FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

SECTION I: PLANS AND SCHEDULES

This section lists all plans approved by AQMD for the purposes of meeting the requirements of applicable AQMD rules specified below. The operator shall comply with all conditions specified in the approval of these plans.

Documents pertaining to the plan applications listed below are available for public review at AQMD Headquarters. Any changes to plan applications will require permit modification in accordance with Title V permit revision procedures.

List of approved plans:

Application	Rule
343039	1150.1
519251	1110.2
519253	431.1
526754	3003

NOTE: This section does not list compliance schedules pursuant to the requirements of Regulation XXX - Title V Permits; Rule 3004(a)(10)(C). For equipment subject to a variance, order for abatement, or alternative operating condition granted pursuant to Rule 518.2, equipment specific conditions are added to the equipment in Section D or H of the permit.

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

APPLICATION NUMBER: 519251

RULE 1110.2 (F) (1) (D) INSPECTION AND MONITORING (I & M) PLAN FOR THE FACILITY LOCATED AT 13130 CROSSROADS PARKWAY, CITY OF INDUSTRY, CA 91746

Please refer to the application you submitted for the evaluation of your Inspection and Monitoring (I & M) plan under District Rule 1110.2 (f) (1) (D), for the facility described above.

The Rule 1110.2 Inspection & Monitoring plan you submitted has been APPROVED.

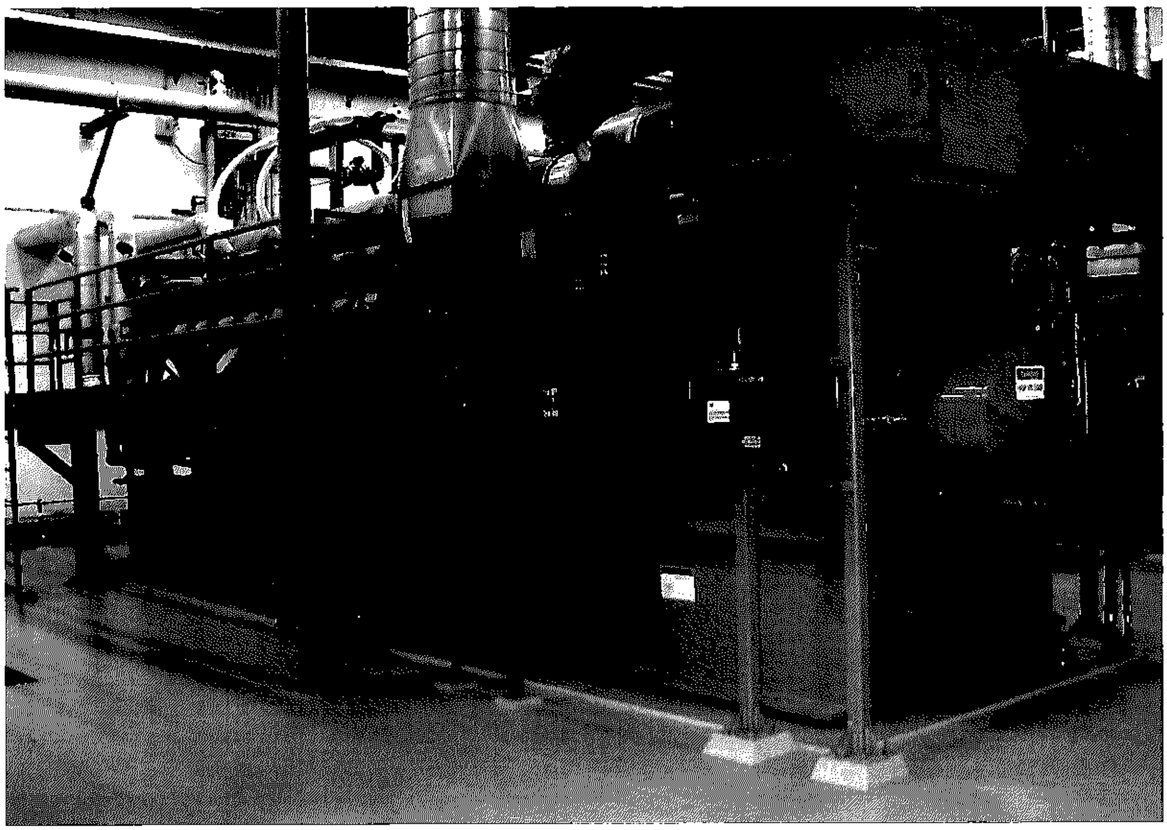
A copy of your approved plan, together with any addendum, statements or declarations you provided during the evaluation of your plan, is attached. In accordance with Rule 1110.2 (f)(1)(D)(ix), any change in equipment, control equipment, operating conditions or emission limits will require that you submit an application to the District for the revision of your I & M plan.

If you have any questions about this approval, please call Mr. Atul Kandhari at (909) 396-2477.

Enclosure(s)

RULE 1110.2 INSPECTION AND MONITORING (I & M) PLAN FOR THREE INTERNAL COMBUSTION ENGINES AT THE PUENTE HILLS LANDFILL PERG II

SCAQMD PERMIT TO OPERATE No. G3774, G3775 AND G3776



Revision 1 January 2011

SANITATION DISTRICTS OF LOS ANGELES COUNTY

County Sanitation Districts of Los Angeles County
1955 Workman Mill Road
Whittier CA, 90601

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Rule 1110.2 Inspection & Monitoring Plan for Three Internal Combustion Engines at the Puente Hills Landfill

1.0 INTRODUCTION

South Coast Air Quality Management District's (SCAQMD) Rule 1110.2 was amended in January 2008. The amended rule has many new requirements for internal combustion engines (ICE). One of the requirements is to submit an Inspection and Monitoring (I&M) plan for certain categories of sources. These plans have to submitted to the SCAQMD for approval and were due August 1, 2008. The I&M plans have to implemented by December 1, 2008. Plans are required for facilities that do not have an Oxides of Nitrogen (NO_x) and/or Carbon Monoxide (CO) CEMS and used as a tool to ensure that engines are in continuous compliance with Rule 1110.2's NO_x and CO limits. Detailed requirements for an I&M plan are presented in Section (f)(1)(D) of Rule 1110.2.

The PERG II engines have existing NO_x CEMS and hence, this I&M plan is for CO only.

2.0 FACILITY INFORMATION

The Puente Hills Landfill has three internal combustion engines. These engines are located at the Internal Combustion Engine (ICE) plant or PERG II. PERG II is located near the existing Gas-to-Energy facility (PERG) and was commissioned in 2006. Electricity generated by the ICE plant is supplied to LACSD's San Jose Creek wastewater treatment facility. Contact information on the facility is provided below:

Owner and Operator:	County Sanitation Districts of Los Angeles County
Facility Name:	LA County Sanitation Districts - Puente Hills Landfill
Address:	13130 Crossroads Parkway South City of Industry, CA 91746
SCAQMD Facility ID:	025070
Facility or Site Engineer:	Don Volmer 562-908-4288 x 6150 dvolmer@lacsd.org
Compliance Engineer:	Wendy Han 562-908-4288 x 2134 whan@lacsd.org
SCAQMD Permit No.:	G3774, G3775 and G3776 (ICEs No. 1, 2 and 3)

3.0 ENGINE DESCRIPTION

Engine Type:	Caterpillar G3616, 16 cylinders, 4261 BHP, lean burn, turbocharged with aftercooler and coupled to a 3000 kW electrical generator
Fuel Type:	Landfill Gas
Emission Controls:	Emissions controlled by Caterpillar propriety control system - ADEM III engine management system
Engine RPM:	900 and constant to maintain generator at 60 Hertz

The Caterpillar G3616 engine is controlled with an engine management system - ADEM III. The management system consists of an Electronic Control Module (ECM), Integrated Combustion Sensing Modules (ICSM) and an operator Machine Information Display System (MIDS). The primary inputs to the ECM and ICSM are the cylinder thermocouples and the combustions sensors. These devices work in conjunction with a fuel regulating valve, detonation sensors, engine choke, turbo-waste gate and associated pressure transducers to control engine operation.

The ECM is a propriety Caterpillar emission and control system for the engine. The engine is completely automated with limited provisions for manual inputs or adjustments. The ECM monitors various inputs from sensors in order to activate relays, solenoids and hydraulic actuators. The ECM supports 5 primary functions; governing of the engine, control of ignition, air-to-fuel ratio control, start/stop control and monitoring engine operation. Control of these parameters is determined using internal engine maps that have been developed by Caterpillar for the engines. The maps include a timing map, air/fuel ratio map, fuel correction factor map, and several other maps. The process of mapping and installation of the maps is a propriety process and can only be done by Caterpillar personnel.

There is no stand-alone air-to-fuel ratio controller on the engine. The ADEM III control system uses the ECM to control air-to-fuel ratio and uses: maps in the ECM, output drivers in the ECM, fuel actuator, air choke actuator, exhaust bypass (waste-gate) actuator, ICSM, thermocouples and cylinder combustion sensors. With the exception of fuel quality all values are locked within the ECM and can only be changed by the manufacturer. Lack of access to operating parameters does not allow operator adjustments to change engine emissions.

4.0 ENGINE OPERATION

The primary goal of the ICE plant operations is to generate power while complying with permit conditions and applicable emission limits (see Section 5.0 for emission limits). The engines have NO_x and O_2 CEMS that provide plant operators with real-time, continuous emissions data. To maintain emissions compliance, visual and audible alarms inform operators of excess NO_x. A portable analyzer will be used to check engine CO emissions. Periodic monitoring will initially consist of a CO reading at each engine taken once each calendar week or every 150 hours of operation, whichever comes later. Excess emissions will result in troubleshooting, corrective actions, and repeat portable analyzer measurements, as appropriate.

Manuals for operation and troubleshooting for the engines are included in Appendix B and C.

5.0 EMISSION LIMITS

Copies of the permits for the engines are included the appendices. Each engine has an efficiency correction factor (ECF)-corrected NO_x concentration limit that is based on the result of the ECF test on each engine. Table 1 has the current permitted emission concentration limits for the engines.

TABLE 1: PERMITTED EMISSION LIMITS

Pollutant	Concentration Limit ppm @ 15% O_2	Comments
NO_x	51	Permit Condition
	54 (ICE 1) 50 (ICE 2) 53 (ICE 3)	Rule 1110.2 ECF-corrected limit
CO	351	Permit Condition
	2000 (before July 1, 2012) 250* (July 1, 2012)	Rule 1110.2
VOC	196	Permit Condition
	40	Rule 1110.2
	20 ppm @ 3% O_2 as hexane or 98% destruction efficiency	Rule 1150.1

* It becomes effective if the technical assessment confirms 250 ppm is achievable

In addition to the concentration limits the permit for the engines includes mass emission limits for NO_x, CO and VOC.

6.0 MAINTENANCE PROCEDURE

One of the keys to operating the engine in compliance with emission limits is an ongoing maintenance program. ICE plant operations perform maintenance as per the manufacturer recommended schedule. This schedule is included in Appendix D.

7.0 PORTABLE ANALYZER MONITORING

CO emissions are first tested at least once a week or every 150 operating hours, whichever is later, using a portable analyzer. These tests are performed using the Protocol for Periodic Monitoring of NO_x, CO and O_2 from Stationary Engines subject to Rule 1110.2. Engines shall not be tuned within 72 hours prior to a portable analyzer tests, unless it is an unscheduled event. Personnel conducting the tests will be trained as per Rule 1110.2 Section (f)(1)(G). If an engine is found to be in compliance for 3 consecutive weeks, without any adjustments, then the frequency of CO tests will change from weekly or 150 operating hours to quarterly or every 2,000 engine operating hours, whichever occurs later per Rule 1110.2(f)(1)(D)(iii)(II), until there is a noncompliant check.

8.0 RESPONSE TO DEVIATIONS

Because the ADEM-III controls all aspects of engine operation and does not allow operators to change any parameters there are limited options to change CO emissions. The following procedure will be followed to correct a CO exceedence during a portable analyzer check:

- Ensure that all relevant operating parameters are in the normal range including cylinder temperatures, fuel quality and fuel flow.
- If necessary adjust individual cylinders air-to-fuel ratio using a local valve to increase or decrease temperature in a cylinder. This is a trimming feature and can be used to change NO_x emissions. However, we are not sure if this will make any difference in CO emissions. The pre-combustion chamber needle valves adjust the air-to-fuel ratio for the small pre-combustion chamber only. Adjusting the needle valve has no effect on the air-to-fuel ratio of the main chamber. However,

if the air-to-fuel ratio of the pre-combustion chamber is incorrect, the pre-combustion chamber will not fire and ignite the main chamber. The main chamber air-to-fuel ratio is regulated by the ECM using the fuel gas inlet valve (main throttle) and turbo waste-gate. This occurs when the engine is loaded more than 40%, if load is under 40% the engine uses the choke only.

- The timeframes within Rule 1110.2 allow an overall engine inspection and review process to identify gross changes to operating condition parameters that may have impacted CO emissions.
- If ICE plant personnel cannot diagnose the problem, then they will proceed to shutdown the engine and have Caterpillar determine the cause for the higher CO emissions. This will have to be done through their proprietary control system.

9.0 REPORTING

Per Rule 1110.2 (f)(1)(H)(i), breakdowns or malfunctions that lead to potential deviations must be reported to SCAQMD within 1 hour of discovery by calling 1-800-CUT-SMOG (1-800-288-7664). Plant personnel will make such calls and identify (1) the time, (2) facility location, (3) equipment involved, (4) contact person, as well as (5) cause of the breakdown, if known, and (6) estimated time for repairs. Plant personnel will also notify LACSD Air Quality when such phone reports are made to SCAQMD.

Per R1110.2 (f)(1)(H)(ii), a written report will be submitted to SCAQMD within 7 calendar days after a breakdown has been corrected, but no later than 30 calendar days from the initial breakdown. This report will be completed by LACSD Air Quality personnel and include: (1) identification of equipment involved in causing, or suspected of having caused, or having been affected by the breakdown, (2) duration of breakdown, (3) date of correction and information that compliance was achieved, (4) type of excess emissions resulting from the breakdown, (5) calculation of excess emission resulting from the breakdown (e.g., NOx or CO in lbs) and basis used to quantify the emissions, (6) description of the corrective action(s) taken to address the breakdown and minimize excess emissions, and (7) description of any measures taken to avoid such breakdowns in the future.

Per R1110.2 (f)(1)(H)(iii), Within 15 days of the end of each calendar quarter, a Quarterly Report will be submitted to SCAQMD that lists each occurrence of breakdown, malfunction, or portable emissions checks that showed potential deviations. The LACSD Air Quality Section will prepare this report.

10.0 PLAN REVISIONS

Any revisions to this I&M Plan will first be reviewed by LACSD Air Quality staff and ICE operations. It will then be submitted to SCAQMD for approval. The plan will be submitted with appropriate fees according to Rule 301. Following plan implementation on December 1, 2008, any changes to this I&M Plan will be effective immediately and reflected in a revised submittal.

APPENDIX A - SCAQMD PERMITS

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

PERMIT TO OPERATE

Permit No. G24806
A/N 501721

Equipment Description:

LANDFILL GAS TO ENERGY SYSTEM NO. 1 CONSISTING OF:

1. INTERNAL COMBUSTION ENGINE NO. 1, CATERPILLAR, MODEL G3616, SIXTEEN CYLINDER, 4261 BHP, LEAN BURN, LANDFILL GAS/NATURAL GAS FIRED, TURBOCHARGED AND AFTERCOOLED, DRIVING A 3 MW ELECTRICAL GENERATOR.
2. COMPRESSOR, 1468 CFM, 300 HP
3. ANCILLARY RADIATOR AND AFTERCOOLER WITH ELECTRIC FANS
4. ANCILLARY MUFFLER EXHAUST STACK.

Conditions:

1. OPERATION OF THIS EQUIPMENT SHALL BE CONDUCTED IN ACCORDANCE WITH ALL DATA AND SPECIFICATIONS SUBMITTED WITH THE APPLICATION UNDER WHICH THIS PERMIT IS ISSUED UNLESS OTHERWISE NOTED BELOW.
   [RULE 204]
2. THIS EQUIPMENT SHALL BE PROPERLY MAINTAINED AND KEPT IN GOOD OPERATING CONDITION AT ALL TIMES.
   [RULE 204]
3. OPERATION OF THIS EQUIPMENT SHALL NOT RESULT IN THE EMISSION OF RAW LANDFILL GAS TO THE ATMOSPHERE.
   [RULE 1150.1]
4. A SAMPLING PORT SHALL BE INSTALLED IN THE LANDFILL GAS LINE TO THE ENGINE TO ALLOW THE COLLECTION OF A GAS SAMPLE.
   [RULE 431.1]
5. A FLOW INDICATING AND RECORDING DEVICE SHALL BE INSTALLED IN THE GAS SUPPLY LINE FOR ALL FUELS TO THE ENGINE.
   [RULE 1303 (b)(2)-OFFSET]
6. THE COMBINED TOTAL LANDFILL GAS FLOW RATE AT PUENTE HILLS LANDFILL SHALL NOT EXCEED 39,800 SCFM.
   [RULE 1303 (b)(2)-OFFSET]

7. THE HEAT INPUT OF GAS TO THE ENGINE SHALL NOT EXCEED 34 MM BTU PER HOUR. A WEEKLY LOG OF THE GAS HEAT INPUT, BASED ON THE RECORDED FLOW RATE (SCFM) AND HIGHER HEATING VALUE, SHALL BE KEPT FOR AT LEAST TWO YEARS AND MADE AVAILABLE TO AQMD PERSONNEL UPON REQUEST.
[RULE 1303 (b)(2)-OFFSET]

8. READINGS OF THE HIGHER HEATING VALUE OF THE GAS AT THE INLET TO THE ENGINE SHALL BE TAKEN WEEKLY WITH AN AQMD APPROVED INSTRUMENT AND THE RESULTS RECORDED.
[RULE 1303 (b)(2)-OFFSET]

9. THE ENGINE SHALL ONLY USE LANDFILL GAS OR A COMBINATION OF LANDFILL GAS AND NATURAL GAS.
[RULE 204]

10. THE TOTAL NATURAL GAS USAGE SHALL NOT EXCEED 25 PERCENT OF THE TOTAL ENGINE HEAT INPUT ON AN AVERAGE DAILY BASIS AND 10 PERCENT ON A MONTHLY BASIS.
[RULE 1303 (b)(2)-OFFSET]

11. OTHER THAN IN THE ENRICHED PRE-COMBUSTION CHAMBER, NATURAL GAS SHALL NOT BE USED IN THIS ENGINE TO GENERATE ELECTRICITY FOR DISTRIBUTION IN THE STATE GRID SYSTEM.
[RULE 1303 (b)(2)-OFFSET]

12. OTHER THAN IN THE ENRICHED PRE-COMBUSTION CHAMBER, NATURAL GAS SHALL ONLY BE FIRED IN THIS ENGINE TO PROVIDE ELECTRICITY TO THE SANITATION DISTRICTS' OPERATED FACILITIES AT THE PUENTE HILLS LANDFILL, SAN JOSE CREEK WATER RECLAMATION PLANT AND THE JOINT ADMINISTRATION OFFICE.
[RULE 1303 (b)(2)-OFFSET]

13. SAMPLING PORTS SHALL BE PROVIDED IN THE ENGINE EXHAUST DUCT, 8-10 DUCT DIAMETERS DOWNSTREAM AND TWO DUCT DIAMETERS UPSTREAM OF ANY FLOW DISTURBANCE, AND SHALL CONSIST OF TWO PROPERLY SIZED WELD NIPPLES WITH PLUGS, 90 DEGREES APART. AN EQUIVALENT METHOD FOR EMISSION SAMPLING MAY BE USED UPON APPROVAL OF THE AQMD. ADEQUATE AND SAFE ACCESS TO THE TEST PORTS SHALL BE SUPPLIED BY THE APPLICANT.
[RULE 217]

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

14. APPLICANT SHALL CONDUCT ANNUAL PERFORMANCE TEST OF THE ENGINE IN ACCORDANCE WITH AQMD TEST PROCEDURES AND FURNISH THE AQMD A WRITTEN RESULT OF SUCH PERFORMANCE TEST. WRITTEN NOTICE OF THE PERFORMANCE TEST SHALL BE PROVIDED TO THE AQMD 10 DAYS PRIOR TO THE TEST SO THAT AN OBSERVER MAY BE PRESENT. A TEST PROTOCOL SHALL BE SUBMITED FOR APPROVAL AT LEAST 60 DAYS PRIOR TO TESTING.

    THE PERFORMANCE TEST SHALL INCLUDE, BUT SHALL NOT BE LIMITED TO A TEST OF THE INLET AND EXHAUST GASES, FOR THE FOLLOWING:

    A. METHANE
    B. TOTAL NON-METHANE HYDROCARBONS
    C. OXIDES OF NITROGEN (EXHAUST ONLY)
    D. CARBON MONOXIDE (EXHAUST ONLY)
    E. PARTICULATES (EXHAUST ONLY)
    F. TOTAL SULFUR COMPOUNDS AS H2S (INLET ONLY)
    G. FLOW RATE
    H. OXYGEN
    I. NITROGEN
    J. CARBON DIOXIDE
    K. MOISTURE
    L. TEMPERATURE
    M. TOXIC AIR CONTAMINANTS INCLUDING BENZENE, CHLOROBENZENE, 1,2-DICHLOROETHANE, 1,1-DICHLOROETHANE, DICHLOROMETHANE, TETRACHLOROETHYLENE, TETRACHLOROMETHANE, TOLUENE, 1,1,1-TRICHLOROETHANE, TRICHLOROETHYLENE, TRICHLOROMETHANE, VINYL CHLORIDE AND XYLENES (EXHAUST ONLY).

    [RULE 1303 (b)(2)-OFFSET, 1401]

15. THE EMISSIONS FROM THE ENGINE SHALL NOT EXCEED THE FOLLOWING:

AIR CONTAMINANT	LBS/HR
NON-METHANE HYDROCARBONS	1.69
NITROGEN OXIDE	4.79
SULFUR DIOXIDE	1.86
CARBON MONOXIDE	23.5
PARTICULATES	1.58

    [RULE 1303 (b)(2)-OFFSET]

16. A CONTINUOUS EMISSIONS MONITORING SYSTEM (CEMS) SHALL BE INSTALLED AND OPERATED TO MEASURE THE ENGINE EXHAUST CONCENTRATION FOR NOX AND O2 ON A DRY BASIS. IN ADDITION, THE SYSTEM SHALL CONVERT THE ACTUAL NOX CONCENTRATION TO A CORRECTED NOX CONCENTRATION AT 15% O2. THIS MONITORING SYSTEM SHALL COMPLY WITH THE REQUIREMENTS OF AQMD RULE 218.
    [RULE 218]

17. ALL RECORDS, SUCH AS FUEL USAGE, MAINTENANCE RECORDS AND PERFORMANCE TEST RESULTS, SHALL BE MAINTAINED FOR FIVE YEARS AND MADE AVAILABLE TO AQMD PERSONNEL UPON REQUEST.
    [RULE 1150.1, 1303 (b)(2)-OFFSET]

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

18. THIS ENGINE SHALL NOT BE OPERATED IN SUCH A MANNER AS TO INTERFERE WITH THE OWNER'S/OPERATOR'S ABILITY TO COMPLY WITH AQMD RULE 1150.1 OR ANY OTHER AQMD RULE LIMITING LANDFILL GAS MIGRATION OR SURFACE EMISSIONS.
[RULE 1150.1]

19. THIS EQUIPMENT SHALL BE OPERATED IN COMPLIANCE WITH ALL APPLICABLE REQUIREMENTS OF 40CFR PART 63, SUBPART ZZZZ – NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS FOR STATIONARY RECIPROCATING INTERNAL COMBUSTION ENGINES.
[40CFR PART 63, SUBPART ZZZZ]

20. THE EXHAUST OXYGEN SHALL BE MAINTAINED IN THE RANGE OF 8% TO 12% AVERAGED OVER 1-HOUR WHENEVER THE ENGINE IS IN OPERATION, EXCEPT DURING PERIODS OF STARTUP AND SHUTDOWN.

CONTINUOUS EXHAUST OXYGEN MONITORING AND RECORDING SYSTEM SHALL BE PURSUANT TO THE OPERATION AND MAINTENANCE REQUIREMENTS SPECIFIED IN 40 CFR PART 64.7. SUCH A SYSTEM SHALL BE INSPECTED, MAINTAINED, AND CALIBRATED ON AN QUARTERLY BASIS IN ACCORDANCE WITH THE MANUFACTURER'S SPECIFICATIONS USING AN APPLICABLE AQMD OR EPA APPROVED METHOD.

FOR THE PURPOSE OF THIS CONDITION, A DEVIATION SHALL BE DEFINED AS WHEN 1-HOUR AVERAGE OXYGEN PERCENTAGE OF LESS THAN 8% OR GREATER THAN 12% OCCURS DURING OPERATION EXCEPT DURING STARTUPS OR SHUTDOWNS. STARTUP OR SHUTDOWN PERIOD SHALL NOT EXCEED 30 MINUTES. THE OPERATOR SHALL REVIEW THE RECORDS OF OXYGEN PERCENTAGE ON A DAILY BASIS TO DETERMINE IF A DEVIATION OCCURED OR SHALL INSTALL AN ALARM SYSTEM TO ALERT THE OPERATOR WHEN A DEVIATION OCCURS.

FOR EACH SEMI-ANNUAL REPORTING PERIOD SPECIFIED IN CONDITION NO. 23 IN SECTION K, WHENEVER AN DEVIATION OCCURS FROM THE OXYGEN RANGE, THE OPERATOR SHALL TAKE IMMEDIATE CORRECTIVE ACTION, AND KEEP RECORDS OF THE DURATION AND CAUSE (INCLUDING UNKNOWN CAUSE, IF APPLICABLE) OF THE DEVIATION AND THE CORRECTIVE ACTION TAKEN.

ALL DEVIATIONS SHALL BE REPORTED TO THE AQMD ON A SEMI-ANNUAL BASIS PURSUANT TO THE REQUIREMENTS SPECIFIED IN 40 CFR PART 64.9 AND CONDITION NOS. 22 AND 23 IN SECTION K OF THIS PERMIT.

THE OPERATOR SHALL SUBMIT AN APPLICATION WITH A QUALITY IMPROVEMENT PLAN (QIP) IN ACCORDANCE WITH 40 CFR PART 64.8 TO THE AQMD IF AN ACCUMULATION OF DEVIATIONS EXCEEDS 5 PERCENT DURATION OF THIS EQUIPMENT'S TOTAL OPERATING TIME FOR ANY SEMI-ANNUAL REPORTING PERIOD SPECIFIED IN CONDITION NO. 23 IN SECTION K OF THIS PERMIT. THE REQUIRED QIP SHALL BE SUBMITTED TO THE AQMD WITHIN 90 CALENDAR DAYS AFTER THE DUE DATE FOR THE SEMI-ANNUAL MONITORING REPORT.

THE OPERATOR SHALL KEEP ADEQUATE RECORDS IN A FORMAT THAT IS ACCEPTABLE TO THE AQMD TO DEMONSTRATE COMPLIANCE WITH ALL APPLICABLE REQUIREMENTS SPECIFIED IN THIS CONDITION AND 40 CFR PART 64.9 FOR A MINIMUM OF FIVE YEARS.

[40CFR PART 64]

Emissions and Requirements:

21. THIS EQUIPMENT IS SUBJECT TO THE APPLICABLE REQUIREMENTS OF THE FOLLOWING RULES AND REGULATIONS:

NMOC: 20 PPMV OR 98% WEIGHT REDUCTION, RULE 1150.1, 40CFR63 SUBPART AAAA
NMOC: 196 PPMV@ 15% O2, RULE 1303 (a)(1)-BACT (AS METHANE, 1 - HR AVG.)
NMOC: 40 PPMV@ 15% O2 AS METHANE, RULE 1110.2
NOX: 51 PPMV@ 15% O2, RULE 1303 (a)(1)-BACT (1- HR AVG.)
NOX: 54 PPMV@ 15% O2, RULE 1110.2 (ECF = 1.49)
CO: 351 PPMV@ 15% O2, RULE 1303 (a)(1)-BACT (1 - HR AVG.)
CO: 2000 PPMV@ 15% O2, RULE 1110.2
PM: RULE 404, SEE APPENDIX B FOR EMISSION LIMITS
CH4: 3000 PPMV@ 15% O2, RULE 1150.1

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

PERMIT TO OPERATE

Permit No. G24807
A/N 501722

Equipment Description:

LANDFILL GAS TO ENERGY SYSTEM NO. 2 CONSISTING OF:

1. INTERNAL COMBUSTION ENGINE NO. 2, CATERPILLAR, MODEL G3616, SIXTEEN CYLINDER, 4261 BHP, LEAN BURN, LANDFILL GAS/NATURAL GAS FIRED, TURBOCHARGED AND AFTERCOOLED, DRIVING A 3 MW ELECTRICAL GENERATOR.
2. COMPRESSOR, 1468 CFM, 300 HP
3. ANCILLARY RADIATOR AND AFTERCOOLER WITH ELECTRIC FANS
4. ANCILLARY MUFFLER EXHAUST STACK.

Conditions:

1. OPERATION OF THIS EQUIPMENT SHALL BE CONDUCTED IN ACCORDANCE WITH ALL DATA AND SPECIFICATIONS SUBMITTED WITH THE APPLICATION UNDER WHICH THIS PERMIT IS ISSUED UNLESS OTHERWISE NOTED BELOW.
[RULE 204]

2. THIS EQUIPMENT SHALL BE PROPERLY MAINTAINED AND KEPT IN GOOD OPERATING CONDITION AT ALL TIMES.
[RULE 204]

3. OPERATION OF THIS EQUIPMENT SHALL NOT RESULT IN THE EMISSION OF RAW LANDFILL GAS TO THE ATMOSPHERE.
[RULE 1150.1]

4. A SAMPLING PORT SHALL BE INSTALLED IN THE LANDFILL GAS LINE TO THE ENGINE TO ALLOW THE COLLECTION OF A GAS SAMPLE.
[RULE 431.1]

5. A FLOW INDICATING AND RECORDING DEVICE SHALL BE INSTALLED IN THE GAS SUPPLY LINE FOR ALL FUELS TO THE ENGINE.
[RULE 1303 (b)(2)-OFFSET]

6. THE COMBINED TOTAL LANDFILL GAS FLOW RATE AT PUENTE HILLS LANDFILL SHALL NOT EXCEED 39,800 SCFM.
[RULE 1303 (b)(2)-OFFSET]

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

7. THE HEAT INPUT OF GAS TO THE ENGINE SHALL NOT EXCEED 34 MM BTU PER HOUR. A WEEKLY LOG OF THE GAS HEAT INPUT, BASED ON THE RECORDED FLOW RATE (SCFM) AND HIGHER HEATING VALUE, SHALL BE KEPT FOR AT LEAST TWO YEARS AND MADE AVAILABLE TO AQMD PERSONNEL UPON REQUEST.
[RULE 1303 (b)(2)-OFFSET]

8. READINGS OF THE HIGHER HEATING VALUE OF THE GAS AT THE INLET TO THE ENGINE SHALL BE TAKEN WEEKLY WITH AN AQMD APPROVED INSTRUMENT AND THE RESULTS RECORDED.
[RULE 1303 (b)(2)-OFFSET]

9. THE ENGINE SHALL ONLY USE LANDFILL GAS OR A COMBINATION OF LANDFILL GAS AND NATURAL GAS.
[RULE 204]

10. THE TOTAL NATURAL GAS USAGE SHALL NOT EXCEED 25 PERCENT OF THE TOTAL ENGINE HEAT INPUT ON AN AVERAGE DAILY BASIS AND 10 PERCENT ON A MONTHLY BASIS.
[RULE 1303 (b)(2)-OFFSET]

11. OTHER THAN IN THE ENRICHED PRE-COMBUSTION CHAMBER, NATURAL GAS SHALL NOT BE USED IN THIS ENGINE TO GENERATE ELECTRICITY FOR DISTRIBUTION IN THE STATE GRID SYSTEM.
[RULE 1303 (b)(2)-OFFSET]

12. OTHER THAN IN THE ENRICHED PRE-COMBUSTION CHAMBER, NATURAL GAS SHALL ONLY BE FIRED IN THIS ENGINE TO PROVIDE ELECTRICITY TO THE SANITATION DISTRICTS' OPERATED FACILITIES AT THE PUENTE HILLS LANDFILL, SAN JOSE CREEK WATER RECLAMATION PLANT AND THE JOINT ADMINISTRATION OFFICE.
[RULE 1303 (b)(2)-OFFSET]

13. SAMPLING PORTS SHALL BE PROVIDED IN THE ENGINE EXHAUST DUCT, 8-10 DUCT DIAMETERS DOWNSTREAM AND TWO DUCT DIAMETERS UPSTREAM OF ANY FLOW DISTURBANCE, AND SHALL CONSIST OF TWO PROPERLY SIZED WELD NIPPLES WITH PLUGS, 90 DEGREES APART. AN EQUIVALENT METHOD FOR EMISSION SAMPLING MAY BE USED UPON APPROVAL OF THE AQMD. ADEQUATE AND SAFE ACCESS TO THE TEST PORTS SHALL BE SUPPLIED BY THE APPLICANT.
[RULE 217]

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

14. APPLICANT SHALL CONDUCT ANNUAL PERFORMANCE TEST OF THE ENGINE IN ACCORDANCE WITH AQMD TEST PROCEDURES AND FURNISH THE AQMD A WRITTEN RESULT OF SUCH PERFORMANCE TEST. WRITTEN NOTICE OF THE PERFORMANCE TEST SHALL BE PROVIDED TO THE AQMD 10 DAYS PRIOR TO THE TEST SO THAT AN OBSERVER MAY BE PRESENT. A TEST PROTOCOL SHALL BE SUBMITED FOR APPROVAL AT LEAST 60 DAYS PRIOR TO TESTING.

    THE PERFORMANCE TEST SHALL INCLUDE, BUT SHALL NOT BE LIMITED TO A TEST OF THE INLET AND EXHAUST GASES, FOR THE FOLLOWING:

    A. METHANE
    B. TOTAL NON-METHANE HYDROCARBONS
    C. OXIDES OF NITROGEN (EXHAUST ONLY)
    D. CARBON MONOXIDE (EXHAUST ONLY)
    E. PARTICULATES (EXHAUST ONLY)
    F. TOTAL SULFUR COMPOUNDS AS H2S (INLET ONLY)
    G. FLOW RATE
    H. OXYGEN
    I. NITROGEN
    J. CARBON DIOXIDE
    K. MOISTURE
    L. TEMPERATURE
    M. TOXIC AIR CONTAMINANTS INCLUDING BENZENE, CHLOROBENZENE, 1,2-DICHLOROETHANE, 1,1-DICHLOROETHANE, DICHLOROMETHANE, TETRACHLOROETHYLENE, TETRACHLOROMETHANE, TOLUENE, 1,1,1-TRICHLOROETHANE, TRICHLOROETHYLENE, TRICHLOROMETHANE, VINYL CHLORIDE AND XYLENES (EXHAUST ONLY).

