gauges indicate that a parameter is outside of the normal operating range. Check gauges.

F2 CHECK FLUID LEVELS – One or more fluid levels are below an acceptable limit. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F3 AUXILIARY EQUIPMENT – One or more problems exist in the interface for the driven equipment. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F4 FUEL SUPPLY SYSTEM – One or more problems exist in the system that controls the fuel. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F5 AIR INLET SYSTEM – One or more problems exist in the system that controls the inlet air. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F6 EXHAUST SYSTEM – One or more problems exist in the exhaust system. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F7 MODULES/WIRING – One or more problems exist with specific control modules and/or the wiring. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F8 COMBUSTION FEEDBACK SYSTEM – One or more problems exist in the controls for the feedback from the combustion system. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F9 IGNITION SYSTEM – One or more problems exist in the ignition system. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F10 SENSORS/DEVICES – One or more problems exist on specific control devices. This includes sensors, actuators, etc. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F11 STARTING SYSTEM – One or more problems exist in the engine starting system. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

F12 DETONATION SYSTEM – One or more problems exist in the system that detects detonation. Observe the diagnostic code(s). Refer to Troubleshooting, SENR6510 for G3600 Engines.

Status Control Module (SCM)

The bottom of the control panel for the ESS contains the Status Control Module (SCM). This displays fault conditions and key engine parameters. The Status Control Module (SCM) accepts information from the operator, magnetic speed pickup (MPU), pressure/temperature module and the Engine Supervisory System (ESS). This information is used to determine the "on/off" state of the engine's fuel and ignition system.

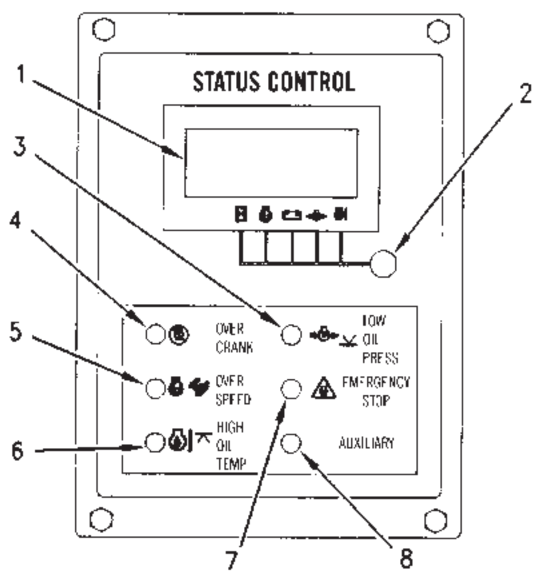


Illustration 20
Status Control Module (SCM)
(1) Liquid Crystal Display (LCD). (2) Switch (display hold switch). (3) Low Oil Pressure Light Emitting Diode (LED). (4) Overcrank LED. (5) Overspeed LED. (6) High Oil Temperature LED. (7) Emergency stop LED. (8) Auxiliary LED (shutdown).

The SCM receives a signal that instructs the SCM to start the engine. The SCM activates the fuel system and the starting motor. When the engine rpm reaches the crank termination speed, the starting motor is disengaged. When the SCM receives a signal to stop the engine, the fuel system is shut off.

The SCM has the following features:

Cycle Crank – The SCM can be programmed to crank-rest-crank for adjustable time periods.

Speed Control – When the engine oil pressure increases past the low oil pressure set point, the SCM will inform the ECM that the ECM should increase the engine speed from idle to rated.

Cooldown – After the SCM receives a signal to perform a normal shut down, the SCM will wait for a preprogrammed amount of time before shutting the engine off via the gas shutoff valve.

Automatic Operation – While in the automatic mode, the SCM can be started by a remote initiate signal. This signal is when the initiate contact (IC) closes. Upon the loss of the signal, the SCM will perform a normal shut down.

Power Down – The ESS system is designed to remove power when in the *off/reset* mode once the postlube cycle is complete. The SCM will not allow the engine to power down until the *Crank Termination Relay* and the *Fuel Control Relay* are both off. Both relays turn off two seconds after zero rpm.

Fuel Solenoid Type – The SCM can be programmed to work with either an Energize To Run (ETR) fuel system or an Energize To Shutdown (ETS) fuel system. In G3600 applications this must be an ETR system.

LED Display – Six LEDs are located on front of the SCM to annunciate overcrank shutdown, overspeed shutdown, low oil pressure shutdown, high oil temperature shutdown, emergency stop and auxiliary shutdown.

Emergency Stop – LED (7) will flash if the *Emergency Stop* button is used to stop the engine.

Pressure/Temperature Module Malfunction – If the signal from the engine mounted oil pressure/temperature transducer module is lost or unreadable, the engine will be shut down via the fuel control. A diagnostic code will be displayed. The SCM can be programmed to ignore the malfunction of the transducer module.

Speed Pickup Malfunction – If the SCM loses the magnetic pickup signal, the engine will be shut down via the ignition system and the fuel control. A diagnostic code will be displayed.

Overcrank Protection – If the engine fails to start within a programmed amount of time, the SCM will cause the starting sequence to cease. LED (4) will flash. The mode control switch must be turned to the *Off/Reset* position before another attempt to start the engine can be made.

Liquid Crystal Display (1) – Service hours, engine speed, system battery voltage, engine oil pressure and engine oil temperature are sequentially displayed in either English or Metric Units. Pressing switch (2) on the front of the SCM will cause the display to lock (stop) on one of the engine parameters. Pressing the switch again will resume the display to normal sequencing. When a fault signal is detected, the display is also used to indicate diagnostic codes. This is to aid in troubleshooting. Refer to Systems Operation, Testing And Adjusting, Status Control Module (SCM), SENR6515, *Troubleshooting Section*, *Diagnosed Problems*.

Note: All diagnostic lights should turn on briefly when the panel is powered up. This is a light test.

Overspeed Protection – If the engine speed exceeds the set point for the overspeed, then the engine will be shut down via the ignition control and the fuel control. LED (5) will flash. The set point for the overspeed is lowered to 75 percent of the original value while the *Overspeed Verify* switch is depressed. This will allow the overspeed circuit to be tested while the engine is operating at rated speed.

Low Oil Pressure Protection – If the engine oil pressure drops below the low oil pressure set point, it will be shut down by means of the fuel control. LED (3) will flash. There are two set points for the low oil pressure. One set point is for when the engine speed is below the oil step speed. The another set point is for when the engine speed is above the oil step speed.

High Oil Temperature Protection – If the engine oil temperature exceeds the set point, the fuel will be shut off. LED (6) will flash. Refer to the Testing And Adjusting section of *G3612 and G3616 Engines Systems Operation and Testing & Adjusting Manual*, SENR5528, for status control module service procedure for information about testing and programming of the SCM.

Note: If a fault occurs and the control for the fuel does not shut down the engine, the ignition is shut off five seconds after the fault has occurred.

Engine Control Module (ECM)

The ECM monitors the fuel energy content for the air/fuel ratio control and for limiting the power. The ECM also has the function of system coordinator. The personality module of the ECM contains many of the protection set points. The personality module controls much of the systems operation. The display on the ECM consists of eight characters and eight lights.

The lights indicate:

STATUS (Green) – When this light is on, this light is for status information. Status information is the desired engine speed, fuel energy (Btu) setting, etc.

COMMUNICATION LINK 1 ACTIVE (Green) – When this light is on, this light will indicate that the ECM is properly communicating with the Timing Control Module (TCM).

COMMUNICATION LINK 2 ACTIVE (Green) – When this light is on, this light will indicate that the ECM is properly communicating with the Computerized Monitoring System (CMS Gauges), the Digital Diagnostic Tool (DDT) ports, and the optional Customer Communication Module (CCM).

CAUTION MODE (Yellow) – One or more problems exist. The code that indicates the exact nature of the condition will be displayed.

SENSOR FAULT (Red) – A problem with one of the sensors has been detected. One or more problems exist. The code that indicates the exact nature of the condition will be displayed.

ACTUATOR FAULT (Red) – A problem with one of the actuators has been detected. The code that indicates the exact nature of the problem will be displayed.

SYSTEM FAULT (Red) – A problem with one of the control systems has been detected. The code that indicates the exact nature of the problem will be displayed.

CONTROL MODULE FAULT (Red) – A problem with one of the control modules has been detected. The code that indicates the exact nature of the problem will be displayed.

The DISPLAY SELECT switch that is located on the right hand side of the ESS control panel door will allow the operator to step through the data on the Engine Control Module display. Every time the switch is toggled, the display steps through to the next item. Items displayed are either status codes or diagnostic codes. These codes are differentiated by one of the lights.

ECM Timing Control Module (TCM)

The Timing Control Module (TCM) maintains the ignition timing that is determined by the ECM. The TCM also protects the engine from unacceptable levels of detonation.

The TCM provides the ECM with information about detonation. The ECM sends a signal to the TCM for the engine timing that is desired. The signal can be retarded up to six crankshaft degrees if detonation is sensed. The engine will be shut down if high levels of detonation persist.

ECM Pyrometer Module

The pyrometer module allows the read out in nine separate temperatures in °C. The module powers up and displays the reading on channel zero (exhaust stack temperature). In order to read the temperature values on the other eight channels, press the *Push To Advance* button on the front of the gauge.

The pyrometer continuously compares channel zero (exhaust stack temperature) to a set point. If the exhaust stack temperature ever exceeds the set point, a contact closes. The ECM shuts down the engine.

Engine Control System

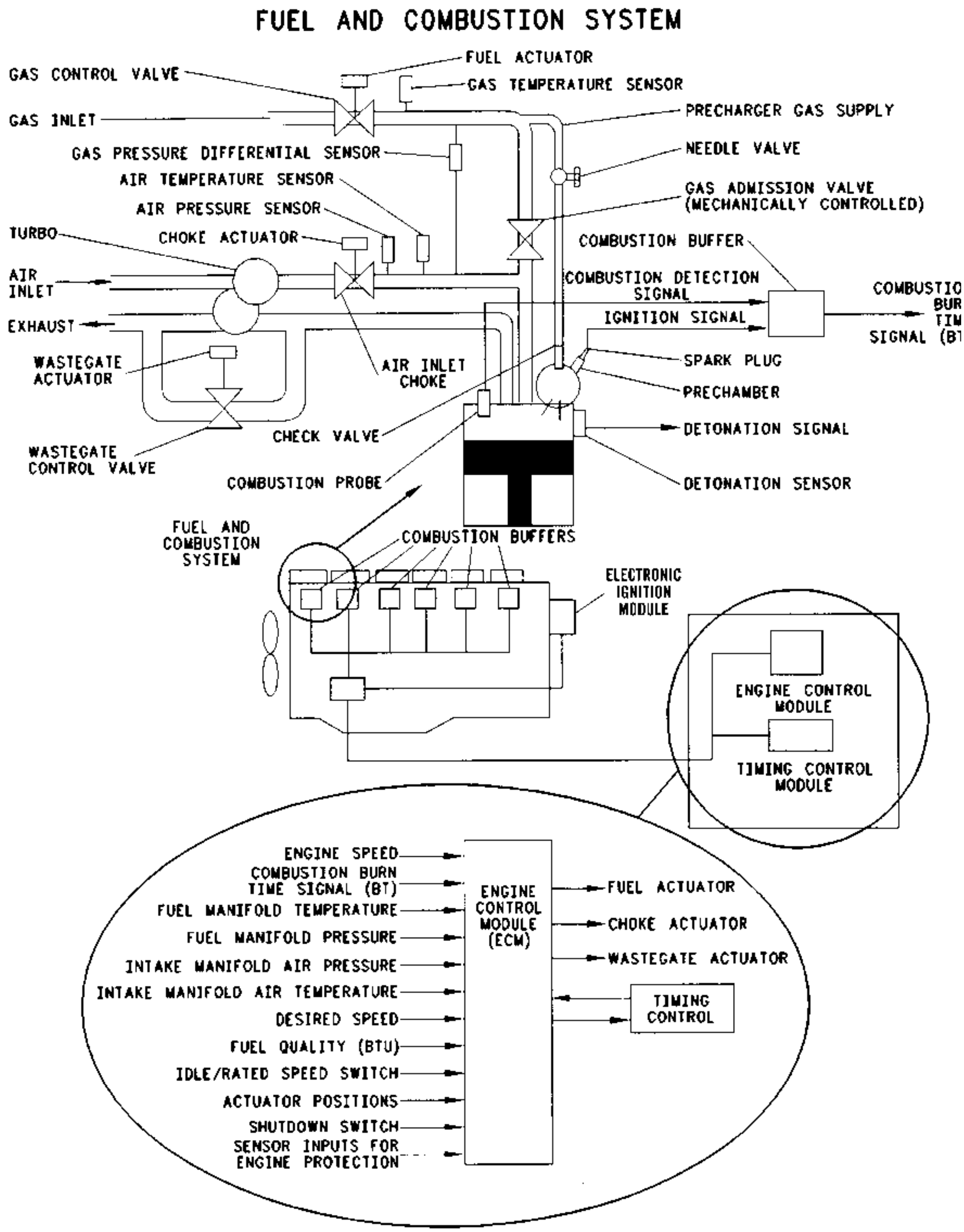


Illustration 21

The Engine Control System consists of the following components:

1. Engine Supervisory System (ESS) Control Panel
   - Engine Control Module (ECM)
   - Timing Control Module (TCM)
   - Desired Speed Potentiometer
   - Fuel Energy Content Potentiometer
2. Engine Mounted Sensors
3. Engine Mounted Actuators
   - Fuel
   - Wastegate
   - Choke

Governor

The Electronic Control Module (ECM) performs the governing function. The governor resembles a diesel engine governor more than a typical gas engine governor. The G3600 Engine is governed by modulating the fuel valve that controls the fuel flow independent of the air flow. The command signal that is sent from the ECM to the fuel actuator is based on the difference between the actual engine speed (as measured by the ECM magnetic pickup) and the desired engine speed.

Speed Droop

A setting from 0 to 10 percent speed droop can be selected by using the *Customer Selectable Parameter Screen*, *Number 31*, on the Digital Diagnostic Tool.

Switchable Governor Response

In order to provide a optimum engine response, with a generator set that operates in parallel with a utility or that operates with other generator sets, there must be two governor settings. The G3600 control system offers a dual dynamics governor. The *Governor Dynamics Switch* will select from either *Stand Alone* or *Paralleled* governor settings. Refer to Installation And Initial Start-up Procedures, SEHS9549, for information regarding switching from *OFF-GRID* to *ON-GRID* governor dynamics.

Desired Speed Control

Desired speed is controlled by an idle/rated switch. Open selects the idle speed of 550 rpm, closed selects the speed set by the desired speed potentiometer. The desired speed input is typically the potentiometer on the front face of the ESS panel. The desired speed may be controlled by an external input to the ECM. Refer to Installation And Initial Start-up Procedures, SEHS9549, for information regarding customer input.

Fuel Limiting

The governor provides the limiting of power on the G3600 Engine. The governor calculates the fuel flow. The governor compares the fuel flow against the maximum allowed flow. The governor protects the engine against over power situations.