    [RULE 1303 (b)(2)-OFFSET, 1401]

15. THE EMISSIONS FROM THE ENGINE SHALL NOT EXCEED THE FOLLOWING:

AIR CONTAMINANT	LBS/HR
NON-METHANE HYDROCARBONS	1.69
NITROGEN OXIDE	4.79
SULFUR DIOXIDE	1.86
CARBON MONOXIDE	23.5
PARTICULATES	1.58

    [RULE 1303 (b)(2)-OFFSET]

16. A CONTINUOUS EMISSIONS MONITORING SYSTEM (CEMS) SHALL BE INSTALLED AND OPERATED TO MEASURE THE ENGINE EXHAUST CONCENTRATION FOR NOX AND O2 ON A DRY BASIS. IN ADDITION, THE SYSTEM SHALL CONVERT THE ACTUAL NOX CONCENTRATION TO A CORRECTED NOX CONCENTRATION AT 15% O2. THIS MONITORING SYSTEM SHALL COMPLY WITH THE REQUIREMENTS OF AQMD RULE 218.
    [RULE 218]

17. ALL RECORDS, SUCH AS FUEL USAGE, MAINTENANCE RECORDS AND PERFORMANCE TEST RESULTS, SHALL BE MAINTAINED FOR FIVE YEARS AND MADE AVAILABLE TO AQMD PERSONNEL UPON REQUEST.
    [RULE 1150.1, 1303 (b)(2)-OFFSET]

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

18. THIS ENGINE SHALL NOT BE OPERATED IN SUCH A MANNER AS TO INTERFERE WITH THE OWNER'S/OPERATOR'S ABILITY TO COMPLY WITH AQMD RULE 1150.1 OR ANY OTHER AQMD RULE LIMITING LANDFILL GAS MIGRATION OR SURFACE EMISSIONS.
[RULE 1150.1]

19. THIS EQUIPMENT SHALL BE OPERATED IN COMPLIANCE WITH ALL APPLICABLE REQUIREMENTS OF 40CFR PART 63, SUBPART ZZZZ – NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS FOR STATIONARY RECIPROCATING INTERNAL COMBUSTION ENGINES.
[40CFR PART 63, SUBPART ZZZZ]

20. THE EXHAUST OXYGEN SHALL BE MAINTAINED IN THE RANGE OF 8% TO 12% AVERAGED OVER 1-HOUR WHENEVER THE ENGINE IS IN OPERATION, EXCEPT DURING PERIODS OF STARTUP AND SHUTDOWN.

CONTINUOUS EXHAUST OXYGEN MONITORING AND RECORDING SYSTEM SHALL BE PURSUANT TO THE OPERATION AND MAINTENANCE REQUIREMENTS SPECIFIED IN 40 CFR PART 64.7. SUCH A SYSTEM SHALL BE INSPECTED, MAINTAINED, AND CALIBRATED ON AN QUARTERLY BASIS IN ACCORDANCE WITH THE MANUFACTURER'S SPECIFICATIONS USING AN APPLICABLE AQMD OR EPA APPROVED METHOD.

FOR THE PURPOSE OF THIS CONDITION, A DEVIATION SHALL BE DEFINED AS WHEN 1-HOUR AVERAGE OXYGEN PERCENTAGE OF LESS THAN 8% OR GREATER THAN 12% OCCURS DURING OPERATION EXCEPT DURING STARTUPS OR SHUTDOWNS. STARTUP OR SHUTDOWN PERIOD SHALL NOT EXCEED 30 MINUTES. THE OPERATOR SHALL REVIEW THE RECORDS OF OXYGEN PERCENTAGE ON A DAILY BASIS TO DETERMINE IF A DEVIATION OCCURED OR SHALL INSTALL AN ALARM SYSTEM TO ALERT THE OPERATOR WHEN A DEVIATION OCCURS.

FOR EACH SEMI-ANNUAL REPORTING PERIOD SPECIFIED IN CONDITION NO. 23 IN SECTION K, WHENEVER AN DEVIATION OCCURS FROM THE OXYGEN RANGE, THE OPERATOR SHALL TAKE IMMEDIATE CORRECTIVE ACTION, AND KEEP RECORDS OF THE DURATION AND CAUSE (INCLUDING UNKNOWN CAUSE, IF APPLICABLE) OF THE DEVIATION AND THE CORRECTIVE ACTION TAKEN.

ALL DEVIATIONS SHALL BE REPORTED TO THE AQMD ON A SEMI-ANNUAL BASIS PURSUANT TO THE REQUIREMENTS SPECIFIED IN 40 CFR PART 64.9 AND CONDITION NOS. 22 AND 23 IN SECTION K OF THIS PERMIT.

THE OPERATOR SHALL SUBMIT AN APPLICATION WITH A QUALITY IMPROVEMENT PLAN (QIP) IN ACCORDANCE WITH 40 CFR PART 64.8 TO THE AQMD IF AN ACCUMULATION OF DEVIATIONS EXCEEDS 5 PERCENT DURATION OF THIS EQUIPMENT'S TOTAL OPERATING TIME FOR ANY SEMI-ANNUAL REPORTING PERIOD SPECIFIED IN CONDITION NO. 23 IN SECTION K OF THIS PERMIT. THE REQUIRED QIP SHALL BE SUBMITTED TO THE AQMD WITHIN 90 CALENDAR DAYS AFTER THE DUE DATE FOR THE SEMI-ANNUAL MONITORING REPORT.

THE OPERATOR SHALL KEEP ADEQUATE RECORDS IN A FORMAT THAT IS ACCEPTABLE TO THE AQMD TO DEMONSTRATE COMPLIANCE WITH ALL APPLICABLE REQUIREMENTS SPECIFIED IN THIS CONDITION AND 40 CFR PART 64.9 FOR A MINIMUM OF FIVE YEARS.

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

[40CFR PART 64]

Emissions and Requirements:

21. THIS EQUIPMENT IS SUBJECT TO THE APPLICABLE REQUIREMENTS OF THE FOLLOWING RULES AND REGULATIONS:

NMOC: 20 PPMV OR 98% WEIGHT REDUCTION, RULE 1150.1, 40CFR63 SUBPART AAAA
NMOC: 196 PPMV@ 15% O2, RULE 1303 (a)(1)-BACT (AS METHANE, 1 - HR AVG.)
NMOC: 40 PPMV@ 15% O2 AS METHANE, RULE 1110.2
NOX: 51 PPMV@ 15% O2, RULE 1303 (a)(1)-BACT (1- HR AVG.)
NOX: 54 PPMV@ 15% O2, RULE 1110.2 (ECF = 1.49)
CO: 351 PPMV@ 15% O2, RULE 1303 (a)(1)-BACT (1 - HR AVG.)
CO: 2000 PPMV@ 15% O2, RULE 1110.2
PM: RULE 404, SEE APPENDIX B FOR EMISSION LIMITS
CH4: 3000 PPMV@ 15% O2, RULE 1150.1

PERMIT TO OPERATE

Permit No. G24808
A/N 501723

Equipment Description:

LANDFILL GAS TO ENERGY SYSTEM NO. 3 CONSISTING OF:

1. INTERNAL COMBUSTION ENGINE NO. 3, CATERPILLAR, MODEL G3616, SIXTEEN CYLINDER, 4261 BHP, LEAN BURN, LANDFILL GAS/NATURAL GAS FIRED, TURBOCHARGED AND AFTERCOOLED, DRIVING A 3 MW ELECTRICAL GENERATOR.

2. COMPRESSOR, 1468 CFM, 300 HP

3. ANCILLARY RADIATOR AND AFTERCOOLER WITH ELECTRIC FANS

4. ANCILLARY MUFFLER EXHAUST STACK.

Conditions:

1. OPERATION OF THIS EQUIPMENT SHALL BE CONDUCTED IN ACCORDANCE WITH ALL DATA AND SPECIFICATIONS SUBMITTED WITH THE APPLICATION UNDER WHICH THIS PERMIT IS ISSUED UNLESS OTHERWISE NOTED BELOW.
   [RULE 204]

2. THIS EQUIPMENT SHALL BE PROPERLY MAINTAINED AND KEPT IN GOOD OPERATING CONDITION AT ALL TIMES.
   [RULE 204]

3. OPERATION OF THIS EQUIPMENT SHALL NOT RESULT IN THE EMISSION OF RAW LANDFILL GAS TO THE ATMOSPHERE.
   [RULE 1150.1]

4. A SAMPLING PORT SHALL BE INSTALLED IN THE LANDFILL GAS LINE TO THE ENGINE TO ALLOW THE COLLECTION OF A GAS SAMPLE.
   [RULE 431.1]

5. A FLOW INDICATING AND RECORDING DEVICE SHALL BE INSTALLED IN THE GAS SUPPLY LINE FOR ALL FUELS TO THE ENGINE.
   [RULE 1303 (b)(2)-OFFSET]

6. THE COMBINED TOTAL LANDFILL GAS FLOW RATE AT PUENTE HILLS LANDFILL SHALL NOT EXCEED 39,800 SCFM.
   [RULE 1303 (b)(2)-OFFSET]

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

7. THE HEAT INPUT OF GAS TO THE ENGINE SHALL NOT EXCEED 34 MM BTU PER HOUR. A WEEKLY LOG OF THE GAS HEAT INPUT, BASED ON THE RECORDED FLOW RATE (SCFM) AND HIGHER HEATING VALUE, SHALL BE KEPT FOR AT LEAST TWO YEARS AND MADE AVAILABLE TO AQMD PERSONNEL UPON REQUEST.
[RULE 1303 (b)(2)-OFFSET]

8. READINGS OF THE HIGHER HEATING VALUE OF THE GAS AT THE INLET TO THE ENGINE SHALL BE TAKEN WEEKLY WITH AN AQMD APPROVED INSTRUMENT AND THE RESULTS RECORDED.
[RULE 1303 (b)(2)-OFFSET]

9. THE ENGINE SHALL ONLY USE LANDFILL GAS OR A COMBINATION OF LANDFILL GAS AND NATURAL GAS.
[RULE 204]

10. THE TOTAL NATURAL GAS USAGE SHALL NOT EXCEED 25 PERCENT OF THE TOTAL ENGINE HEAT INPUT ON AN AVERAGE DAILY BASIS AND 10 PERCENT ON A MONTHLY BASIS.
[RULE 1303 (b)(2)-OFFSET]

11. OTHER THAN IN THE ENRICHED PRE-COMBUSTION CHAMBER, NATURAL GAS SHALL NOT BE USED IN THIS ENGINE TO GENERATE ELECTRICITY FOR DISTRIBUTION IN THE STATE GRID SYSTEM.
[RULE 1303 (b)(2)-OFFSET]

12. OTHER THAN IN THE ENRICHED PRE-COMBUSTION CHAMBER, NATURAL GAS SHALL ONLY BE FIRED IN THIS ENGINE TO PROVIDE ELECTRICITY TO THE SANITATION DISTRICTS' OPERATED FACILITIES AT THE PUENTE HILLS LANDFILL, SAN JOSE CREEK WATER RECLAMATION PLANT AND THE JOINT ADMINISTRATION OFFICE.
[RULE 1303 (b)(2)-OFFSET]

13. SAMPLING PORTS SHALL BE PROVIDED IN THE ENGINE EXHAUST DUCT, 8-10 DUCT DIAMETERS DOWNSTREAM AND TWO DUCT DIAMETERS UPSTREAM OF ANY FLOW DISTURBANCE, AND SHALL CONSIST OF TWO PROPERLY SIZED WELD NIPPLES WITH PLUGS, 90 DEGREES APART. AN EQUIVALENT METHOD FOR EMISSION SAMPLING MAY BE USED UPON APPROVAL OF THE AQMD. ADEQUATE AND SAFE ACCESS TO THE TEST PORTS SHALL BE SUPPLIED BY THE APPLICANT.
[RULE 217]

FACILITY PERMIT TO OPERATE
LA CNTY SANITATION DISTRICT-PUENTE HILLS

14. APPLICANT SHALL CONDUCT ANNUAL PERFORMANCE TEST OF THE ENGINE IN ACCORDANCE WITH AQMD TEST PROCEDURES AND FURNISH THE AQMD A WRITTEN RESULT OF SUCH PERFORMANCE TEST. WRITTEN NOTICE OF THE PERFORMANCE TEST SHALL BE PROVIDED TO THE AQMD 10 DAYS PRIOR TO THE TEST SO THAT AN OBSERVER MAY BE PRESENT. A TEST PROTOCOL SHALL BE SUBMITED FOR APPROVAL AT LEAST 60 DAYS PRIOR TO TESTING.

    THE PERFORMANCE TEST SHALL INCLUDE, BUT SHALL NOT BE LIMITED TO A TEST OF THE INLET AND EXHAUST GASES, FOR THE FOLLOWING:

    A. METHANE
    B. TOTAL NON-METHANE HYDROCARBONS
    C. OXIDES OF NITROGEN (EXHAUST ONLY)
    D. CARBON MONOXIDE (EXHAUST ONLY)
    E. PARTICULATES (EXHAUST ONLY)
    F. TOTAL SULFUR COMPOUNDS AS H2S (INLET ONLY)
    G. FLOW RATE
    H. OXYGEN
    I. NITROGEN
    J. CARBON DIOXIDE
    K. MOISTURE
    L. TEMPERATURE
    M. TOXIC AIR CONTAMINANTS INCLUDING BENZENE, CHLOROBENZENE, 1,2-DICHLOROETHANE, 1,1-DICHLOROETHANE, DICHLOROMETHANE, TETRACHLOROETHYLENE, TETRACHLOROMETHANE, TOLUENE, 1,1,1-TRICHLOROETHANE, TRICHLOROETHYLENE, TRICHLOROMETHANE, VINYL CHLORIDE AND XYLENES (EXHAUST ONLY).

    [RULE 1303 (b)(2)-OFFSET, 1401]

15. THE EMISSIONS FROM THE ENGINE SHALL NOT EXCEED THE FOLLOWING:

AIR CONTAMINANT	LBS/HR
NON-METHANE HYDROCARBONS	1.69
NITROGEN OXIDE	4.79
SULFUR DIOXIDE	1.86
CARBON MONOXIDE	23.5
PARTICULATES	1.58

    [RULE 1303 (b)(2)-OFFSET]

16. A CONTINUOUS EMISSIONS MONITORING SYSTEM (CEMS) SHALL BE INSTALLED AND OPERATED TO MEASURE THE ENGINE EXHAUST CONCENTRATION FOR NOX AND O2 ON A DRY BASIS. IN ADDITION, THE SYSTEM SHALL CONVERT THE ACTUAL NOX CONCENTRATION TO A CORRECTED NOX CONCENTRATION AT 15% O2. THIS MONITORING SYSTEM SHALL COMPLY WITH THE REQUIREMENTS OF AQMD RULE 218.
    [RULE 218]

17. ALL RECORDS, SUCH AS FUEL USAGE, MAINTENANCE RECORDS AND PERFORMANCE TEST RESULTS, SHALL BE MAINTAINED FOR FIVE YEARS AND MADE AVAILABLE TO AQMD PERSONNEL UPON REQUEST.
    [RULE 1150.1, 1303 (b)(2)-OFFSET]

18. THIS ENGINE SHALL NOT BE OPERATED IN SUCH A MANNER AS TO INTERFERE WITH THE OWNER'S/OPERATOR'S ABILITY TO COMPLY WITH AQMD RULE 1150.1 OR ANY OTHER AQMD RULE LIMITING LANDFILL GAS MIGRATION OR SURFACE EMISSIONS.
[RULE 1150.1]

19. THIS EQUIPMENT SHALL BE OPERATED IN COMPLIANCE WITH ALL APPLICABLE REQUIREMENTS OF 40CFR PART 63, SUBPART ZZZZ – NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS FOR STATIONARY RECIPROCATING INTERNAL COMBUSTION ENGINES.
[40CFR PART 63, SUBPART ZZZZ]

20. THE EXHAUST OXYGEN SHALL BE MAINTAINED IN THE RANGE OF 8% TO 12% AVERAGED OVER 1-HOUR WHENEVER THE ENGINE IS IN OPERATION, EXCEPT DURING PERIODS OF STARTUP AND SHUTDOWN.

    CONTINUOUS EXHAUST OXYGEN MONITORING AND RECORDING SYSTEM SHALL BE PURSUANT TO THE OPERATION AND MAINTENANCE REQUIREMENTS SPECIFIED IN 40 CFR PART 64.7. SUCH A SYSTEM SHALL BE INSPECTED, MAINTAINED, AND CALIBRATED ON AN QUARTERLY BASIS IN ACCORDANCE WITH THE MANUFACTURER'S SPECIFICATIONS USING AN APPLICABLE AQMD OR EPA APPROVED METHOD.

    FOR THE PURPOSE OF THIS CONDITION, A DEVIATION SHALL BE DEFINED AS WHEN 1-HOUR AVERAGE OXYGEN PERCENTAGE OF LESS THAN 8% OR GREATER THAN 12% OCCURS DURING OPERATION EXCEPT DURING STARTUPS OR SHUTDOWNS. STARTUP OR SHUTDOWN PERIOD SHALL NOT EXCEED 30 MINUTES. THE OPERATOR SHALL REVIEW THE RECORDS OF OXYGEN PERCENTAGE ON A DAILY BASIS TO DETERMINE IF A DEVIATION OCCURED OR SHALL INSTALL AN ALARM SYSTEM TO ALERT THE OPERATOR WHEN A DEVIATION OCCURS.

    FOR EACH SEMI-ANNUAL REPORTING PERIOD SPECIFIED IN CONDITION NO. 23 IN SECTION K, WHENEVER AN DEVIATION OCCURS FROM THE OXYGEN RANGE, THE OPERATOR SHALL TAKE IMMEDIATE CORRECTIVE ACTION, AND KEEP RECORDS OF THE DURATION AND CAUSE (INCLUDING UNKNOWN CAUSE, IF APPLICABLE) OF THE DEVIATION AND THE CORRECTIVE ACTION TAKEN.

    ALL DEVIATIONS SHALL BE REPORTED TO THE AQMD ON A SEMI-ANNUAL BASIS PURSUANT TO THE REQUIREMENTS SPECIFIED IN 40 CFR PART 64.9 AND CONDITION NOS. 22 AND 23 IN SECTION K OF THIS PERMIT.

    THE OPERATOR SHALL SUBMIT AN APPLICATION WITH A QUALITY IMPROVEMENT PLAN (QIP) IN ACCORDANCE WITH 40 CFR PART 64.8 TO THE AQMD IF AN ACCUMULATION OF DEVIATIONS EXCEEDS 5 PERCENT DURATION OF THIS EQUIPMENT'S TOTAL OPERATING TIME FOR ANY SEMI-ANNUAL REPORTING PERIOD SPECIFIED IN CONDITION NO. 23 IN SECTION K OF THIS PERMIT. THE REQUIRED QIP SHALL BE SUBMITTED TO THE AQMD WITHIN 90 CALENDAR DAYS AFTER THE DUE DATE FOR THE SEMI-ANNUAL MONITORING REPORT.

    THE OPERATOR SHALL KEEP ADEQUATE RECORDS IN A FORMAT THAT IS ACCEPTABLE TO THE AQMD TO DEMONSTRATE COMPLIANCE WITH ALL APPLICABLE REQUIREMENTS SPECIFIED IN THIS CONDITION AND 40 CFR PART 64.9 FOR A MINIMUM OF FIVE YEARS.

[40CFR PART 64]

Emissions and Requirements:

21. THIS EQUIPMENT IS SUBJECT TO THE APPLICABLE REQUIREMENTS OF THE FOLLOWING RULES AND REGULATIONS:

NMOC: 20 PPMV OR 98% WEIGHT REDUCTION, RULE 1150.1, 40CFR63 SUBPART AAAA
NMOC: 196 PPMV@ 15% O2, RULE 1303 (a)(1)-BACT (AS METHANE, 1 - HR AVG.)
NMOC: 40 PPMV@ 15% O2 AS METHANE, RULE 1110.2
NOX: 51 PPMV@ 15% O2, RULE 1303 (a)(1)-BACT (1- HR AVG.)
NOX: 54 PPMV@ 15% O2, RULE 1110.2 (ECF = 1.49)
CO: 351 PPMV@ 15% O2, RULE 1303 (a)(1)-BACT (1 - HR AVG.)
CO: 2000 PPMV@ 15% O2, RULE 1110.2
PM: RULE 404, SEE APPENDIX B FOR EMISSION LIMITS
CH4: 3000 PPMV@ 15% O2, RULE 1150.1

APPENDIX B - SYSTEMS OPERATION TESTING & ADJUSTING

CATERPILLAR®

RENR5908-06
May 2004

Systems Operation Testing and Adjusting

G3600 Engines

BLB1-Up (Engine)
BKE1-Up (Engine)
BEN1-Up (Engine)
4ZS1-Up (Engine)

i01658146

Important Safety Information

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

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

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

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

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

⚠ WARNING

The meaning of this safety alert symbol is as follows:

Attention! Become Alert! Your Safety is Involved.

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

Operations that may cause product damage are identified by "NOTICE" labels on the product and in this publication.

Caterpillar cannot anticipate every possible circumstance that might involve a potential hazard. The warnings in this publication and on the product are, therefore, not all inclusive. If a tool, procedure, work method or operating technique that is not specifically recommended by Caterpillar is used, you must satisfy yourself that it is safe for you and for others. You should also ensure that the product will not be damaged or be made unsafe by the operation, lubrication, maintenance or repair procedures that you choose.

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

⚠ WARNING

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

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

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Systems Operation Section

Testing and Adjusting Section

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Systems Operation Section

Engine Design

i01748174

Engine Design

SMCS Code: 1000

S/N: 4ZS1-Up

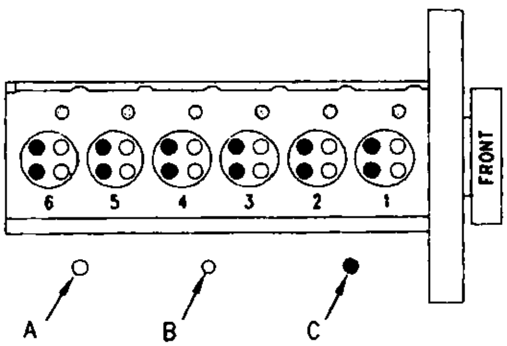


Illustration 1 g00283190

Cylinder and valve location

(A) Inlet valve
(B) Exhaust valve
(C) Gas admission valve

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

Valves per cylinder

Inlet valves 2

Exhaust valves 2

Gas admission valve 1

Bore .... 300 mm (11.8 inch)

Stroke .... 300 mm (11.8 inch)

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

Compression ratio 9.2:1

Compression ratio 11:1

Combustion .... Spark Ignited

Firing order

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

Valve lash

Inlet valve .... 0.50 mm (0.020 inch)

Exhaust valve .... 1.27 mm (0.050 inch)

Gas admission valve .... 0.64 mm (0.025 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.

i01748180

Engine Design

SMCS Code: 1000

S/N: BEN1-Up

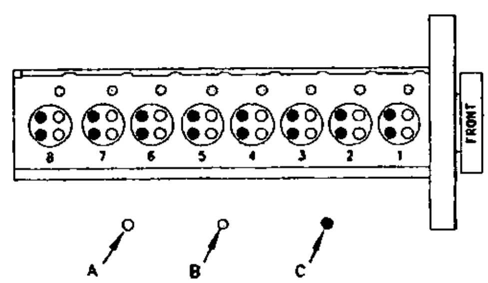


Illustration 2 g00465539

Cylinder and valve location

(A) Inlet valve
(B) Exhaust valve
(C) Gas admission valve

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

Valves per cylinder

Inlet valves 2

Exhaust valves 2

Gas admission valve 1

Bore .... 300 mm (11.8 inch)

Stroke .... 300 mm (11.8 inch)

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

Compression ratio 9.2:1

Compression ratio 11:1

Combustion .... Spark Ignited

Firing order

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

Valve lash

Inlet valve .... 0.50 mm (0.020 inch)

Exhaust valve .... 1.27 mm (0.050 inch)

Gas admission valve .... 0.64 mm (0.025 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.

i02112687

Engine Design

SMCS Code: 1000

S/N: BKE1-Up

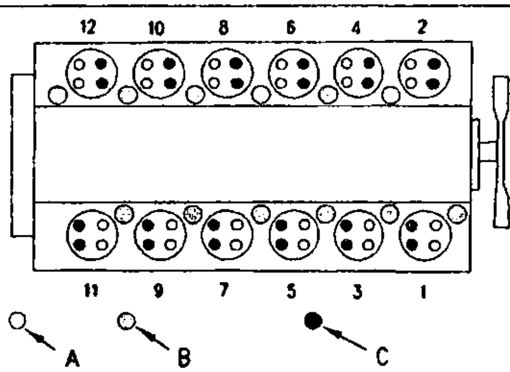


Illustration 3 g00471973

Cylinder and valve location

(A) Inlet valve
(B) Gas admission valve
(C) Exhaust valve

Number and arrangement of cylinders .... 50 degree Vee 12

Valves per cylinder

Inlet valves 2

Exhaust valves 2

Gas admission valve 1

Bore .... 300 mm (11.8 inch)

Stroke .... 300 mm (11.8 inch)

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

Compression ratio 9.2:1

Compression ratio 11:1

Combustion .... Spark ignited

Firing order

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

Valve lash

Inlet valve .... 0.50 mm (0.020 inch)

Exhaust valve .... 1.27 mm (0.050 inch)

Gas admission valve .... 0.64 mm (0.025 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 on the right side. The number 2 cylinder is the front cylinder on the left side.

i02112691

Engine Design

SMCS Code: 1000

S/N: BLB1-Up

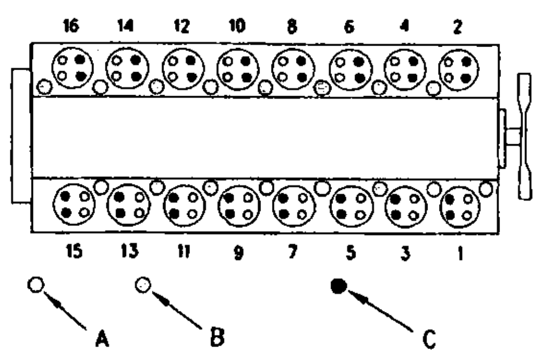


Illustration 4 g00472128

Cylinder and valve location

(A) Inlet valve
(B) Gas admission valve
(C) Exhaust valve

Number and arrangement of cylinders .... 50 degree Vee 16

Valves per cylinder

Inlet valves 2

Exhaust valves 2

Gas admission valve 1

Bore .... 300 mm (11.8 inch)

Stroke .... 300 mm (11.8 inch)

Displacement .... 339.3 L (20,700 cu 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 valve .... 0.50 mm (0.020 inch)

Exhaust valve .... 1.27 mm (0.050 inch)

Gas admission valve .... 0.64 mm (0.025 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 on the right side. The number 2 cylinder is the front cylinder on the left side.

Electronic Control System

i01748215

Electronic Control System Operation

SMCS Code: 1900

Control System

The following components are included in the control system:

- An Electronic Control Module (ECM) and an emergency stop button in an engine mounted junction box
- Optional remote control panel with a Machine Information Display System (MIDS)
- Integrated Combustion Sensing Module (ICSM)
- Gas Shutoff Valve (GSOV)
- Ignition system that is controlled by the ECM
- Detonation sensor for each two cylinders
- A system for prelube that includes the solenoid and prelube pump
- Actuators that are hydraulically actuated and electronically controlled for the fuel, for the air choke, and for the exhaust bypass (wastegate)
- A system for cranking that includes the solenoid and starting motor

The ECM controls most of the functions of the engine. The module is an environmentally sealed unit that is in an engine mounted junction box. The ECM monitors various inputs from sensors in order to activate relays, solenoids, etc at the appropriate levels. The ECM supports the following five primary functions:

- Governing of the engine
- Control of ignition
- Air/fuel ratio control
- Start/stop control
- Monitoring of engine operation

The ECM does not have a removable personality module. The software and maps are changed by using the Caterpillar Electronic Technician (Cat ET) to flash program a file.

Governing of the Engine RPM

Desired engine speed is determined by the status of the idle/rated switch, of the desired speed input (analog voltage or 4 to 20 mA), and of parameters that are programmed into the software. Actual engine speed is detected via a signal from the engine speed/timing sensor. Parameters such as idle speed and governor gain can be programmed with Cat ET.

The ECM monitors the actual engine speed. The ECM calculates the difference between the actual engine speed and the desired engine speed. The ECM controls the fuel actuator in order to maintain the desired engine speed. The fuel actuator is located at the flange of the inlet air manifold.

If the actual engine speed is less than the desired engine speed, the ECM commands the fuel actuator to move toward the open position in order to increase the fuel flow. The increase of fuel accelerates the engine speed.

Control of Ignition

Each cylinder has an ignition transformer. To initiate combustion, the ECM sends a pulse of approximately 108 volts to the primary coil of each ignition transformer at the appropriate time and for the appropriate duration. The transformer increases the voltage which creates a spark across the spark plug electrode.

The ECM provides variable ignition timing that is sensitive to detonation. Detonation sensors monitor the engine for excessive detonation. The engine has one detonation sensor for each two adjacent cylinders. The sensors generate data on vibration that is processed by the ECM in order to determine detonation levels. If detonation reaches an unacceptable level, the ECM retards the ignition timing of the affected cylinder or cylinders. If retarding the timing does not limit detonation to an acceptable level, the ECM shuts down the engine.

Levels of detonation can be displayed by the Machine Information Display System (MIDS) on the optional control panel. Alternatively, the "Cylinder X Detonation Level" screen of Cat ET can also be used. The "X" represents the cylinder number.

The ECM provides extensive diagnostics for the ignition system.

Air/Fuel Ratio Control

The ECM provides control of the air/fuel mixture for performance and for efficiency at low emission levels. The system includes the following components: maps in the ECM, output drivers in the ECM, fuel actuator, air choke actuator, exhaust bypass actuator (wastegate), ICSM, thermocouples, and combustion sensors. Illustration 5 is a diagram of the system's main components and of the system's lines of communication.

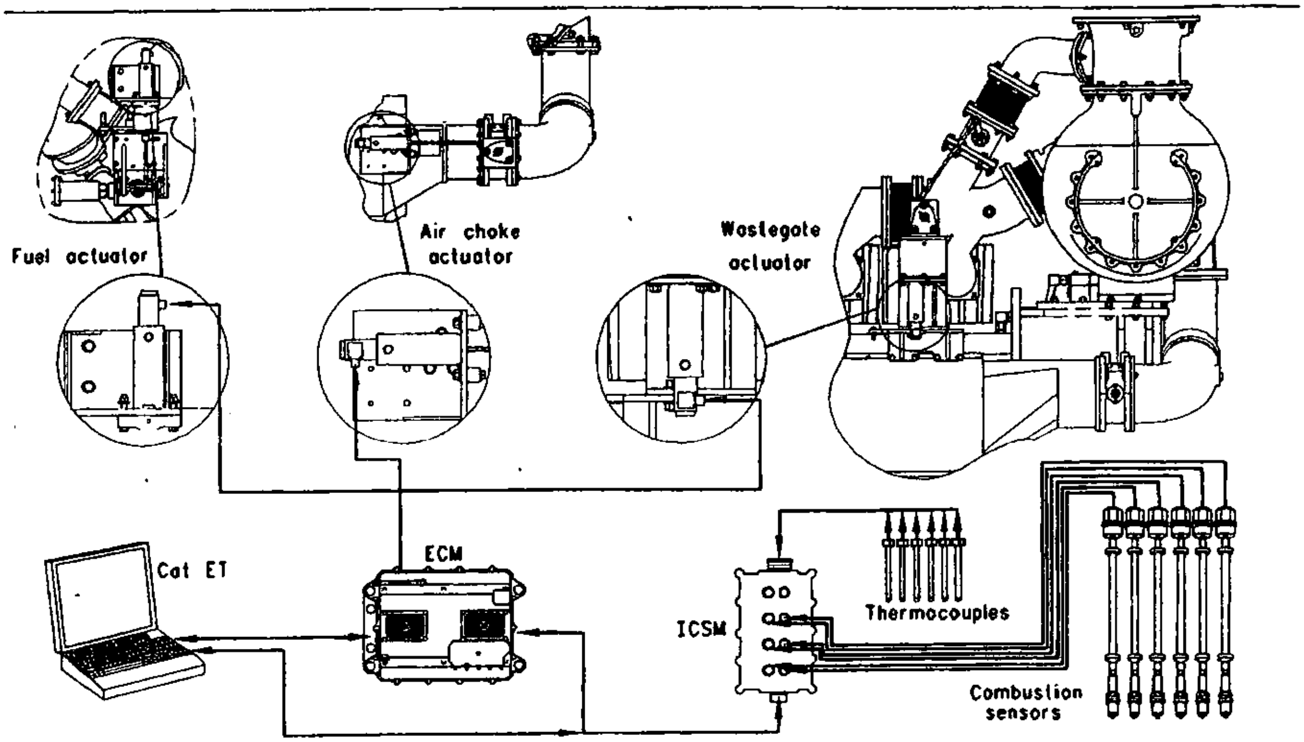


Illustration 5

g00910538

The desired air/fuel ratio is based on maps that are stored in the ECM. The maps are specific for different applications, for engine speeds, and for engine loads.

The engine load is calculated from the fuel flow. For example, zero fuel flow is zero load and fuel flow of 100 cfm might be 50 percent of the rated load.

Note: The calculated engine load varies. Several variables affect the calculated engine load, including timing, settings for emissions, fuel quality, and specific gravity of the fuel.

The system has five modes of operation for the air/fuel ratio:

- Start-up
- No feedback
- Exhaust port temperature feedback
- Combustion feedback
- Prechamber calibration

Error for the inlet manifold air pressure – This is the absolute difference between the actual inlet manifold air pressure and the desired inlet manifold air pressure.

In each of these modes, the air/fuel ratio is controlled by either the air choke actuator or the wastegate actuator: only one of the actuators operates at any time. The active actuator is determined by the ability to provide the desired inlet manifold air pressure. Both of the actuators regulate the air flow. The regulation is based on an error that is calculated for the inlet manifold air pressure. Both of the actuators are controlled by a map for the air/fuel ratio.

The software is also programmed to correct the fuel flow according to the temperature of the jacket water and the engine speed. This occurs when the coolant temperature is not at the water temperature regulator's rated temperature. If the temperature is cooler than the rating, the fuel in the cylinder head is also cooler and more dense. Because the denser fuel provides an air/fuel mixture that is richer than the desired mixture, the calculation of the fuel flow is corrected for the lower temperature. This tends to lean the actual air/fuel ratio. If the temperature is warmer than the rating, the fuel in the cylinder head is less dense. Because the warmer fuel provides a leaner air/fuel mixture, the calculation of the fuel flow is corrected for the higher temperature. This tends to richen the air/fuel ratio.

Note: When the engine is operating in combustion feedback mode, the temperature of the jacket water only affects the fuel correction factor.

The relationship of the modes of operation to the engine load and the transitions between the modes are represented in Illustration 6. The modes of operation are explained in more detail below.

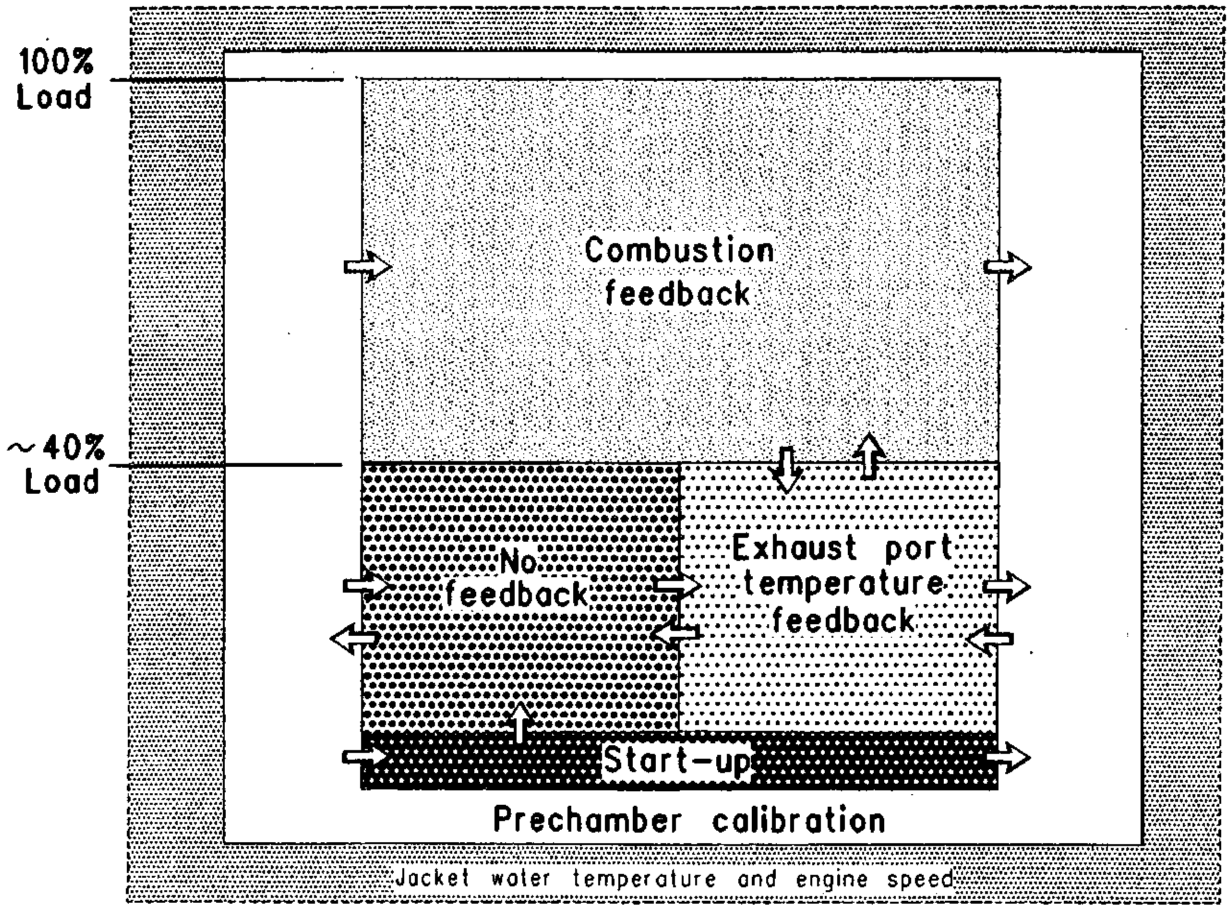


Illustration 6 g00910198

Schematic of the modes of operation, of transitions, and of the engine load

Note: Control of the inlet manifold air pressure is not determined directly by the engine load. The active actuator is determined by the ability to provide the desired inlet manifold air pressure.

At loads that are less than approximately 40 percent, the air/fuel ratio is controlled by the air choke actuator. The air choke controls the flow of air during engine start-up. The air choke continues to control the air flow during the increase in the engine speed and in load. As the engine speed and load are increased, the required inlet manifold air pressure increases. The air choke opens in order to provide more combustion air. When the air choke becomes fully open, the air choke cannot further increase the air flow. Then, the wastegate becomes active.

Conversely, the required inlet manifold air pressure is reduced as the engine speed and load are reduced. As the requirement for combustion air is reduced, the wastegate opens. When the wastegate is fully open, the wastegate cannot regulate a smaller quantity of combustion air. Then, the air choke becomes active again.

During start-up, the air choke is maintained at a fixed position until ten seconds after the engine achieves the desired speed. This enables a correction of the excessive error for inlet manifold air pressure. The starting position for the air choke is set in the Cat ET configuration screen. The starting position depends on the number of cylinders. Typically, the starting position is closed 60 to 80 percent. If the starting position is set too high, the engine will not get enough combustion air.

If the starting position is set too high and the engine speed does not increase to the desired speed, the programming in the software opens the air choke in steps until the engine speed increases. This enables a steady increase of the engine speed until the desired speed is achieved.

The maximum position for the air choke can also be set in the Cat ET configuration screen. The maximum position is set in order to enable a sufficient flow of air for combustion when the engine is running at no load. Typically, the maximum position is closed 75 to 85 percent.

At ten seconds after the engine reaches the desired speed, the air/fuel ratio is controlled directly by the map for the air/fuel ratio. No correction factors are related to any feedback: this is a correction factor of 100 percent. This mode of operation uses no feedback.

Normally, the map is calculated in order to provide a low air/fuel ratio for loads up to approximately 40 percent. This provides a mixture that is sufficiently rich for operation at low temperatures. The air/fuel ratio will continue to be controlled by the map until the conditions allow operation in one of the feedback modes or in the prechamber calibration mode.

A low air/fuel ratio is critical for operation after start-up in order to keep the air choke partially closed. Otherwise, the air choke may open fully and the wastegate will control the inlet manifold air pressure. This results in a period of misfire and of excessive fuel flow. Because of the excessive fuel flow, the calculated engine load is excessive.

Programmable "Desired Engine Exhaust Port Temp" parameter – This parameter is set in the Cat ET configuration screen. This is the desired exhaust port temperature for a load of 25 percent. The control uses this parameter during operation in the exhaust port temperature feedback mode.

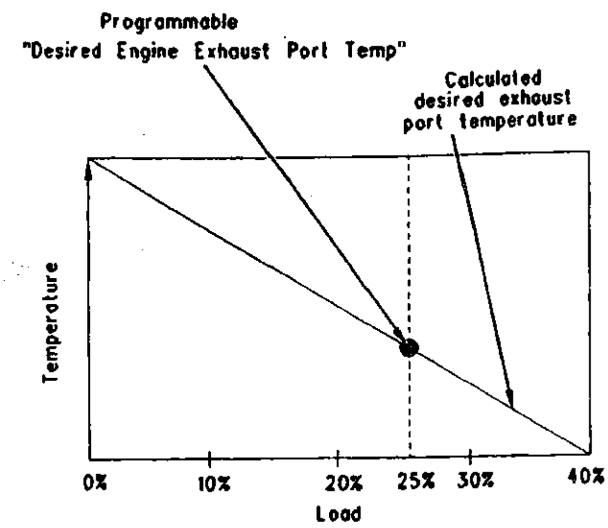


Illustration 7 g00914203

Graph of the calculated desired exhaust port temperature

The calculated desired exhaust port temperature varies from the programmable "Desired Engine Exhaust Port Temp" by 1 °C (1.8 °F) per 1 percent of engine load. For each 1 percent of engine load below 25 percent, the calculated desired exhaust port temperature increases by 1 °C (1.8 °F). For each 1 percent of engine load above 25 percent, the calculated desired exhaust port temperature decreases by 1 °C (1.8 °F).

Control's average exhaust port temperature – The ICSM continuously calculates the average exhaust port temperature. If the actual temperature of any cylinder exhaust port is less than 273 °C (523 °F), the ICSM substitutes a temperature of 273 °C (523 °F) for that cylinder. This temperature is substituted for any number of cylinders with an exhaust port temperature that is less than 273 °C (523 °F). The temperature is used in the calculation of the average for all of the monitored cylinders.

Exhaust port temperature feedback – In this mode of operation, the air/fuel ratio is controlled in order to achieve a desired exhaust port temperature. Each cylinder exhaust port has a thermocouple that is monitored by an ICSM. The ICSM monitors the actual exhaust port temperatures for one bank of cylinders. The ICSM calculates an average exhaust port temperature for the bank of cylinders. The ECM calculates the desired exhaust port temperature for the load. The ECM sends the desired exhaust port temperature to the ICSM. The ICSM calculates the difference between the average exhaust port temperature and the desired exhaust port temperature. The ICSM sends a fuel correction factor to the ECM. The ECM uses the fuel correction factor to control the air choke actuator in order to maintain the desired exhaust temperature.

After start-up, the exhaust port temperature feedback mode is activated for the following conditions:

- The calculated control's average exhaust port temperature exceeds the desired exhaust port temperature.
- The calculated control's average exhaust port temperature ceases to increase. The engine load is less than approximately 40 percent.
- The timer for operation with no feedback expires.

The transition to the exhaust port temperature feedback mode can also occur for the following circumstances:

- The air/fuel ratio is controlled by combustion feedback. The engine load is reduced to approximately 40 percent or less than 40 percent. The transition occurs in a 15 second period.
- The engine operation exits the prechamber calibration mode. The engine load is approximately 40 percent or less than 40 percent. In this case, the fuel correction factor begins at 100 percent. Then, the fuel correction factor is adjusted in order to achieve the desired exhaust port temperature.

The programmed air/fuel ratio control begins to use a correction factor in order to modify the air/fuel ratio that is specified in the map for the air/fuel ratio. The correction factor is based on an error for the exhaust port temperature.

If the average exhaust temperature is too low, the ECM commands the air choke actuator to move toward the closed position in order to richen the air/fuel mixture. Combustion of the richer air/fuel mixture increases the exhaust port temperatures.

Combustion feedback – In this mode of operation, the air/fuel ratio is controlled in order to achieve the desired combustion burn time.

When the load reaches approximately 40 percent, the air/fuel ratio is controlled by the wastegate actuator which is trimmed by the combustion burn time.

Combustion burn time – The combustion burn time is measured in each cylinder. Each cylinder has a combustion sensor. The pulse of the ignition starts a timer in the ICSM. The flame travels in the cylinder from the spark plug to the combustion sensor. The ICSM monitors the voltage across the combustion sensor. When the flame reaches the combustion sensor, the ionization that surrounds the sensor changes the voltage. When the ICSM detects the change of the sensor's voltage, the ICSM stops the timer. The combustion burn time is a method of measuring the air/fuel ratio. A rich air/fuel mixture provides a faster combustion burn time. A lean air/fuel mixture provides a slower combustion burn time.

Each ICSM calculates an average combustion burn time for all of the cylinders in one bank. The ECM sends a point from the map of the desired combustion burn time to the ICSM. The ICSM calculates the difference between the average combustion burn time and the desired combustion burn time. The ICSM sends a fuel correction factor to the ECM. The ECM controls the wastegate actuator in order to maintain the desired combustion burn time.

A command for the desired inlet manifold air pressure is sent from the ECM to the wastegate actuator. The actuator adjusts the inlet manifold air pressure in order to correct the combustion burn time.

If the average desired combustion burn time is too fast, the ECM commands the wastegate actuator to move toward the closed position in order to provide more air for a leaner air/fuel mixture. This provides a slower combustion burn time. If the average desired combustion burn time is too slow, the ECM commands the wastegate actuator to move toward the open position in order to provide less air for a richer air/fuel mixture. The richer air/fuel mixture burns faster. This is a continuous process during operation at loads that are greater than approximately 40 percent.

The combustion feedback mode is activated for either of the following conditions:

- The air/fuel ratio is in the exhaust port temperature feedback mode. The engine load exceeds approximately 40 percent. The average exhaust port temperature is stable and the desired exhaust port temperature is established. The transition occurs in a 15 second period.
- The engine operation exits the prechamber calibration mode and the engine load is greater than approximately 40 percent.

Prechamber calibration mode – This mode can be activated with Cat ET. This mode can be activated during operation at any load. The mode is used for adjustment of the precombustion chambers' needle valves in order to achieve the desired exhaust emissions. In the prechamber calibration mode, the fuel correction factor is maintained at 100 percent. After an exit from this mode, the fuel correction factor is adjusted in order to achieve the desired air/fuel ratio.

Start/Stop Control

The ECM contains the logic and the outputs for control of engine prelubrication, of starting, of shutdown, and of postlube. The customer programmable logic responds to signals from the following components: engine control switch, emergency stop switch, remote start switch, data link, and other inputs.

To control the engine at the appropriate times, the ECM provides +Battery voltage to the solenoids that control the prelube pump, the starting motor, and the gas shutoff valve.

When the programmable logic determines that the prelubrication function is necessary, the ECM supplies +Battery voltage to the solenoid for the prelube pump. The prelubrication must develop sufficient engine oil pressure before the engine will crank. The engine has a pressure switch for the prelube. When the engine oil pressure is sufficient, the pressure switch closes and the engine can be cranked.

When the programmable logic determines that it is necessary to crank the engine, the ECM supplies +Battery voltage to the solenoid for the starting motor. Rotation of the crankshaft also operates the pump for the electrohydraulic actuators. The pump develops hydraulic oil pressure for operation of the fuel actuator, the air choke actuator, and the wastegate actuator.

The engine has an energize-to-run type of Gas Shutoff Valve (GSOV). When the programmable logic determines that fuel is required to start the engine or to run the engine, the ECM supplies +Battery voltage to the valve's solenoid.

At one second after the GSOV is energized, the pressure differential between the fuel and the air is monitored. This parameter is monitored in order to ensure that no fuel is entering the fuel manifold before the ECM issues a command to the fuel actuator. If the differential pressure for fuel to air is less than 0.5 kPa (0.073 psi), the ECM supplies +Battery voltage to the fuel actuator's solenoid.

The ECM controls the fuel actuator by adjusting the current flow through the actuator's solenoid. During start-up, the combustion chambers are usually filled with excessive combustion air. The ECM operates the fuel actuator in order to supply sufficient fuel for a combustible air/fuel mixture.

The ECM removes the voltage from the starting motor's solenoid when the programmable crank terminate speed is reached or when a programmable cycle crank time has expired. The starter motor pinion disengages from the flywheel ring gear.

When the programmable logic determines that an engine shutdown is necessary, the ECM removes +Battery voltage from the solenoids for the fuel actuator and for the GSOV. The fuel is shut off.

The prelube system is programmed to perform a postlube cycle during engine shutdown. This supplies the turbocharger with adequate lubrication during shutdown.

Engine Monitoring and Protection

The ECM monitors both the engine operation and the electronic system.

Problems with engine operation cause the ECM to generate an event code. The ECM can issue a warning or a shutdown for events. This depends on the severity of the condition.

For example, a high pressure pump provides hydraulic pressure with oil for the electrohydraulic system. The oil supply is separate from the engine oil. The high pressure oil supply is monitored by a pressure switch. If the pressure drops below an acceptable level, the ECM generates an event code and the ECM shuts down the engine.

For more information on monitoring of the engine, refer to Systems Operation, "Electronic Control System Parameters".

The ICSM monitors the combustion sensors and the thermocouples for the cylinders and for the turbocharger. The ICSM sends signals regarding the parameters to the ECM over the CAT Data Link. If any parameter exceeds the acceptable range, the ECM can initiate a warning or a shutdown.

Problems with the electronic system such as an open circuit produce a diagnostic code. For more information, refer to the engine's Troubleshooting manual.

Optional Control Panel

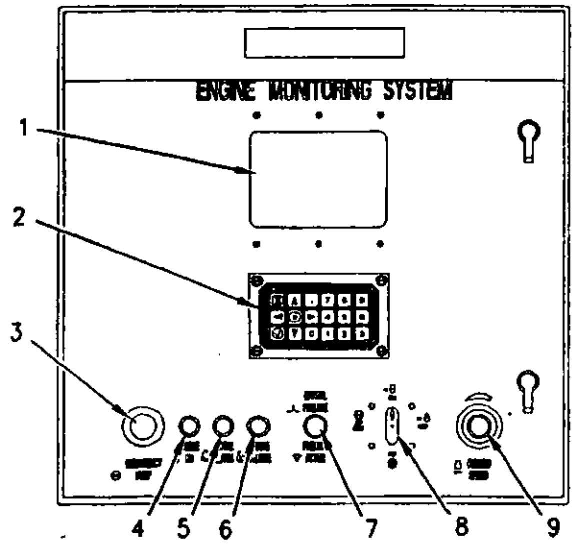


Illustration 8 g00824832

Control panel

(1) Display for the MIDS
(2) Keypad for the MIDS
(3) "EMERGENCY STOP" button
(4) "ENGINE ON" indicator
(5) "ACTIVE ALARM" indicator
(6) "ENGINE FAILURE" indicator
(7) "MANUAL PRELUBE" switch and "PRELUBE ACTIVE" indicator
(8) Engine control switch
(9) "DESIRED SPEED" potentiometer

The features of the control panel are described below.

MIDS

The MIDS is a device which enables the operator to monitor engine operation. The MIDS receives information from the ECM. The device cannot be used for programming. A screen display and a keypad provide the interface for the operator.

The keypad is protected in a sealed membrane. When you press a key, press firmly. When a key is pressed sufficiently, a small red indicator in the upper left corner of the keypad will flash once.

When the control panel is powered up, the screen becomes active. To view the options for the display, press the "?" key. Table 1 lists the menu.

Table 1

	Menu
(1)	Status Information
(2)	Detonation Levels
(3)	Ignition Timing
(4)	Filtered Burn Times
(5)	Unfiltered Burn Times
(6)	Exhaust Temperatures
(7)	Turbo Temperatures
(8)	Events and Diagnostics
(9)	Display Setup

To select an option, press the number on the keypad that corresponds to the selection. To exit the option, press the "?" key or any of the numbered keys. It is not necessary to return to the menu in order to select a different option. When you press a different numbered key, the corresponding option is displayed.

For more information on the MIDS, refer to the engine's Operation and Maintenance Manual, "Control Panel".

"EMERGENCY STOP" Button

NOTICE

Only use the "Emergency Stop" button in order to stop the engine in an emergency situation. Do not use the "Emergency Stop" button for normal engine stopping.

To prevent damage to the engine, use the mode control switch or use the remote start/stop initiate contact for normal engine stopping.

The fuel and the ignition are immediately shut off when the "EMERGENCY STOP" button is pressed. No postlube cycle occurs.

The "EMERGENCY STOP" button and the engine control switch must be reset before the engine will start. To reset the "EMERGENCY STOP" button, turn the button clockwise. To reset the engine control switch, turn the switch to the OFF/RESET position.

Note: More than one "EMERGENCY STOP" button may be available for use.

Indicators

The remote panel has three indicators for the status of the engine operation.

Illumination of the green "ENGINE ON" indicator indicates normal operation.

The yellow "ACTIVE ALARM" indicator illuminates if the control system initiates a warning for an event or a diagnostic condition.

The red "ENGINE FAILURE" indicator illuminates if the control system shuts down the engine due to an event or a diagnostic condition. The "ENGINE FAILURE" indicator also illuminates if an emergency stop is performed.

"MANUAL PRELUBE" Switch and "PRELUBE ACTIVE" Indicator

All G3600 Engines require lubrication prior to start-up. The ECM will not permit the engine to start until sufficient prelube pressure has been achieved.

Lubrication of the engine is required prior to rotation of the crankshaft. 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.

The "MANUAL PRELUBE" switch enables the operator to prelube the engine by pressing the switch.

A lamp behind the switch illuminates when the prelube is active. This is the "PRELUBE ACTIVE" indicator. If the engine control switch is in the "AUTO" position and the remote start/stop initiate contact closes, the prelube system will operate and the lamp will illuminate. The lamp will also illuminate during the postlube.

Note: The ECM is programmed to provide engine lubrication after the engine is shut off. The typical duration of the postlube is 180 seconds.

Engine Control Switch

The engine control switch has four positions: "AUTO", "START", "STOP", and "OFF/RESET"

"AUTO" – When the engine control switch is in the "AUTO" position (12 o'clock), the system is configured for remote operation. When the remote start/stop initiate contact closes, the prelube system will operate. When the prelube pressure is sufficient, 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.

"START" – When the engine control switch is turned to the "START" position (3 o'clock), the prelube system will operate. When the prelube pressure is sufficient, the engine will start. The engine will operate until the ECM receives a shutdown signal.

The following conditions cause a shutdown signal:

- The remote start/stop initiate contact opens when the engine control switch is in the "AUTO" position.
- The engine control switch is turned to the "STOP" position.
- The engine control switch is turned to the "OFF/RESET" position.
- The "EMERGENCY STOP" button is pressed.
- An undesirable operating condition is sensed and an engine shutdown is initiated by the ECM.

"STOP" – When the engine control switch is turned to the "STOP" position (6 o'clock), 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. When the engine is coasting to a stop, a postlube cycle will operate. The power to the control panel is maintained when the engine control switch is in the "STOP" position. The "STOP" position can be used to troubleshoot some problems without starting the engine.

"OFF/RESET" – When the engine control switch is turned to the "OFF/RESET" position (9 o'clock), the engine is immediately shut off and the diagnostic lights are reset. Power is removed from the control panel and from the actuators after the engine completes the postlube cycle.

"DESIRED SPEED" Potentiometer

The "DESIRED SPEED" potentiometer allows the operator to adjust the desired engine speed. This is achieved by providing a 0 to 5 volt input to the ECM.

i01863887

Electronic Control System Parameters

SMCS Code: 1901

Configuration Parameters

Certain parameters are unique for each engine application. Table 4 is a list of the parameters that can be configured for G3600 Engines. The values of the parameters can be viewed on the "Configuration" screen of the Caterpillar Electronic Technician (Cat ET).

Table 2

Configuration Parameters for G3600 Engines
Air/Fuel Ratio Control
"Fuel Quality"
"Gas Specific Gravity"
"Desired Engine Exhaust Port Temp"
"Maximum Choke Position"
"Engine Start Choke Position"
"Wastegate (Proportional) Gain Percentage"
"Wastegate (Integral) Stability Percentage"
"Wastegate (Derivative) Compensation Percentage"
"Choke (Proportional) Gain Percentage"
"Choke (Integral) Stability Percentage"
"Choke (Derivative) Compensation Percentage"
Speed Control
"Low Idle Speed"
"Minimum Engine High Idle Speed"
"Maximum Engine High Idle Speed"
"Engine Accel. Rate"
"Desired Speed Input Configuration"
"Governor Type Setting"
"Engine Speed Droop"
"Governor (Proportional) Gain Percentage"
"Governor (Integral) Stability Percentage"
"Governor (Derivative) Compensation Percentage"
"Governor Auxiliary 1 (Proportional) Gain Percentage"
"Governor Auxiliary 1 (Integral) Stability Percentage"
"Governor Auxiliary 1 (Derivative) Compensation Percentage"
Start/Stop Control
"Driven Equipment Delay Time"
"Crank Terminate Speed"
"Engine Purge Cycle Time"
"Engine Cooldown Duration"
"Cycle Crank Time"
"Engine Overcrank Time"
"Engine Speed Drop Time"
"Engine Pre-lube Time Out Period"
Monitoring and Protection
"High Inlet Air Temp Engine Load Set Point"
Information for the Electronic Control Module (ECM)
"Engine Serial Number"
"Equipment ID"
"Customer Password #1"
"Customer Password #2"
"Total Tattletale"

Governing of the Air/Fuel Ratio Control and of the Engine Speed

Gain, stability, and compensation can be adjusted for the following functions:

- Primary governor
- Auxiliary governor
- Air choke
- Exhaust bypass (wastegate)

Gain determines the speed of the control's response in adjusting for the difference between the desired condition and the actual condition. Increasing the gain provides a faster response to the difference between the desired condition and the actual condition.

Stability controls the speed for elimination of the error in the difference between the desired condition and the actual condition. The stability dampens the response to the error. Increasing the stability provides less damping.

Compensation is used to adjust for the time delay between the control signal and the movement of the actuator. If the compensation is too low, the engine speed will slowly hunt. If the compensation is too high, the engine speed will rapidly fluctuate.

Illustration 9 shows some typical curves for transient responses.

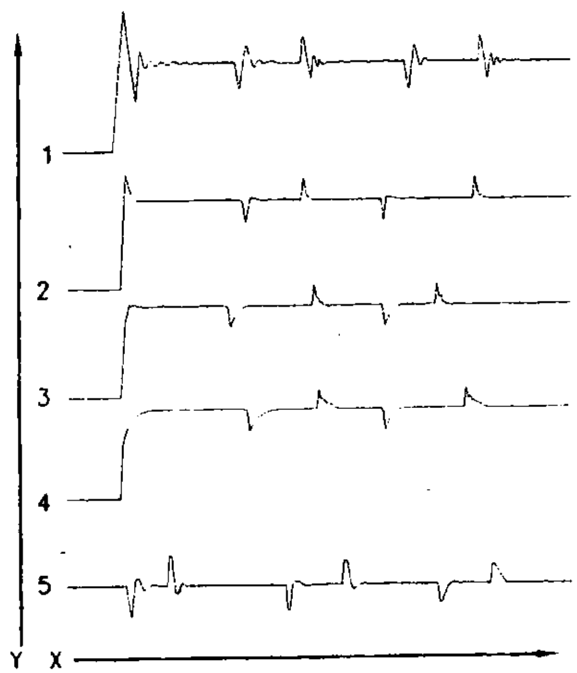


Illustration 9 g00806254

(Y) Engine speed
(X) Time
(1) The gain is too high and the stability is too low. There is a large overshoot on start-up and there are secondary overshoots on transient loads.
(2) The gain is slightly high and the stability is slightly low. There is a slight overshoot on start-up but the response to transient loads is optimum.
(3) The gain is slightly low and the stability is slightly high. There is optimum performance on start-up but slow response for transient loads.
(4) The gain is too low and the stability is too high. The response for transient loads is too slow.
(5) The response to transient loads is adjusted for optimum performance.

Illustration 10 is a graphic representation of adjusting the compensation.

Illustration 10 g00806274

The increased width of the line for the actuator voltage indicates that the linkage is more active as the compensation increases.

(Y) Actuator voltage
(X) Time in seconds

The default values should be sufficient for initial start-up. However, the values may not provide optimum performance.

If you have a problem with instability, always investigate other causes before you adjust the settings. For example, diagnostic codes and unstable gas pressure can cause instability.

To change the gain, stability, or compensation, use the "Graph" feature on the "Governor Gain" screen of Cat ET. The graph provides the best method for observing the effects of the adjustment.

After you make adjustments, always test the stability by interrupting the engine speed. Use the "Bump" feature on Cat ET. Operate the engine through the entire range of speeds and of loads in order to ensure stability.

Air/Fuel Ratio Control

"Fuel Quality"

This parameter is programmed to the Lower Heating Value (LHV) of the primary fuel. The fuel ratio control of the ECM will compensate for some inaccuracy in this setting. The ECM assumes a corrected value that is equal to the customer programmed "Fuel Energy Content" that is multiplied by the "Fuel Correction Factor". This factor is displayed on the Cat ET screen. An event code is generated if the "Fuel Correction Factor" exceeds a limit that is programmed at the factory. The event code will indicate the need to reprogram this value. Obtain a gas analysis in order for this parameter to be accurately programmed.

"Gas Specific Gravity"

The ECM requires an input for the "Gas Specific Gravity" in order to precisely meter the air/fuel ratio. Obtain a gas analysis in order to determine the specific gravity of the fuel.

"Desired Engine Exhaust Port Temp"

This parameter is programmed to the desired exhaust port temperature at a load of 25 percent. The ECM uses this temperature to trim the air choke during operation in the exhaust port temperature feedback mode.

"Maximum Choke Position"

This is the maximum position for the air choke. The maximum position is set in order to enable a sufficient flow of air for combustion when the engine is running at no load. Usually, this position is closed 75 to 85 percent.

"Engine Start Choke Position"

This is the position for the air choke at start-up. At start-up, this position is maintained until ten seconds after the engine achieves the desired speed. The air choke is held in this position in order to ensure that the inlet manifold air pressure is not excessive. This position depends on the number of cylinders. Usually, this position is closed 60 to 80 percent.

"Wastegate (Proportional) Gain Percentage"

This parameter determines the speed of the control's response in adjusting the wastegate in order to achieve the desired inlet manifold air pressure.

"Wastegate (Integral) Stability Percentage"

This parameter controls the speed for elimination of the error in the difference between the desired position of the wastegate and the actual position. The stability dampens the response to the error. Increasing the stability provides less damping.

"Wastegate (Derivative) Compensation Percentage"

This parameter is used to adjust for the time delay between the control signal and the movement of the wastegate actuator. If the compensation is too low, the wastegate actuator will slowly hunt. If the compensation is too high, the wastegate actuator will rapidly fluctuate.

"Choke (Proportional) Gain Percentage"

This parameter determines the speed of the control's response in adjusting the air choke in order to achieve the desired inlet manifold air pressure.

"Choke (Integral) Stability Percentage"

This parameter controls the speed for elimination of the error in the difference between the desired inlet manifold air pressure and the actual inlet manifold air pressure. The stability dampens the response to the error. Increasing the stability provides less damping.

"Choke (Derivative) Compensation Percentage"

This parameter is used to adjust for the time delay between the control signal and the movement of the air choke actuator. If the compensation is too low, the air choke actuator will slowly hunt. If the compensation is too high, the air choke actuator will rapidly fluctuate.

Speed Control

"Low Idle Speed"

Program this parameter to the desired low idle rpm. The low idle rpm can be programmed from 500 to 700 rpm.

"Minimum Engine High Idle Speed"

Program this parameter to the desired minimum high idle rpm. The actual high idle speed is regulated by the desired speed input. The regulation is linear in proportion to the input. An input of 0 percent results in the minimum high idle rpm and an input of 100 percent results in the maximum high idle rpm. This parameter can be programmed from 700 to 1000 rpm.

"Maximum Engine High Idle Speed"

Program this parameter to the desired maximum high idle rpm. The actual high idle speed is regulated by the desired speed input. The regulation is linear in proportion to the input. An input of 0 percent results in the minimum high idle rpm and an input of 100 percent results in the maximum high idle rpm. This parameter can be programmed from 700 to 1000 rpm.

"Engine Accel. Rate"

This parameter controls the rate for engine response to a change in the desired engine speed. For example, the engine can be programmed to accelerate at a rate of 50 rpm per second when the "Idle/Rated" switch is turned to the "Rated" position.

Speed Selection

The desired speed operates at low idle speed or high idle speed. The speed is selected by the position of the idle/rated switch and by the status of the engine oil pressure. If the switch is in the idle position, the ECM will always select the low idle speed. If the engine oil pressure is less than the trip point for the low oil pressure warning, the ECM will always select low idle speed regardless of the position of the idle/rated switch. If the engine oil pressure is greater than the trip point for the low oil pressure warning and the switch is in the rated position, the ECM will select the high idle speed.

"Desired Speed Input Configuration"

This parameter determines the signal input to the ECM for control of the desired speed. The signal can be either 0 to 5 VDC or 4 to 20 mA.

Note: The ECM is not configured to accept a pulse width modulated signal for input of the desired engine speed. If you try to select a Pulse Width Modulated input (PWM), the ECM will reject the selection. An error will be generated.

"Governor Type Setting"

The "Governor Type Setting" parameter can be set to "Droop Operation" or to "Isochronous Mode". This setting is dependent upon the application of the engine.

Engine Speed Droop

This programmable parameter enables the precise control of the droop for applications such as load sharing units. The "Governor Type Setting" parameter must be set to "Droop". The droop can be programmed to a value between 0 and 10 percent.

"Governor (Proportional) Gain Percentage"

This parameter is based on a proportional multiplier. This parameter changes the reaction of the governor when the "Grid Status" parameter is "OFF". If this gain is adjusted and the "Grid Status" is "ON", the stability is not affected. If changing this gain causes no effect, check the "Grid Status" in order to make sure that the status is "OFF".

"Governor (Integral) Stability Percentage"

This parameter is based on an integral multiplier. This parameter changes the reaction of the governor when the "Grid Status" parameter is "OFF". If this gain is adjusted and the "Grid Status" is "ON", the stability is not affected. If changing the compensation causes no effect, check the "Grid Status" in order to make sure that the status is "OFF".

"Governor (Derivative) Compensation Percentage"

This parameter is based on a derivative multiplier when the "Grid Status" parameter is "Off". If the gain is changed and the "Grid Status" is "On", the stability of the engine will not change. If changing the stability causes no effect, check the "Grid Status" in order to make sure that the status is "OFF".

"Governor Auxiliary 1 (Proportional) Gain Percentage"

This parameter is based on a proportional multiplier when the engine's "Grid Status" parameter is "On". If the gain is changed and the "Grid Status" is "Off", the stability of the engine will not change. If changing this gain causes no effect, check the "Grid Status" in order to make sure that the status is "ON".

"Governor Auxiliary 1 (Integral) Stability Percentage"

This parameter is based on an integral multiplier when the engine's "Grid Status" parameter is "On". If the gain is changed and the "Grid Status" is "Off", the stability of the engine will not change. If changing this gain causes no effect, check the "Grid Status" in order to make sure that the status is "ON".

"Governor Auxiliary 1 (Derivative) Compensation Percentage"

This parameter is based on a derivative multiplier when the engine's "Grid Status" parameter is "On". If the gain is changed and the "Grid Status" is "Off", the stability of the engine will not change. If changing this gain causes no effect, check the "Grid Status" in order to make sure that the status is "ON".

Start/Stop Control Parameters

"Driven Equipment Delay Time"

The ECM provides a switch input for the driven equipment in order to delay engine start-up until the equipment is ready. The ECM will not attempt to start the engine until the switch closes to ground and the prelubrication is complete. An event code is generated if the programmed time for the driven equipment elapses without the closure of the switch. The delay time for the switch must be programmed to 0 in order to disable this feature.

"Crank Terminate Speed"

The ECM disengages the starting motor when the engine speed exceeds the programmed "Crank Terminate Speed". The default value of 250 rpm should be sufficient for all applications.

"Engine Purge Cycle Time"

The "Engine Purge Cycle Time" is the duration for cranking without fuel before the crank cycle begins. The ignition is disabled during this time. The "Engine Purge Cycle Time" allows any unburned fuel to exit through the exhaust before you crank the engine.

"Engine Cooldown Duration"

When the ECM receives a "Stop" request, the engine will continue to run in the "Cooldown Mode" for the programmed cooldown period. The "Cooldown Mode" is exited early if a request for an emergency stop is received by the ECM. If the "Engine Cooldown Duration" is programmed to zero, the engine will immediately shut down when the ECM receives a "Stop" request.