Transient Fuel Limiting

In order to prevent the engine from operating at an air/fuel ratio that is excessively rich, the command signal that is sent to the fuel actuator may be limited. This will limit the amount of fuel flow into the engine during engine starting, engine acceleration or variable load operating conditions.

Personality Module

The Engine Control System contains a Personality Module. The Personality Module provides the engine application control maps. The Personality Module attaches to the ECM and the Personality Module communicates with the ECM. The Personality Module receives input from the engine control system sensors. The Personality Module monitors and controls the engine according to the parameters that are within the Personality Module. The Personality Module contains application specific engine control maps, protection set points and customer defined settings.

Air/Fuel Ratio Control

The G3600 Engine does not have a carburetor. The air flow and the fuel flow are independently controlled. The governor has complete control of the fuel flow. This leaves the air flow as the only parameter for adjusting the air/fuel ratio. The air flow is controlled by the exhaust wastegate system in order to maintain the desired air/fuel ratio or the desired combustion burn time (BT).

Fuel Flow

The ECM will calculate the fuel flow by using the following inputs:

- measured fuel manifold pressure
- measured fuel manifold temperature
- measured air inlet manifold pressure
- measured air inlet manifold temperature
- engine speed
- Btu setting

Air Flow

The ECM calculates the air flow based on the measured inlet manifold air pressure, the measured inlet manifold temperature, and the engine speed.

Desired Air/Fuel Ratio

The desired air/fuel ratio varies depending on engine speed and load. These values are stored in application specific maps in the Personality Module. These maps were created to achieve optimum engine performance (efficiency and emissions) as the engine speed and load varies.

Combustion Burn Time (BT)

Combustion Burn Time is the time measured for combustion flame propagation from the ignition spark in the precombustion chamber to the combustion sensing probe. The probe is mounted in the main combustion chamber.

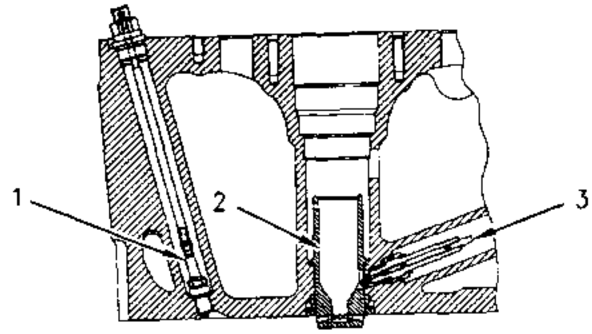


Illustration 22
Cylinder Ignition and Sensor
(1) Combustion sensor. (2) Precombustion chamber.
(3) Gas ignition spark plug.

In-cylinder combustion sensing for each cylinder, allows the engine to respond rapidly to changes in ambient conditions, fuel quality or speed and load changes. This results in a more precise control of the engine emissions and the fuel consumption. The combustion sensor is a nonconventional 14 mm (.55 in.) spark plug. The spark plug operates in conjunction with an electronic combustion buffer. This measures the actual time between the spark and the passage of the flame across the sensor. This information is averaged and compared with a desired map setting in the personality module. Corrections for variations in fuel quality, temperatures, etc. are made automatically as well as more quickly and accurately than manual adjustments.

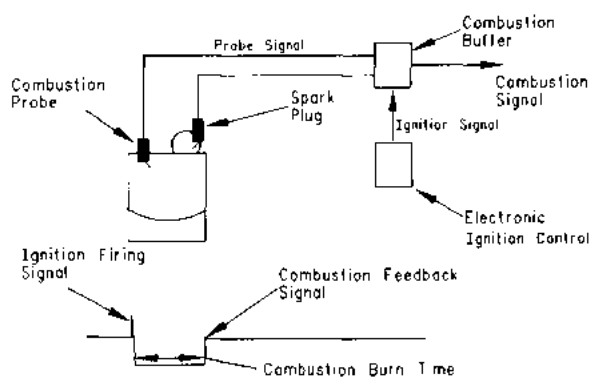


Illustration 23
Basic Combustion Probe System Diagram

The measured combustion burn time signals are sent to the ECM on two separate circuits. One circuit is dedicated to the Cylinder No. 1.

Another circuit sends the signals for the remaining cylinders to the ECM. The signals are received by the ECM in the firing order sequence.

Air Flow Control

Once the ECM has determined a desired air flow, the ECM modulates the exhaust bypass valve by changing the position of the wastegate actuator.

When the engine is operating in a normal operation mode, at an engine load that is typically greater than 50 percent, the air/fuel ratio is automatically controlled based on the average Combustion Burn Time (BT).

The position command signal that is sent from the ECM to the wastegate actuator is based on the difference between the average BT that is measured from the cylinders and the desired BT that is programmed into the personality module. Maintaining the desired BT ensures optimum engine performance and stable engine operation even when the quality of the fuel changes or when ambient conditions change.

When the engine is operating in precombustion chamber calibration mode or at an engine load that is typically less than 50 percent, the position command signal that is sent from the ECM to the wastegate actuator is the difference between the measured air/fuel ratio and the desired air/fuel ratio. The measured air/fuel ratio is a calculated value that is based on sensor inputs from the engine to the ECM. The inputs to the ECM that are required to calculate the air/fuel ratio are fuel manifold pressure, fuel manifold temperature, inlet manifold air pressure, inlet manifold air temperature, engine speed and fuel quality (Fuel Energy Content potentiometer setting). At start-up, the fuel energy content (Btu) is adjusted in order to agree with the fuel analysis by using the Fuel Energy Content potentiometer on the ESS control panel. When the engine is operating at greater than 50 percent load, the engine control overrides the manual fuel setting and provides fuel quality information. This is based upon the actual combustion burn time measurements that are taken during the combustion process. The manual setting of the Btu potentiometer will provide a starting point for the Air/Fuel Ratio Control system until the BT information is available from the combustion sensors.

Fuel Correction Factor

The fuel correction system will use the desired burn time along with the measured burn time in order to compute a fuel correction factor.

The percent fuel correction factor represents the difference in the actual energy content (Btu/ft^3) and the setting of the *Fuel Energy Content* potentiometer. The potentiometer is located on the front control panel of the ESS.

For example: the engine air/fuel ratio had been properly adjusted using a Btu dial setting of 900 Btu. After the engine has been running for a period of time, the quality of the fuel that is supplied to the engine will change from 900 to 990 Btu/ft^3. The result would be that the combustion flame would be faster. The ECM would slow down the combustion time by changing the air/fuel ratio to a leaner setting. The ECM would display a calculated fuel correction factor of 110 percent (990/900 times 100).

Fuel System

To ensure precise regulation of fuel flow on G3600 engines, carburetors are not used. Fuel flow is controlled electronically in order to maintain precise control of fuel delivery to the engine. The fuel system contains the following components: a gas shutoff valve, a fuel control valve, a electronic actuator, a fuel manifold, a gas admission valve, a needle valve, a check valve, and a precombustion chamber.

Gas is delivered to the engine through a customer supplied regulator (2). Fuel pressure must be 310 ± 14 kPa (45 ± 2 psi) and the fuel pressure must be regulated to 1.7 kPa (.25 psi). Lower fuel pressure may result in reduced power. The regulator is connected to a gas shutoff valve (3), which is controlled by the Engine Control Module (ECM).

Control valve (4), which is controlled by the electronic actuator (10) regulates the gas pressure in the fuel manifold (5). The electronic actuator controls the fuel manifold pressure. This control is based on a signal that was received from the engine control module. The engine control module determines the signal. The signal is based on the difference between the actual engine rpm and the desired engine rpm. Engine speed is controlled by the fuel manifold pressure. The fuel manifold (5) supplies gas to all cylinders.

Each cylinder has an orificed fuel line that is connected to the fuel manifold. The fuel line delivers gas to the gas admission valve (11) and from the gas admission valve on to the main combustion chamber. A separate fuel line (8) and adjustable needle valve (7) provide a new supply of gas to the precombustion chamber (12).

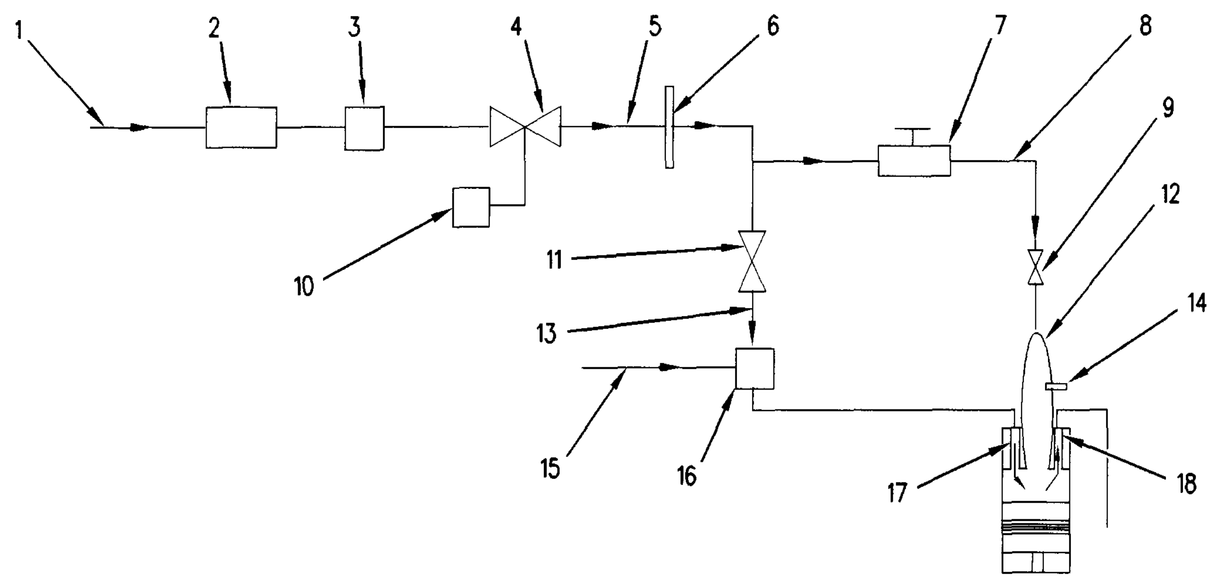


Illustration 24
Fuel System Schematic Diagram
(1) Gas input. (2) Customer supplied regulator. (3) Gas shutoff valve. (4) Control valve. (5) Fuel manifold. (6) Orifice. (7) Needle valve. (8) Precombustion chamber supply line. (9) Precombustion chamber check valve. (10) Electronic actuator. (11) Gas admission valve. (12) Precombustion chamber. (13) Main gas supply. (14) Spark plug. (15) Combustion air. (16) Cylinder head inlet port. (17) Inlet valve. (18) Exhaust valve.

Main Combustion Chamber

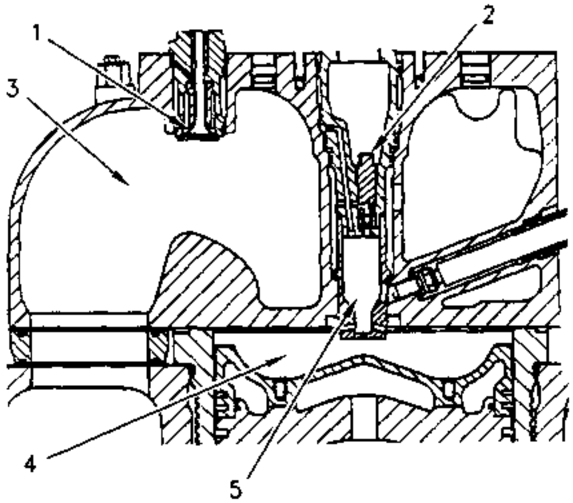


Illustration 25
(1) Gas admussion valve. (2) Check valve. (3) Inlet air.
(4) Main combustion chamber. (5) Precombustion chamber.

The gas admission valve (1) is mounted in the inlet port and is actuated by the camshaft. As the gas admission valve is opened, gas is admitted into the inlet port. The gas mixes with the combustion air in the inlet port. The gas and combustion air mix and flow into the cylinder.

Combustion air flow into the cylinder head is regulated (depending on the engine load) by the exhaust bypass valve (wastegate) and inlet air choke. As air flows into the cylinder head inlet valve chamber, the cam operated gas admission valve (1) admits gas to the air flow as the inlet valve opens. At the same time, an additional, separate, new gas supply is added to the precombustion chamber (5) through a ball type check valve (2).

Precombustion Chamber

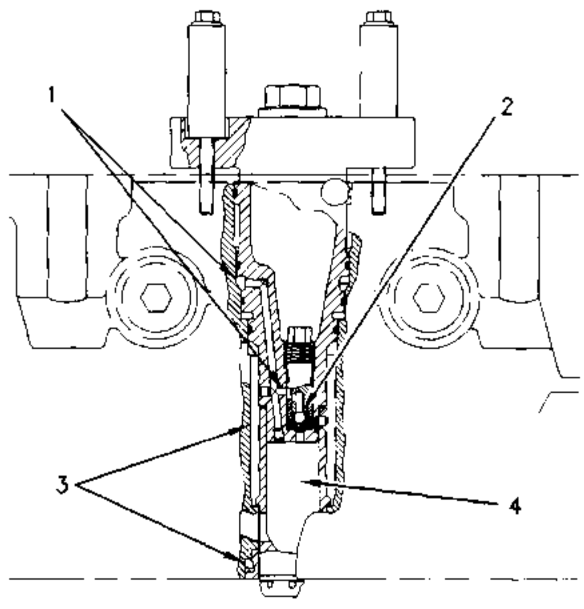


Illustration 26
PC Check Valve and Fuel Supply Path
(1) Fuel inlet passage. (2) Check valve. (3) Passageways for the jacket water coolant. (4) Precombustion chamber.

The new gas supply for the precombustion chamber (4) comes from the manifold. The new gas goes through a separate line and an adjustable needle valve. The new gas flows through the fuel inlet passage (1) into a ball type check valve (2). The check valve is located at the top of the precombustion chamber (4). The main charge of the air/fuel mixture flows through the inlet valves and into the cylinder. The check valve opens. The check valve adds new gas supply to the precombustion chamber. The gas in the precombustion chamber is ignited by the spark plug. The ignited gas in the precombustion chamber ignites the gas mixture in the cylinder in order to ensure consistent combustion and complete combustion.

Adjustment of the needle valve settings is a calibration procedure that is done by using the Digital Diagnostic Tool (DDT). The needle valve settings are adjusted in order to provide the desired combustion burn time. This depends on the engine speed and the engine load.

The need for low emissions and consistent combustion requires the use of an enriched precombustion chamber. To further enhance the overall effectiveness of this system, the side mounted spark plug is installed low in the precombustion chamber. With this design, the initiation of the flame front in the precombustion chamber is near the outlet to the main combustion chamber. This ensures that the rich fuel mixture is more completely burned prior to entering the main chamber than the fuel mixture would be burned if the ignition source was at the top of the precombustion chamber. Mixing of the fuel in the precombustion chamber with the lean combustion air from the main chamber during cylinder compression, yields an optimum air/fuel mixture for initiation of combustion.

Ignition System

The components of the gas engine ignition group and the fully shielded ignition system wiring are used with the magneto in order to provide spark ignition.