"Cycle Crank Time"

The "Cycle Crank Time" is the amount of time for activation of the starting motor and the gas shutoff valve for start-up. If the engine does not start within the specified time, the attempt to start is suspended for a "Rest Cycle" that is equal to the "Cycle Crank Time".

"Engine Overcrank Time"

The "Engine Overcrank Time" is the duration for attempting engine start-up. An event is generated if the engine does not start within this period of time.

Example Setting

Table 3

Examples of the Settings for Start-up	
Parameter	**Time**
"Purge Cycle Time"	10 seconds
"Cycle Crank Time"	30 seconds
"Overcrank Time"	45 seconds

The following sequence will occur if the parameters are programmed according to the example in Table 3:

1. The fuel and the ignition are OFF. The engine will crank for 10 seconds in order to purge gas from the engine via the exhaust system.

2. The fuel and the ignition are enabled. The engine will continue to crank for a maximum of 30 seconds.

3. If the engine does not start, the ignition, the fuel, and the starting motor are disabled for a 30 second "Rest Cycle".

With this example, a complete cycle is 70 seconds: a purge cycle of 10 seconds, a cycle crank of 30 seconds, and a rest cycle of 30 seconds. A maximum of one crank cycle is recommended. The "Overcrank Time" of 45 seconds allows one crank cycle.

"Engine Speed Drop Time"

After the cooldown period has elapsed, the ECM shuts off the gas shutoff valve. The ignition continues until the engine speed drops below 40 rpm. If the engine rpm does not drop at least 100 rpm within the programmed drop time, the ECM terminates the ignition and the ECM issues an emergency stop.

"Engine Pre-Lube Time Out Period"

The ECM energizes the prelube pump's solenoid prior to cranking the engine. The ECM uses a switch input to monitor the engine for acceptable prelube pressure. After the prelube is completed, the prelube's pressure switch closes. If the ECM does not detect closure of the switch within the programmable "Engine Pre-Lube Time Out Period", the ECM monitors the engine oil pressure sensor. If the engine oil pressure is insufficient, an event code is activated and the starting sequence is terminated. The range for the "Engine Pre-Lube Time Out Period" is 30 to 300 seconds.

"Monitoring and Protection"

"High Inlet Air Temp Engine Load Setpoint"

The programmable setpoint is a value that separates low engine load from high engine load for events that are activated by high inlet air temperature. An "Engine Load Factor" can be displayed on a Cat ET status screen. If the load factor is less than the setpoint and the inlet air temperature reaches the trip point, a "High Inlet Air Temperature at Low Engine Load" event is activated. If the load factor is greater than the setpoint and the inlet air temperature reaches the trip point, a "High Inlet Air Temperature at High Engine Load" event is activated.

Information for the ECM

"Engine Serial Number"

The engine serial number is programmed into the ECM at the factory. The number is stamped on the engine Information Plate.

"Equipment ID"

The customer can assign an "Equipment ID" for the purpose of identification.

Customer Passwords

Two customer passwords can be entered. The passwords are used to protect certain configuration parameters from unauthorized changes.

Note: Factory level security passwords are required for clearing certain logged events and for changing certain programmable parameters. Because of the passwords, only authorized personnel can make changes to some of the programmable items in the ECM. When the correct passwords are entered, the changes are programmed into the ECM.

"Total Tattletale"

This item displays the number of changes that have been made to the configuration parameters.

Default Settings of the Configuration Parameters

Table 4 is a list of the default settings for most of the configuration parameters. The values may require adjustment for the particular installation.

Table 4

Default Settings of Configuration Parameters for G3600 Engines				
Parameter	**Engine**			
	G3606	**G3608**	**G3612**	**G3616**
Air/Fuel Ratio Control				
"Fuel Quality"	36.00 MJ per cubic normal meter			
"Gas Specific Gravity"	0.600			
"Desired Engine Exhaust Port Temp"	540 °C	535 °C	540 °C	535 °C
"Maximum Choke Position"	75 %	70 %	84 %	85 %
"Engine Start Choke Position"	66 %	60 %	76 %	77 %
"Wastegate (Proportional) Gain Percentage"	97.7 %			
"Wastegate (Integral) Stability Percentage"				
"Wastegate (Derivative) Compensation Percentage"				
"Choke (Proportional) Gain Percentage"				
"Choke (Integral) Stability Percentage"				
"Choke (Derivative) Compensation Percentage"				
Speed Control				
"Low Idle Speed"	550 rpm			
"Minimum Engine High Idle Speed"	700.0 rpm			
"Maximum Engine High Idle Speed"	1000.0 rpm			
"Engine Accel. Rate"	100 rpm per second			
"Desired Speed Input Configuration"	0 to 5 VDC			
"Governor Type Setting"	Isochronous			
"Engine Speed Droop"	0.0			

(continued)

(Table 4, contd)

Default Settings of Configuration Parameters for G3600 Engines				
Parameter	Engine			
	G3606	G3608	G3612	G3616
"Governor (Proportional) Gain Percentage"	100.0 %			
"Governor (Integral) Stability Percentage"				
"Governor (Derivative) Compensation Percentage"				
"Governor Auxiliary 1 (Proportional) Gain Percentage"				
"Governor Auxiliary 1 (Integral) Stability Percentage"				
"Governor Auxiliary 1 (Derivative) Compensation Percentage"				
Start/Stop Control				
"Driven Equipment Delay Time"	40.0 seconds			
"Crank Terminate Speed"	250 rpm			
"Engine Purge Cycle Time"	0 seconds			
"Engine Cooldown Duration"	0 minutes			
"Cycle Crank Time"	30 seconds			
"Engine Overcrank Time"	40 seconds			
"Engine Speed Drop Time"	15.000 seconds			
"Engine Pre-lube Time Out Period"	30.000 seconds			
Monitoring and Protection				
"High Inlet Air Temp Engine Load Set Point"	50%			

i01829188

Engine Sensors (In-Line)

SMCS Code: 1559; 1912; 1917

S/N: BEN1-Up

S/N: 4ZS1-Up

Sensors provide information to the engine control module and to the integrated combustion sensing module. The information is used for monitoring engine operation. The information enables the modules to control the engine as efficiently as possible over a wide range of operating conditions. The locations of the sensors are described in the following illustrations.

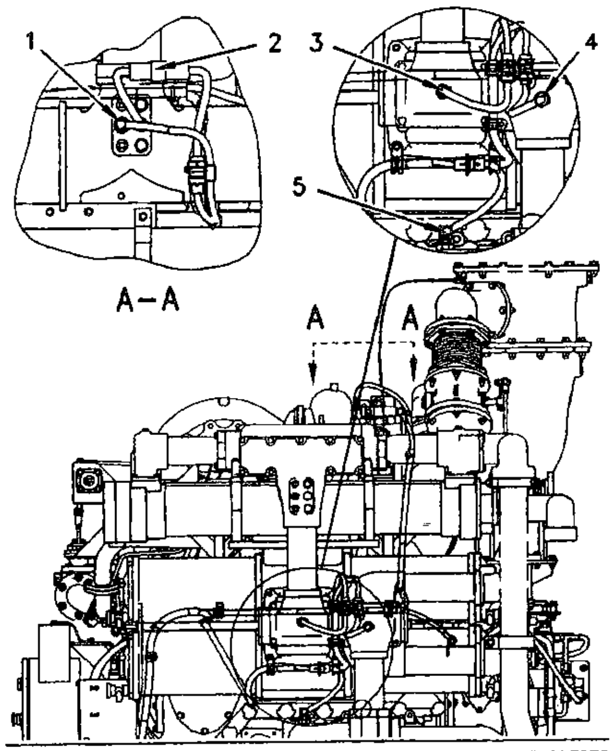


Illustration 11 g00895272

Front view

(1) Sensor for the temperature of the jacket water
(2) Sensor for the outlet pressure of the jacket water
(3) Unfiltered engine oil pressure sensor
(4) Engine oil temperature sensor
(5) Filtered engine oil pressure sensor

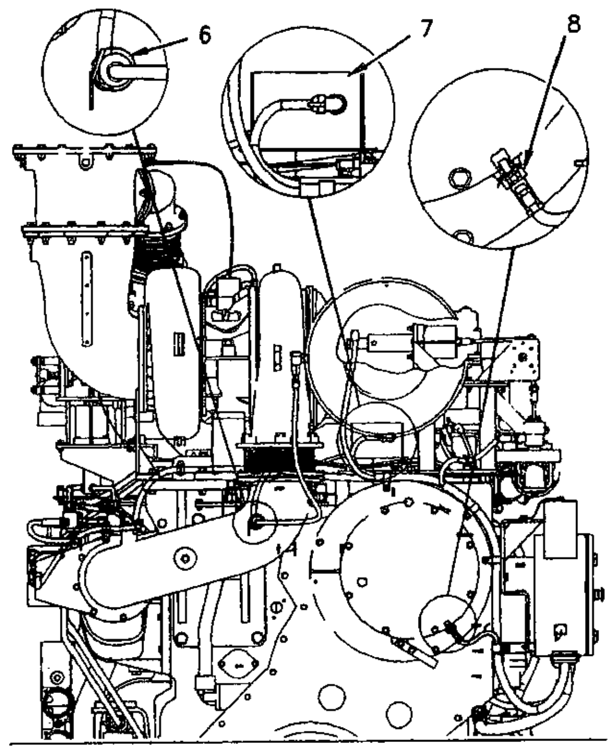


Illustration 12 g00895316

Rear view

(6) Inlet air restriction's switch
(7) Air/fuel pressure module
(8) Engine speed/timing sensor

Note: There is one detonation sensor between each pair or cylinders.

Note: The switches for connector (14) can be supplied by the customer or by the factory.

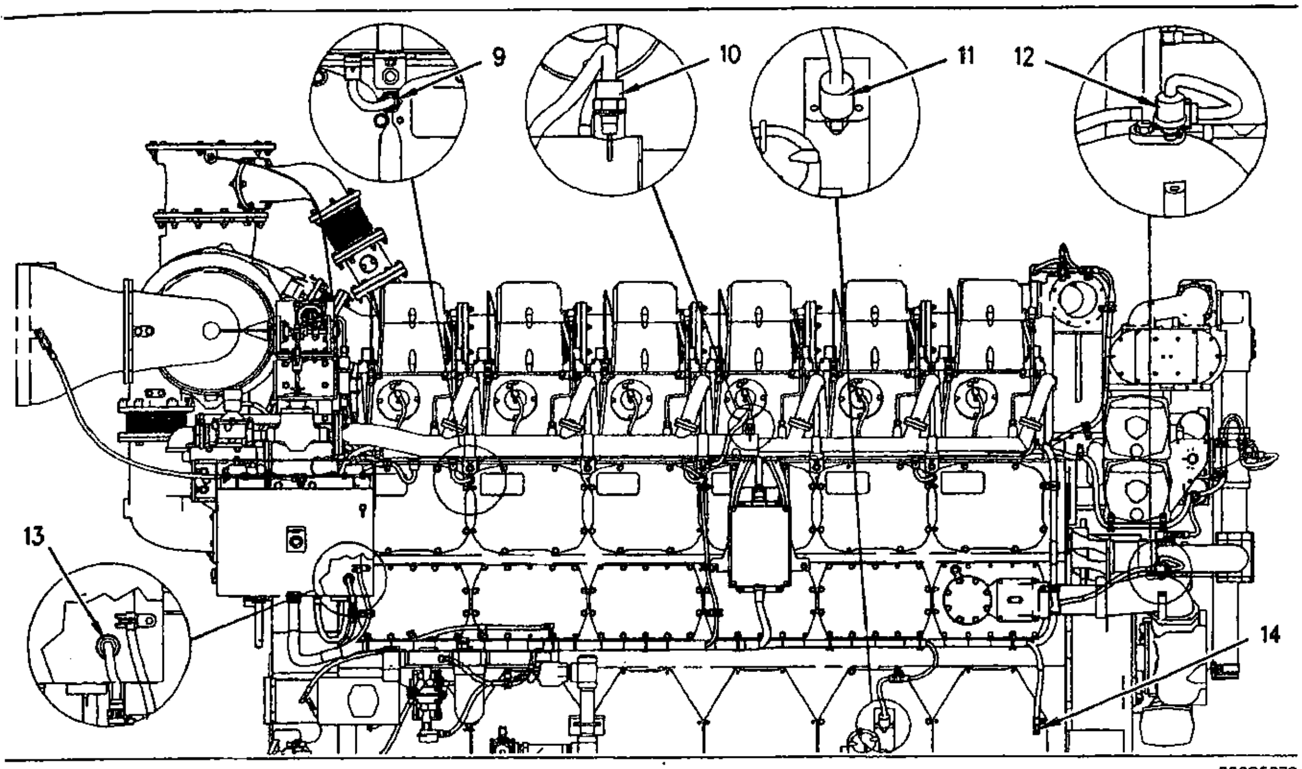


Illustration 13 g00895279

Right side view

(9) Detonation sensor
(10) Fuel temperature sensor
(11) Crankcase pressure sensor
(12) Pressure switch for the inlet of the jacket water
(13) Pressure switch for the prelube
(14) Connector for the switches for low engine oil level and for low coolant level

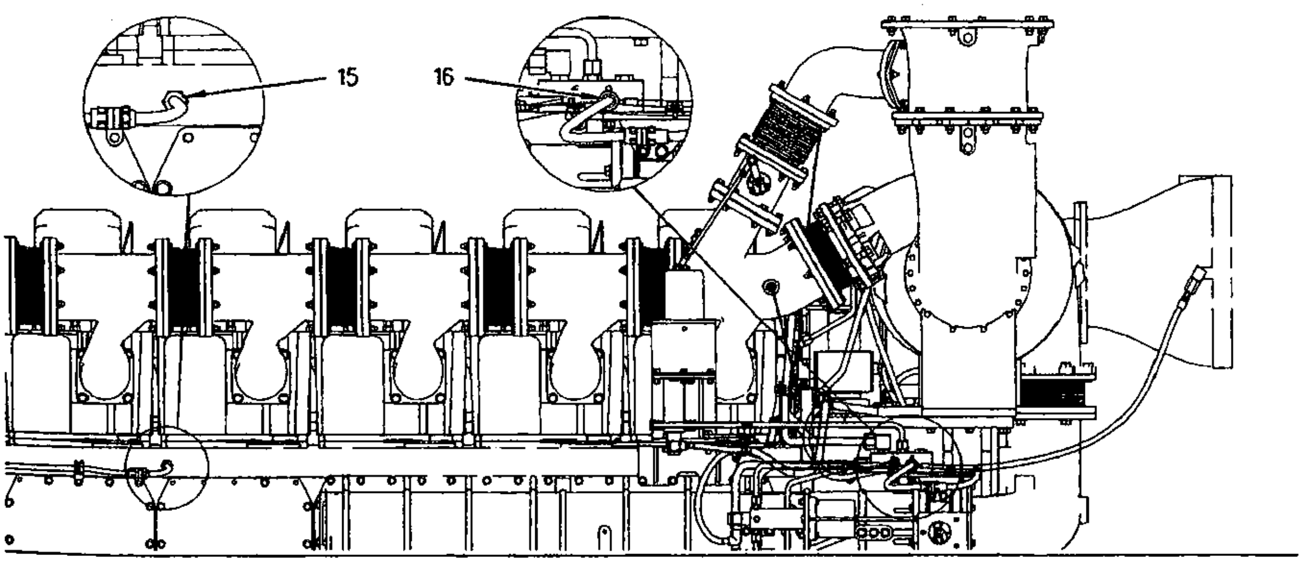


Illustration 14 g00895328

Left side view

(15) Inlet manifold air temperature's sensor
(16) Pressure switch for the electrohydraulic actuators

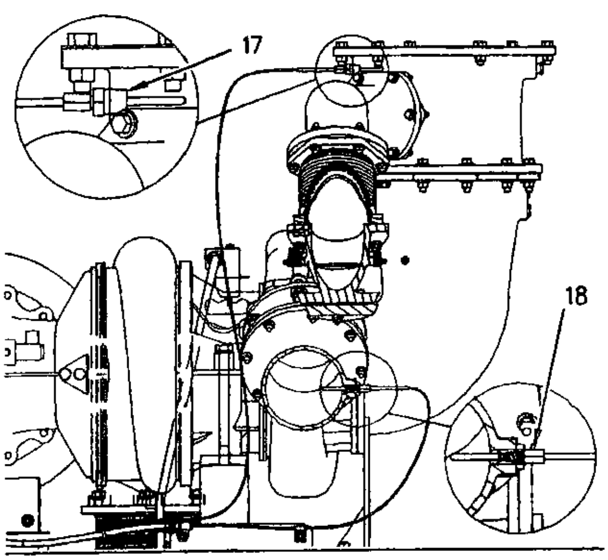


Illustration 15 g00895336

Left side rear view

(17) Temperature sensor for the exhaust after the turbocharger
(18) Temperature sensor for the exhaust before the turbocharger

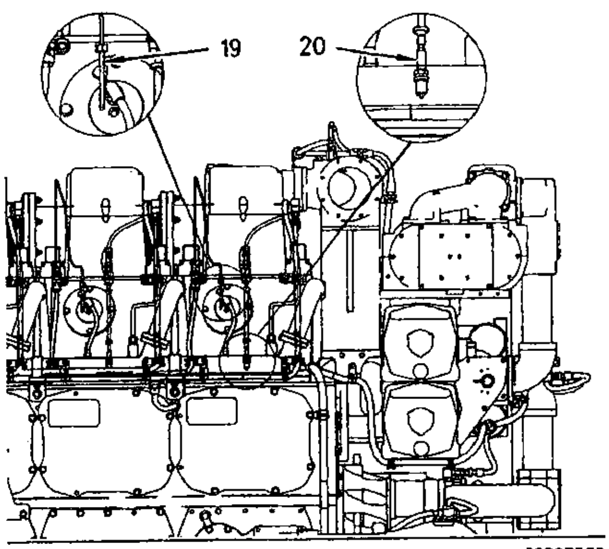


Illustration 16 g00895356

Right side front view

(19) Temperature sensor for the cylinder exhaust port
(20) Combustion sensor

Note: For each cylinder, there is one temperature sensor for the exhaust port (19) and one combustion sensor (20).

i01829245

Engine Sensors (Vee)

SMCS Code: 1559; 1912; 1917

S/N: BLB1-Up

S/N: BKE1-Up

Sensors provide information to the engine control module and the integrated combustion sensing modules. The information is used for monitoring engine operation. The information enables the modules to control the engine as efficiently as possible over a wide range of operating conditions. The locations of the sensors are described in the following illustrations.

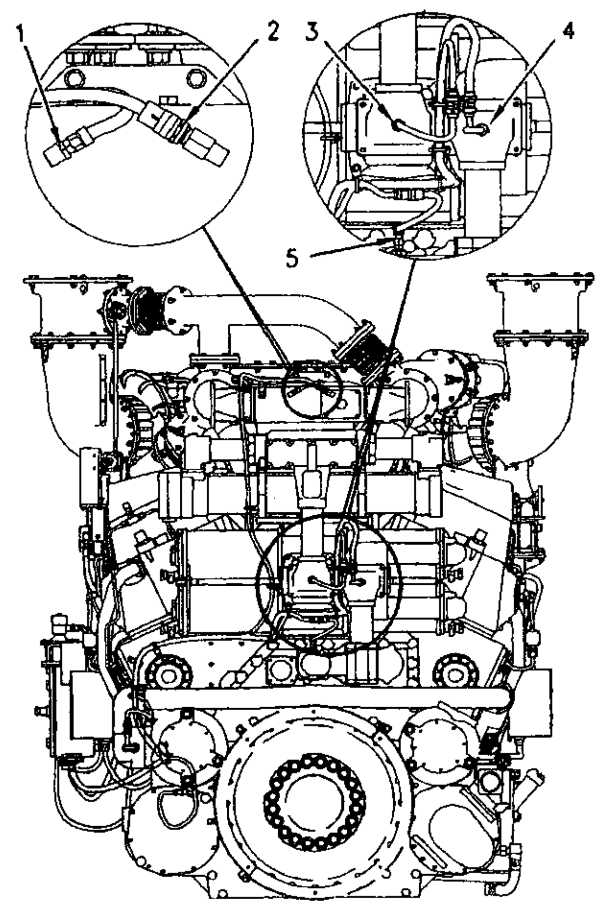


Illustration 17 g00803846

Front view

(1) Sensor for the outlet pressure of the jacket water
(2) Sensor for the temperature of the jacket water
(3) Unfiltered engine oil pressure sensor
(4) Engine oil temperature sensor
(5) Filtered engine oil pressure sensor

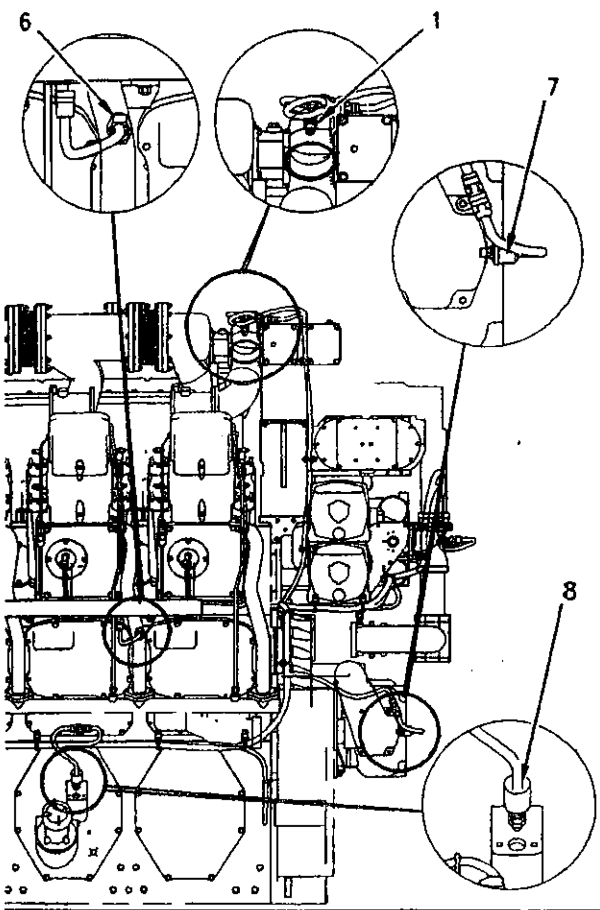


Illustration 18 g00825637

Right side front view

(1) Sensor for the outlet pressure of the jacket water
(6) Detonation sensor
(7) Pressure switch for the inlet of the jacket water
(8) Crankcase pressure's switch

Note: There is one detonation sensor between each pair of cylinders.

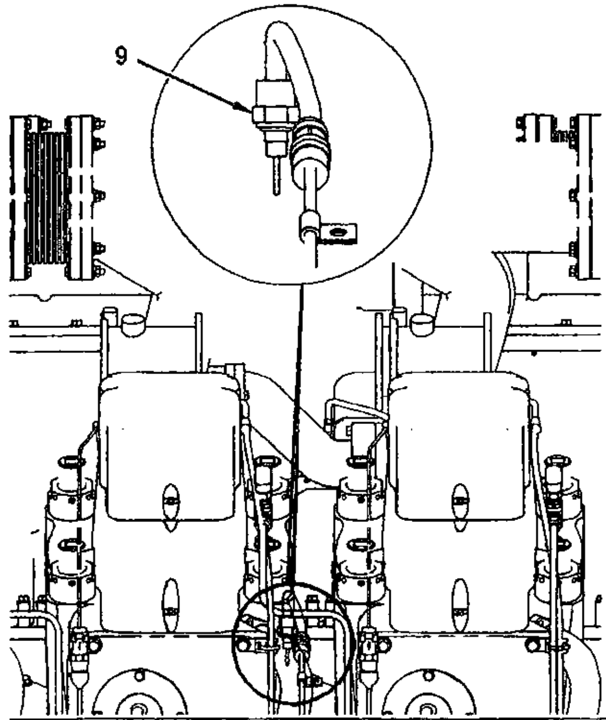


Illustration 19 g00825893

The inlet manifold air temperature's sensor is installed in the inlet air manifold between the two center cylinder heads on the right side of the engine.

(9) Sensor for the inlet manifold air temperature

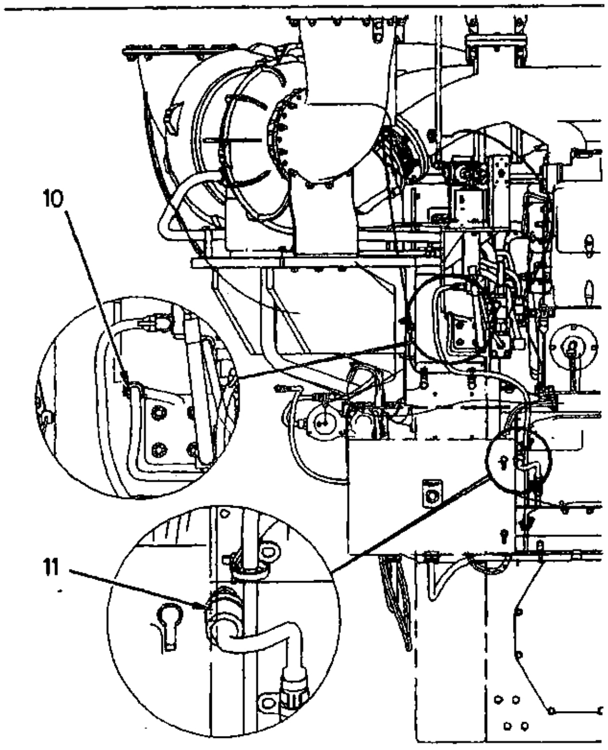


Illustration 20 g00825717

Right side rear view

(10) Pressure switch for the electrohydraulic actuators
(11) Pressure switch for the prelube

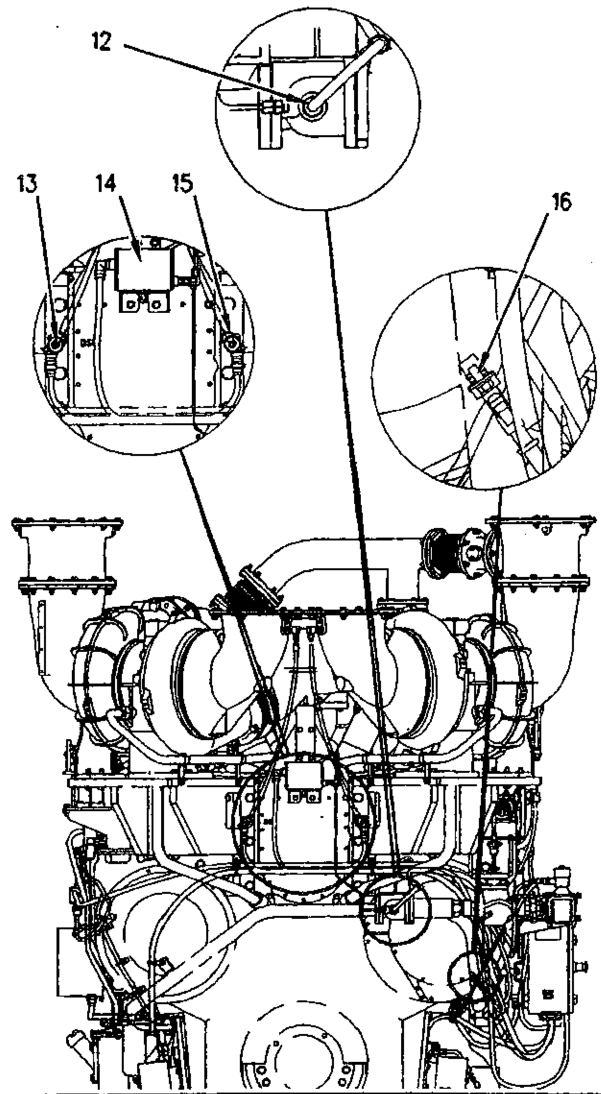


Illustration 21 g00825638

Rear view

(12) Fuel temperature sensor
(13) Inlet air restriction's switch (left)
(14) Air/fuel pressure module
(15) Inlet air restriction's switch (right)
(16) Engine speed/timing sensor

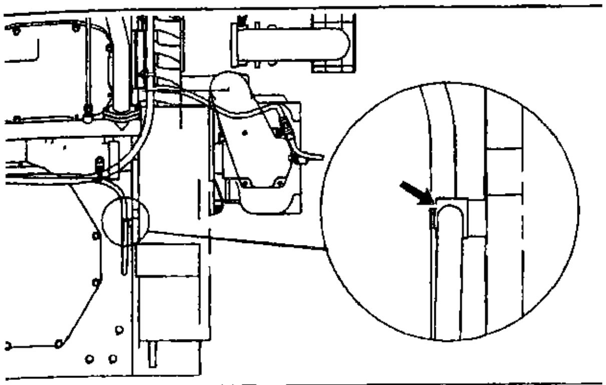


Illustration 22 g00902969

Right side front view

Engine harness connector for the engine oil level switch and the coolant level switch

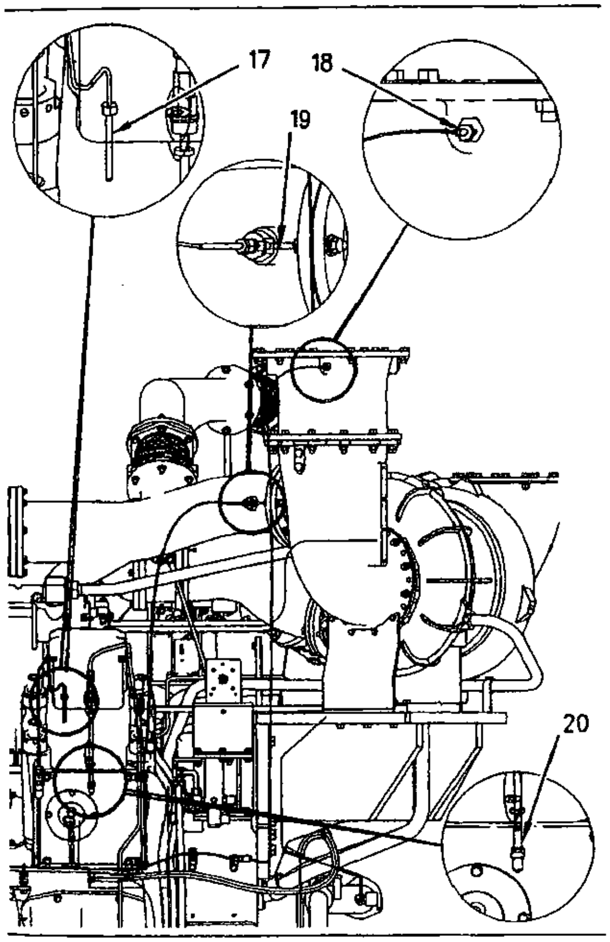


Illustration 23 g00825730

Left side rear view

(17) Temperature sensor for the cylinder exhaust port
(18) Temperature sensor for the exhaust after the turbocharger
(19) Temperature sensor for the exhaust before the turbocharger
(20) Combustion sensor

Note: For each cylinder, there is one temperature sensor for the exhaust port (17) and one combustion sensor (20). For each turbocharger, there is one temperature sensor for the exhaust after the turbocharger (18) and one temperature sensor for the exhaust before the turbocharger (19).

Engine Monitoring System

i02112697

Engine Monitoring System

SMCS Code: 1900; 1901

Monitoring System Parameters

The Electronic Control Module (ECM) monitors the operating parameters of the engine. The ECM can initiate a warning or a shutdown if a specific engine parameter exceeds an acceptable range. The default settings for the parameters are programmed at the factory.

To accommodate unique applications and sites, many of the parameters may be reprogrammed with the Caterpillar Electronic Technician (Cat ET). The screens of Cat ET provide guidance for the changing of trip points. Use Cat ET to perform the following activities:

- Select the available responses.
- Program the level for monitoring.
- Program delay times for each response.

Note: Some of the parameters are protected by factory passwords. Other parameters can be changed with customer passwords.

"Low Engine Oil Pressure"

The trip point for this parameter is set at the factory. The trip point cannot be changed. If the engine oil pressure is less than the trip point for the engine speed, the ECM will generate a warning or a shutdown. The trip point depends on the engine speed. For example, if the engine is operating at less than 600 rpm and the engine oil pressure is reduced to 175 kPa (25 psi), a warning is generated. If the engine is operating at a minimum of 600 rpm and the engine oil pressure is reduced to 400 kPa (58 psi), a warning is generated. This parameter is always active.

"Low System Voltage"

The trip point for this parameter is set at the factory. The trip point cannot be changed. If the system voltage reaches the trip point, the ECM will generate a warning or a shutdown. This parameter is always active.

"High Engine Coolant Temperature"

If the engine coolant temperature reaches the trip point, the ECM will generate a warning or a shutdown. The trip point for the warning can be programmed with a customer password. The trip point for the shutdown requires a factory password. The warning can be turned On and Off. The shutdown is always active. The trip points depend on the rating of the water temperature regulators for the engine coolant.

"Low Engine Coolant Temperature"

If the engine coolant temperature reaches the trip point, the ECM will generate a warning. The trip point for the warning can be programmed with a customer password. This parameter can be turned On and Off.

"High Inlet Jacket Water Pressure"

If the pressure in the jacket water inlet reaches the trip point, the ECM will activate an engine shutdown. The trip point for this parameter is set at the factory. The trip point cannot be changed. This parameter is always active.

"Low Outlet Jacket Water Pressure"

If the pressure in the jacket water outlet reaches the trip point, the ECM will activate an engine shutdown. The trip point for this parameter is set at the factory. The trip point cannot be changed. This parameter is always active.

"Engine Overspeed"

If the engine speed reaches the trip point, the ECM will activate an engine shutdown. A typical trip point is 113 percent of the engine's rated speed. The trip point for the shutdown requires a factory password. This parameter is always active.

"Engine Overload"

If the engine speed reaches the trip point, the ECM will activate a warning. A typical trip point is 110 percent of the engine's rated load. The control system will limit the fuel in order to prevent further overloading. This parameter is always active.

"High Engine Oil Temperature"

If the engine oil temperature reaches the trip point, the ECM will generate a warning or a shutdown. The trip point for the warning can be programmed with a customer password. The trip point for the shutdown requires a factory password. The warning can be turned On and Off. The shutdown is always active.

"Engine Oil Pressure High"

If the engine oil pressure reaches the trip point, the ECM will generate a warning or a shutdown. The trip point can be programmed with a customer password. The warning can be turned On and Off. The shutdown is always active.

"Engine Oil Filter Diff Pressure High"

If the differential pressure of the engine oil filter reaches the trip point, the ECM will generate a warning or a shutdown. The trip point for the warning can be programmed with a customer password. The trip point for the shutdown requires a factory password. The warning can be turned On and Off. The shutdown is always active.

"Engine Oil Filter Diff Pressure Low"

If the differential pressure of the engine oil filter is reduced to the trip point, the ECM will generate a warning or a shutdown. The trip point for the warning can be programmed with a customer password. The trip point for the shutdown requires a factory password. The warning and the shutdown can be turned On and Off.