Ignition Transformer

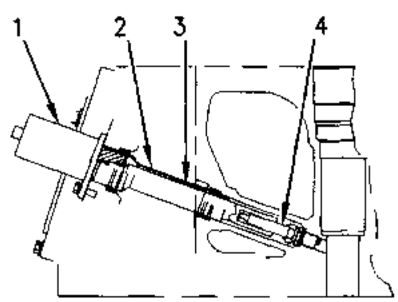


Illustration 27
Components of the Gas Engine Ignition Group
(1) High energy ignition transformer. (2) Tube.
(3) Extension with a spring loaded rod. (4) Spark plug.

The ignition transformer causes an increase of the primary voltage. The increased voltage is needed to send a spark (secondary electrical impulse) across the electrodes of the spark plugs. For good operation, the connections (terminals) must be clean and tight. The negative transformer terminals for each transformer are connected together and the terminals are connected to ground.

Timing Control System

The Caterpillar Detonation Sensitive Timing Control (DSTC) system provides detonation protection for the engine and electronic adjustment of ignition timing with a variable timing.

Timing Control System

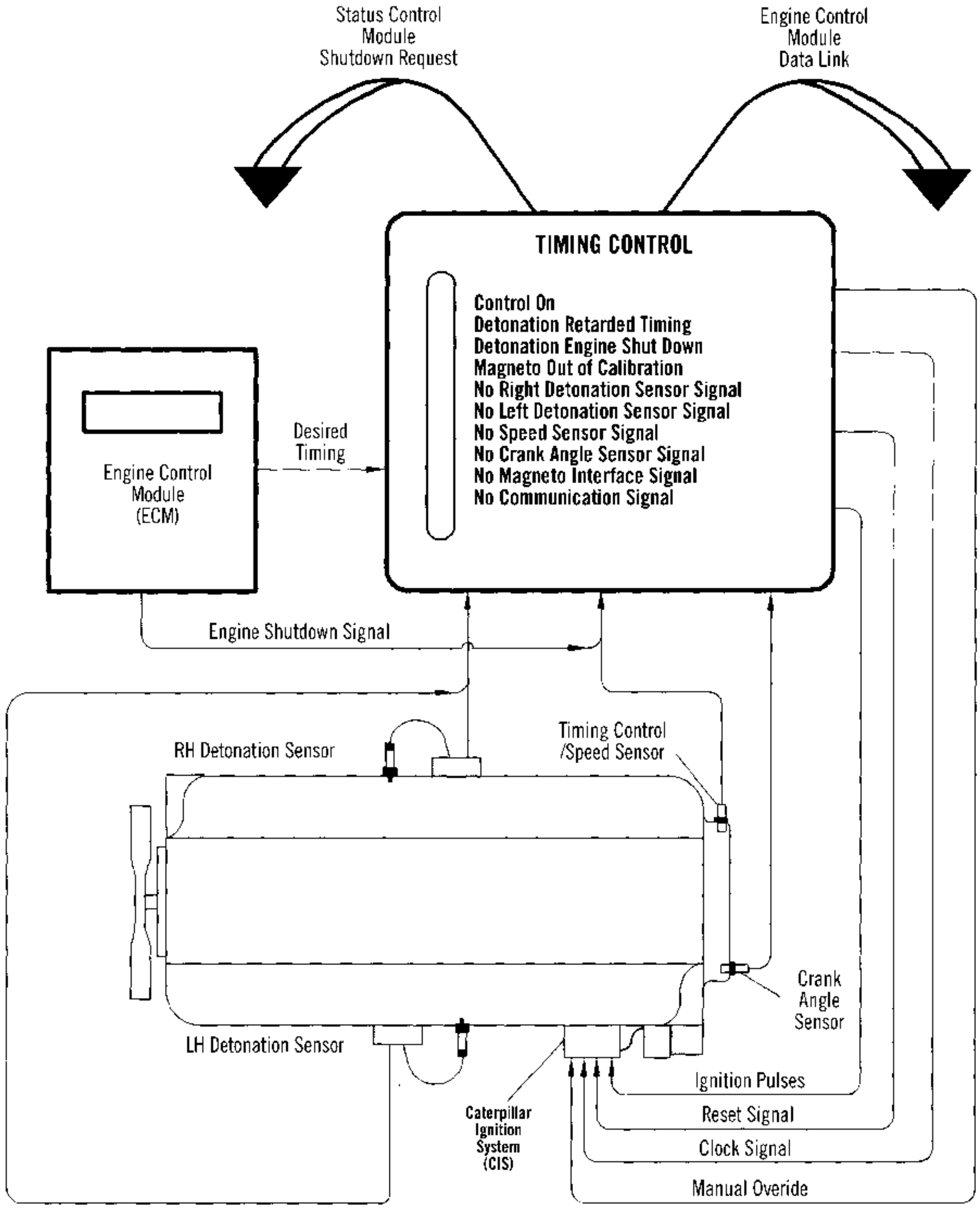


Illustration 28

Timing Control Module (TCM)

The TCM determines the ignition timing. The TCM communicates the ignition timing with the Caterpillar Ignition System (CIS). The TCM provides the system diagnostics.

Engine timing, controlled by the TCM, is based upon the desired timing signal received from the ECM. The desired timing signal from the ECM varies depending on engine speed, engine load and engine detonation.

The ignition timing is controlled by three signals that are sent from the TCM to the CIS. The CIS sends a signal that indicates that the plug is firing to the TCM. The TCM uses this signal to calculate actual engine timing.

Timing Control Sensors

The TCM uses two sensor signals for the ignition timing control. The TCM uses the detonation sensors for detonation protection. The Crank Angle Sensor (CAS) and the Speed Sensor (TCMPU) provide top center (TC) and rotational position needed to control timing. The detonation sensors provide an electrical signal of the engine's mechanical vibrations that are used in order to calculate the detonation levels.

Crank Angle Sensor (CAS)

This passive magnetic speed sensor indicates the crankshaft angle to the TCM. The crank angle sensor provides the TC signal used to control timing and calculate actual timing. The signal is generated when the TC hole (for the No. 1 piston) in the flywheel face passes the sensor.

Speed Sensor (TCMPU)

This passive magnetic speed sensor indicates engine speed to the TCM. The speed sensor produces a signal whenever a ring gear tooth on the flywheel passes the sensor. The signal is used to calculate engine speed, to monitor the crankshaft angle between TC pulses and to clock the MIB electronics.

Detonation Sensors

The detonation sensor is a powered device that outputs a filtered electrical signal and a amplified electrical signal of the engine's mechanical vibrations. When increased levels of vibration are occurring, the ECM calculates the engine detonation. If necessary, the ECM will adjust the ignition timing in order to control detonation. This is done by sending a desired timing signal that is retarded as much as six crank degrees to the TCM, When the level of vibration has returned to normal, the ECM will adjust the desired timing signal in order to gradually allow the ignition timing to return to operation. This adjustment is based on the desired timing map that is part of the personality module.

G3600 Ignition Timing System

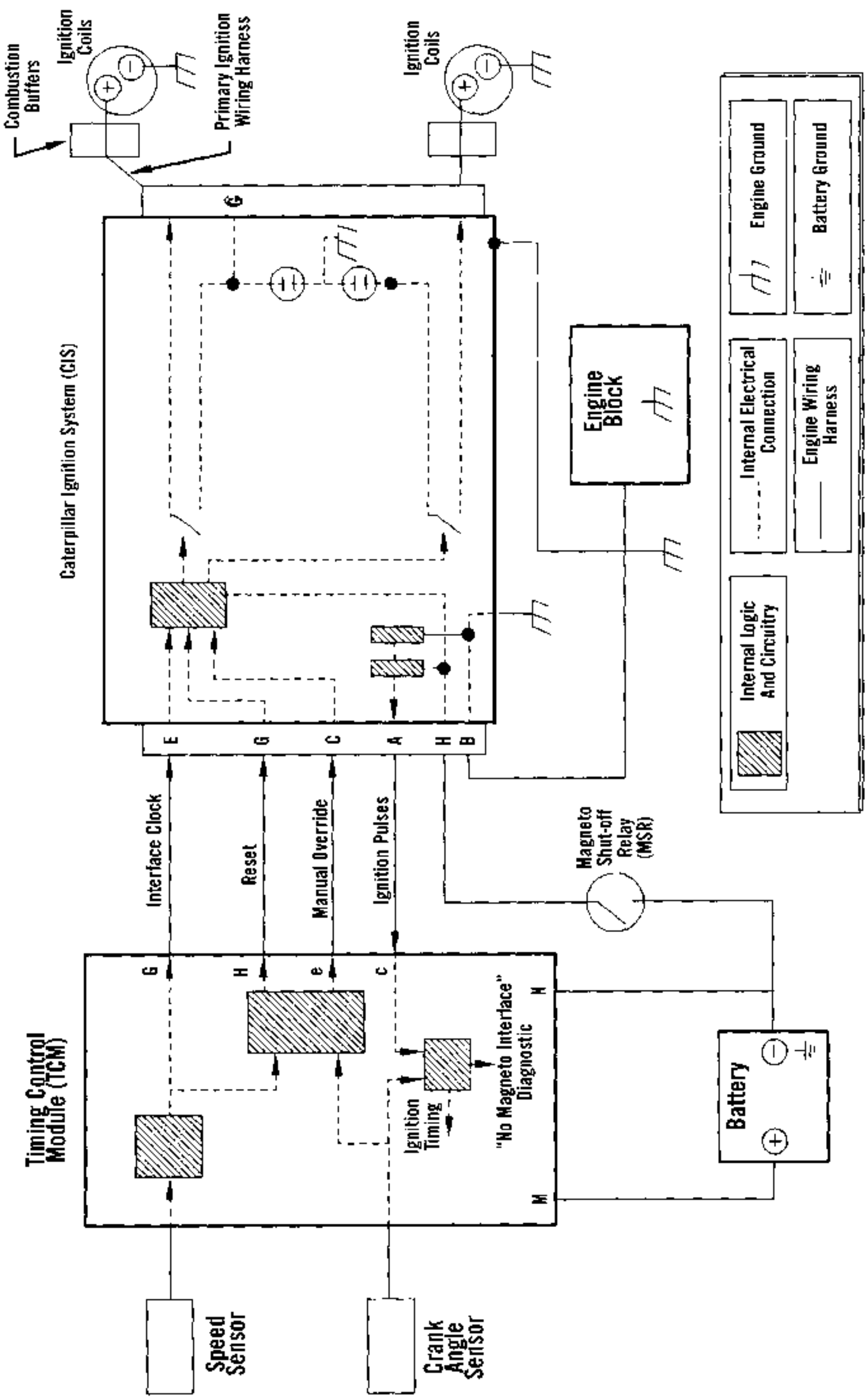


Illustration 29

The Timing Control provides three signals to the Caterpillar Ignition System (CIS) in order to communicate the desired ignition timing. These signals are the Ignition Interface Clock, the Reset Pulse signal, and the Manual Override signal. The CIS returns the Ignition Pulses to the Timing Control. The Timing Control calculates the Actual Engine Timing. The Timing Control performs some ignition diagnostics from this signal.

Ignition Interface Clock

The Ignition Interface Clock signal is a square wave version of the speed sensor signal. This signal provides a timing clock for the CIS.

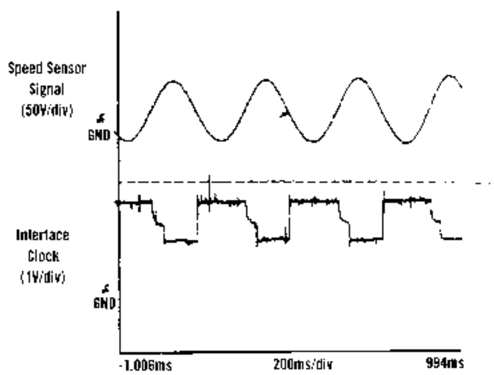


Illustration 30
Relationship Between Speed Sensor and Clock Signals

Sent from Timing Control (pin-G) to CIS (pin-E, 10 pin Connector).

The waveform is a square wave version of the speed sensor signal, with peak voltage of 2.5 V and minimum voltage of 1 V. The positive-going edge of the clock signal should align with the negative-going zero-crossing of the speed sensor signal.

Reset Pulse

The Reset Pulse signal indicates to the CIS the ignition timing desired by the Timing Control. The pulse is sent once from TC to TC.

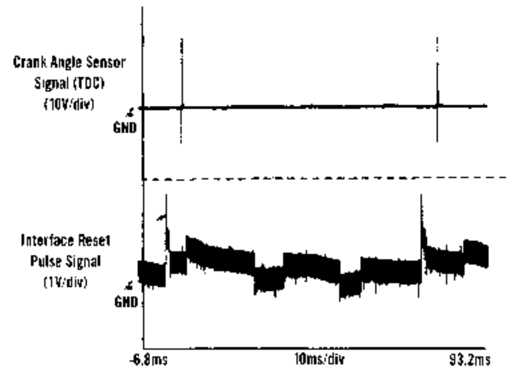


Illustration 31
Interface Reset Pulse Signal Relative to Crank Angle TC Signal

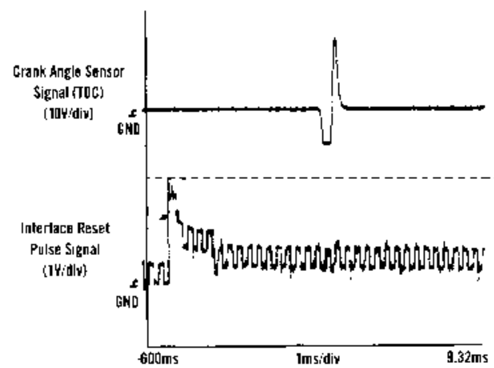


Illustration 32
Close Up of Interface Reset Pulse Signal Relative to Crank Angle TC Signal

Sent from Timing Control (pin-H) to CIS (pin-G, 10 pin Connector).

The Interface Reset Pulse signal is normally below 1 V. The Reset Pulse goes high to about 2.5 V. This signal should go high once from Top Center (TC) to TC.

Manual Override ("Mag Cal" Mode As Seen In DDT)

The Manual Override signal tells the CIS to control fully advanced ignition timing.

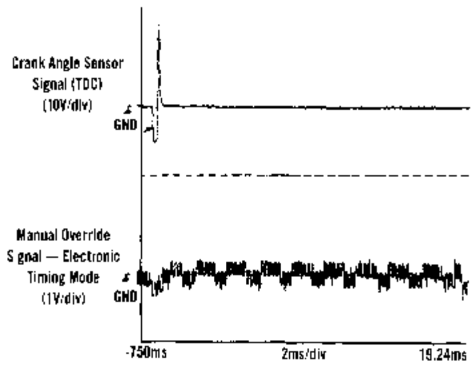


Illustration 33
Manual Override Signal, Timing Control in Electronic Timing Mode

Sent from Timing Control (pin-E) to CIS (pin-C, 10 pin Connector).

The manual override signal should remain below 1 V when the system is in Electronic Timing Control mode. A 5 V signal on this line will tell the CIS to run the ignition at fully advanced timing.

Ignition Pulses

The Ignition Pulse signal is the odd number bank's capacitor charge. The signals waveform indicates the discharge of the CIS and firing of cylinders. One pulse is shown for each number cylinder. This signal is used by the TCM to calculate ignition timing and some ignition diagnostics.