"High Gas Temperature"

If the fuel temperature reaches the trip point, the ECM will generate a warning. The trip point for the warning can be programmed with a customer password. The warning can be turned On and Off.

"Low Gas Fuel Differential Pressure"

If the differential pressure of the fuel filter is reduced to the trip point, the ECM will generate a warning. The trip point for the warning can be programmed with a customer password. The warning can be turned On and Off.

"High Gas Fuel Differential Pressure"

If the differential pressure of the fuel filter reaches the trip point, the ECM will generate a warning. The trip point for the warning can be programmed with a customer password. The warning can be turned On and Off.

"Jacket Water to Engine Oil Temp Low"

If the differential temperature of the jacket water and the engine oil reaches the trip point, the ECM will generate a warning or a shutdown. The trip point for the warning can be programmed with a customer password. The trip point for the shutdown requires a factory password. The warning can be turned On and Off. The shutdown is always active.

"High System Voltage"

The trip point for this parameter is set at the factory. The trip point cannot be changed. If the system voltage reaches the trip point, the ECM will generate a warning.

Trip Point of the Engine Load for High Inlet Air Temperature

This feature provides a trip point between high engine load and low engine load. The trip point is used for events that involve high inlet air temperature. The trip points for high inlet air temperature are based on the engine load. The possible responses of the system include warning and shutdown. The trip point for the warning can be programmed with a customer password. The trip point for the shutdown requires a factory password.

The "Service/Configuration" screen of Cat ET defines the "High Inlet Air Temp Engine Load Set Point". The ECM can activate a warning or a shutdown if the inlet air temperature reaches the trip point during the operation at the load that is defined.

For information on the "High Inlet Air Temp Engine Load Setpoint", refer to Systems Operation, "Electronic Control System Parameters".

Default Settings of the Monitoring System

Examples of the default settings for the parameters are listed in Table 5. The values may have changed. Use the Cat ET to determine the programming for your engine. Many of the items can be reprogrammed in order to accommodate the requirements of individual sites.

Table 5

Default Settings of the Programmable Monitoring System								
Parameter	**Event Code**	**System Response**	**State**	**Trip Point**	**Delay in Seconds**	**Security Level Password**	**Range**	**Range of the Delay in Seconds**
"Low Engine Oil Pressure"	E100 (1)	Warning	On [1]	175 kPa [2]	5	This item cannot be programmed.		
				400 kPa [3]				
	E040 (3)	Shutdown		100 kPa [2]	0			
				350 kPa [3]				
"Low System Voltage"	E043 (1)	Warning	On	20 volts	20			
	E042 (3)	Shutdown	On [1]	18 volts	10			
"High Engine Coolant Temperature" 88 °C Jacket Water	"E017 (1)"	Warning	On	93 °C	60	Customer	80 to 129 °C	1 to 60
	"E016 (3)"	Shutdown	On [1]	98 °C	20			
"High Engine Coolant Temperature" 99 °C Jacket Water	"E017 (1)"	Warning	On	105 °C	60			
	"E016 (3)"	Shutdown	On [1]	110 °C	20			
"High Engine Coolant Temperature" 110 °C Jacket Water	"E017 (1)"	Warning	On	115 °C	60			
	"E016 (3)"	Shutdown	On [1]	120 °C	20			
"Low Engine Coolant Temperature"	E038 (1)	Warning	On	25 °C	20		5 to 80 °C	
"High Inlet Jacket Water Pressure"	E224 (3)	Shutdown	On	462 kPa	10	This item cannot be programmed.		
"Low Outlet Jacket Water Pressure"	E135 (3)			138 kPa				
"Engine Overspeed" 900 RPM Rating	E004 (3)	Shutdown	On [1]	1017 rpm	0	Factory	800 to 1300 rpm	0
"Engine Overspeed" 1000 RPM Rating				1130 rpm				
"Engine Overload"	E242	Warning		110 %	0	This item cannot be programmed.		

(continued)

...5, contd)

Default Settings of the Programmable Monitoring System								
...arameter	Event Code	System Response	State	Trip Point	Delay in Seconds	Security Level Password	Range	Range of the Delay in Seconds
...n Engine Oil ...mperature"	E020 (1)	Warning	On	88 °C	5	Customer	85 to 102 °C	
	E019 (3)	Shutdown	On (1)	90 °C	1	Factory	85 to 104 °C	
...ngine Oil ...sure High"	E125 (1)	Warning	On	650 kPa	25		600 to 1200 kPa	
	E126 (3)	Shutdown	On (1)	1000 kPa		Customer	600 to 1200 kPa	
...ine Oil Filter ...Pressure ...High"	E129 (1)	Warning	Off	100 kPa	15		0 to 350 kPa	
	E130 (3)	Shutdown	On (1)	300 kPa	25	Factory		
...ne Oil Filter ...Pressure ...Low"	E127 (1)	Warning	On	5 kPa	10	Customer	0 to 150 kPa	1 to 60
	E128 (3)	Shutdown	Off	3 kPa		Factory		
...igh Gas ...mperature"	E223 (1)		On	60 °C	20		0 to 60 °C	
...Gas Fuel ...fferential ...ressure"	E864 (1)	Warning		5 kPa	60	Customer	0 to 100 kPa	
...h Gas Fuel ...ifferential ...ressure"	E865 (1)		On	160 kPa	30		0 to 195 kPa	
...acket Water ...Engine Oil ...emp Low"	E123 (1)		On	10 °C	60		0 to 80 °C	
	E124 (3)	Shutdown	On (1)	15 °C		Factory		
...gh System ...Voltage"	E050 (1)	Warning	On	32 volts	20	This item cannot be programmed.		

(continued)

(Table 5, contd)

<table>
<tr><th colspan="9">Default Settings of the Programmable Monitoring System</th></tr>
<tr><th>Parameter</th><th>Event Code</th><th>System Response</th><th>State</th><th>Trip Point</th><th>Delay in Seconds</th><th>Security Level Password</th><th>Range</th><th>Range of the Delay in Seconds</th></tr>
<tr><td rowspan="2">"High Inlet Air Temperature" (low load) 54 °C SCAC</td><td>E027 (1)</td><td>Warning</td><td>On</td><td>82 °C</td><td rowspan="12">20</td><td rowspan="12">Customer</td><td rowspan="6">32 to 100 °C</td><td rowspan="12">1 to 60</td></tr>
<tr><td>E026 (3)</td><td>Shutdown</td><td>On [1]</td><td>85 °C</td></tr>
<tr><td rowspan="2">"High Inlet Air Temperature" (low load) 43 °C SCAC</td><td>E027 (1)</td><td>Warning</td><td>On</td><td>77 °C</td></tr>
<tr><td>E026 (3)</td><td>Shutdown</td><td>On [1]</td><td>80 °C</td></tr>
<tr><td rowspan="2">"High Inlet Air Temperature" (low load) 32 °C SCAC</td><td>E027 (1)</td><td>Warning</td><td>On</td><td>72 °C</td></tr>
<tr><td>E026 (3)</td><td>Shutdown</td><td>On [1]</td><td>75 °C</td></tr>
<tr><td rowspan="2">"High Inlet Air Temperature" (high load) 54 °C SCAC</td><td>E027 (1)</td><td>Warning</td><td>On</td><td>72 °C</td><td rowspan="6">32 to 120 °C</td></tr>
<tr><td>E026 (3)</td><td>Shutdown</td><td>On [1]</td><td>75 °C</td></tr>
<tr><td rowspan="2">"High Inlet Air Temperature" (high load) 43 °C SCAC</td><td>E027 (1)</td><td>Warning</td><td>On</td><td>65 °C</td></tr>
<tr><td>E026 (3)</td><td>Shutdown</td><td>On [1]</td><td>68 °C</td></tr>
<tr><td rowspan="2">"High Inlet Air Temperature" (high load) 32 °C SCAC</td><td>E027 (1)</td><td>Warning</td><td>On</td><td>57 °C</td></tr>
<tr><td>E026 (3)</td><td>Shutdown</td><td>On [1]</td><td>60 °C</td></tr>
</table>

(1) This parameter is permanently active. This parameter cannot be turned off.
(2) This trip point is active for engine speeds of less than 600 rpm.
(3) This trip point is active for engine speeds of 600 rpm or more than 600 rpm.

Separate timers are used in the ECM for each response that is associated with a parameter. If a trip point is reached, the timer for that event is started.

For example, the warning for "High Engine Coolant Temperature E017 (1)" can be set to 95 °C with a five second delay. The timer starts counting if the coolant temperature reaches 95 °C. If the temperature is not reduced to less than 95 °C within five seconds, the event becomes active and the event is logged.

Conditions for Parameters

Some of the programmable parameters are dependent on the status of an ECM output before the parameters are allowed to function. Some of the parameters are allowed to function after the crank terminate relay has been energized for more than 30 seconds. Other parameters are allowed to function after the output for the fuel control relay is energized. Some parameters are not dependent upon any conditions.

The conditions are designed to eliminate false events during start-up if the customer has programmed a delay time to zero. The conditions are listed in Table 6.

Table 6

Conditions for Activation for Monitoring the Parameters	
Parameter	**Condition**
"Low System Voltage"	None
"High Engine Coolant Temperature"	The crank terminate relay is energized for more than 30 seconds.
"Low Engine Coolant Temperature"	None
"Engine Overspeed"	None
"High Engine Oil Temperature"	The crank terminate relay is energized for more than 30 seconds.
"High Oil Filter Differential Pressure"	
"Low Oil Filter Differential Pressure"	
"High Fuel Temperature"	
"Low Fuel Pressure"	The fuel control relay is energized.
"High Jacket Water to Engine Oil Temp Differential"	The crank terminate relay is energized for more than 30 seconds.
"High System Voltage"	None
"High Inlet Air Temperature at Low Engine Load"	The crank terminate relay is energized for more than 30 seconds.
"High Inlet Air Temperature at High Engine Load"	

If the trip point for a shutdown is programmed to activate before the trip point for a warning, the engine will shut down and the warning will not be activated.

Integrated Combustion Sensing Module (ICSM)

The ICSM monitors the temperatures of the cylinder exhaust ports, the inlets of the turbocharger turbine, and the outlets of the turbocharger turbines. The ICSM also monitors the combustion sensors.

If a temperature exceeds an acceptable range, the ICSM can initiate a warning or a shutdown. Both of the responses are available for all of the parameters.

Note: To initiate the responses, the ICSM sends commands to the ECM via the Cat Data Link.

The default settings for the parameters are programmed at the factory. To accommodate unique applications and sites, the parameters may be reprogrammed with Cat ET. The screens of Cat ET provide guidance for changing trip points. Use Cat ET to perform the following activities:

- Select the available responses.
- Program the level for monitoring.
- Program delay times for each response.

Table 7 lists default examples of the values for the parameters. However, the values may have changed. Use Cat ET to determine the programming for your engine.

Table 7

Default Settings for the Integrated Combustion Sensing Module								
Parameter	**Event Code**	**System Response**	**State**	**Trip Point**	**Delay in Seconds**	**Security Level Password**	**Range**	**Range of the Delay in Seconds**
"High Exhaust Port Temp"	E801 (1) through E816 (1)	Warning	On	600 °C	10	Customer	100 to 1000 °C	1 to 1200
	E801 (3) through E816 (3)	Shutdown		650 °C				
"Exhaust Port Temp Deviating High"	E821 (1) through E836 (1)	Warning		50 °C	240		10 to 500 °C	
	E821 (3) through E836 (3)	Shutdown	Off	100 °C	600			
"Exhaust Port Temp Deviating Low"	E841 (1) through E856 (1)	Warning	On	120 °C	300			
	E841 (3) through E856 (3)	Shutdown	Off	400 °C				
"High Turbo Turbine Inlet Temperature"	E245 (1) E246 (1)	Warning	On	600 °C	10		400 to 700 °C	
	E245 (3) E246 (3)	Shutdown		650 °C				
"High Turbo Turbine Outlet Temperature"	E243 (1) E244 (1)	Warning		570 °C			400 to 650 °C	
	E243 (3) E244 (3)	Shutdown		600 °C				

Separate timers are used in the ICSM for each response that is associated with a parameter. If a trip point is exceeded, the timer for that event is started.

For example, the warning for the "High Exhaust Temperature" (E801 (1)) can be set to 495 °C with a five second delay. The timer starts counting if the exhaust port temperature of the number 1 cylinder reaches 495 °C. If the temperature is not reduced to less than 495 °C within five seconds, the event becomes active and the event is logged.

Ignition System

i01544274

Ignition System

SMCS Code: 1550

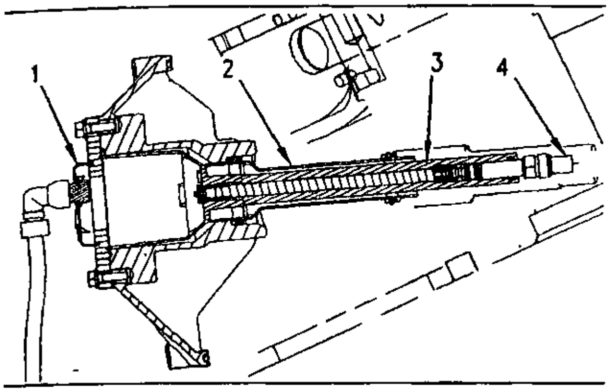


Illustration 24 g00822915

(1) Ignition transformer
(2) Tube
(3) Extension
(4) Spark plug

Each cylinder has an ignition transformer. To initiate combustion, the ECM sends a pulse of approximately 108 volts to the primary coil of each ignition transformer at the appropriate time and for the appropriate duration. The transformer increases the voltage which creates a spark across the spark plug electrode.

The connections (terminals) must be clean and tight. The negative transformer terminals are connected together and the terminals are connected to ground.

Detonation sensors monitor the engine for excessive detonation. The engine has one detonation sensor for each two adjacent cylinders. The sensors generate data on vibration that is processed by the ECM in order to determine detonation levels. If detonation reaches an unacceptable level, the ECM retards the ignition timing of the affected cylinder or cylinders. If retarding the timing does not limit detonation to an acceptable level, the ECM shuts down the engine.

The ECM provides extensive diagnostics for the ignition system. The ECM also provides a switch for ignition timing in order to allow operation with alternate fuels that require a timing offset.

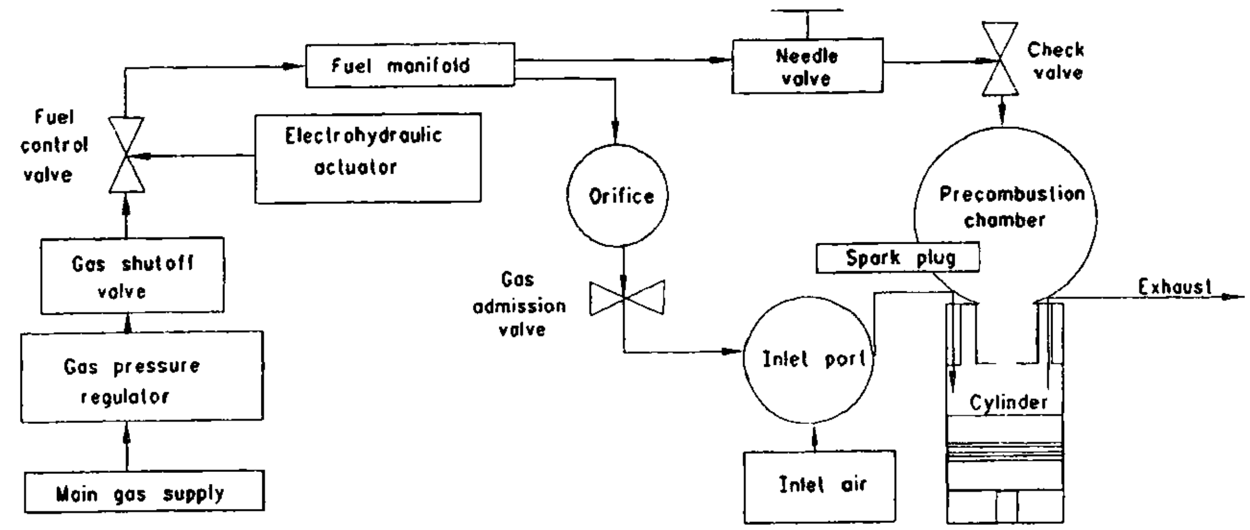
Fuel System

i01544213

Fuel System

SMCS Code: 1250

To ensure precise regulation of fuel flow, carburetors are not used. Fuel flow is controlled with a hydraulic actuator in order to maintain precise control of fuel delivery to the engine. Illustration 25 is a schematic of the fuel system.



g00815620

Illustration 25

Schematic of the fuel system

Gas from the main gas supply flows through a gas pressure regulator. Pressure to the regulator must be 379 to 1034 kPa (55 to 150 psi). Lower pressure may result in reduced power. Pressure from the regulator to the engine must be 310 ± 14 kPa (45 ± 2 psi). The fuel pressure must be stable to ± 1.7 kPa (± .25 psi).

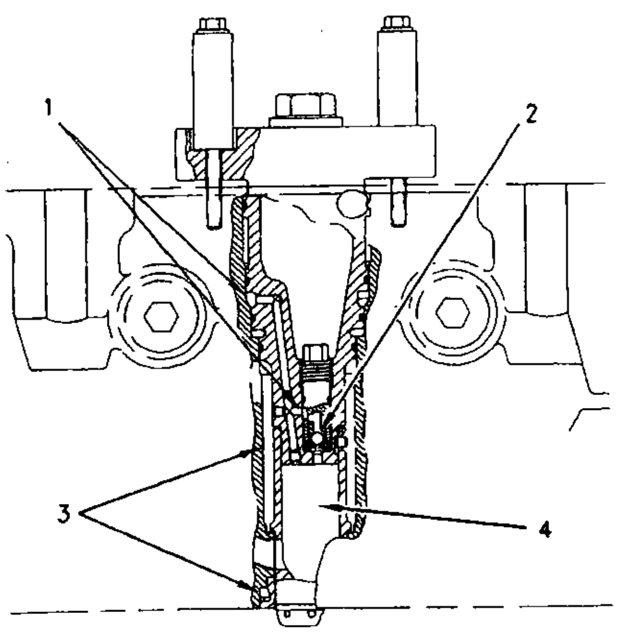
The gas flows through a gas shutoff valve into the fuel control valve. The ECM issues a command signal to an electrohydraulic actuator in order to control the flow of fuel to the fuel manifold. The signal is based on the difference between the actual engine rpm and the desired engine rpm.

The flow of gas from the fuel manifold is divided. There is a gas line for each cylinder. Most of the gas flows through the gas line, an orifice, and a gas admission valve to the inlet port for the cylinder. The inlet air that is necessary for combustion also flows into the inlet port. The gas and combustion air flow through the inlet port and the openings for the inlet valves to the cylinder's main combustion chamber.

Each cylinder has a smaller gas line. The remainder of the gas flows through the smaller gas line. The gas is regulated by an adjustable needle valve before the gas flows into the precombustion chamber.

The rich air/fuel mixture in the precombustion chamber is ignited by the spark plug. This ignites the leaner air/fuel mixture in the main combustion chamber. Exhaust exits the cylinder through the openings for the exhaust valves.

Precombustion Chamber and Main Combustion Chamber



g00292465

Illustration 26

(1) Fuel inlet passage
(2) Check valve
(3) Passages for the engine coolant
(4) Precombustion chamber

The gas supply flows through a small line from the fuel manifold through an adjustable needle valve. Adjustment of the needle valve helps to provide the desired combustion burn time.

The gas flows through fuel inlet passage (1) into check valve (2) at the top of precombustion chamber (4). A ball at the bottom of the check valve moves away from the orifice during the intake stroke in order to admit gas into the precombustion chamber.

The gas in the precombustion chamber is mixed with some combustion air from the main combustion chamber. The rich air/fuel mixture in the precombustion chamber is ignited by the spark plug. The ball at the bottom of the check valve is forced upward by compression from combustion in order to stop the flow of gas through the check valve.

Coolant flows through passages (3) in order to cool the precombustion chamber.

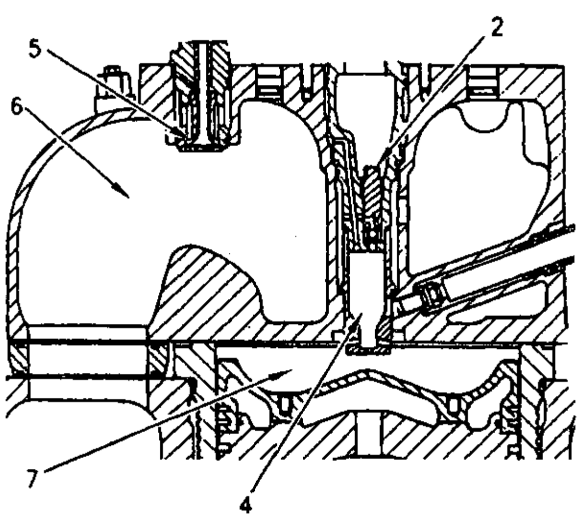


Illustration 27 g00815667

(2) Check valve
(4) Precombustion chamber
(5) Gas admission valve
(6) Combustion air
(7) Main combustion chamber

The flow of combustion air (6) into the cylinder head is regulated by the exhaust bypass (wastegate) and the air choke. This regulation depends on the engine load. As the inlet valve admits air into the cylinder head, gas admission valve (5) admits gas.

Gas admission valve (5) is mounted in the inlet port. The valve is actuated by the camshaft. As the gas admission valve opens, gas is admitted into the inlet port. The gas mixes with combustion air (6) in the inlet port. The gas and combustion air are mixed before flowing into main combustion chamber (7). The ignited gas in the precombustion chamber ignites the air/fuel mixture in the main combustion chamber.

The need for low emissions and consistent combustion requires the use of a rich fuel in the 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. The rich fuel is more completely burned prior to entering the main chamber. Mixing of the fuel in the precombustion chamber with the combustion air from the main chamber during cylinder compression yields an optimum air/fuel mixture for initiation of combustion.

Fuel Limiting

The engine's control strategy has a fuel limit. The limit allows the engine to operate at a maximum of 110 percent of the engine's rated torque at any given engine speed. This limit was established in order to prevent damage to the engine due to excessive engine loads. The limit also enables engine operation when the conditions change.

A cylinder misfire could drive the engine into an overload condition. The calculated load is based partly on the fuel flow.

The fuel flow increases when cylinder misfire occurs. This increased fuel flow is the combined result of the unburned gas that is passing through the misfiring cylinder and the increased fuel consumption of the remaining cylinders that must pick up the additional load. Although the engine is not actually overloaded, an increase in the fuel flow due to misfire will result in a higher indicated engine load.

Air Inlet and Exhaust System

i01749289

Air Inlet and Exhaust System

SMCS Code: 1050

Air Inlet and Exhaust System Components

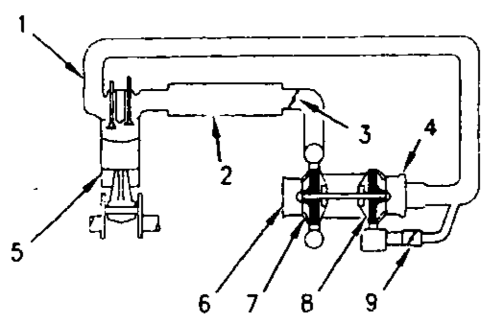


Illustration 28 g00328151

(1) Exhaust manifold
(2) Aftercooler
(3) Air choke
(4) Exhaust inlet to the turbocharger
(5) Cylinder
(6) Air inlet
(7) Turbocharger compressor wheel
(8) Turbocharger turbine wheel
(9) Exhaust bypass (wastegate)

Clean inlet air from the air cleaners is drawn through air inlet (6) into the turbocharger compressor by compressor wheel (7). The air is compressed and the air is forced through air choke (3). The air flows through aftercooler (2). The aftercooler reduces the temperature of the compressed air before the air enters the air plenum. The air enters the air inlets in the cylinder heads.

Air flow into cylinder (5) is controlled by the inlet valves. The camshaft controls the opening of the valves. There are two inlet valves, two exhaust valves, and one gas admission valve for each cylinder. The inlet valves and the gas admission valve open when the piston moves down on the intake stroke. The air/fuel mixture is pulled into the cylinder through the inlet port. For more information, refer to "Valve System Components".

The gas admission valve 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 leaner air/fuel mixture in the cylinder is mixed with the richer air/fuel mixture in the precombustion chamber. The combustible mixture in the precombustion chamber is ignited by the spark plug. This ignites the air and fuel in the cylinder.

The force of the combustion pushes down on the piston for the power stroke. The piston moves up again on the exhaust stroke. The exhaust valves open and the piston pushes exhaust gases through the exhaust port into exhaust manifold (1). After the exhaust stroke, the exhaust valves close. The four stroke cycle continues: intake, compression, power, and exhaust.

Exhaust gas from exhaust manifold (1) is directed through the exhaust inlet to the turbocharger. The exhaust gas turns turbocharger turbine wheel (8). The turbine wheel is connected to the shaft that drives the compressor wheel.

If too much compressed air is supplied by the turbocharger, exhaust gas can be diverted directly to the exhaust elbow by exhaust bypass (9) (wastegate). This depends on the requirements for inlet manifold air pressure.

An electrohydraulic actuator controls the position of the exhaust bypass (wastegate) (9). The actuator provides the desired inlet manifold air pressure. The position of the actuator is determined by the Electronic Control Module (ECM).

Aftercooler

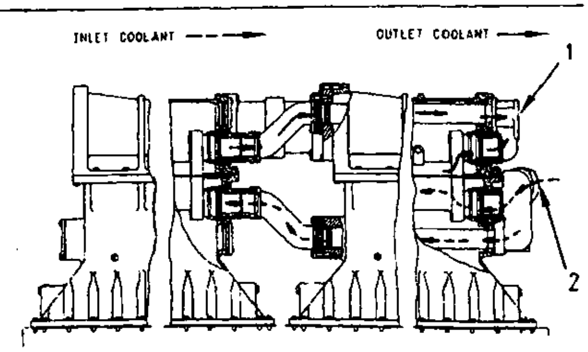


Illustration 29 g00485390

Vee engines

(1) Coolant outlet
(2) Coolant inlet

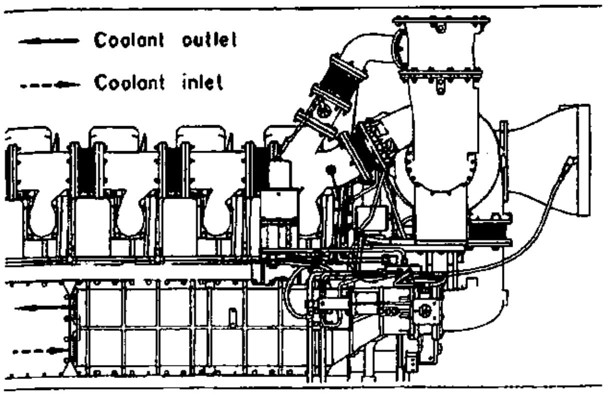


Illustration 30 g00895403

In-line engines

Coolant from the water pump on the left side of the engine flows through the coolant inlet. Coolant circulates through the aftercooler core's assemblies. Inlet air from the compressor side of the turbocharger flows into the air side of the aftercooler housing. The inlet air passes the fins in the core assemblies. The compressed inlet air exchanges heat with the coolant. The temperature of the air is reduced in the aftercooler core. The cooler air flows into the air plenum and through the inlet ports of the cylinder heads.

Reducing the temperature of the inlet air increases the density of the air. This results in more efficient combustion and in lower fuel consumption.

The coolant exits the aftercooler through the coolant outlet.

Turbocharger

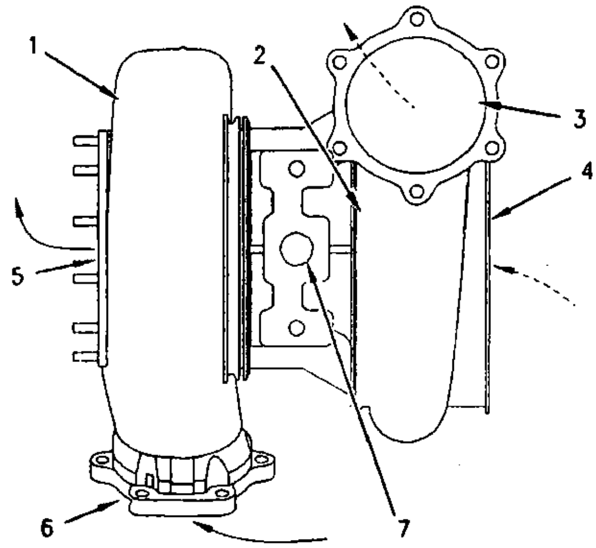


Illustration 31 g00825487

Typical example

(1) Turbine housing
(2) Compressor housing
(3) Outlet for the air from the compressor
(4) Air inlet for the compressor
(5) Outlet for the exhaust from the turbine
(6) Inlet for the exhaust to the turbine
(7) Outlet for the engine oil

Turbine housing (1) is connected between the exhaust manifold and the exhaust elbow. Compressor housing (2) is connected between the air cleaners and the aftercooler.

Exhaust gas flows into the turbocharger through inlet (6). The exhaust gas pushes the blades of the turbine wheel in the turbine housing. The exhaust gas exits the turbine housing through outlet (5).

The turbine wheel is connected to a compressor wheel in the compressor housing. Rotation of the turbine wheel causes the compressor wheel to rotate.

Clean air from the air cleaner is drawn into air inlet (4) by the rotation of the compressor wheel. The compressor wheel compresses the inlet air. The air exits the compressor housing through outlet (3) and the air flows to the aftercooler. Compression of the air provides the engine with more power because the engine can burn additional fuel with greater efficiency.

Pressurized engine oil enters an inlet to passages in the center section of the turbocharger in order to lubricate the bearings. The engine oil exits through outlet (7).

The bearing housing in the turbocharger is cooled by coolant that flows through coolant passages in the bearing housing.

Exhaust Bypass

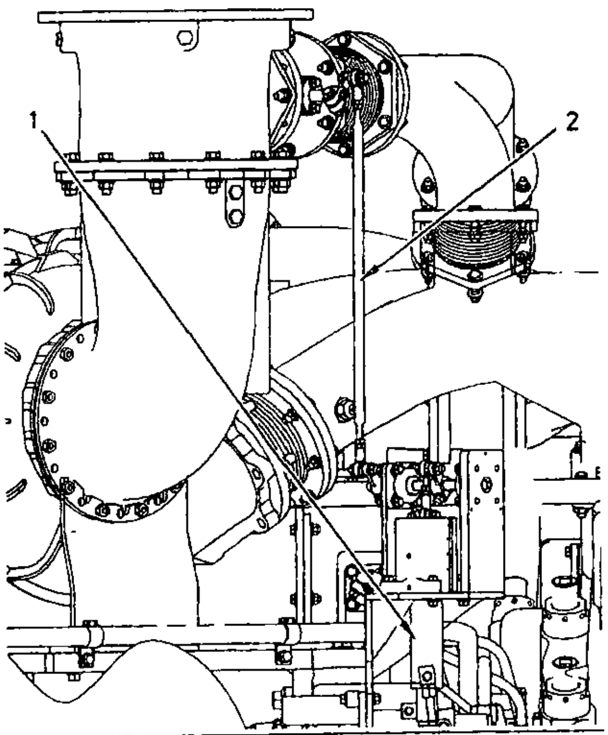


Illustration 32 g00815802

Vee engines

(1) Electrohydraulic actuator
(2) Linkage

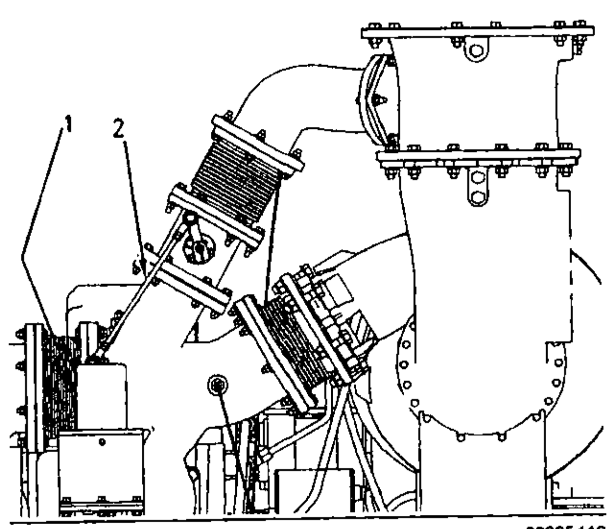


Illustration 33 g00895410

In-line engines

(1) Electrohydraulic actuator (not shown)
(2) Linkage

Actuator (1) for the exhaust bypass receives an electronic command signal from the ECM. The command signal is a pulse width modulated signal (PWM). The signal is based on the difference between the average combustion burn time and the desired combustion burn time. The signal causes the actuator to move linkage (2) in order to operate the exhaust bypass.

When the ECM requests a slower combustion burn time or a leaner air/fuel ratio, the actuator moves the exhaust bypass toward the closed position. This directs more of the exhaust gas to the turbocharger turbine wheel. The additional exhaust gas increases the rpm of the turbine wheel and of the compressor wheel. A greater quantity of air is compressed for combustion. This increases the amount of air in the air/fuel mixture.

When the ECM requests a faster combustion burn time or a richer air/fuel ratio, the actuator opens the plate of the exhaust bypass. This diverts some of the exhaust gas directly to the exhaust elbow instead of through the turbocharger. The reduction of exhaust gas to the turbine wheel reduces the rpm of the turbine wheel and of the compressor wheel. Less inlet air is compressed for combustion. This reduces the amount of air in the air/fuel mixture.

Air Choke

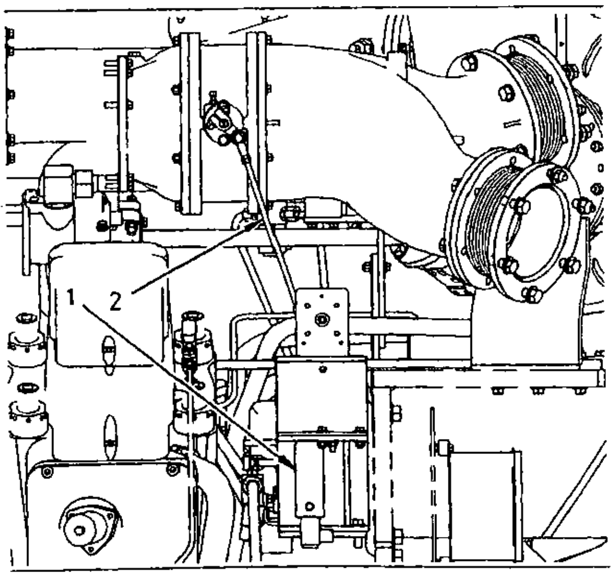


Illustration 34 g00815989

Vee engines

(1) Electrohydraulic actuator
(2) Linkage

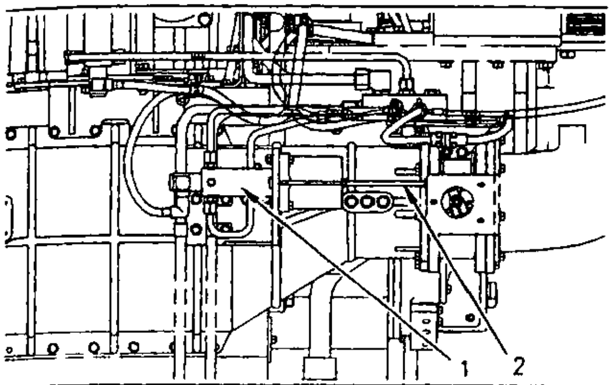


Illustration 35 g00895414

In-line engines

(1) Electrohydraulic actuator
(2) Linkage

Actuator (1) receives an electronic command signal from the ECM. The signal is based on the exhaust port temperatures. The signal causes the actuator to move linkage (2) in order to operate the air choke. Movement of the air choke's plate controls the flow of inlet air from the turbocharger to the aftercooler.

At full load and full speed, the air choke is in the fully open position. This reduces the restriction of the air flow. The engine efficiency is improved.

As engine load decreases, the air choke begins to restrict air flow. This maintains a sufficiently rich air/fuel mixture for combustion at lighter engine loads.

Exhaust Manifold

The dry exhaust manifold provides maximum heat to the turbine. The exhaust manifold is insulated. The insulation helps retain the heat in the exhaust system. The energy from the heat helps to drive the turbocharger turbine. The insulation also helps protect the components that are outside of the exhaust system from the heat.

NOTICE

The soft wrap must remain on the exhaust manifolds at all times. The soft wrap prevents the wiring from burning. The soft wrap also prevents the oil lines and the water lines from heating up.

A dry exhaust manifold is possible because of the lower exhaust temperatures of lean combustion. Engine performance is enhanced.

Valve System Components

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

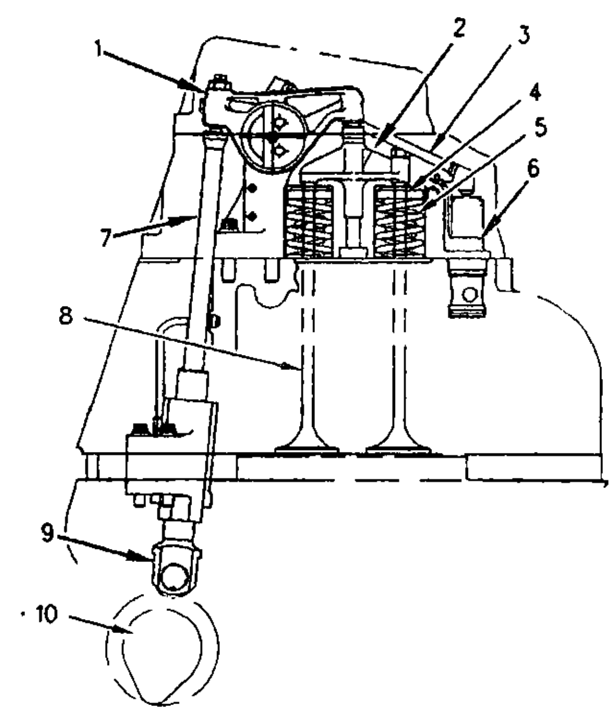


Illustration 36 g00825443

(1) Rocker arm
(2) Valve bridge
(3) Rod
(4) Valve rotator
(5) Valve spring
(6) Gas admission valve
(7) Pushrod
(8) Inlet valve
(9) Valve lifter
(10) Camshaft lobe

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 movement of the piston and movement of the valves.

The camshafts have three camshaft lobes (10), valve lifters (9), and pushrods (7) for each cylinder. One lobe operates valve bridge (2) that moves two inlet valves (8). One lobe operates the valve bridge that moves the two exhaust valves. The center lobe operates gas admission valve (6). As the camshaft turns, the camshaft lobes cause the valve lifters and pushrods to move up and down.

One pushrod moves rod (3) in order to operate gas admission valve (6). The other two pushrods move rocker arms (1). Movement of the rocker arms cause valve bridges (2) to move up and down on a dowel in the cylinder head. This movement operates inlet valves (6) and the exhaust valves. One valve bridge enables one rocker arm to operate two valves simultaneously. There are two inlet valves and two exhaust valves for each cylinder.

Valve rotator (4) turns the valve during engine operation. The rotation of the valves keeps the deposit of carbon on the valves to a minimum. This provides longer service life for the valves.

When valve lifter (9) moves downward, valve spring (5) closes the valve.

Lubrication System

i01749321

Lubrication System

SMCS Code: 1300

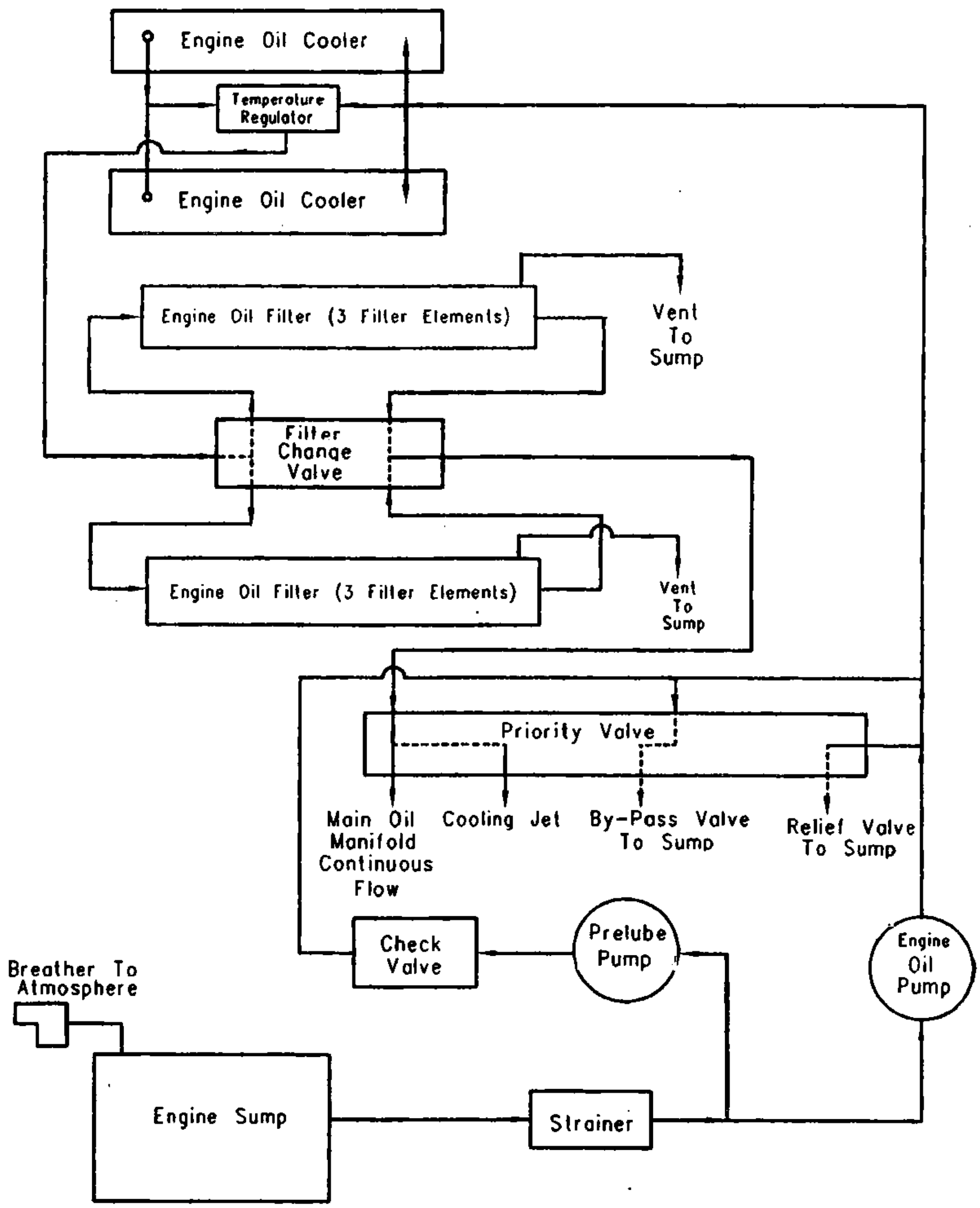
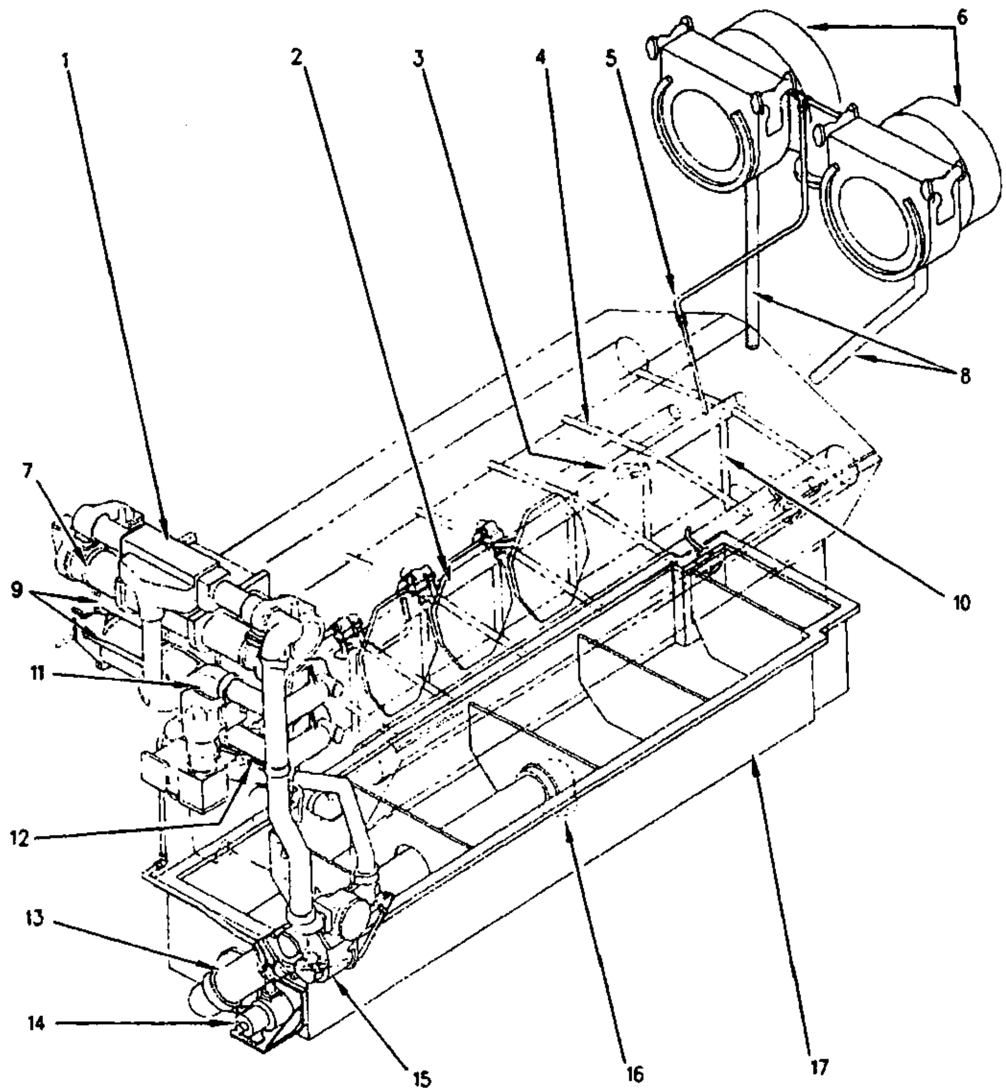


Illustration 37 g00827644

Lubrication system schematic



g00292619

Illustration 38

Lubrication system components (Vee engines)

(1) Temperature regulator housing
(2) Main engine oil gallery
(3) Piston cooling jets
(4) Drilled passage between the main engine oil gallery and the camshaft bearings
(5) Tube for engine oil to the turbocharger
(6) Turbochargers
(7) Engine oil cooler
(8) Drain lines for the engine oil from the turbochargers
(9) Engine oil filter housing
(10) Drilled passage between the main engine oil gallery and the crankshaft main bearings
(11) Valve for the engine oil filters
(12) Priority valve
(13) Suction tube
(14) Prelube pump
(15) Engine oil pump
(16) Suction bell
(17) Engine oil pan

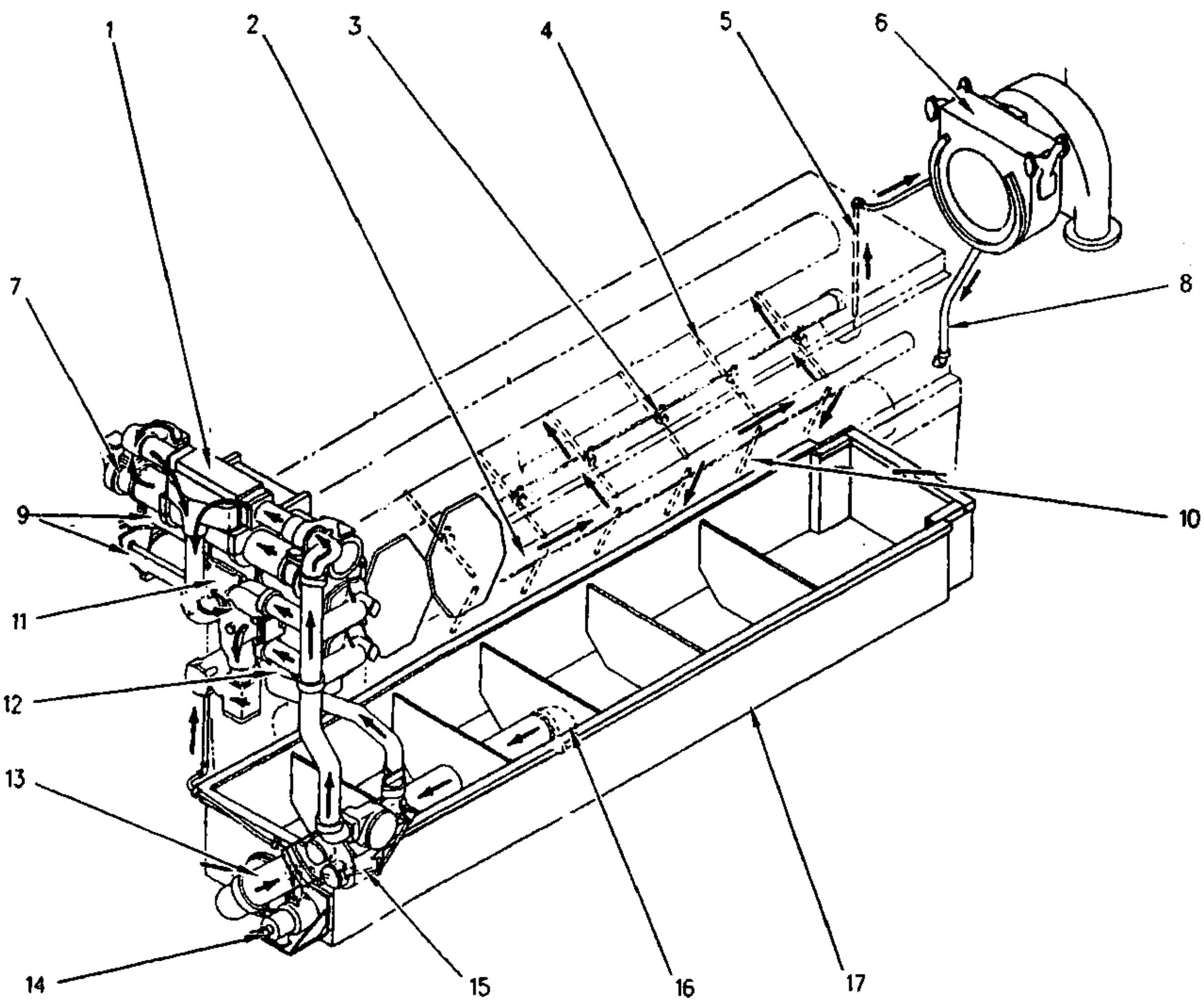


Illustration 39 g00895421

Lubrication system components (In-line engines)

(1) Temperature regulator housing
(2) Main engine oil gallery
(3) Piston cooling jets
(4) Drilled passage between the main engine oil gallery and the camshaft bearings
(5) Tube for engine oil to the turbocharger
(6) Turbochargers
(7) Engine oil cooler
(8) Drain lines for the engine oil from the turbochargers
(9) Engine oil filter housing
(10) Drilled passage between the main engine oil gallery and the crankshaft main bearings
(11) Valve for the engine oil filters
(12) Priority valve
(13) Suction tube
(14) Prelube pump
(15) Engine oil pump
(16) Suction bell
(17) Engine oil pan

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

Engine oil pump (15) is mounted on the front left side of the front housing. The engine oil pump pulls engine oil from the pan through suction bell (16) and suction tube (13). The suction bell has a screen in order to strain the engine oil.

The engine oil pump has a relief valve. If the pressure from the pump reaches 1000 kPa (145 psi), the relief valve opens and some of the engine oil returns to the engine oil pan. This helps prevent damage to the lubrication system components when the engine oil is cold.

Engine oil is pumped to the ports on the bypass valve of priority valve (12). If the pressure in the main oil gallery becomes excessive, the bypass valve opens in order to divert the engine oil back to the engine oil pan.

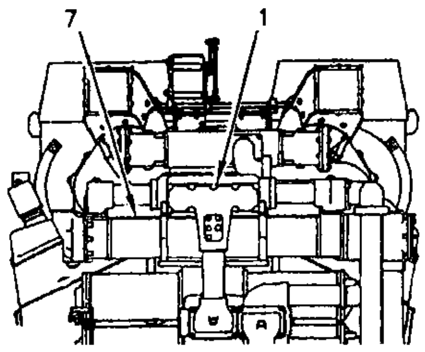


Illustration 40 g00292624

(1) Temperature regulator housing
(7) Engine oil coolers

The engine oil is pumped to temperature regulator housing (1). The temperature regulators and engine oil coolers (7) maintain the 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. If the engine oil temperature is higher than 85 °C (185 °F), the flow is directed to the engine oil coolers. Engine oil flows from the engine oil coolers through valve (11) to engine oil filter housing (9).

At cooler oil temperatures, the engine oil bypasses the engine oil coolers and the engine oil flows directly to the engine oil filter housing.

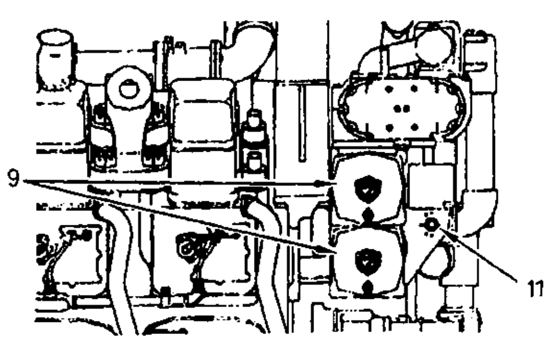


Illustration 41 g00825761

(9) Engine oil filter housing
(11) Valve for the engine oil filters

Each engine oil filter housing (9) contains three engine oil filter elements. Each housing has a port in order to purge air for draining and for filling.

Valve (11) allows the filter elements for each housing to be changed separately during engine operation.

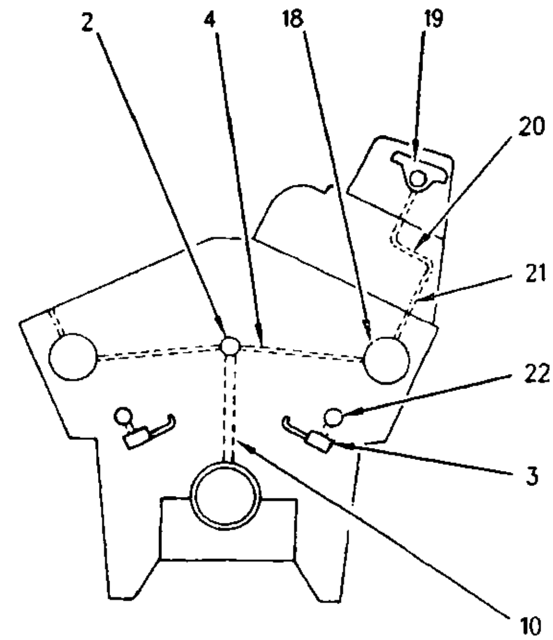


Illustration 42 g00292623

Engine oil flow through the cylinder block (Vee engines)

(2) Main engine oil gallery
(3) Piston cooling jets
(4) Drilled passage between the main engine oil gallery and the camshaft bearings
(10) Drilled passage between the main engine oil gallery and the crankshaft main bearings
(18) Camshaft bearing
(19) Rocker arm assembly
(20) Drilled passage between the camshaft bearings and the cylinder head
(21) Tube
(22) Gallery for the piston cooling jets

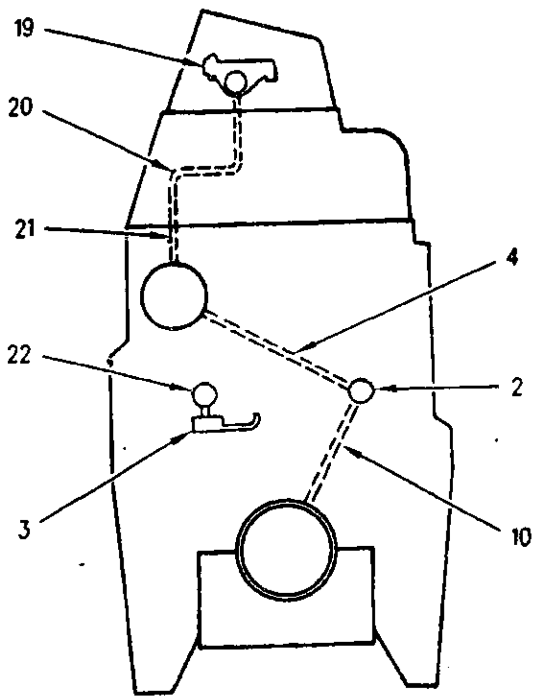


Illustration 43 g00895430

Engine oil flow through the cylinder block (In-line engines)

(2) Main engine oil gallery
(3) Piston cooling jets
(4) Drilled passage between the main engine oil gallery and the camshaft bearings
(10) Drilled passage between the main engine oil gallery and the crankshaft main bearings
(18) Camshaft bearing
(19) Rocker arm assembly
(20) Drilled passage between the camshaft bearings and the cylinder head
(21) Tube
(22) Gallery for the piston cooling jets

The engine oil flows from the engine oil filters through priority valve (12) into main engine oil gallery (2) and into gallery (22) for the piston cooling jets.

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

When the pressure in the system reaches 140 kPa (20 psi), priority valve (12) admits the engine oil to gallery (22) for the piston cooling jets. The priority valve will not allow engine oil into the gallery until there is pressure in main engine oil gallery (2). This reduces the amount of time that is necessary for the pressure to build up during start-up. The priority valve also helps maintain pressure at low idle speed.

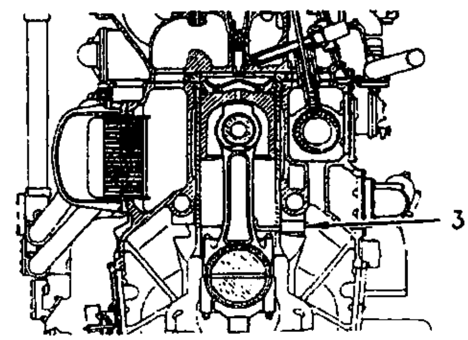


Illustration 44 g00292627

(3) Piston cooling jet

Piston cooling jet (3) is located in the engine block below each piston. Each piston cooling jet has two tubes with open ends. One tube distributes engine oil to an opening in the bottom of the piston for an engine oil gallery in the piston. This gallery provides engine oil to a manifold behind the ring band of the piston. The manifold provides engine oil to a slot (groove) in the side of both piston pin bores. The other tube directs engine oil to the center of the piston. This provides lubrication to the piston pin and for the piston undercrown. This also helps cool the piston.

The camshaft bearings receive engine oil from main engine oil gallery (2) through drilled passages (4) in the cylinder block. The engine oil lubricates each camshaft bearing (18).

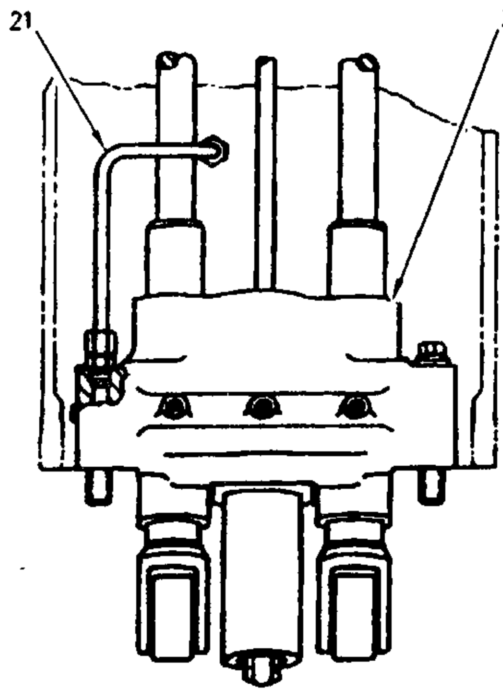


Illustration 45 g00292626

(21) Tube
(23) Valve lifter guide

Engine oil from the camshaft bearing flows through a drilled passage in the cylinder block to valve lifter guide (23) and to tube (21).

Tube (21) connects the valve lifter guide with passage (20). Engine oil flows through the tube and through the passage to the cylinder head and to rocker arm assembly (19).

Tube (5) provides engine oil for lubrication of the turbocharger bearings. The engine oil drains from the turbocharger to the flywheel housing through drain lines (8).

Engine oil is pumped to the front gear group and to the rear gear group through tubes and through drilled passages in the front housing and in the rear housing.

After the lubrication is completed, the engine oil returns to the engine oil pan.

Cooling System

i01749384

Cooling System

SMCS Code: 1350

The engine has two cooling systems. The jacket water system cools the cylinder block, cylinder heads, and turbochargers. A separate system cools the aftercooler and the engine oil cooler.

Water temperature regulators are used in each circuit in order to maintain correct operating temperatures. The water temperature regulators can control the minimum temperature to the inlet of the water pump or the minimum temperature at the outlet from the engine. This depends on the installation of the water temperature regulators.

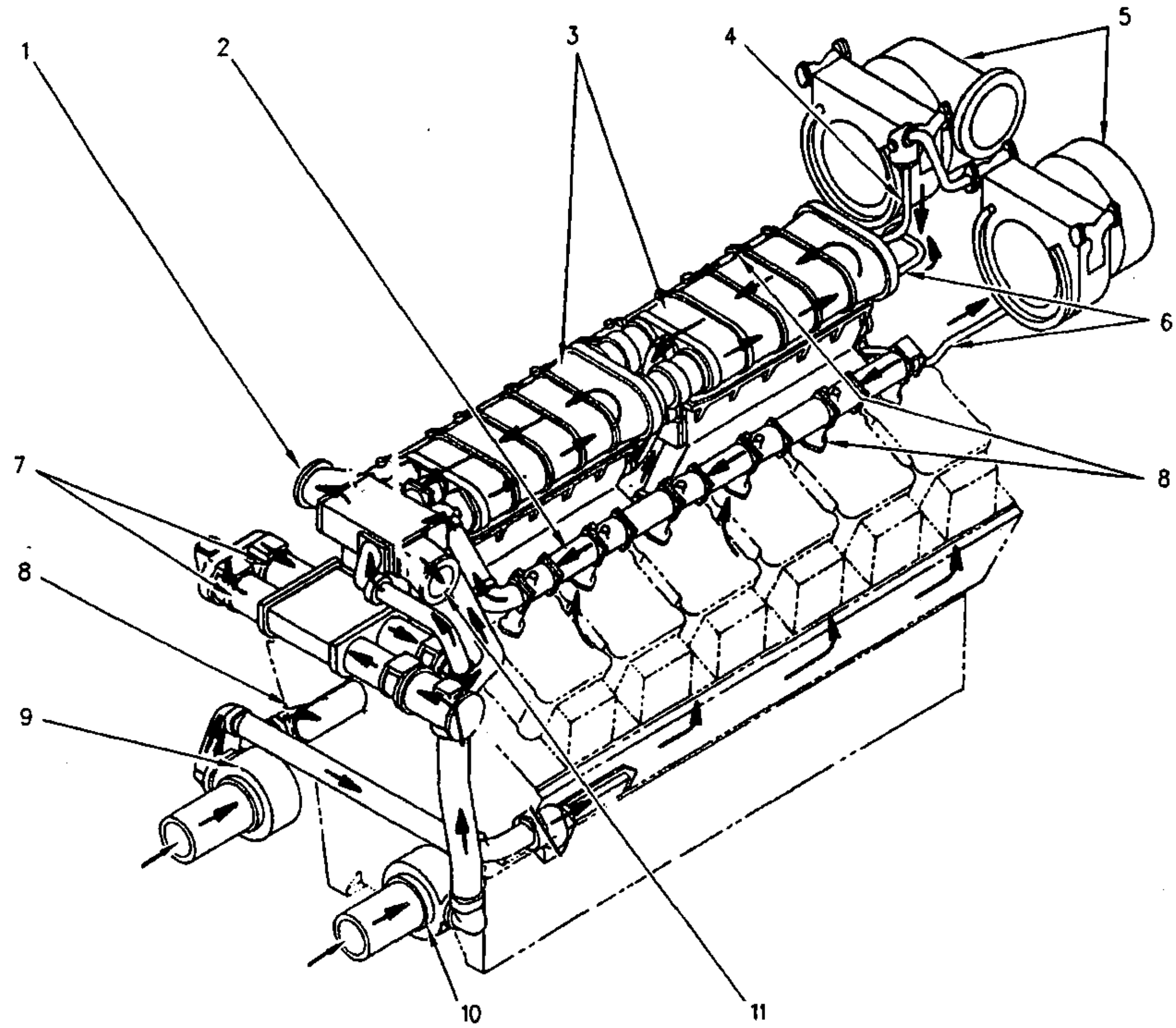
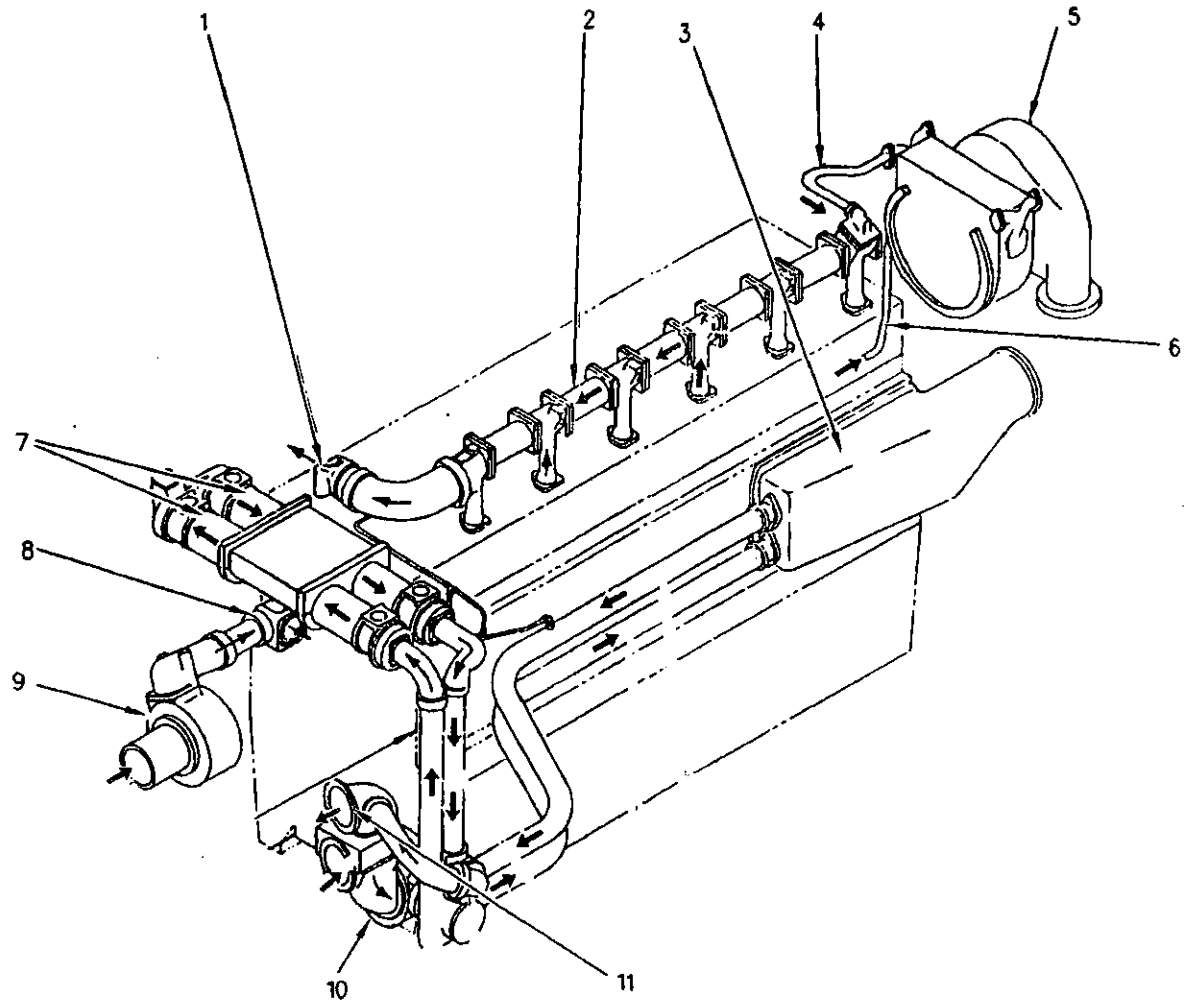


Illustration 46 g00895481

Vee engine

(1) Coolant outlet to the heat exchanger (jacket water)
(2) Water manifold
(3) Aftercooler
(4) Return line for coolant from the turbocharger
(5) Turbocharger
(6) Supply line for coolant to the turbocharger
(7) Engine oil coolers
(8) Elbow
(9) Jacket water pump
(10) Water pump for the aftercooler and oil cooler circuit
(11) Coolant outlet to the heat exchanger (aftercooler and oil cooler circuit)



g00895482

Illustration 47

In-line engine

(1) Coolant outlet to the heat exchanger (jacket water)
(2) Water manifold
(3) Aftercooler
(4) Return line for coolant from the turbocharger
(5) Turbocharger
(6) Supply line for coolant to the turbocharger
(7) Engine oil coolers
(8) Elbow
(9) Jacket water pump
(10) Water pump for the aftercooler and oil cooler circuit
(11) Coolant outlet to the heat exchanger (aftercooler and oil cooler circuit)

Jacket Water Cooling System

Water pump (9) (Illustrations 46 and 47) is located on the right front side of the engine. The water pump has a gear that is driven by the lower right front gear group. Coolant from the expansion tank enters the inlet to the pump. The rotation of the impeller in the water pump pushes the coolant to the side of the cylinder block through elbow (8).