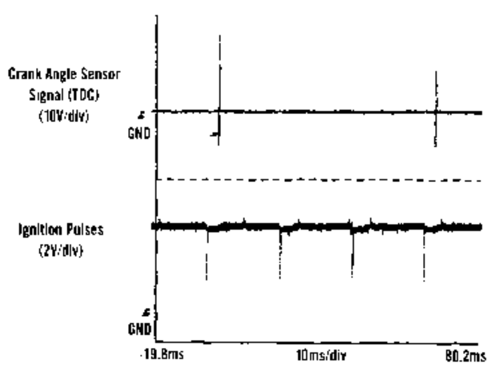


Illustration 34
Ignition Pulses Relative to Crank Angle TC Signal (Six Cylinder Engine)

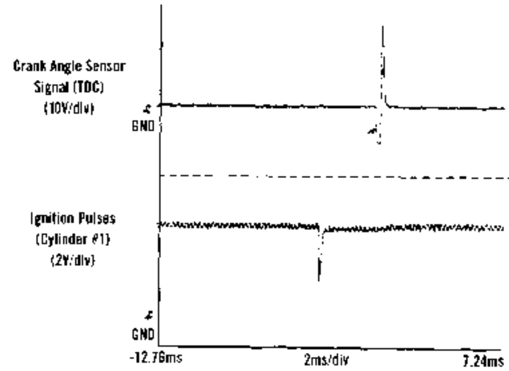


Illustration 35
Close Up of Ignition Pulses Relative to Crank Angle TC Signal (Six Cylinder Engine)

Sent from CIS (pin-A, 10 pin Connector) to Timing Control (pin-C).

From TC to TC, this waveform should show one pulse for each number cylinder. The pulse is normally at 5 V and goes below 2 V when the MIB detects the ignition firing.

Interaction Of The Interface Signals

The manual override signal is held below one volt, the CIS is placed in *Mag Cal* Mode. The TCM generates the Clock signal by squaring the Speed Sensor (TCMPU) signal. This clock signal is used by the CIS electronics in order to keep track of the rotational position. When the the Reset pulse is received from the TCM, the CIS counts nine Clock signal edges. The CIS will then signal to fire Cylinder Number One. The CIS continues to monitor the Clock. The CIS signals to fire the remaining cylinders through the rotation. When the CIS discharges to fire the cylinder, an ignition pulse is generated. The Ignition Pulse signal is a reduced voltage signal of the odd number bank's capacitor voltage. Ignition Timing is calculated by comparing the timing offset between TC from the Crank Angle Sensor and the Ignition Pulse for Cylinder Number One.

When the Manual Override signal goes above one volt, the CIS operates in Manual (Standard) Mode. The CIS will no longer control ignition firing. The CIS will generate an ignition pulse at the most advanced ignition timing. The Ignition Timing is calculated in the same manner as in Electronic Timing Mode.

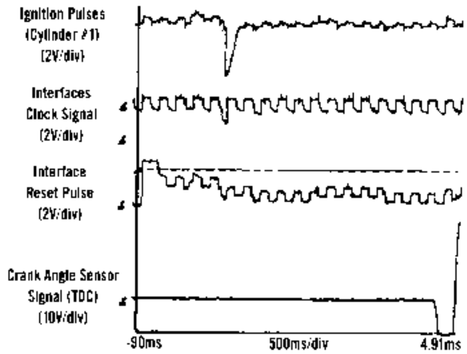


Illustration 36
Interaction of Reset, Clock, Ignition Pulse and TC Signal

When the CIS receives the Reset Pulse, the CIS generates a ignition pulse after 9 Clock Signal edges (both rising and falling edges). The CIS generates the Ignition Pulse for Cylinder Number One. This should occur before the TC signal of the engine.

Ignition Pulse Firings

From TC to TC, this waveform should show one pulse for each cylinder. The pulses should go from 190 V to ground when the cylinder is signaled to fire.

Engine Start-up

At engine start-up, the Timing Control performs some system checks not done once the engine is running. The Manual Override signal places the CIS in Manual Mode until the engine speed is above 500 rpm. Once the engine speed increases between 300 and 500 rpm, the Timing Control will compare the timing of Cylinder No. 1 firing to the *Mag Cal* Timing stored in internal memory. If the two timing values do not match, the Timing Control will display the “Magneto Out Of Calibration” fault.

Air Inlet and Exhaust System

General Information

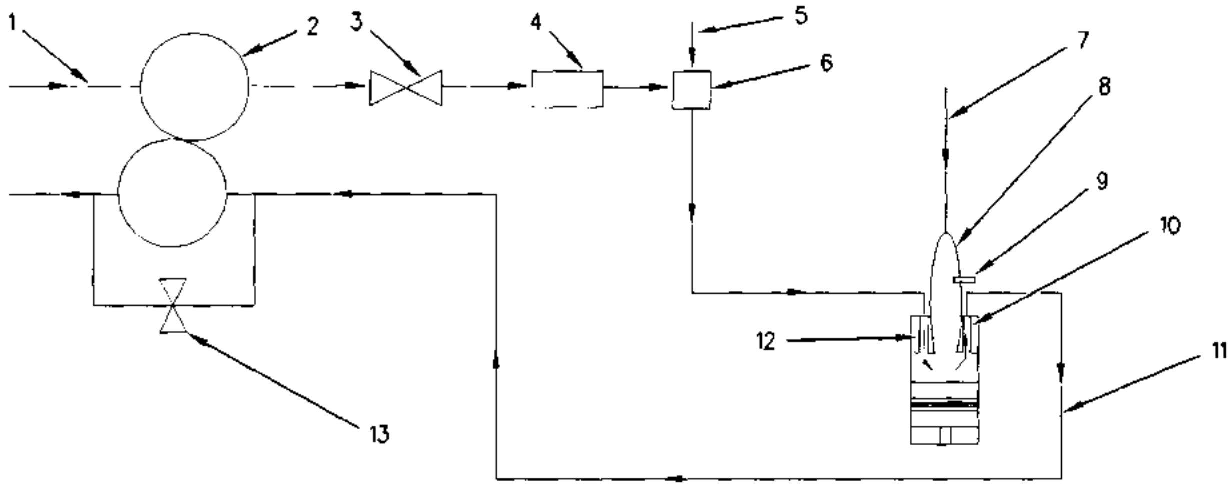


Illustration 37
(1) Air inlet. (2) Turbocharger. (3) Air inlet choke. (4) Aftercooler. (5) Main gas supply. (6) Cylinder head inlet port.
(7) Precombustion chamber gas supply. (8) Precombustion chamber. (9) Spark plug. (10) Exhaust valve. (11) Exhaust.
(12) Inlet valve. (13) Exhaust bypass control valve.

The components of the air inlet and exhaust system control the quality and the amount of air that is available for combustion. The inlet manifold (air plenum) is a passage inside the cylinder block. This passage connects the aftercooler to the inlet ports in the cylinder head. The camshaft controls the movement of the valve system components.

Air Inlet and Exhaust System Components

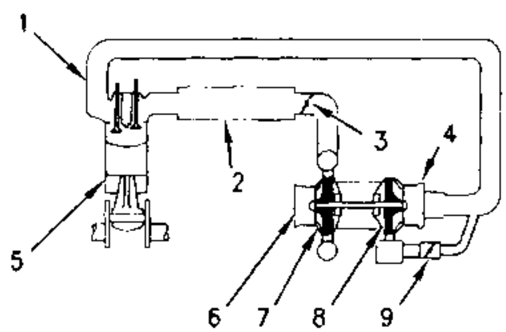


Illustration 38
(1) Exhaust manifold. (2) Aftercooler. (3) Air choke.
(4) Exhaust outlet. (5) Engine cylinder. (6) Air inlet.
(7) Turbocharger compressor wheel. (8) Turbocharger turbine wheel. (9) Exhaust bypass valve.

Clean inlet air from the air cleaners is pulled through air inlet (6) into the turbocharger compressor by the turbocharger compressor wheel (7). The rotation of the turbocharger compressor wheel causes the air to compress. The rotation of the turbocharger compressor wheel then forces the air through an elbow to the aftercooler (2). The aftercooler lowers the temperature of the compressed air before the air enters the air plenum. This cooled and compressed air fills the air plenum. The air fills the inlet chambers in the cylinder heads. Air flow from the inlet chamber into the cylinder is controlled by the inlet valves. Fuel (gas) flow into the cylinder is controlled by the gas admission valve.

There are five valves in each cylinder head. There is one gas admission valve (refer to System Operation, *Fuel System*), two inlet valves and two exhaust valves for each cylinder. Make reference to “Valve System Components”. The inlet valves and the gas admission valve, open when the piston moves down on the intake stroke.

The camshaft controls the opening of the valves. The cooled, compressed air is pulled into the cylinder from the inlet chamber along with the gas that is supplied through the gas admission valve. The gas admission valves and 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, the rich air fuel mix in the precombustion chamber has been leaned to a combustible mix and is ignited by the spark plug. The force of the combustion pushes the piston down on the power stroke. When the piston moves up again the piston is on the exhaust stroke. The exhaust valves open and the exhaust gases are pushed through the exhaust port into the exhaust manifold (1). After the piston makes the exhaust stroke, the exhaust valves close. The cycle (intake, compression, power, exhaust) starts again.

Exhaust gases from the exhaust manifold cause the turbocharger turbine wheel (8) to turn. The turbine wheel is connected to the shaft that drives the compressor wheel. Depending on the speed and the load requirements of the engine, exhaust gases are directed either through the exhaust outlet to the turbocharger or through the exhaust bypass valve.

An actuator controls the position of the exhaust bypass (wastegate) valve (9). The wastegate actuator provides the desired inlet manifold air pressure. This is based on a command signal that the actuator receives from the ECM. The ECM determines the command signal. The command signal is based on the difference between the actual air/fuel ratio (or average combustion burn time) and the desired air/fuel ratio (desired combustion burn time).

The position of air choke (3) is controlled by an actuator. The choke actuator provides the desired inlet manifold air pressure during part load operation. This is based on a command signal that actuator receives from the ECM. The ECM determines the command signal based on the engine speed (rpm) and the engine load (calculated value based on pressures and temperatures that are measured on the engine).

Aftercooler

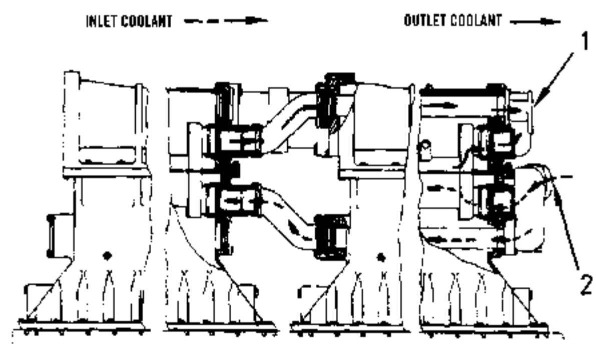


Illustration 39
Air Inlet and Exhaust System Components
(1) Coolant outlet connection. (2) Coolant inlet connection.

The aftercooler is located on the left rear side of the engine at the rear opening of the plenum. The aftercooler has a coolant charged core assembly. Coolant from the water pump on the left side of the engine flows through coolant inlet connection (2). Coolant circulates through the core assemblies. The coolant then exits the aftercooler through the coolant outlet connection (1).

Inlet air from the compressor side of the turbocharger flows into the aftercooler housing. The inlet air passes the fins in the core assemblies. The aftercooler core lowers the temperature of the air. The cooler air is directed into the air plenum. The cooler air is directed up and through the inlet ports of the cylinder heads.

Lowering the temperature of the inlet air will increase the density of the air (per volume). The increased air density will result in more efficient combustion and in lower fuel consumption.

Turbochargers

The turbine side of the turbocharger is connected to the exhaust manifold. The compressor side of the turbocharger is connected to the aftercooler. Both the turbine (exhaust) and compressor (inlet) are connected to the same shaft and rotate together.

The exhaust gases go into the turbocharger through the exhaust inlet adapter. The exhaust gases push the blades of the turbine wheel. This causes the turbine wheel and compressor wheel to turn.

Clean air from the air cleaner is pulled through the compressor housing air inlet by the rotation of the compressor wheel. The action of the compressor wheel blades causes a compression of the inlet air. This compression gives the engine more power because it makes it possible for the engine to burn additional fuel with greater efficiency.

The bearings in the turbocharger use engine oil under pressure for lubrication. The oil comes in through the oil inlet. The oil goes through the passages in the center section for lubrication of the bearings. The oil goes out of the oil outlet. The oil returns to the oil pan.

The turbocharger turbine (exhaust) section and the center (bearings) sections are enclosed in a water cooled housing.

Exhaust Bypass

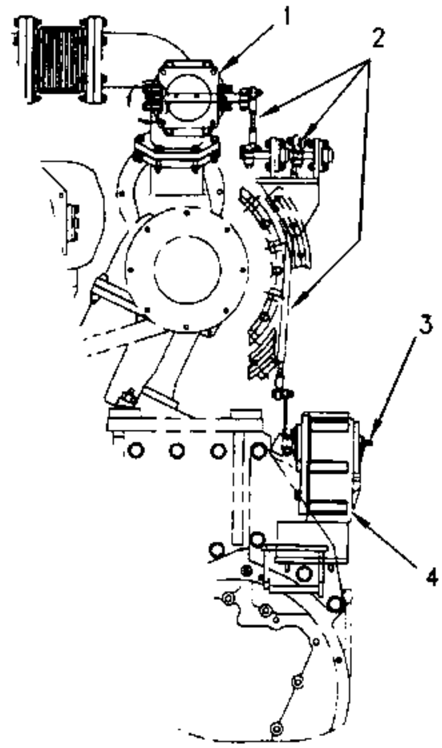


Illustration 40
(1) Exhaust bypass valve. (2) Adjustable linkage.
(3) Actuator indicator. (4) Exhaust bypass actuator.

The exhaust bypass is operated by one of the three actuators that are used to control the air/fuel ratio of the engine. One actuator controls fuel flow. The other two work together in order to control the amount of air supplied to the engine throughout the entire speed and the load range. The exhaust bypass actuator (4) is located on the left rear of the engine, next to the gas inlet actuator. The exhaust bypass actuator receives an electronic command signal from the Engine Control Module. The signal mechanically changes the position of the exhaust bypass valve (1) in order to give the optimum air/fuel ratio for the operating conditions. The position of the valve is changed through an adjustable linkage (2).

The position of the plate for the exhaust bypass valve is represented by the slot that is cut into the end of the shaft. When the Engine Control Module requests a leaner air/fuel ratio, the actuator will move the adjustable linkage (2) in order to close the exhaust bypass valve. This will allow more of the exhaust gases to go into the turbocharger. The additional exhaust gases will increase the rpm of the turbocharger. The increase in the rpm will cause more inlet air to be drawn into the engine. The inlet air will be compressed and the inlet air will be sent to the cylinders. When the Engine Control Module requests a richer air/fuel ratio, the actuator will open the exhaust bypass valve. The opening of the exhaust bypass valve will allow a portion of the exhaust gases to go out of the exhaust adapter instead of through the turbocharger. Less of the inlet air is compressed and sent to the cylinders.