The coolant inside the cylinder block flows around the cylinder liners. The water jacket is smaller near the top of the cylinder liners. This shelf causes the coolant to flow faster for better cooling of the cylinder liner. The coolant is pumped up through water directors and into the cylinder heads. The coolant flows through passages around the valves and around the exhaust gases in the cylinder head.

The coolant flows out of the cylinder head through an elbow into water manifold (2). The coolant flows through the manifold to coolant outlet (1). The coolant exits the outlet and flows through a remote mounted water temperature regulator and through the heat exchanger. The coolant then flows back to the expansion tank.

Coolant flows from the water jacket at the rear of the cylinder block through supply line (6) to turbocharger (5). Coolant from the turbocharger is returned to the cylinder block through return line (4).

A customer supplied vent line is required from the top of the turbochargers to the expansion tank. The vent line from the connection must be straight and the vent line must have a slight upward slope. The vent must not be obstructed.

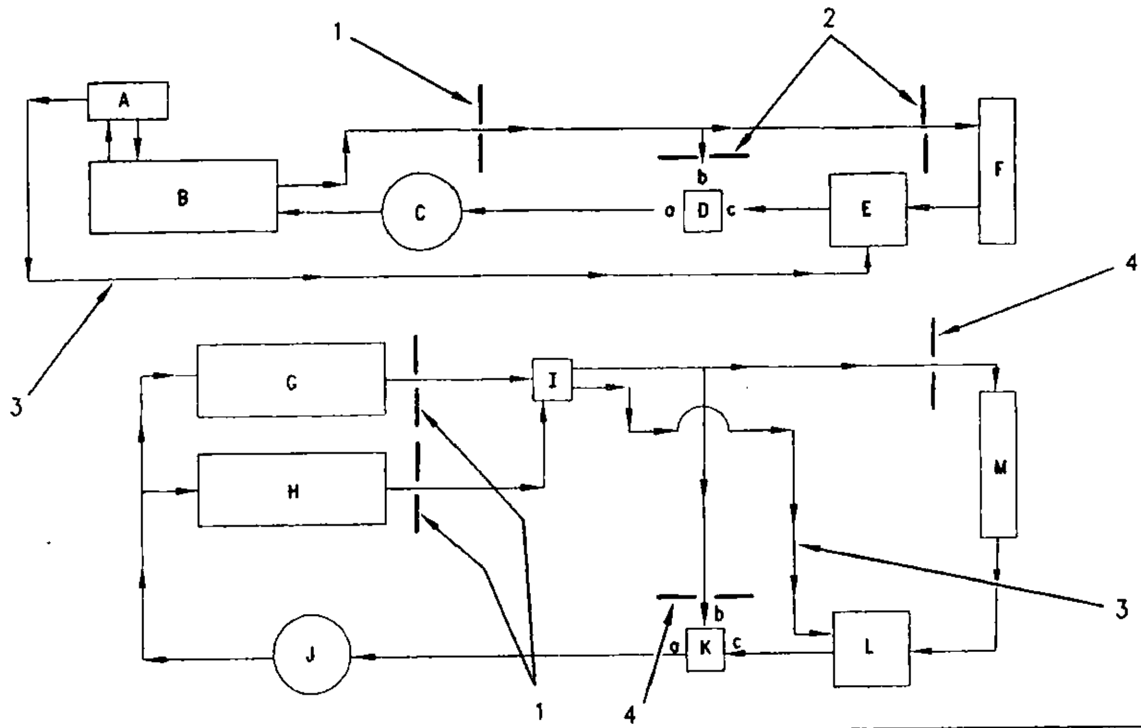
Aftercooler and Oil Cooler System

Water pump (10) (Illustrations 46 and 47) is located on the left front side of the engine. The water pump has a gear that is driven by the lower left front gear group. Coolant from the heat exchanger enters the inlet to the water pump. The rotation of the impeller in the water pump pushes the coolant to the engine oil cooler bonnet. Coolant flow is divided at the engine oil cooler bonnet. Part of the coolant flows to engine oil coolers (7). The remainder of the coolant flows to aftercooler (3). After the coolant flows through the aftercooler and through the engine oil coolers, the coolant returns to the heat exchanger through outlet (11).

A makeup line from the expansion tank to the coolant inlet helps maintain the coolant to the correct level.

A customer supplied vent line is required between the top of the housing for the engine oil coolers to the expansion tank. The vent line from the connection must be straight and the vent line must have a slight upward slope. The vent must not be obstructed.

Inlet Flow Control



g00829027

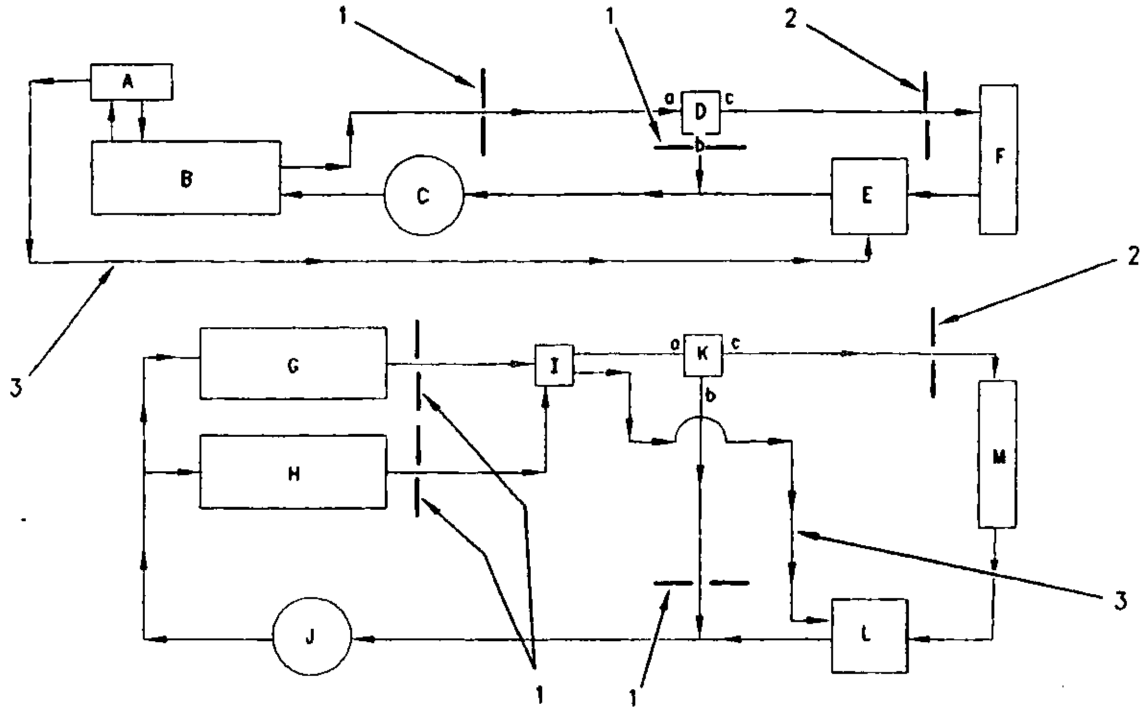
Illustration 48

Schematic of a cooling system with inlet flow control

(1) Orifices that are supplied by the factory
(2) Orifices that are supplied by the factory or the customer
(3) Vent lines
(4) Orifices that are supplied by the customer
(A) Turbocharger
(B) Cylinder block and cylinder head
(C) Jacket water pump
(D) Water temperature regulator housing (jacket water)
(E) Expansion tank
(F) Heat exchanger
(G) Engine oil cooler
(H) Aftercooler
(I) Mixer housing
(J) Water pump for the separate circuit
(K) Water temperature regulator housing (separate circuit)
(L) Expansion tank
(M) Heat exchanger
(a) Port
(b) Port
(c) Port

The inlet flow control maintains a minimum inlet temperature to the water pump. The temperature regulators control coolant flow through the water temperature regulator housing by passing all of the coolant across the regulators. When the coolant temperature is below the rating of the water temperature regulators, the coolant flows through bypass port (b) across the temperature regulators and out of port (a). As the coolant temperature rises, the water temperature regulators open. The coolant from the heat exchanger flows through port (c) in order to mix with the remainder of the coolant as the coolant exits the water temperature regulator housing.

Outlet Flow Control



829027

Illustration 49 g00829000

Schematic of a cooling system with outlet flow control

(1) Orifices that are supplied by the factory
(2) Orifices that are supplied by the factory or the customer
(3) Vent lines
(A) Turbocharger
(B) Cylinder block and cylinder head
(C) Jacket water pump
(D) Water temperature regulator housing (jacket water)
(E) Expansion tank
(F) Heat exchanger
(G) Engine oil cooler
(H) Aftercooler
(I) Mixer housing
(J) Water pump for the separate circuit
(K) Water temperature regulator housing (separate circuit)
(L) Expansion tank
(M) Heat exchanger
(a) Port
(b) Port
(c) Port

ing

The outlet flow control maintains a minimum temperature at the outlet from the engine. The coolant flows from the engine's outlet across the temperature sensing bulbs in port (a). The temperature sensing bulbs determine the direction of flow through the water temperature regulator housing. When the coolant temperature is below the water temperature 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 water temperature regulators open. Some of the flow is diverted through port (c) to the heat exchanger.

Basic Engine

i01749507

Basic Block

SMCS Code: 1201

Cylinder Block, Liners and Cylinder Heads

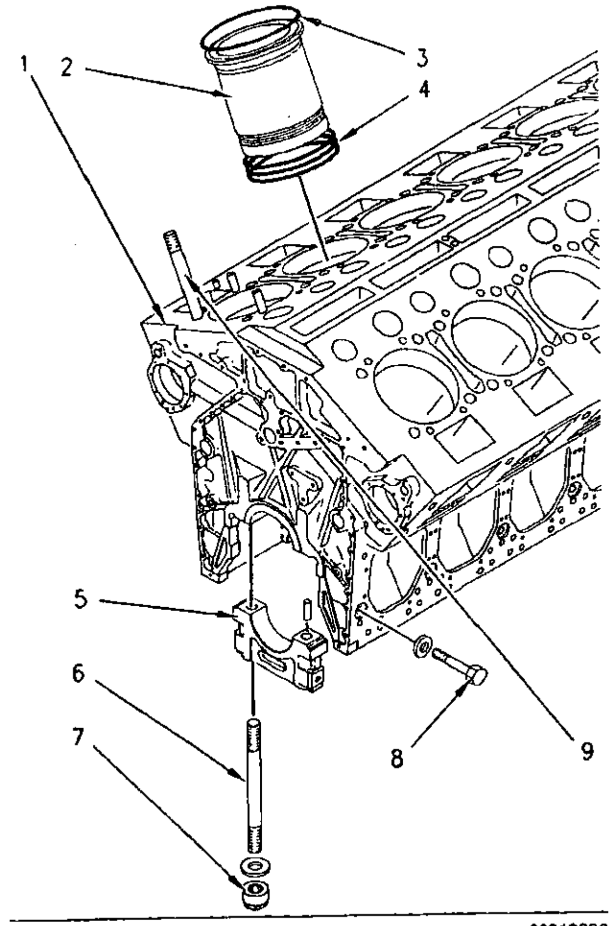


Illustration 50

Vee engine

g00816330

(1) Cylinder block
(2) Cylinder liner
(3) Filler band
(4) O-ring seals
(5) Main bearing cap
(6) Stud
(7) Nut
(8) Saddle bolt
(9) Stud

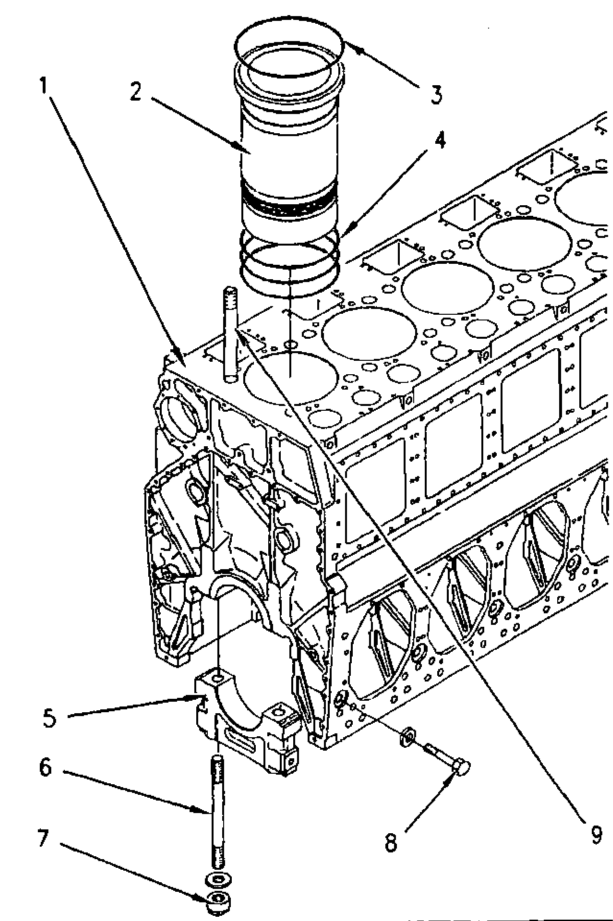


Illustration 51

In-line engine

g00895512

(1) Cylinder block
(2) Cylinder liner
(3) Filler band
(4) O-ring seals
(5) Main bearing cap
(6) Stud
(7) Nut
(8) Saddle bolt
(9) Stud

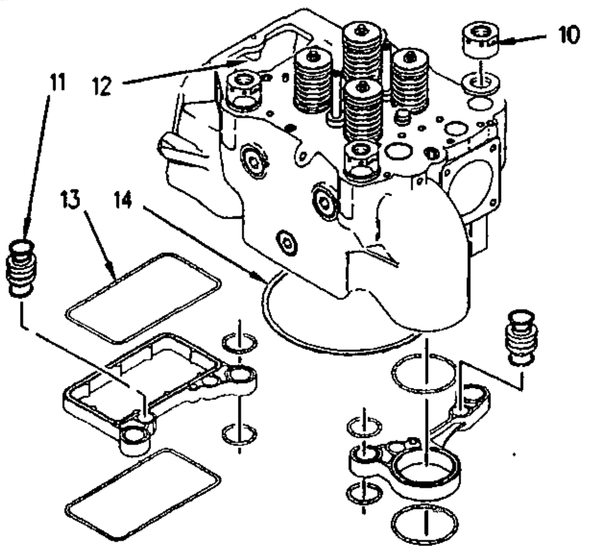


Illustration 52 g00816362

Cylinder head

(10) Nut
(11) O-ring seal
(12) Opening
(13) O-ring seal
(14) Combustion gasket

Cylinder block (1) is a one-piece casting. The air inlet plenum extends for the full length of the cylinder block in order to provide even distribution of air to the cylinders.

Cylinder liners (2) can be removed for replacement. The top surface of the cylinder block is the seat for the cylinder liner flange. Engine coolant flows around the cylinder liners in order to keep the cylinder liners cool. Filler band (3) and three O-ring seals (4) seal the coolant in the cylinder block.

Main bearing caps (5) are fastened to the cylinder block with two studs (6) per cap. Nuts (7) for the studs are hydraulically tensioned. Each main bearing cap has one saddle bolt (8) on each side of the cylinder block. The saddle bolts help prevent the movement of the main bearing cap. The saddle bolts also add strength to the lower area of the cylinder block.

The engine has a separate cylinder head for each cylinder. Each cylinder head is fastened to the cylinder block by four studs (9) and by four nuts (10). The studs are hydraulically tensioned. The nuts are tightened by hand and the hydraulic tension is released.

Each cylinder head contains the valve mechanism for inlet air, for fuel, and for exhaust gas. For information on the valve mechanism, refer to Systems Operation, "Air Inlet and Exhaust System". The inlet and exhaust valves move in replaceable valve guides which are pressed into the cylinder head.

O-ring seals (11) seal coolant that flows to the cylinder head through four adapters. Engine oil that returns to the engine oil pan through opening (12) is sealed with O-ring seals (13). The seals are installed in two plates for each cylinder head.

Combustion gas is sealed by combustion gasket (14) that is installed between the cylinder liner flange and the cylinder head.

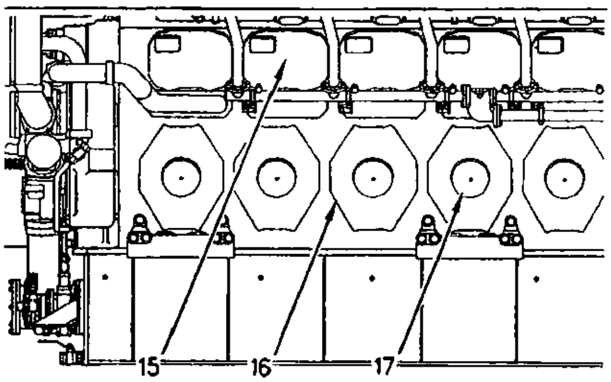


Illustration 53 g00816437

(15) Cover for the camshaft
(16) Cover for the crankcase
(17) Crankcase explosion relief valve

Covers (15) allow access to the camshafts, to the valve lifters, and to the valve lifter guides.

Covers (16) allow access to the crankshaft, to the connecting rods, to the piston cooling jets, and to the main bearings.

Crankcase explosion relief valves (17) open in order to relieve the pressure in case of an explosion in the crankcase. The valves 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. Do not change the total number of crankcase explosion relief valves that are installed on the engine.

Pistons, Rings and Connecting Rods

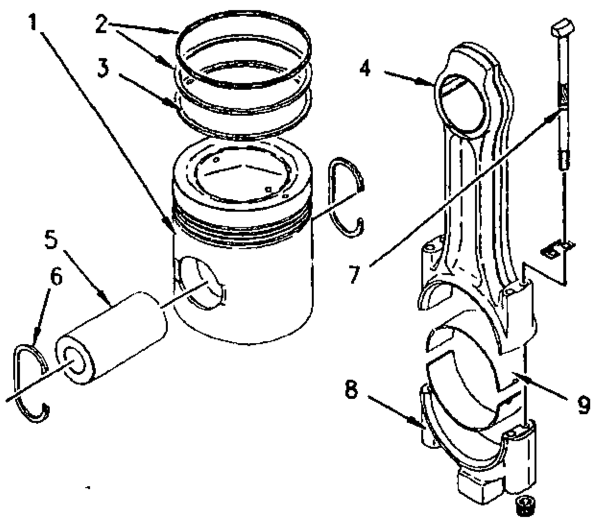


Illustration 54 g00816458

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

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

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

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

Crankshaft

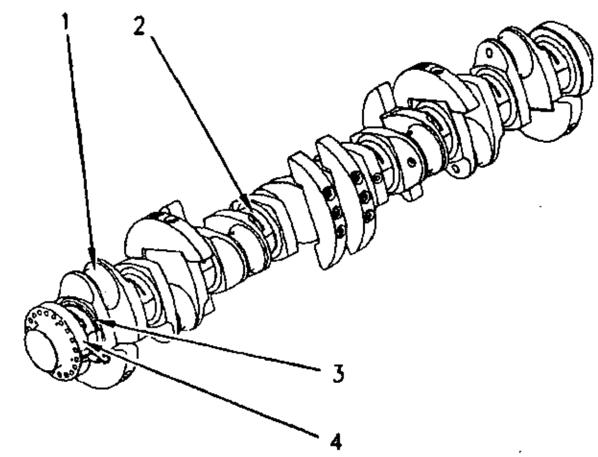


Illustration 55 g00816471

Typical example

(1) Journal
(2) Main bearing
(3) Thrust plates
(4) Flange

The crankshaft changes the combustion forces in the cylinders into usable rotating torque which powers the driven equipment. The connecting rods for the pistons are connected to journals (1). A counterweight for each cylinder is welded to the crankshaft.

Pressurized engine oil is supplied to main bearings (2) through drilled passages in the webs of the cylinder block. The engine oil flows through passages that are drilled in the crankshaft in order to provide lubrication for the connecting rod bearings.

Two thrust plates (3) control the end play of the crankshaft. Flanges (4) are machined at both ends of the crankshaft for mounting of the flywheel and of the vibration damper.

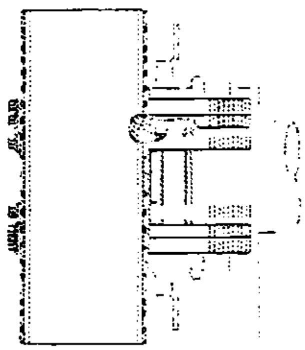


Illustration 56 g00816530

Vibration damper

The vibration damper is bolted to the front of the crankshaft in order to reduce torsional vibrations (twist) that can cause damage to the engine.

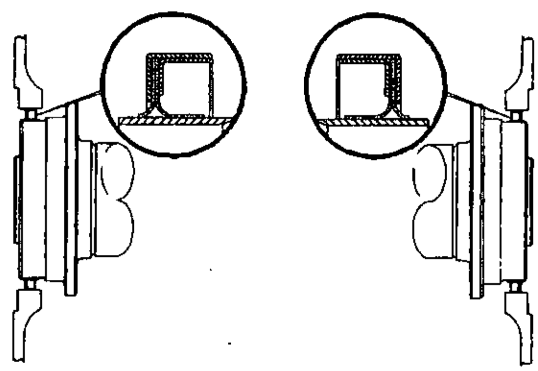


Illustration 57 g00807826

Cross sections of the crankshaft seals and wear sleeves

Seals and wear sleeves are used at both ends of the crankshaft. Oil is sealed by the lip seals and the wear sleeves help prevent wear on the crankshaft.

The crankshaft drives the front gear group and the rear gear group.

Camshafts

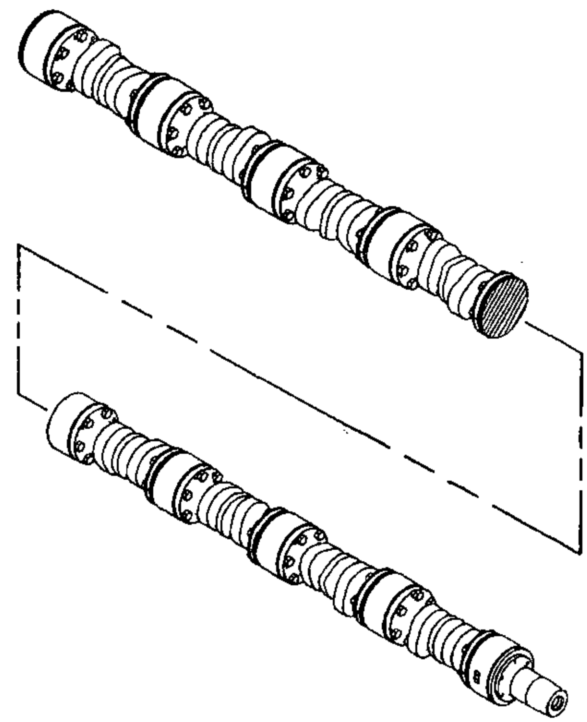


Illustration 58 g00816510

Typical camshaft assembly

The engine has a camshaft assembly for each bank.

The camshafts are assembled with identical segments, journals, spacers and a drive end. Each segment has three lobes. Individual segments can be replaced for each cylinder through access holes in the cylinder block. The camshaft assembly 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. Each outer lifter assembly moves a pushrod for two inlet valves or for two exhaust valves. The center lifter assembly moves a pushrod that operates the gas admission valve.

The relation of the camshaft to the crankshaft position cause the valves to operate at the correct time. The camshaft must be in time with the crankshaft.

Front Gear Group

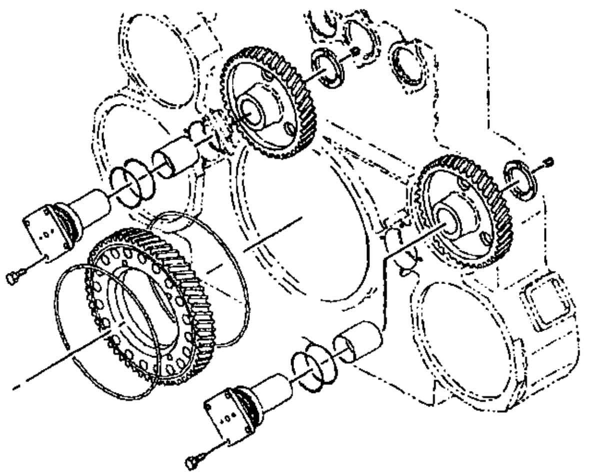


Illustration 59 g00816519

The gear group in the front housing of the engine drives the jacket water pump, the aftercooler/oil cooler pump, the engine oil pump, and the pump for the hydraulic oil.

Rear Gear Group

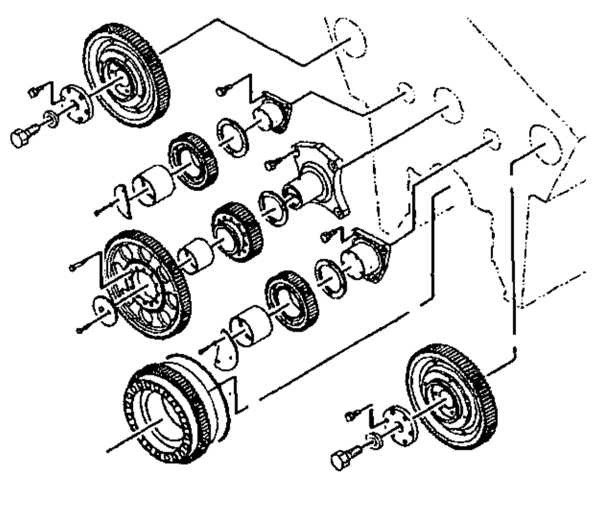


Illustration 60 g00816521

Rear gears on the Vee engines

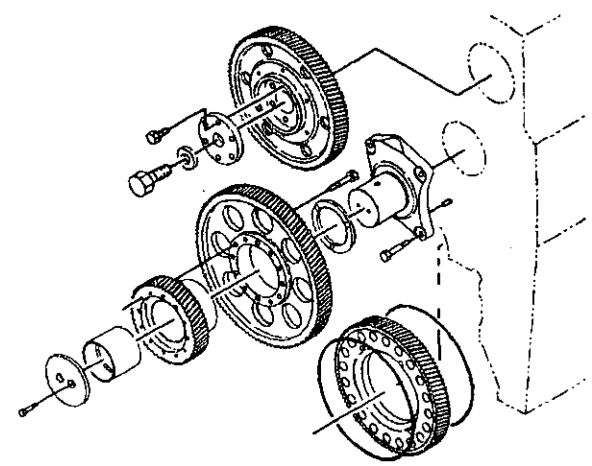


Illustration 61 g00895519

Rear gears on the In-line engines

The rear gear group drives the driven equipment and the camshafts.

i01752101

Manual Barring Group (50:1 Reduction)

SMCS Code: 1235

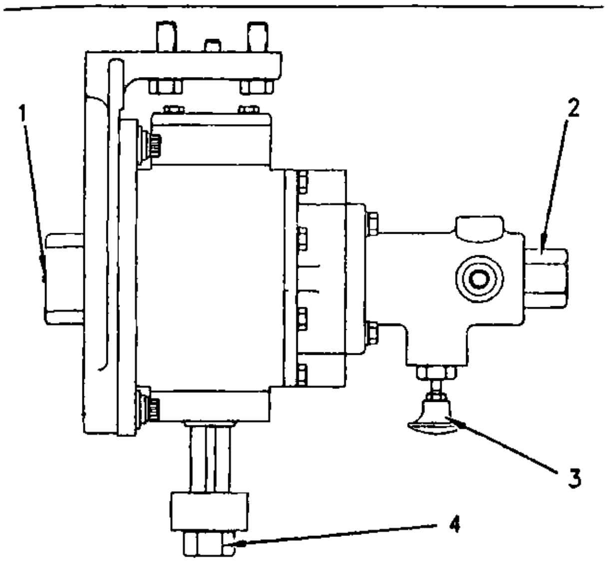


Illustration 62 g00322856

Manual barring group

(1) Shaft with gear and grease fitting
(2) Locking nut
(3) Knob
(4) Adapter

The manual barring group allows an electrically driven motor to be used in order to turn the engine slowly. The manual barring group is used while service work is being performed.

Use the following procedure in order to engage the manual barring group:

NOTICE
Do not use an impact wrench to operate the barring device. The use of an impact wrench will cause gear tooth failure.

1. Loosen locking nut (2).

NOTICE
If the barring group's knob is not pulled fully outward during engagement of the pinion and during disengagement of the pinion, the knob's shaft will damage the pinion shaft's O-ring seals. Make sure that the knob is pulled fully outward when you engage the pinion and when you disengage the pinion.

2. Pull knob (3) fully outward and press locking nut (2) until the nut is flush with the housing.

Note: Locking nut (2) is part of the spring loaded pinion shaft. If the locking nut cannot become flush with the housing, the shaft gear is not meshed with the flywheel ring gear. Maintain inward pressure on the nut and carefully adjust adapter (4). Turn the adapter in a clockwise direction or a counterclockwise direction. The adjustment may require the adapter to be turned more than one revolution in any direction. Adjust the adapter until the locking nut can become flush with the housing.

3. After locking nut (2) is flush with the housing, release knob (3) and slowly remove hand pressure from the locking nut until the knob engages in the pinion shaft's slot.

When the manual barring group is in the engaged position, the engine starting system is disabled.

To turn the engine crankshaft, use the motor control. The manual barring group is directly coupled to an electric motor. The electric motor produces the torque that is required to turn the crankshaft in either direction.

If only the engine crankshaft is turned, approximately 10 N·m (7 lb ft) of torque is required. More torque is required if the flywheel ring gear is engaged with driven equipment.

The engine crankshaft is locked in place when the pinion gear on shaft (1) is engaged with the flywheel ring gear.

Use the following procedure in order to disengage the manual barring group:

1. Pull knob (3) fully outward and press locking nut (2) until the spring on shaft (1) moves the pinion to the disengaged position.

2. Make sure that the pinion gear is fully disengaged.

Note: The pinion gear is fully disengaged when locking nut (2) passes by the housing.

3. After the pinion gear is fully disengaged, release knob (3).

4. Tighten locking nut (2) to a torque of 70 ± 15 N·m (50 ± 11 lb ft).

Note: If shaft (1) fails to fully disengage, rotate adapter (4) in either direction. Rotating the adapter in either direction reduces the side loading (friction) between the pinion gear and the flywheel ring gear.

NOTICE
Do not operate the engine starting motor until the barring group pinion gear is fully disengaged from the flywheel ring gear. Serious damage to the engine could result.

When the manual barring group is not activated, the manual barring group must be disengaged from the flywheel and the manual barring group must be secured in the disengaged position.

Air Starting System

i01546841

Air Starting System

SMCS Code: 1450

An air starting motor is used 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's control 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 duration for rotation of the flywheel is determined by the tank's volume, air pressure, and air restriction.

For starting the engines which do not have heavy loads, the air pressure is approximately 1034 kPa (150 psi). This pressure provides a good relationship between the duration of the flywheel's rotation and the cranking speed.

Note: Minimum recommended 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 air pressure regulator must be adjusted in order to provide enough speed for easy starting.

The air 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 maximum pressure for use in the air starting motor is 1723 kPa (250 psi). This will provide sufficient cranking speed for a heavily loaded engine. With the correct air pressure, the air starting motor can turn the heavily loaded engine at the same speed and for the same duration as the air starting motor can turn a lightly loaded engine.

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

Electrical System

i02112737

Electrical System

SMCS Code: 1400; 1406; 1450

The electrical system is a 24 VDC system. The load rating of the system is 15 amp. 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 bearing 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 negative "-" battery terminal for the control system to the ground plane.

If rubber couplings are used to 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 voltage will damage the electrical system.

Always disconnect the power when you are working on the engine's electronics.

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

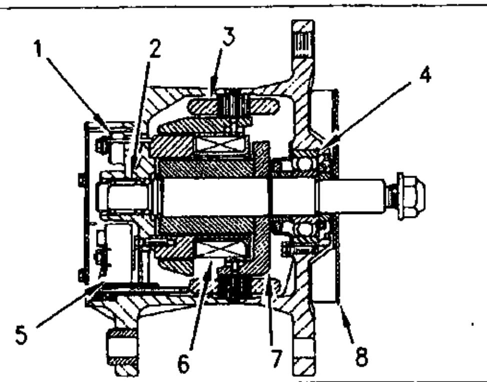


Illustration 63 g00285111

Alternator components (typical example)

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

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

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

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

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

Voltage regulator (1) is a solid-state, electronic switch. The regulator senses the voltage in the system. The regulator opens and the regulator closes the field current many times in one second in order to control the field current to the alternator. The output voltage from the alternator supplies the needs of the battery and the other components in the electrical system. The rate of charge cannot be adjusted.

Other Components

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 gets hot. This heat causes a distortion of the metal disc. The disc opens the contact in order to break the circuit.

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

Testing and Adjusting Section

Electronic Control System

i02112761

General Information (Electronic Control System)

SMCS Code: 1901

Connecting the Caterpillar Electronic Technician (Cat ET) to the Electronic Control Module (ECM)

Table 8

Tools Needed	Qty
This PC configuration is recommended: Intel Pentium II 333 mHz processor 64 megabyte of RAM 4.3 GB hard drive Drive for floppy disks (3.5 inch with 1.44 MB) 14X speed CD-ROM drive VGA monitor or display RS-232 port with 16550AF UART Windows NT 4.0 (1) Windows 95 (1) Windows 98 (1) Mouse	1
This PC configuration has the minimum requirements: IBM PC compatible 100 MHz processor 32 megabyte of RAM 10 MB of available hard drive space CD-ROM drive Drive for floppy disks (3.5 inch with 1.44 MB) Windows NT 4.0 (1) Windows 95 (1) Windows 98 (1) RS-232 port with 16550AF UART VGA monitor or display Mouse	1
Single user license for Cat ET Use the most recent version of this software. "JERD2124"	1
Software Data subscription for all engines "JERD2129"	1
160-0141 Adapter Cable	1
171-4401 Communication Adapter II	1
207-6845 Adapter Cable As (CAT Data Link)	1
7X-1414 Adapter Cable	1

(1) Any of these operating systems are acceptable.

Cat ET is designed to run on a personal computer. Cat ET can display the following information:

- Parameters
- Diagnostic codes
- Event codes
- Engine configuration
- Status of the monitoring system

Cat ET can perform the following functions:

- Diagnostic tests
- Sensor calibration
- Flash downloading
- Set parameters

For instructions on using Cat ET, refer to the User's Manual that is included with the software.