The electronic command signal that is sent to the actuator is a percent pulse width modulated (PWM) signal. For diagnostic purposes, the actuator sends a VDC position feedback signal back to the ECM.

Inlet Air Choke

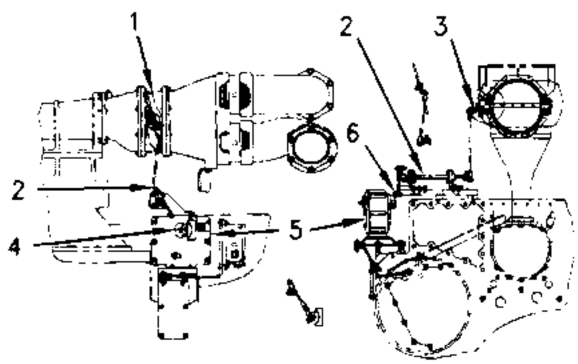


Illustration 41
(1) Air choke plate. (2) Cross shaft. (3) Choke lever and adjustable rod. (4) Actuator indicator. (5) Air choke actuator. (6) Actuator lever and adjustable rod.

The air (choke) actuator (5) is one of three actuators that is used to control the air/fuel ratio of the engine. One actuator controls fuel flow. The other two actuators work together in order to control the amount of air that is supplied to the engine throughout the entire speed and load range. The actuator is located on the left rear of the engine. The actuator receives an electronic signal from the Engine Control Module. The actuator mechanically changes the position of the air choke plate (1) via an actuator lever and adjustable rod (6).

The position of the plate is represented by the slot that is cut into the end of the shaft. The movement of the choke plate controls the air flow from the turbocharger outlet, through the inlet air choke. The air will then flow through the aftercooler into the cylinder block air plenum, and then into the cylinder head. Fuel is introduced to the air in the cylinder head by the gas admission valve.

At full load and full speed, the actuators will operate the engine with the air choke in the fully open position. This in order to reduce the restriction to the air flow and improve the engine operating efficiency. The ECM will use the exhaust bypass system in order to control the air/fuel ratio of the engine. As engine load decreases, the inlet air choke begins to restrict air flow into the air plenum of the cylinder block. This is done in order to maintain a sufficiently rich mixture for good combustion at lighter engine loads. This combination of control (exhaust bypass/inlet air choke) provides for the increased improvement in fuel consumption at part load conditions, while also allowing complete control at full load conditions.

Exhaust Manifold

The exhaust manifold is a dry design that utilizes an exhaust manifold thermal blanket for reduced radiant heat rejection. A dry manifold is possible because of the inherently low exhaust manifold temperatures of lean burn combustion. Engine performance is enhanced, especially for constant torque and variable speed industrial applications, by retaining the exhaust system energy in order to drive the turbocharger.

Valve System Components

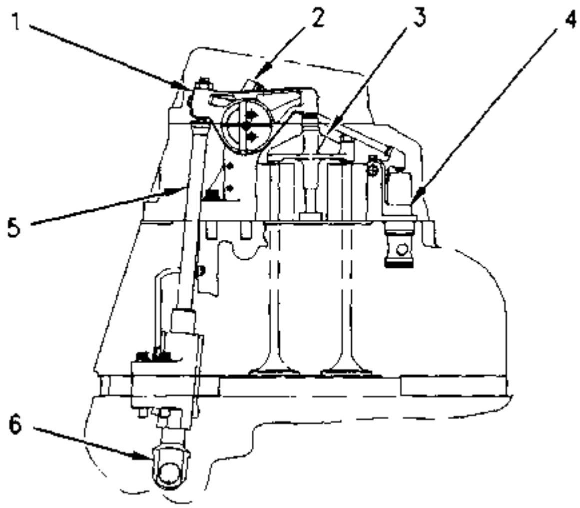


Illustration 42
(1) Rocker arm. (2) Gas admission valve rocker arm linkage. (3) Bridge. (4) Gas admission valve. (5) Pushrod. (6) Lifter.

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

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

The camshaft has three camshaft lobes for each of the cylinders. One lobe operates the bridge that moves the two inlet valves. One lobe operates the bridge that moves the two exhaust valves. The center lobe operates the single gas admission valve.

As the camshaft turns, the lobes of the camshaft cause lifters (6) to go up and down. The movement of the lifters will cause the pushrods (5) to move the rocker arms (1). Movement of the rocker arms will cause the bridges (3) to move up and down on dowels in the cylinder head. This movement will operate the valves. The bridges will allow one rocker arm to open or close the two valves (inlet or exhaust) at the same time. A separate lifter and gas admission valve rocker arm linkage (2) are working together (no bridge) in order to operate the gas admission valve (4). There is one gas admission valve, two inlet valves and two exhaust valves for each cylinder

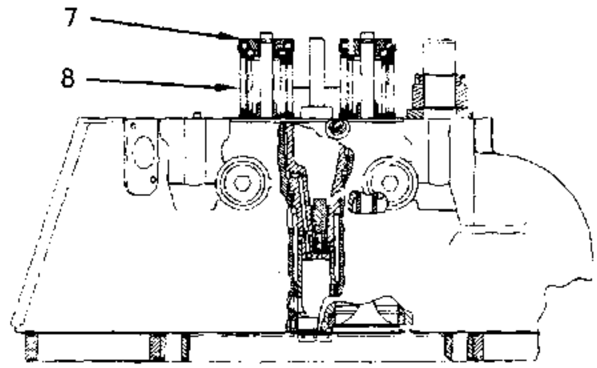


Illustration 43
(7) Rotocoil. (8) Valve spring.

Rotocoils (7) cause the valves (gas admission valve, inlet valve and exhaust valve) to turn while the engine is running. The rotation of the valves keeps the deposit of carbon on the valves to a minimum. The rotation of the valves gives the valves longer service life.

Valve springs (8) cause the valves to close when the lifters move down.

Lubrication System

Oil Flow Through The Cylinder Block

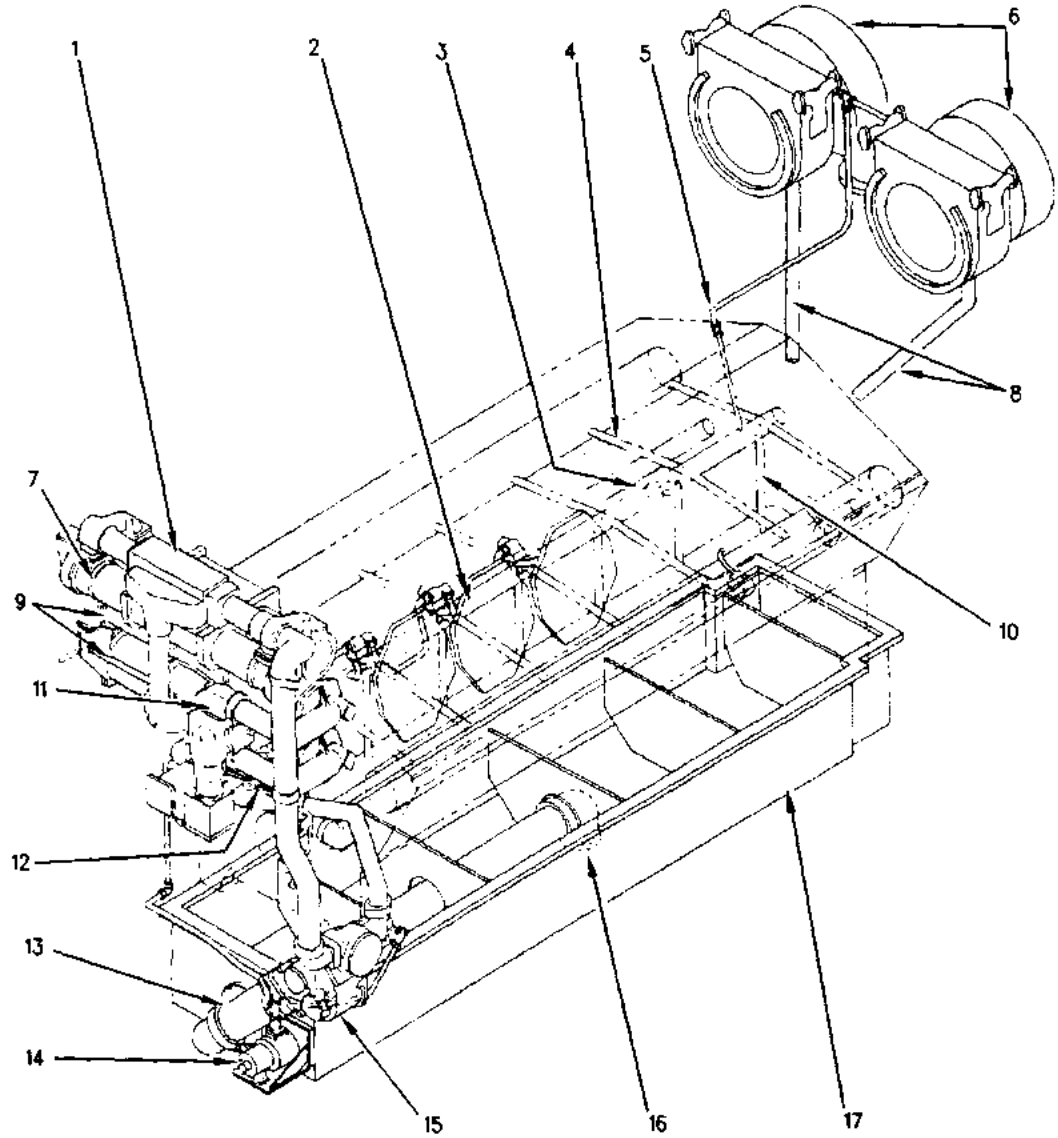


Illustration 44
(1) Oil temperature regulator housing. (2) Main oil gallery. (3) Piston cooling jets. (4) Drilled passage in the cylinder block from the main oil gallery to the camshaft bearings. (5) Turbocharger oil supply line. (6) Turbochargers. (7) Engine oil coolers. (8) Turbocharger oil drain lines. (9) Engine oil filters. (10) Drilled passage in the cylinder block from the main oil gallery to the crankshaft main bearings. (11) Engine oil filter change valve. (12) Priority valve. (13) Tube. (14) Prelube pump. (15) Engine oil pump. (16) Suction bell. (17) Engine oil pan.

Lubrication System Schematic

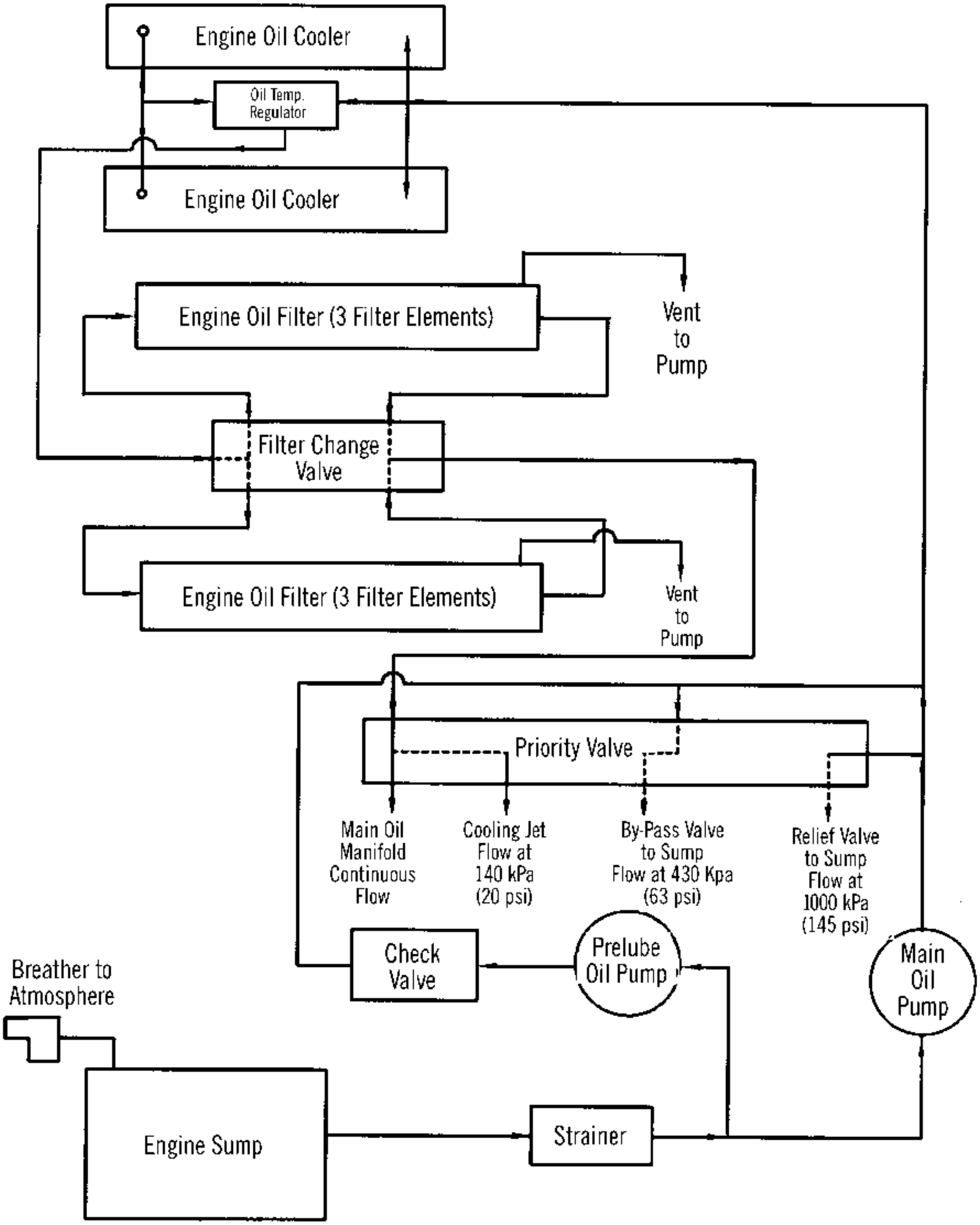


Illustration 45

Engine Oil Pumps

The prelube oil pump (14) can be driven by either an electric motor or an air motor. The prelube pump provides oil in order to lubricate the engine bearings before the engine is started and after the engine is shut down. A one-way check valve is located in the line between the prelube pump and the oil manifold. The check valve prevents pressurized oil from the engine oil pump from going through the prelube pump after the engine is started. The Engine Supervisory System will not allow the engine to start, until the engine has been through a prelube and the minimum amount of oil lubrication is provided to the engine.

The lubrication system uses an external engine oil pump (15). The engine oil pump is mounted on the front left side of the front housing. Oil is pulled through suction bell (16) and suction tube (13) by the engine oil pump. There is a screen in the tube between the suction bell (16) and tube (13).

Oil Flow

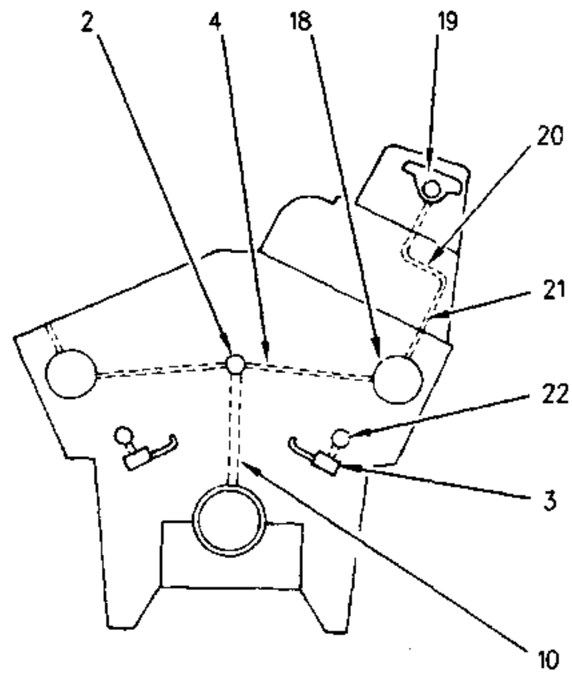


Illustration 46
Oil Flow Through the Cylinder Block
(2) Main oil gallery. (3) Piston cooling jets. (4) Drilled passage in the cylinder block between the main oil gallery and the camshaft bearings. (10) Drilled passage in the cylinder block between the main oil gallery and the crankshaft main bearings. (18) Camshaft bearing. (19) Rocker arm assembly. (20) Drilled passage in the cylinder block between the camshaft bearings and the cylinder head. (21) Tube. (22) Piston cooling jet oil gallery.

The engine oil pump pushes oil to the relief valve and the ports on the bypass valve of the priority valve (12). The relief valve opens in order to send oil back to the engine sump when the pressure in the engine oil pump exceeds 1000 kPa (145 psi). This helps to prevent damage to the lubrication system components when the engine oil is cold.

The bypass valve opens in order to send oil back to the engine sump when the system pressure (pressure in the main oil gallery) exceeds 430 kPa (62 psi).

Engine Oil Coolers And Temperature Regulators

The engine oil pump also pushes oil to the oil temperature regulator housing (1). If the oil temperature is higher than 85°C (185°F) the oil flow will be directed to the engine oil coolers (7). Oil flows from the engine oil coolers through the engine oil filter change valve (11) to the engine oil filters (9). From the engine oil filters, the oil flows through the priority valve (12) into the oil gallery (2) and (22) in the cylinder block.

Engine Oil Coolers

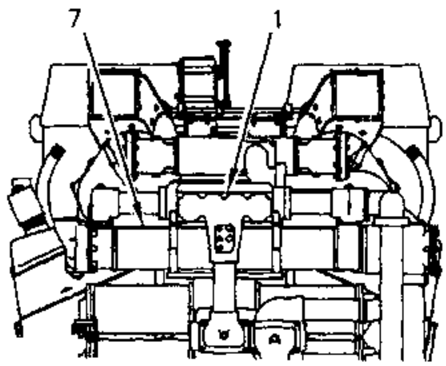


Illustration 47
(1) Oil temperature regulator housing. (7) Engine oil coolers.

Engine oil coolers (7) and temperature regulators in the oil temperature regulator housing (1) maintain engine oil temperature. The core assemblies in the engine oil cooler are connected in parallel with the aftercooler. Water flows through the inside of the tubes in the bundle of the engine oil coolers.

Engine oil flow is in parallel through the core assemblies in the engine oil cooler. Oil from the engine oil pump enters the manifold on the engine oil coolers. At cooler oil temperatures, the oil bypasses the engine oil cooler and the oil is directed to the engine oil filters.

Engine Oil Filters

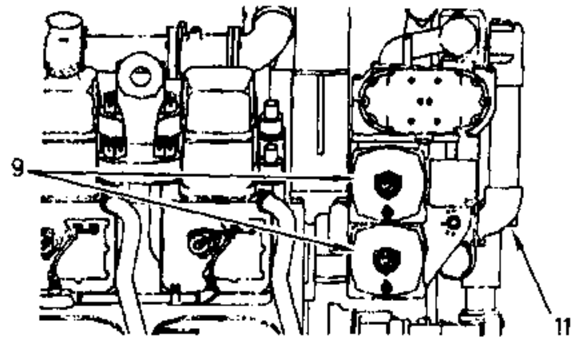


Illustration 48
(9) Engine oil filters. (11) Engine oil filter change valve.

The engine oil filters (9) contain six replaceable oil filter elements. There are two banks of filter elements with three filter elements in each bank. Each bank has a purge line port in order to purge the air for draining and for filling.

The engine oil filter change valve (11) allows the filters for each bank to be changed separately while the engine is operating. The oil filter elements should be changed at an interval of every 1,000 hours. The oil filter elements should be changed when the oil filter bypass indicator registers a 100 kPa (14.5 psi) pressure drop. This pressure drop is measured across the filter with the engine at operating temperature and the engine running at rated speed.

Internal Lubrication

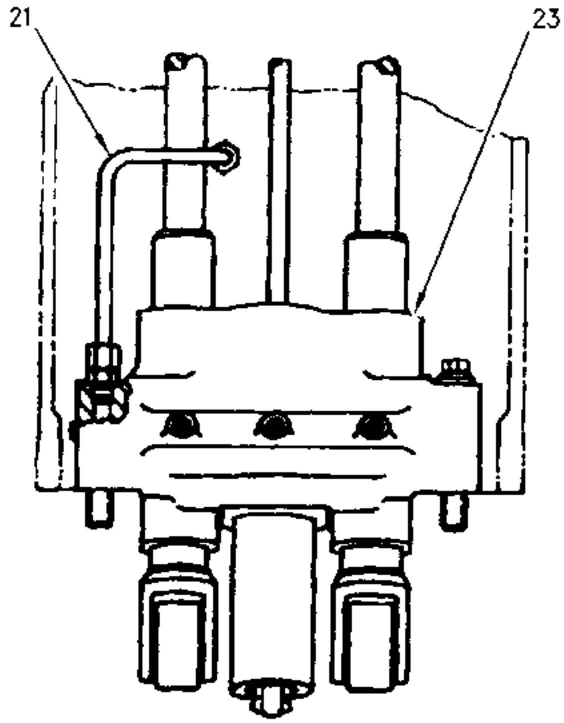


Illustration 49
(21) Tube. (23) Valve lifter guide.

The camshaft bearings receive oil from the main oil gallery (2) through drilled passages (4) in the cylinder block. The oil goes around each camshaft bearing (18), then the oil goes through a drilled passage in the block to the valve lifter guide (23) and the tube (21). The tube connects the valve lifter guide with another drilled passage in the block (20). Oil flows through the tube and the passage to the cylinder head and rocker arm assembly (19).

The main oil gallery (2) is connected to the crankshaft main bearings by a drilled passage (10) in the cylinder block. Drilled holes in the crankshaft connect the main bearing oil supply to the connecting rod bearings.

Priority valve (12) allows the oil to go to the piston cooling jet oil gallery (22) when the pressure in the system reaches 140 kPa (20 psi). The priority valve will not let oil into the piston cooling jet oil galleries until there is pressure in the main oil gallery (2). This decreases the amount of time that is necessary for the pressure to build up when the engine is being started. The priority valve also helps sustain oil pressure at the low idle speed.

Piston Cooling Jets

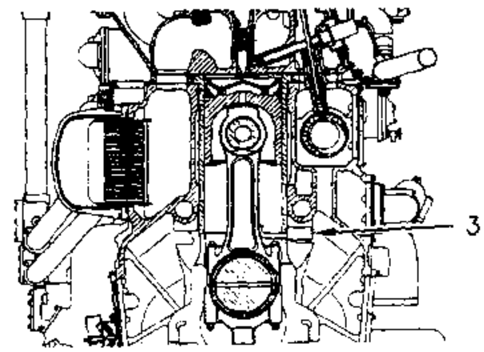


Illustration 50
Typical Example
(3) Piston cooling jet.

There is a piston cooling jet (3) below each piston. The oil from the piston cooling jet enters the piston outer cooling chamber through a drilled passage in the piston body. Oil flows from the outer cooling chamber to the inner cooler chamber and drains out of the piston through a hole above the piston pin. This provides lubrication for the piston pin bearing.

Turbocharger oil supply line (5) sends oil to the turbocharger (6). Turbocharger oil drain lines (8) return oil to the engine oil pan through the rear housing.

Oil is sent to the front and the rear gear groups through tubes and drilled passages in the front and the rear housings.

After the oil for lubrication has done the lubrication, the oil goes back to the engine sump.

An inlet valve lubrication metering pump is mounted on the engine in order to provide lubrication for the inlet valves. The oil flow rate is adjusted at the factory. The rate should not need adjustment unless the pump is replaced.

Cooling System

Water Flow Through the Cylinder Block

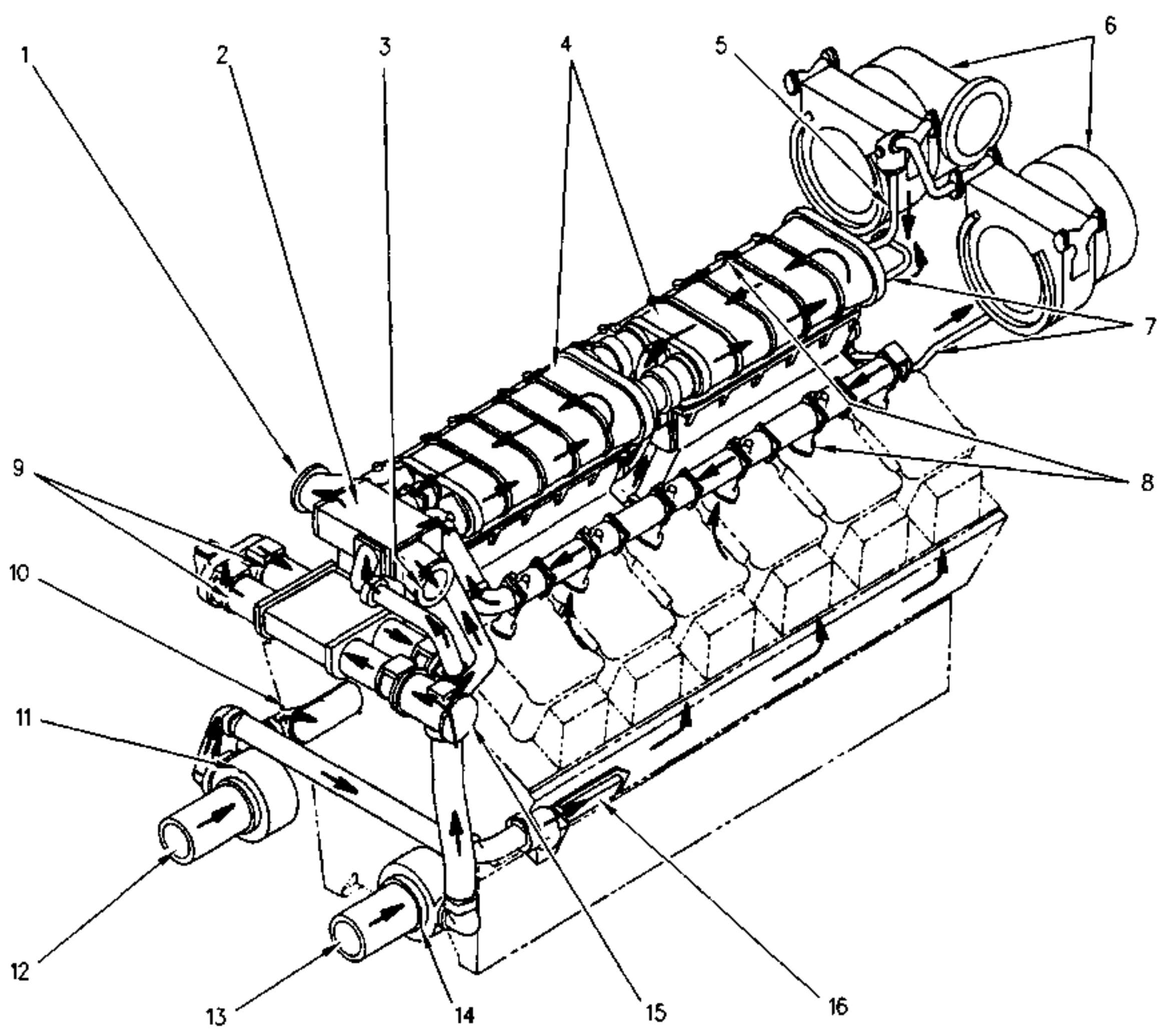


Illustration 51
(1) Coolant outlet to the heat exchanger (jacket water). (2) Mixer housing. (3) Coolant outlet to the heat exchanger (engine oil cooler and aftercooler circuit). (4) Aftercooler. (5) Turbocharger coolant return tube. (6) Turbochargers. (7) Turbocharger coolant supply tube. (8) Water manifold. (9) Engine oil coolers. (10) Elbow. (11) Right side water pump (jacket water). (12) Coolant inlet from the heat exchanger (jacket water). (13) Coolant inlet from the heat exchanger (engine oil cooler and aftercooler circuit). (14) Left side water pump (engine oil cooler and aftercooler circuit). (15) Engine oil cooler bonnet. (16) Elbow.

Jacket Water and Separate Circuit Cooling System

These engines use a separate circuit cooling system. The jacket water system (cylinder block, cylinder heads and turbochargers) is on one circuit. The aftercooler and the engine oil cooler are on a separate circuit. Water pumps are mounted on the front housing and driven by the front gear train. Coolant for the jacket water circuit is supplied by the right hand water pump. Coolant for the circuit with the aftercooler and the engine oil cooler is supplied by the left hand water pump. Water temperature regulators are used in each circuit in order to maintain correct operating temperatures.

Water temperature regulator housings can be mounted in order to provide a controlled minimum pump inlet temperature (inlet controlled), or a minimum engine outlet temperature (outlet controlled).

Separate Circuit Cooling System

In the separate circuit cooling system, the left side water pump (14) pulls coolant from the heat exchanger through inlet (13). Coolant flow from the left side water pump flows to the engine oil cooler bonnet (15). Coolant flow is divided at the engine oil cooler bonnet. Part of the coolant is sent to the engine oil coolers (9) while the rest of the coolant is sent to the aftercooler (4). After the coolant flows through the aftercooler and the engine oil coolers, the coolant returns to the heat exchanger through mixer housing (2) and coolant outlet (3).

There is a makeup line from the expansion tank to the coolant inlet (13). This line helps keep the coolant in the circuit (engine oil cooler and aftercooler) at the correct level.

A customer installed vent line is required between the top of the housing for the engine oil cooler and the expansion tank. This is for the circuit (aftercooler and engine oil cooler).

Jacket Water Cooling System

The right side water pump (11) pulls coolant from the expansion tank through the coolant inlet (12). Coolant from the right side water pump flows to the side of the cylinder block through elbows (10) and (16).

The coolant flows upward through the cylinder water jacket. The coolant flows around the cylinder liners from the bottom to the top. Near the top of the cylinder liners, the water jacket is made smaller. This is the area that has the hottest temperature. This shelf (smaller area) causes the coolant to flow faster for better liner cooling. Coolant from the top of the liners flows into the cylinder head which sends the coolant around the parts that have the hottest temperature. The coolant flows to the top of the cylinder head (one at each cylinder). The coolant flows out of the cylinder head through an elbow into the water manifold (8). The coolant then flows through the manifold to the coolant outlet (1). The coolant exits the outlet and flows through a remote mounted water temperature regulator and the heat exchanger. The coolant then flows back to the expansion tank.

Coolant is sent from the water jacket at the rear of the cylinder block through turbocharger coolant supply tubes (7) to the turbochargers (6). Coolant from the turbochargers is returned to the cylinder block through turbocharger coolant return tubes (7).

A customer installed vent line is required between the top of the turbochargers to the expansion tank. This is for the jacket water system.

Inlet Controlled Cooling System

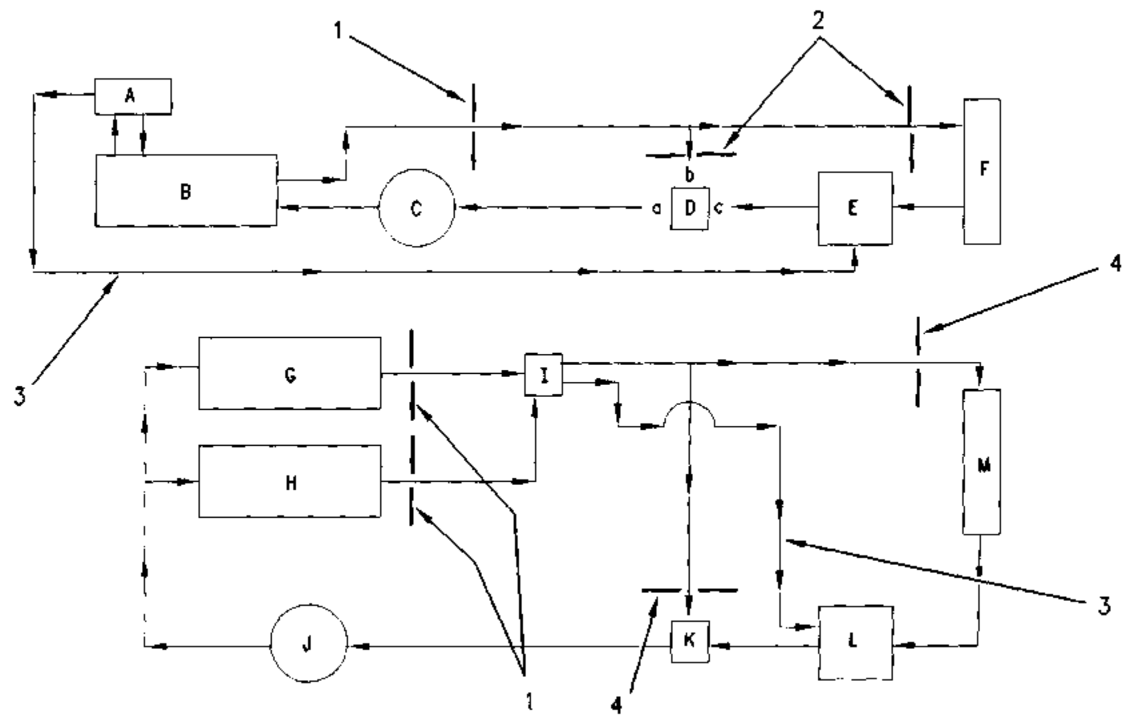


Illustration 52
(1) Factory orifices. (2) Factory or customer orifices. (3) Vent lines. (4) Customer orifices. (A) Turbocharger. (B) Cylinder block and cylinder head. (C) Jacket water pump. (D) Temperature regulator housing (jacket water system). (E) Expansion tank. (F) Heat exchanger. (G) Engine oil cooler. (H) Aftercooler. (1) Mixer housing. (J) Separate circuit water pump. (K) Temperature regulator housing (separate circuit system). (L) Expansion tank. (M) Heat exchanger. (a) Port a. (b) Port b. (C) Port C.

The inlet controlled systems, sometimes referred to as mixing control, maintain a minimum inlet temperature to the water pump. The temperature regulators control coolant flow through the regulator housing by passing all coolant across the regulators. While the coolant temperature is below the rating of the regulators, the coolant is drawn through the bypass port (b), and flows across the temperature regulators and out port (a). As the coolant temperature rises, the regulator opens and allows the coolant from the heat exchanger, through port (C), to mix with the bypass coolant. This occurs as the coolant exits the regulator housing.

Outlet Controlled Cooling System

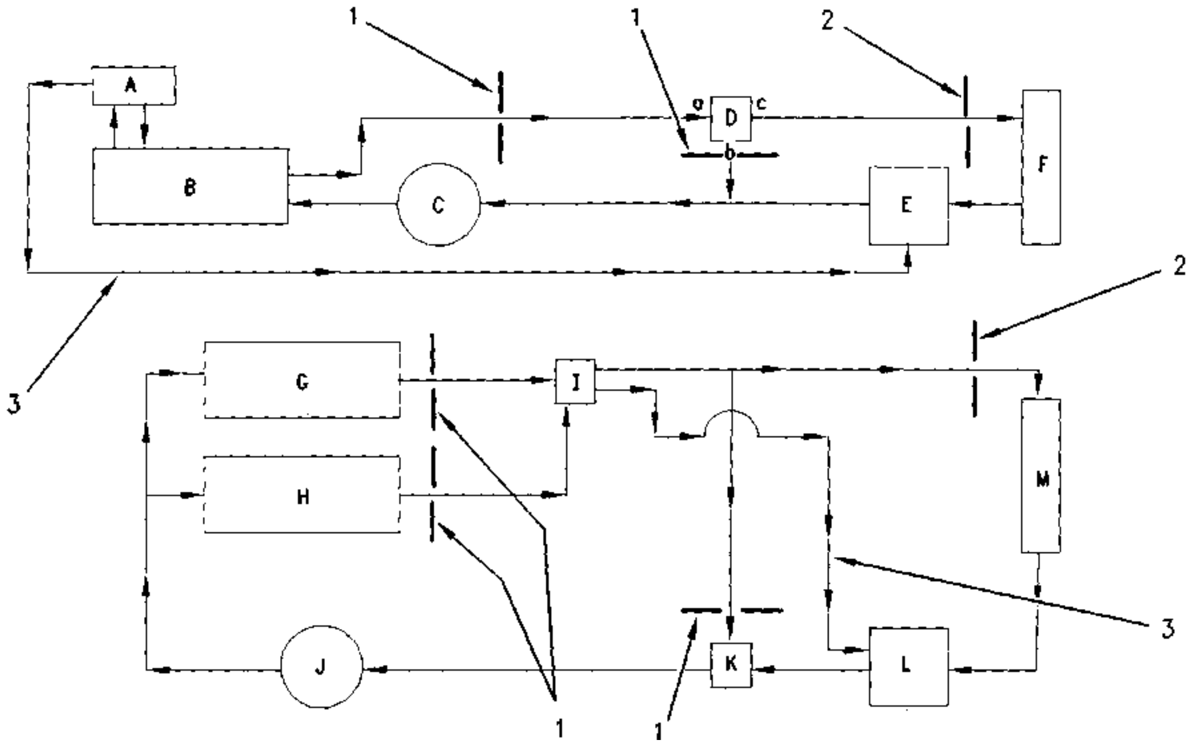


Illustration 53

(1) Factory orifices. (2) Factory or customer orifices. (3) Vent lines. (A) Turbocharger. (13) Cylinder block and cylinder head. (C) Jacket water pump. (D) Temperature regulator housing (Jacket water system). (E) Expansion tank. (F) Heat exchanger. (G) Engine oil cooler. (H) Aftercooler. (1) Mixer housing. (J) Separate circuit water pump. (K) Temperature regulator housing (separate circuit system). (L) Expansion tank. (M) Heat exchanger. (a) Port a. (b) Port b. (C) Port C.

The outlet controlled systems, sometimes referred to as diverting control, maintains a minimum coolant outlet temperature. The coolant flows from the engine outlet across the temperature sensing bulbs in port (a). The temperature sensing bulbs determine the direction of flow through the regulator housing. While the coolant temperature is below the regulators rated temperature, the coolant is bypassed around the external heat exchanger, through port (b), to the inlet of the pump. As the coolant temperature increases, the regulator opens diverting some of the flow through port (C) to the heat exchanger.

Coolant Mixture

A properly maintained coolant mixture consisting of water (that meets minimum water quality specifications) combined with supplemental coolant additive (also called cooling system conditioner), or water mixed with both supplemental coolant additive and antifreeze (either ethylene or propylene glycol) is required.

The type and condition of the coolant will directly effect the efficiency and the service life of the cooling system and the engine. Refer to the Operation And Maintenance Manual for the recommended coolant mixture specifications and the maintenance procedures.

Basic Block

Cylinder Block, Liners And Cylinder Heads

The cylinder block is a one-piece casting of heavily ribbed, weldable gray iron alloy. The air inlet plenum runs the full engine length, providing even air distribution to the cylinders.

The main bearing caps are fastened to the cylinder block with two studs per cap. The studs are hydraulically tensioned. Each main bearing cap has two saddle bolts, one through each side of the cylinder block. The saddle bolts are used in order to prevent the movement of the main bearing cap. The saddle bolts are also used in order to add stiffness to the lower area of the cylinder block.

The cylinder liners are made from high alloy iron castings. The cylinder liners are induction hardened and jacket water cooled over the liners full length. The cylinder liners can be removed for replacement. The cylinder liner seats on the top face of the cylinder block. The cylinder liner is piloted below the liner flange at the top. The cylinder liner is sealed with an O-ring seal at the top and three O-ring seals at the bottom. The O-ring seals provide a seal between the cylinder liner and the cylinder block.

The engine has a separate cylinder head for each cylinder. Each cylinder head contains the following components: two inlet valves, two exhaust valves, four replaceable valve seats, and one gas inlet valve. The inlet and exhaust valves move in replaceable valve guides which are pressed into the cylinder head.

The valves are actuated by the following components: roller type cam followers, pushrods, rocker arms, and bridge and guide dowel assemblies. Each pair of inlet and exhaust valves are actuated by separate bridges which contact the rocker arm.

A third lobe on the camshaft moves the cam follower, the pushrod and the rocker arm that operates the gas inlet valve.

Combustion gas is sealed by a rectangular cross section steel ring gasket that is located between the cylinder liner flange and the head. Rubber O-ring seals are used in order to seal air, water and oil connections between the cylinder head and cylinder block. The seals are located in two plates for each cylinder.

Each cylinder head is fastened to the cylinder block by four studs and four nuts. These studs are hydraulically tensioned. The nuts are turned down by hand and the hydraulic tension is released. The entire stud load is carried by the combustion seal ring gasket.

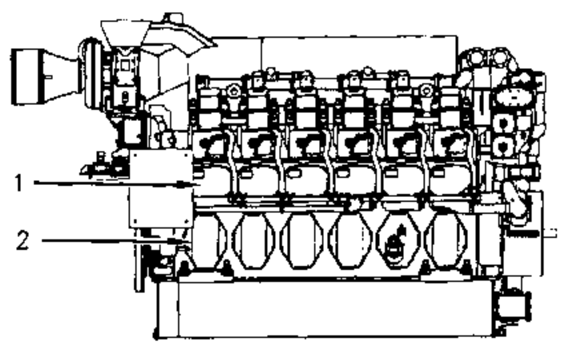


Illustration 54
Right Side of Engine
(1) Covers (for the camshaft). (2) Covers (for the inspection of the connecting rod bearings and the main bearings.

Covers (1) allow access in order to inspect and perform maintenance of the camshafts, the valve lifters and the valve lifter guides.

Covers (2) allow access in order to inspect and perform maintenance of the crankshaft, the connecting rods, the piston cooling jets and the main bearings.

Pistons, Rings And Connecting Rods

The piston is a two-piece unit. A steel crown is held to a forged aluminum body by four studs and nuts. An inner cooling chamber and outer cooling chamber are formed inside the crown. The cooling jet oil flow enters the outer chamber through a drilled passage in the piston body. After entering the outer shaker chamber, the oil flows to the inner shaker chamber. Then the oil returns to the sump through a centrally located drain hole that is located above the small end of the connecting rod.

Three piston rings are used on the piston assembly for sealing combustion gas and oil control. The top and middle piston rings are located in a hardened steel groove in the piston crown. The third piston ring (oil control) is located in the aluminum body.

The oil control ring is located in the lower groove in the aluminum body. Four holes are drilled from the bottom edge of the oil groove to the interior of the piston. The four holes drain excess oil from the oil ring.

The piston has two 1/2 -13 NC threaded holes in the crown for lifting the piston and connecting rod assembly.

The connecting rod has a taper on the pin bore end. This gives the connecting rod and the piston more strength in the areas with the most load. Four bolts and nuts hold the connecting rod cap to the connecting rod.

Crankshaft

The crankshaft changes the combustion forces in the cylinders into a usable rotating torque in order to send power from the crankshaft. Vibration dampers are used at the front of the crankshaft to reduce torsional vibrations (twist on crankshaft).

The crankshaft has the following characteristics: press forging, induction hardened, and regrindable. A counterweight for each cylinder is welded to the crankshaft then ultrasonically examined to ensure weld integrity.

Identical flanges are machined at each end of the crankshaft for the flywheel and vibration damper mounting. The front of the crankshaft can be distinguished from the rear of the crankshaft by the marking *FRONT* stamped on the center of the front hub. Also, the rear flange has tapped holes in order to mount the crankshaft timing pin bracket.

The crankshaft for the G3612 engine is supported by seven main bearings. The crankshaft for the G3616 engine is supported by nine main bearings. Crankshaft thrust is taken by two half-circle, steel backed aluminum plates located in the counterbores of each side of the rear bearing saddle in the cylinder block.

The crankshaft drives a group of gears on the front and rear of the engine. The gear group on the front of the engine drives the oil pump and water pumps. The gear group on the rear of the engine drives the camshafts and the optional alternator.

Lip type crankshaft seals are used at each end of the crankshaft. The seal assemblies are fastened to the front housing and the rear housing. The lips of the seals contact the adapters that are bolted to each end of the crankshaft.

Pressure oil is supplied to all the main bearings through drilled passages in the webs of the cylinder block. The oil flows through holes drilled in the crankshaft in order to provide oil for the connecting rod bearings.

Camshafts

The engine has a camshaft group for each side of the engine.

The camshafts are made from identical cam segments, journals, spacers and a drive end. Each cam segment has three lobes. The cam segments are replaceable at each cylinder through access holes in the cylinder block. Each camshaft group is supported by seven bearings. A thrust plate at the rear of each camshaft controls end play.

As the camshaft turns, each lobe moves a lifter assembly. There are three lifter assemblies for each cylinder. The outer lifter assemblies each move a pushrod and a set of valves (inlet or exhaust). The center lifter assembly moves a pushrod that operates the gas inlet valve.

Each camshaft must be in time with the crankshaft and with each other. The relation of the cam lobes to the crankshaft position will cause the valves (inlet and exhaust) and the gas inlet valve in each cylinder to operate at the correct time. Timing relationship of the camshaft and crankshaft is established from the No. 1 cylinder, Top Center (TC) position. Timing pins are provided for the camshaft and the crankshaft in order to establish No. 1 Top Center Position.

Front Gear Train

The front gear train provides the drives for the engine oil pump, the jacket water pump, the engine oil cooler and the aftercooler water pump. The oil pump drive gear is supported by the pump. The water pump drive gears are supported by bearings on the ends of the shafts.

Rear Gear Train

The rear gear train provides the drives for the camshaft, the power take-off and the alternator. The crankshaft gear is piloted on the crankshaft. The crankshaft goes between the flywheel mounting adapter and the crankshaft flywheel flange. In addition to the flywheel bolts, four bolts are used to hold the adapter and gear to the crankshaft.

Crankcase Explosion Relief Valves

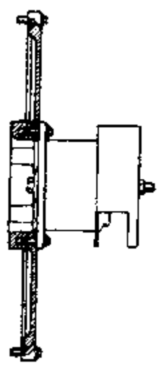


Illustration 58
Crankcase Explosion Relief Valve

The crankcase explosion relief valves open in order to relieve the pressure from a crankcase explosion. The valves then close immediately in order to keep fresh air from entering the crankcase. A pressure of 7 kPa (1 psi) is required to open the valve. An oil screen quenches any flames from an explosion.

Five crankcase explosion relief valves are used on G3612 engines. Six crankcase explosion relief valves are used on G3616 engines. Do not change the total number of crankcase explosion relief valves that are installed on the engine.

Air Starting System

An air starting motor can be used in order to turn the engine flywheel with enough rpm in order to start the engine. Operation of the air starting motor is controlled by the Engine Supervisory System. The air starting motor will engage when the requirements for prelube have been met.

The air starting motor is usually mounted on the left side of the engine. Air is normally contained in a storage tank. The following conditions will determine the length of time that the engine flywheel can be turned: the volume of the tank, the air pressure in the tank, and the amount of the restriction in the system.

For starting the engines which do not have heavy loads, the regulator setting is approximately 1034 kPa (150 psi). This setting gives a good relationship between the cranking speeds that are fast enough for easy starting and the length of time that the air starting motor can turn the engine flywheel before the air supply is gone.

Note: Minimum recommended starter cranking speed for start-up is 80 rpm. The fuel system and the ignition system are activated at engine speeds above 50 rpm. The maximum cranking speed of the air starting motor is 150 rpm.

If the engine has a heavy load which cannot be disconnected during starting, the setting of the air pressure regulating valve needs to be higher in order to get high enough speed for easy starting.

The air starter consumption is directly related to speed. The air pressure is related to the effort that is necessary in order to turn the engine flywheel. The setting of the air pressure regulator can be up to 1723 kPa (250 psi). This will get the correct cranking speed for a heavily loaded engine. With the correct setting, the air starting motor can turn the heavily loaded engine as fast and as long as the air starting motor can turn a lightly loaded engine. The maximum pressure for use in the air starting motor is 1723 kPa (250 psi).

For good life of the air starting motor, the air supply should be free of dirt and water. Use a lubricator with 10W nondetergent oil for temperature above 0°C (32°F). Use air tool oil for temperatures below 0°C (32°F).

Electrical System

The electrical system has two separate circuits. The circuits are the charging circuit and the starting circuit. Some of the electrical system components are used in more than one circuit. The battery, the circuit breaker, the cables, and the battery wires are common in each of the circuits.

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.

Grounding Practices

Proper grounding is necessary for optimum engine performance and reliability. Improper grounding will result in uncontrolled electrical circuit paths and in unreliable electrical circuit paths.

Uncontrolled electrical circuit paths can result in damage to main bearings, to crankshaft journal surfaces, and to aluminum components. Uncontrolled electrical circuit paths can also cause electrical activity that may degrade the engine electronics and communications.

Ensure that all grounds are secure and free of corrosion.

The engine alternator must be grounded to the negative "-" battery terminal with a wire that is adequate to carry the full charging current of the alternator.

For the starting motor, do not attach the battery negative terminal to the engine block. Ground the engine block with a ground strap that is furnished by the customer. Connect this ground strap to the ground plane.

Use a separate ground strap to ground the battery negative terminal for the control system to the ground plane.

If rubber couplings may connect the steel piping of the cooling system and the radiator, the piping and the radiator can be electrically isolated. Ensure that the piping and the radiator are continuously grounded to the engine. Use ground straps that bypass the rubber couplings.

NOTICE

This engine is equipped with a 24 volt starting system. Use only equal voltage for boost starting. The use of a welder or higher will damage the electrical system.

Unlike many electronic systems of the past, this engine is tolerant to common external sources of electrical noise. However, electromechanical alarms can cause disruptions in the power supply. The engine's electronic control module (ECM) is powered through two power sources. One power source comes directly from the battery through a circuit breaker. The other power source comes through the keyswitch and another circuit breaker. Disconnect the power with the disconnect switch for the main power when you are working on the engine's electronics. The switch is by the battery box.

Charging System Components

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.

Alternator

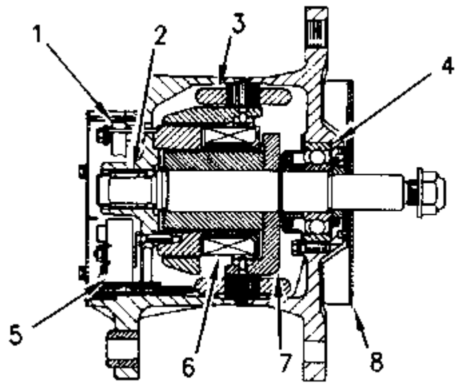


Illustration 56
Alternator Components (Typical Example)
(1) Regulator. (2) Roller bearing. (3) Stator winding.
(4) Ball bearing. (5) Rectifier bridge. (6) Field winding.
(7) Rotor assembly (7) Fan.

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 the regulator is part of the alternator.

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

The rotor assembly has many magnetic poles with air space between each opposite pole.

The poles have residual magnetism that produces a small amount of magnetic lines of force between the poles. As the rotor assembly begins to turn between the field winding and the stator windings, a small amount of alternating current (AC) is produced in the stator windings. 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 the rectifier bridge. Most of this current charges the battery and supplies the low amperage circuit. The remainder of the current is sent to the field windings. The DC current flow through the field windings (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 the stator windings. The increased speed of the rotor assembly also increases the current and voltage output of the alternator.

The voltage regulator is a solid-state, electronic switch. The regulator feels the voltage in the system. The regulator turns on and the regulator turns off 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.

Starting System Components

Starting Solenoid

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

- Closes the high current starting motor circuit with a low current start switch circuit.
- Engages the starting motor pinion with the ring gear.

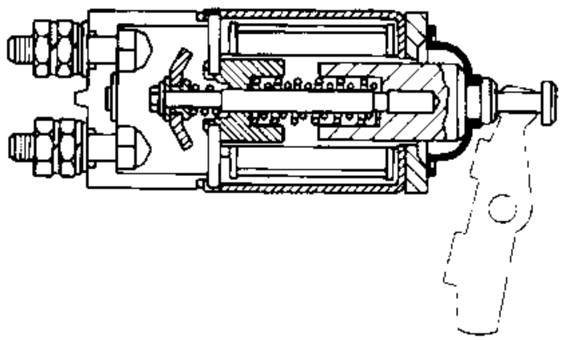


Illustration 57
Typical Solenoid Schematic

The solenoid has windings (one or two sets) around a hollow cylinder. There is a plunger with a spring load inside the cylinder. 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 winding and the pull-in winding. 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.

Starting Motor

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

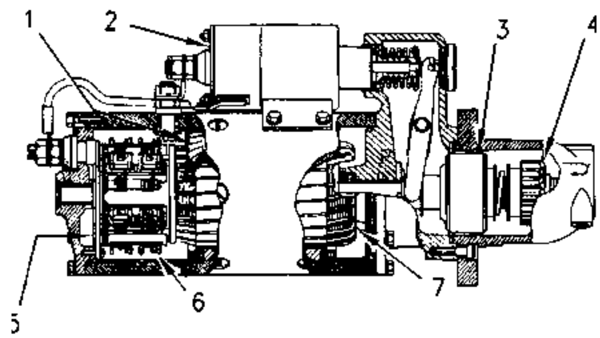


Illustration 58
Starting Motor Cross Section (Typical Example)
(1) Field. (2) Solenoid. (3) Clutch. (4) Pinion. (5) Commutator. (6) Brush assembly. (7) Armature.

The starting motor has a solenoid. When the start switch is activated, electricity will flow through the windings of the solenoid. The solenoid core will move in order to push the starting motor pinion with a mechanical linkage. This will engage with the ring gear on the flywheel of the engine. The starting motor pinion will engage with the ring gear before the electric contacts in the solenoid close the circuit between the battery and the starting motor. When the circuit between the battery and the starting motor is complete, the pinion 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, the starting motor pinion will move away from the flywheel ring gear.

Other Components

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 starting motor is running. The control feature will not allow starting motor engagement if the speed is above 0 rpm.

- The starting motor is protected from continued starting motor operation from an operator holding the key in the “Start” position after the engine starts. This is accomplished by disengaging the starting motor solenoid after engine speed reaches 300 rpm.

Magnetic Pickup

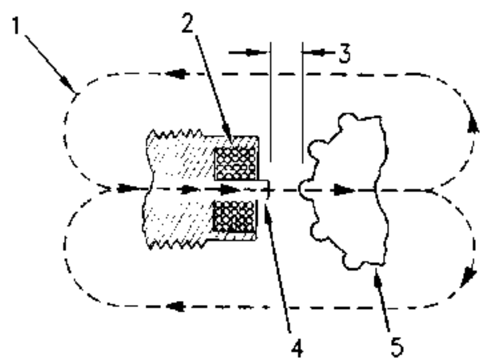


Illustration 59
Schematic of Magnetic Pickup Diagram
(1) Magnetic lines of force. (2) Wire coils. (3) Gap.
(4) Pole piece. (5) Flywheel ring gear.

The magnetic pickup is a single pole, permanent magnet generator. The magnetic pickup is made of wire coils (2). The coils go around a permanent magnet pole piece (4).

As the teeth of the flywheel ring gear (5) cut through the magnetic lines of force (1) around the pickup, an AC voltage is generated. The frequency of this voltage is directly proportional to engine speed.

Electrical System Circuit Breaker

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.

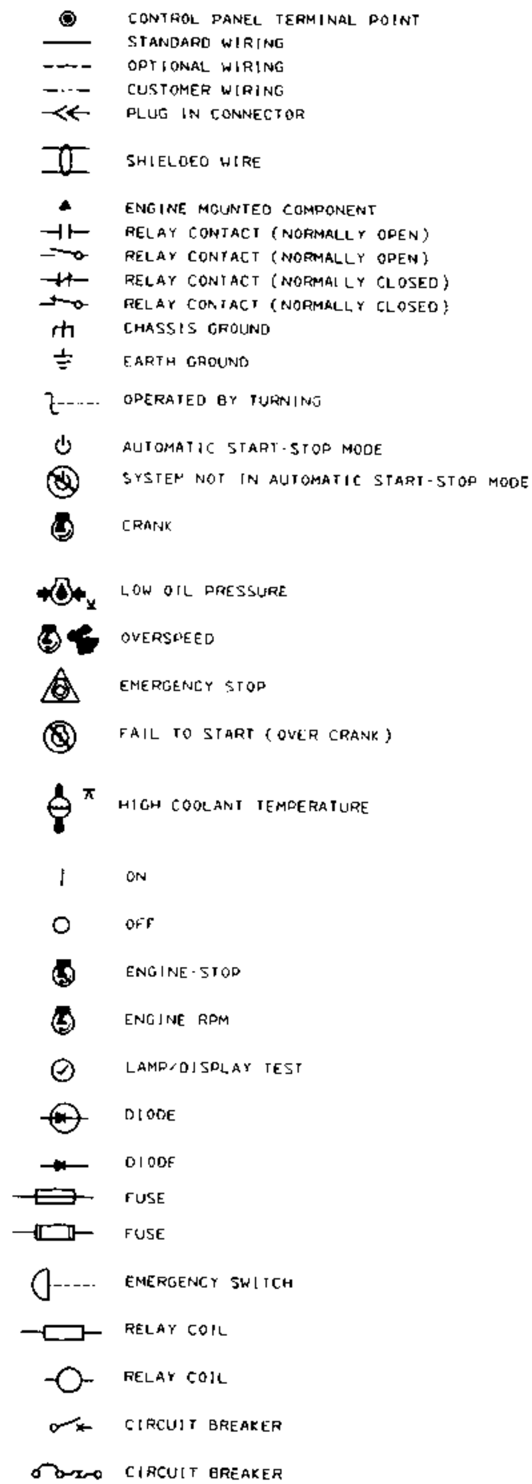
A heat activated metal disc with a contact point completes the electric circuit through the circuit breaker. If the current in the electrical system gets too high the metal disc will get hot. This heat causes a distortion of metal disc. The disc opens the contacts. The disc breaks the circuit.

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

Abbreviations and Symbols

ALT	ALTERNATOR
ASSV	AIR START SOLENOID VALVE
AWG	AMERICAN WIRE GAUGE
BATT	BATTERY
BT	COMBUSTION BURN TIME
BTU	BRITISH THERMAL UNIT (ENERGY CONTENT/CU FT)
C	COMMON
CAS	CRANK ANGLE SENSOR
CB	CIRCUIT BREAKER
CCM	CUSTOMER COMMUNICATION MODULE
CCW	COUNTERCLOCKWISE
CMS	COMPUTERIZED MONITORING SYSTEM
CSPS	CUSTOMER SHUTDOWN POWER SUPPLY
CTR	CRANK TERMINATION RELAY
CW	CLOCKWISE
D	DIODE
DDT	DIGITAL DIAGNOSTIC TOOL
DDTC	DIGITAL DIAGNOSTIC TOOL CONNECTOR
ECM	ENGINE CONTROL MODULE
ECS	ENGINE CONTROL SWITCH
EFR	ENGINE FAILURE RELAY
EFRX	ENGINE FAILURE RELAY X (EXTERNAL)
ESPB	EMERGENCY STOP PUSH BUTTON
ESS	ENGINE SUPERVISORY SYSTEM
EXTP	COOLANT TEMPERATURE PROBE
F	FUSE
FCR	FUEL CONTROL RELAY
GSOV	GAS SHUTOFF VALVE
LHDS	LEFT HAND DETONATION SENSOR
MAN	MANUAL
MGR	MAGNETIC GROUNDING RELAY
PLPSR	PRELUBE PRESSURE SWITCH RELAY
PLR	POSTLUBE RELAY
PS	PINION SOLENOID
PWM	PULSE WIDTH MODULATION
RHDS	RIGHT HAND DETONATION SENSOR
RR	RUN RELAY
SCM	ENGINE STATUS CONTROL MODULE
SEC	SECOND
SIG	SIGNAL
SM	STARTING MOTOR
SMMS	STARTING MOTOR MAGNETIC SWITCH
SMR	STARTING MOTOR RELAY
SR1	SLAVE RELAY NUMBER 1
SR2	SLAVE RELAY NUMBER 2
TCM	TIMING CONTROL MODULE
TCMPU	TIMING CONTROL MODULE SPEED PICKUP
XDUCER	TRANSDUCER



Index

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