The battery supplies the communication adapter with 24 VDC. Use the following procedure to connect Cat ET and the communication adapter to the engine.

1. Turn the engine control switch to the OFF/RESET position.

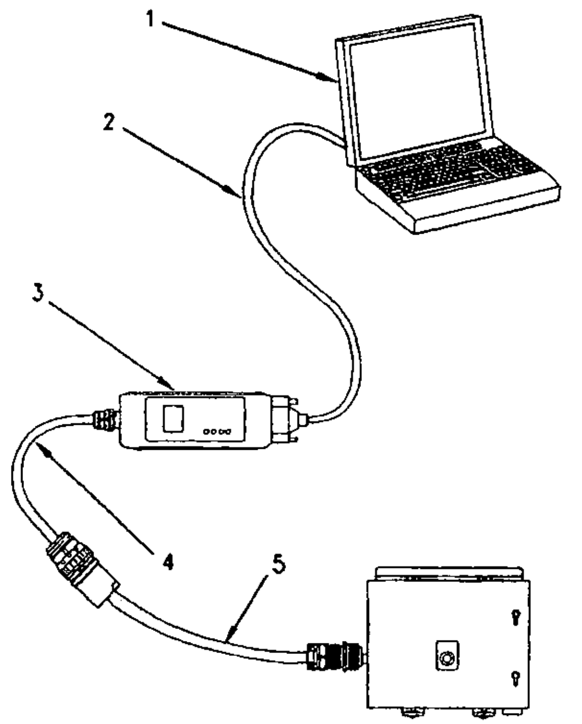


Illustration 64 g00825138

(1) PC
(2) 160-0141 Adapter Cable
(3) 171-4401 Communication Adapter II
(4) 207-6845 Adapter Cable As (CAT Data Link)
(5) 7X-1414 Adapter Cable

2. Connect cable (2) to the RS232 serial port of PC (1).

3. Connect cable (2) to communication adapter (3).

4. Connect cable (4) to communication adapter (3).

5. Connect cable (4) to cable (5).

6. Connect cable (5) to the service tool connector of the terminal box.

   Alternatively, connect the cable to the service tool connector on the optional control panel.

7. Turn the engine control switch to the STOP position. The engine should be OFF.

   If Cat ET and the communication adapter do not communicate with the ECM, refer to Troubleshooting, RENR5910, "Electronic Service Tool Will Not Communicate With ECM".

Flash Programming

Software is located in the flash memory of the Electronic Control Module (ECM) and in the Integrated Combustion Sensing Module (ICSM). The Caterpillar Electronic Technician (Cat ET) can be used to flash new software into the ECM and into the ICSM. The flash is accomplished by transferring the data from Cat ET to the module via data link wiring. The Software, JERD2124 or Software, JERD2129 is used.

If the slowest baud rate of Cat ET is selected, flash programming can last up to 15 minutes. Be sure to set the baud rate to the fastest rate for your PC.

To select the baud rate, open the "Utilities/ Preferences" menu in Cat ET. Select the "Communications" tab and click on "Advanced...". Then select the baud rate from the "Advanced Communication Settings" menu and click the "OK" button.

If a communication error occurs, select a slower baud rate in order to improve the reliability.

1. Connect Cat ET to the service tool connector.

2. Turn the engine control switch to the STOP position.

   Cat ET will not flash if the engine control switch is in the OFF position or in the START position.

3. Select "WinFlash" from the "Utilities" menu on Cat ET.

   "WinFlash" will try to detect an ECM.

4. When an ECM has been detected, the "ECM Selector" window will appear. Select the appropriate ECM and then select "OK".

   The "Flash File Selection" window will appear.

5. The flash files are located on a disk drive and in a directory. Select the correct disk drive and the directory from "Drives" and "Directories" on Cat ET.

   A list of flash files will appear.

6. Select the correct file from the list of flash files. Read the "Description" and the "File Info" in order to verify that the correct file is selected. Select "Open".

7. Select the "Begin Flash" button in order to program the personality module.

   When the flash is completed, this message will appear: "Flash Completed Successfully".

8. Program the configuration parameters and the monitoring system parameters.

   The parameters must be programmed in order to ensure proper engine operation. Refer to Troubleshooting, "Programming Parameters".

9. Start the engine and check for proper operation.

   a. If a diagnostic code of 268-02 "Check Programmable Parameters" is generated, program any parameters that were not in the original software.

   b. Access the "Configuration" screen under the "Service" menu in order to determine the parameters that require programming. Look under the "Tattletale" column. All of the parameters should have a tattletale of 1 or more. If a parameter has a tattletale of 0, program that parameter.

"WinFlash" Error Messages

If you receive any error messages during flash programming, click on the "Cancel" button in order to stop the process. Access the information about the "ECM Summary" under the "Information" menu. Make sure that you are flashing the correct file for your engine.

Recommendations for Programming the System Configuration Parameters

For descriptions of the parameters, refer to Systems Operation, "Electronic Control System Parameters". The values of the parameters can be viewed on the "Configuration" screen of Cat ET.

Programmable parameters enable the engine to be configured in order to meet the requirements of the application. The system configuration parameters must be programmed when the application is installed. Perform this programming before the initial engine start-up.

Data from a gas analysis and data on engine performance are required in order to determine the correct settings for the fuel quality and for the specific gravity of the gas. Incorrect programming of parameters may lead to complaints about performance and/or to engine damage.

If the ECM is replaced, the appropriate parameters must be copied from the old ECM. This can be done with the "Copy Configuration" feature of Cat ET. Alternatively, the settings can be recorded on paper and then programmed into the new module.

NOTICE

Changing the parameters during engine operation can cause the engine to operate erratically. This can cause engine damage.

Only change the settings of the parameters when the engine is STOPPED.

Changing the Settings of the Monitoring System

For descriptions of the monitoring system parameters, refer to Systems Operation, "Engine Monitoring System".

To change the settings of the parameters, use Cat ET and select the "Service/Monitoring System" screen.

Use care when you program the trip points and the delay times. Ensure that the response of the ECM is correct for the application. The monitoring system will accept any settings within the ranges.

NOTICE

Changing the parameters during engine operation can cause the engine to operate erratically. This can cause engine damage.

Only change the settings of the parameters when the engine is STOPPED.

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i02113039

Engine Governing - Adjust

SMCS Code: 1901-025

The responses of the electrohydraulic actuators can be individually adjusted by using the Caterpillar Electronic Technician (Cat ET) to change these three parameters:

- Gain
- Stability
- Compensation

These adjustments are provided in order to obtain optimum responses to changes in the load and in the speed. The adjustments also provide stability during steady state operation.

Note: Adjustment of the gain directly affects the speed of the fuel actuator when there is a difference between the actual engine speed and the desired engine speed. An excessive increase of the gain may amplify instability.

To set the gain, increase the gain until the actuator becomes unstable. Slowly reduce the gain in order to stabilize the actuator. Use Cat ET to bump the engine speed. Observe that the engine operates properly with little overshoot or undershoot.

The adjustment of stability dampens the actuator's response to changes in load and in speed. Increasing the stability provides less damping. Decreasing the stability provides more damping. To reduce overshoot, decrease the stability. To reduce undershoot, increase the stability.

Note: An increase of the stability may require a decrease of the gain in order to maintain a stable operation.

Note: Adjustment of the stability directly affects the damping of the fuel actuator. An excessive increase of the compensation may amplify instability.

Decrease the compensation until a slow, periodic instability is observed. Then, slightly increase the compensation. Repeat the adjustments of the gain and of the stability. Continue to increase the compensation and readjust the gain and stability until stability is achieved and the engine's response to changes in load and in speed is optimized.

Note: The default setting of gain, of stability, and of compensation is 100 percent. The range is 0 percent to 3200 percent. To reduce the responses of the parameters, reduce the value. To increase the responses, increase the values.

Governor Type

Use Cat ET to select the "Governor Type Setting" configuration parameter.

For generator set applications, there are two sets of responses for the fuel actuator. The "Isochronous Mode" is used to provide "off grid" engine stability for synchronization. The "Droop Operation" is for "on grid" stability. Adjustment to the settings for the fuel actuator relates to both of the responses.

Adjustments for the Hydraulic Oil Pressure

To operate properly, the electrohydraulic actuators require correct oil pressure. If the pressure is insufficient, the engine will not start. If the pressure is excessive, the hydraulic system can be damaged. Two adjustments can be made for the hydraulic oil pressure:

- The hydraulic lines have a pressure relief valve that regulates the hydraulic system's pressure. This pressure relief valve is adjusted in order to achieve sufficient pressure for start-up and for normal operation. If the pressure becomes excessive, the valve diverts the oil back to the pump.
- The hydraulic oil pump has a pressure relief valve that is a backup to the pressure relief valve in the hydraulic lines. If the pressure becomes excessive, the pump circulates the oil internally.

Adjustment of the Hydraulic Lines' Pressure Relief Valve

Table 9

Tools Needed	Qty
8T-0855 Pressure Gauge	1

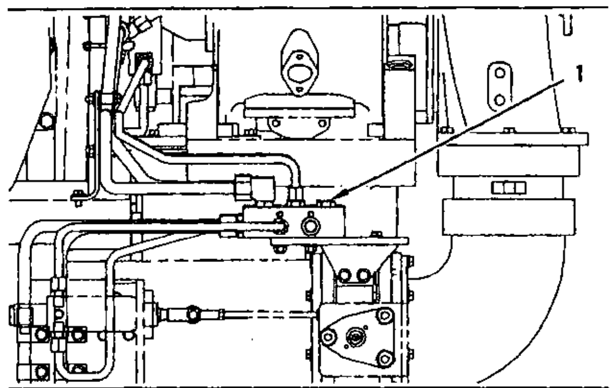


Illustration 65 g00917032

Left side view (In-line engine)

(1) Plug

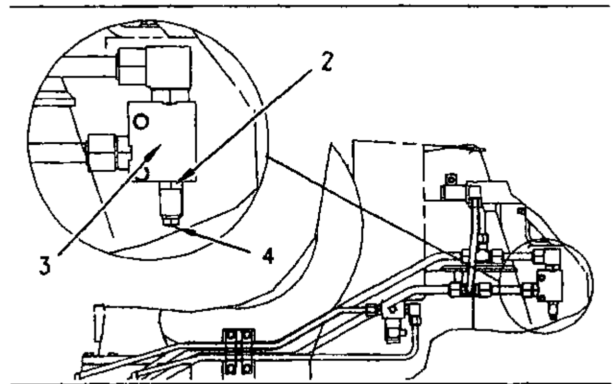


Illustration 66 g00897160

Rear view (In-line engine)

(2) Locknut
(3) Pressure relief valve
(4) Adjusting bolt

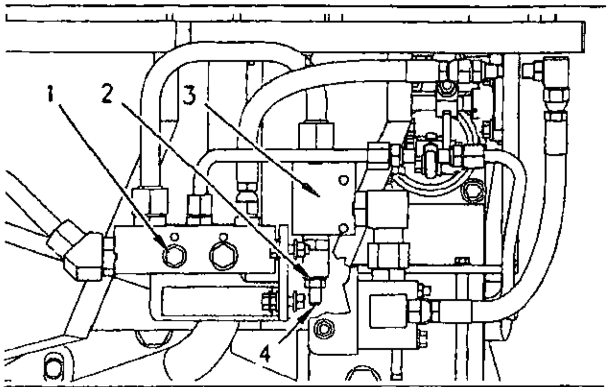


Illustration 67 g00823694

Vee engine

(1) Plug
(2) Locknut
(3) Pressure relief valve
(4) Adjusting bolt

1. Remove plug (1) from the manifold. Attach the 8T-0855 Pressure Gauge onto the opening for the plug.

2. Run the engine at rated speed. Loosen locknut (2) on the bottom of pressure relief valve (3). Use an allen wrench to turn adjusting bolt (4) in order to obtain a pressure of 1550 ± 35 kPa (225 ± 5 psi).

Note: Sometimes, the pressure must be increased in order to avoid the generation of diagnostic codes during start-up. This is usually due to restarting an engine that has a low viscosity of hydraulic oil because the oil is hot. If this occurs, the pressure can be increased to a maximum of 1725 kPa (250 psi).

3. Tighten locknut (2).

4. Stop the engine.

5. Remove the pressure gauge. Install plug (1) into the manifold.

Adjustment of the Hydraulic Oil Pump's Pressure Relief Valve

Normally, the hydraulic oil pump's pressure relief valve is unlikely to require adjustment. Use the following procedure if the pump is serviced.

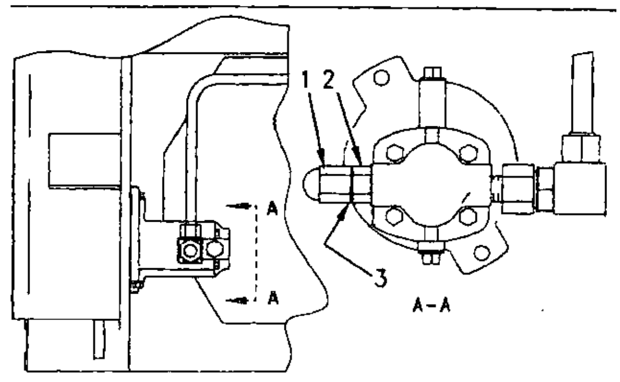


Illustration 68 g00897106

Side view and end view of the pump

(1) Cap
(2) Locknut
(3) Adjusting screw (not shown)

1. Remove cap (1) in order to gain access to adjusting screw (3) (not shown). Loosen locknut (2).

2. Turn adjusting screw (3) fully inward. Then, turn the adjusting screw outward for two and one-half turns.

3. Tighten locknut (2) and install cap (1).

Ignition System

i01860090

Ignition System

SMCS Code: 1550

Ignition Transformer

If an ignition transformer is suspect, use the following procedure to check the transformer:

WARNING

Ignition systems can cause electrical shocks. Avoid contacting the ignition system components and wiring.

Do not attempt to remove the transformers when the engine is operating. The transformers are grounded to the valve covers. Personal injury or death may result and the ignition system will be damaged if the transformers are removed during engine operation.

1. Turn the engine control switch to the OFF/RESET position. Switch the circuit breaker for the engine OFF.

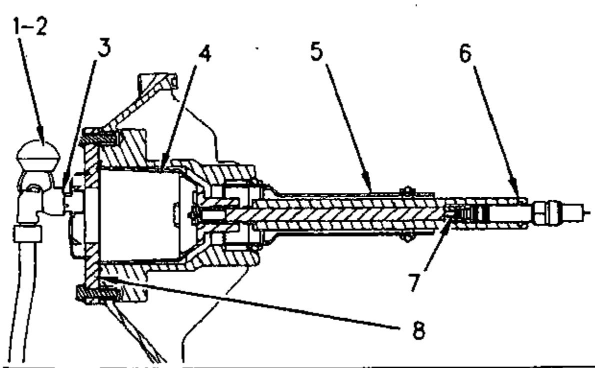


Illustration 69 g00948220

(1) Wire seal
(2) Lockwire
(3) Ignition harness
(4) Transformer
(5) Extension
(6) O-ring seal
(7) Terminal for the spark plug
(8) Mounting flange for the transformer

2. Remove wire seal (1) and lockwire (2).

3. Disconnect ignition harness (3) from transformer (4). Remove the transformer and extension (5) as a unit.

4. Inspect the body of the transformer and of the extension for corrosion and/or for damage.

5. Inspect O-ring seal (6) inside the extension for damage.

   If the O-ring seal is cracked or hard, install a new O-ring seal.

6. Inspect terminal (7) inside the extension for looseness, for corrosion, and/or for damage. Insert an extra spark plug into the transformer and check for spring pressure of the terminal.

NOTICE

The extension can be scratched and damaged with a wire brush. Do not use a wire brush on the extension.

7. Clean any deposits from the inside of the extension. Use a 6V-7093 Brush with isopropyl alcohol.

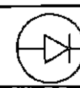


Illustration 70 g00754013

Symbol for a diode

8. Measure the voltage of the diode for the primary circuit.

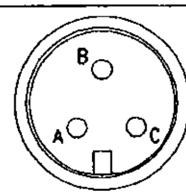


Illustration 71 g00829100

Transformer's connector for the ignition harness

(A) Positive
(B) Negative
(C) Unused

   a. Set the multimeter to the diode scale. Measure the voltage between pin "A" and pin "B" on the transformer's connector for the ignition harness. The polarity is not important.

   b. Reverse the polarity of the probe and measure the voltage between the pins again.

      For the diode of the primary circuit, the correct voltage between pin "A" and pin "B" is approximately 0.4 to 0.6 VDC. When the polarity is reversed, there is no reading.

      Voltage that is significantly outside of this range could indicate a problem with the transformer.

9. Measure the resistance of the secondary circuit.

a. Set the multimeter to the 40,000 Ohm scale. Measure the resistance between terminal (7) for the spark plug and mounting flange (8) for the transformer.

The correct resistance between the terminal for the spark plug and the mounting flange for the transformer is between 19,000 to 21,000 Ohms.

Resistance that is significantly outside of this range could indicate a problem with the transformer or with the extension.

10. Switch the suspect transformer with a transformer from a different cylinder that is known to be good. Install the transformers.

11. Reset the control system. Clear any logged diagnostic codes.

12. Start the engine and operate the engine in order to generate a diagnostic code.

If the problem follows the transformer, replace the transformer. **Make sure that you use the correct transformer for the engine.** Reset the control system. Clear any logged diagnostic codes.

If the problem stays with the cylinder, there is a problem with the spark plug or with the electrical circuit for the transformer.

For instructions on inspection and replacement of the spark plug, refer to the engine's Operation and Maintenance Manual.

For more information on troubleshooting the primary side of the ignition system, refer to Troubleshooting, "Ignition Transformers Primary Circuit".

Note: After you service the transformer, always install a new lockwire and a wire seal on the transformer's connector for the ignition harness.

Fuel System

i02117442

Procedure for Engine Timing

SMCS Code: 1000

The engine is timed when the following conditions are met:

- The No. 1 cylinder is at the Top Center position on the compression stroke.
- The crankshaft timing pin is engaged in the bracket which is attached to the crankshaft.
- The camshaft timing pin is engaged in the hole in the camshaft assembly. For Vee engines, both of the camshaft timing pins must be engaged.

Engine Prelubrication

Always prelube the engine when you rotate the crankshaft.

The switch for the engine prelube is located on the remote control panel. The switch enables manual lubrication of the engine.

DO NOT use the starting motor to rotate the crankshaft. If the crankshaft is rotated too fast, lubrication with the prelube pump is not sufficient for protecting the engine.

Use the manual barring group to rotate the crankshaft for service work. Keep the prelube pump running when the crankshaft is rotated. Damage can result if the crankshaft is rotated on dry bearing surfaces.

NOTICE

In order to avoid possible damage to the engine, the prelube pump should not be operated continuously for extended periods of time. During repairs, if the prelube pump has run for more than three hours continuously, any oil that may have collected in the cylinders and/or above the valves should be removed before attempting to start the engine.

Finding the Top Center Compression Position for the No. 1 Cylinder

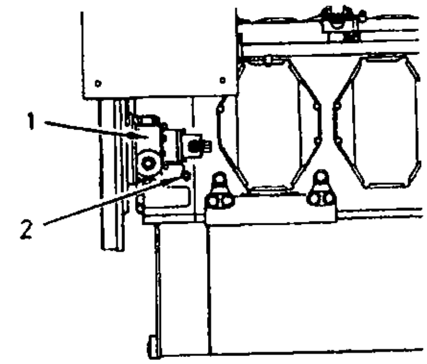


Illustration 72 g00311103

(1) Barring device
(2) Storage position for the timing pin

1. Remove the timing pin from storage position (2) that is located below barring device (1).

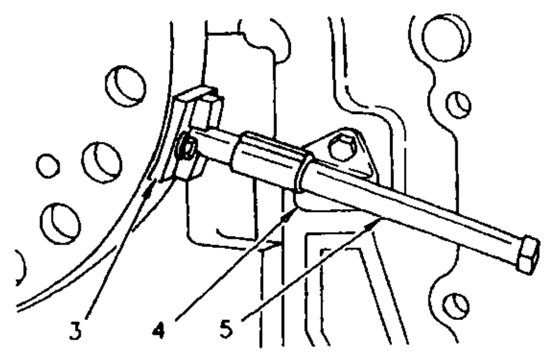


Illustration 73 g00311105

Installation of the timing pin

(3) Timing bracket
(4) Mounting bracket for the timing pin
(5) Timing pin

2. Operate the prelube pump. Use the barring device to turn the flywheel in the direction of normal engine rotation. Turn the flywheel until timing pin (5) can be installed through bracket (4) into timing bracket (3).

Note: If the flywheel is turned beyond the point of installation in timing bracket (3), the play must be removed from the timing gears. Turn the flywheel in the opposite direction of normal rotation for approximately 20 degrees. Then turn the flywheel in the direction of normal engine rotation until the timing pin can be installed.

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

4. The inlet and exhaust valves for the No. 1 cylinder are fully closed if No. 1 piston is on the compression stroke and the rocker arms can be moved by hand. If the rocker arms cannot be moved and the valves are slightly open, the No. 1 piston is on the exhaust stroke. For the cylinders to service according to the corresponding crankshaft position, refer to "Crankshaft Positions for Valve Lash Setting".

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

Crankshaft Positions for Valve Lash Setting

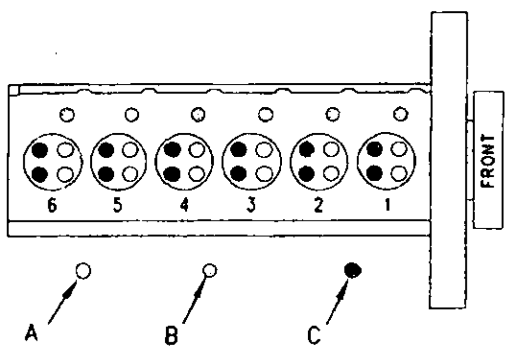


Illustration 74 g00283190

G3606 Engine cylinder and valve location

(A) Inlet valve
(B) Gas admission valve
(C) Exhaust valve

Table 10

Crankshaft Positions for Valve Lash Setting			
Standard Counterclockwise Rotation [1]			
G3606 Engine	Inlet Valves	Exhaust Valves	Gas Admission Valves
TC Compression Stroke	1-2-4	1-3-5	1-4-5
TC Exhaust Stroke	3-5-6	2-4-6	2-3-6
Firing Order	1-5-3-6-2-4		

[1] Put the No. 1 piston at the Top Center position (TC). Ensure the identification for the correct stroke. Refer to "Finding the Top Center Compression Position for the No. 1 Cylinder". After adjustments for the correct cylinders, remove the timing pin. Operate the prelube pump and turn the flywheel for 360 degrees in the direction of normal rotation. This will put the No. 1 piston at the TC position on the opposite stroke. Install the timing pin in the crankshaft and complete the adjustments for the cylinders that remain.

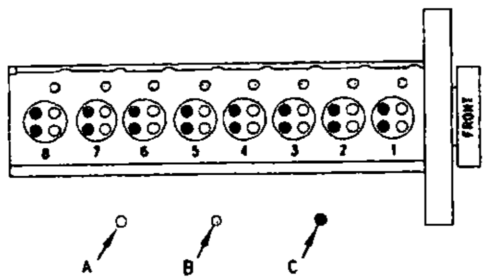


Illustration 75 g00465539

G3608 Engine cylinder and valve location

(A) Inlet valve
(B) Gas admission valve
(C) Exhaust valve

Table 11

Crankshaft Positions for Valve Lash Setting			
Standard Counterclockwise Rotation [1]			
G3608 Engine	Inlet Valves	Exhaust Valves	Gas Admission Valves
TC Compression Stroke	1-4-6-7	1-2-4-6	1-4-6-7
TC Exhaust Stroke	2-3-5-8	3-5-7-8	2-3-5-8
Firing Order	1-6-2-5-8-3-7-4		

[1] Put the No. 1 piston at the Top Center position (TC). Ensure the identification for the correct stroke. Refer to "Finding the Top Center Compression Position for the No. 1 Cylinder". After adjustments for the correct cylinders, remove the timing pin. Operate the prelube pump and turn the flywheel for 360 degrees in the direction of normal rotation. This will put the No. 1 piston at the TC position on the opposite stroke. Install the timing pin in the crankshaft and complete the adjustments for the cylinders that remain.

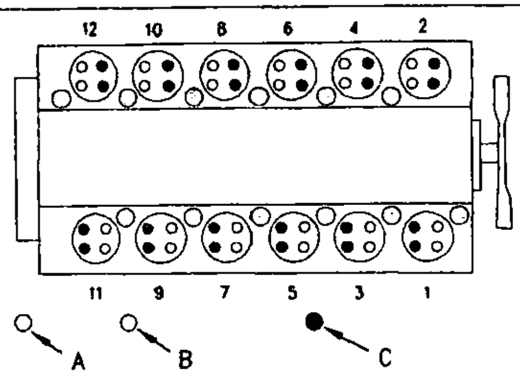


Illustration 76 g00471973

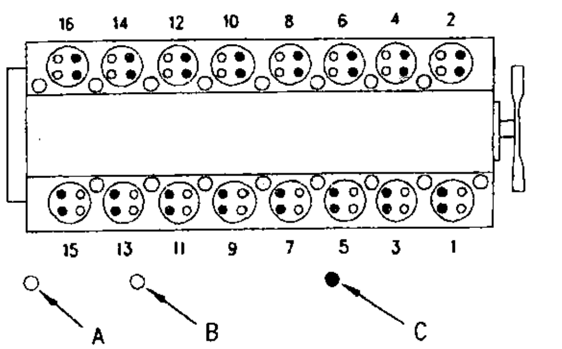
G3612 Engine cylinder and valve location

(A) Inlet valve
(B) Gas admission valve
(C) Exhaust valve

Table 12

Crankshaft Positions for Valve Lash Setting			
Standard Counterclockwise Rotation (1)			
G3612 Engine	Inlet Valves	Exhaust Valves	Gas Admission Valves
TC Compression Stroke	1-3-6-7-10-12	1-4-5-6-9-12	1-6-7-9-10-12
TC Exhaust Stroke	2-4-5-8-9-11	2-3-7-8-10-11	2-3-4-5-8-11
Firing Order	1-12-9-4-5-8-11-2-3-10-7-6		

(1) Put the No. 1 piston at the Top Center position (TC). Ensure the identification for the correct stroke. Refer to "Finding the Top Center Compression Position for the No. 1 Cylinder". After adjustments for the correct cylinders, remove the timing pin. Operate the prelube pump and turn the flywheel for 360 degrees in the direction of normal rotation. This will put the No. 1 piston at the TC position on the opposite stroke. Install the timing pin in the crankshaft and complete the adjustments for the cylinders that remain.



g00472128

Illustration 77

G3616 Engine cylinder and valve location

(A) Inlet valve
(B) Gas admission valve
(C) Exhaust valve

Table 13

Crankshaft Positions for Valve Lash Setting			
Standard Counterclockwise Rotation (1)			
G3616	Inlet Valves	Exhaust Valves	Gas Admission Valves
TC Compression Stroke	1-2-5-7-8-12-13-14	1-2-3-4-5-6-7-8	1-2-5-6-7-8-13-14
TC Exhaust Stroke	3-4-6-9-10-11-15-16	9-10-11-12-13-14-15-16	3-4-9-10-11-12-15-16
Firing Order	1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8		

(1) Put the No. 1 piston at the Top Center position (TC). Ensure the identification for the correct stroke. Refer to "Finding the Top Center Compression Position for the No. 1 Cylinder". After adjustments for the correct cylinders, remove the timing pin. Operate the prelube pump and turn the flywheel for 360 degrees in the direction of normal rotation. This will put the No. 1 piston at the TC position on the opposite stroke. Install the timing pin in the crankshaft and complete the adjustments for the cylinders that remain.

Camshaft Timing Check

1. Remove the rear camshaft inspection cover. For Vee engines, remove the covers from both sides of the engine.
2. Put the No. 1 piston at the Top Center Position on the compression stroke. Refer to " Finding the Top Center Compression Position for the No. 1 Cylinder" and "Crankshaft Position for Valve Lash Setting".
3. When the crankshaft timing pin is installed and the No. 1 piston is on the compression stroke, remove the camshaft timing pin from the storage position.

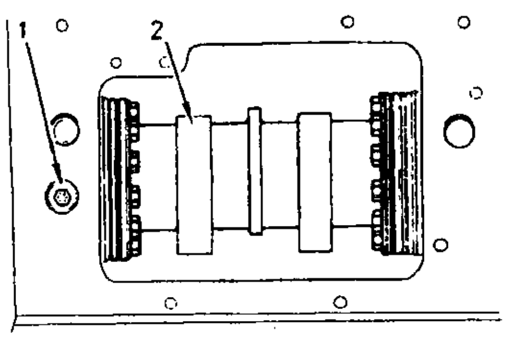


Illustration 78 g00311143

Installation of the camshaft timing pin

(1) Timing pin
(2) Camshaft

4. Install timing pin (1) through the timing pin hole and into the hole in camshaft (2).

   If the timing pin does not go into the hole in the camshaft, the engine is not in time and the camshaft position must be adjusted. Refer to "Camshaft Timing Adjustment" for the procedure.

Camshaft Timing Adjustment

Table 14

Tools Needed	Qty
6V-6080 Torque Multiplier Gp	1
5P-1748 Socket	1

Note: Before you perform any timing adjustments, check the timing in order to ensure that an adjustment is necessary. Refer to "Camshaft Timing Check" for the procedure.

If the camshaft is not timed with the crankshaft, the camshaft drive gear must be removed and the camshaft must be rotated. Perform the following procedure.

1. Put the No. 1 cylinder in the Top Center Position of the compression stroke and install the crankshaft timing pin. Refer to "Finding the Top Center Compression Position for the No. 1 Cylinder" and "Crankshaft Position for Valve Lash Setting". Remove all of the valve covers from the side of the engine that requires adjustment.

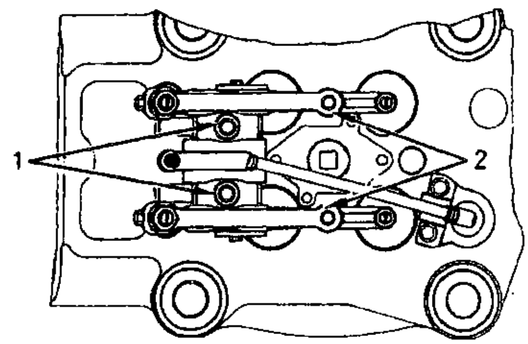


Illustration 79 g00311255

(1) Bolts
(2) Rocker arm shaft

2. Loosen bolts (1) that hold rocker arm shafts (2) until all of the rocker arms are free from the valve bridges.

Note: For Vee engines, the gas tubes must be removed from the rear of the engine in order to remove the camshaft drive gear covers. Before you work on the fuel system, make sure that the main gas supply is OFF. Purge any remaining gas from the fuel system.

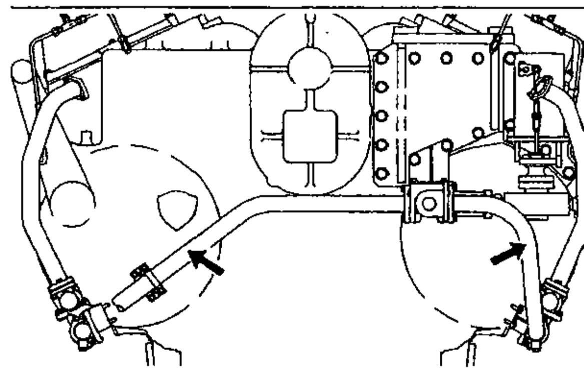
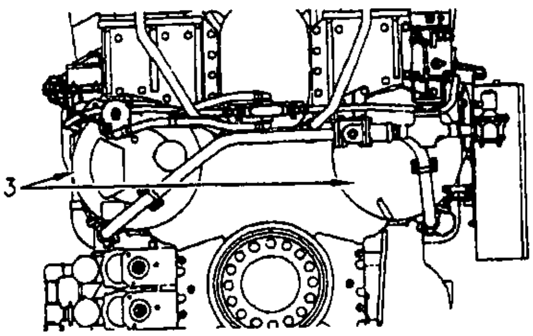


Illustration 80 g00948300

Gas tubes on the rear of a Vee engine

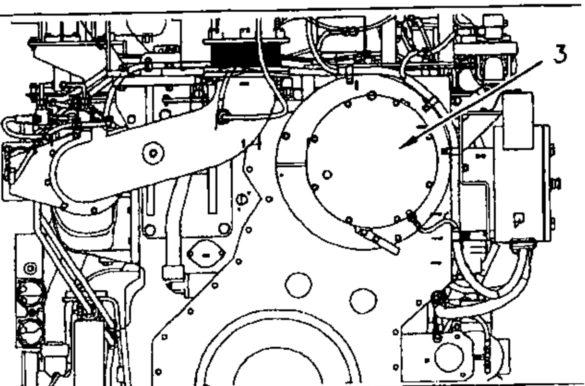


g00488801

Illustration 81

Rear of the Vee engine

(3) Camshaft drive gear covers



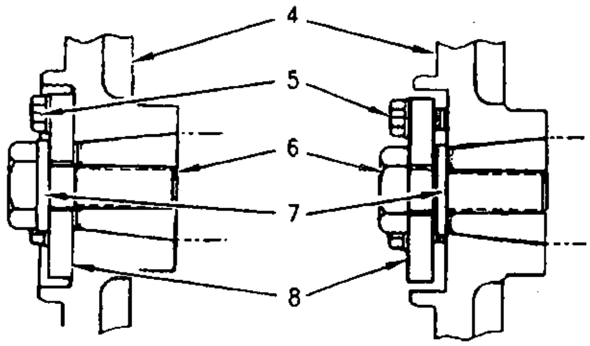
g00896688

Illustration 82

Rear of the In-line engine

(3) Camshaft drive gear covers

3. Remove the crankshaft timing pin and camshaft drive gear cover (3) from the rear housing. For Vee engines, remove both timing pins and camshaft covers.



g00311258

Illustration 83

Camshaft drive gear

(4) Camshaft drive gear
(5) Bolt
(6) Bolt
(7) Washer
(8) Plate

4. Use the following procedure to loosen camshaft drive gears (4):

   a. Use the 6V-6080 Torque Multiplier Gp and the 5P-1748 Socket to loosen bolt (6).

   b. Remove bolt (6) and washer (7). Remove bolts (5) and plate (8).

   c. Put washer (7) between the camshaft and plate (8). Install bolt (6) finger tight.

   d. Install bolt (5) finger tight.

⚠ WARNING

Sudden movement of camshaft drive gear can occur when the camshaft drive gear is pulled off the taper of the camshaft. To prevent possibly personal injury, be sure that the bolt is installed (finger tight) to restrict the movement of the camshaft drive gear when the camshaft drive gear is pulled off of the taper of the camshaft.

   e. Tighten bolt (5) evenly in order to pull camshaft drive gear (4) off the taper of the camshaft.

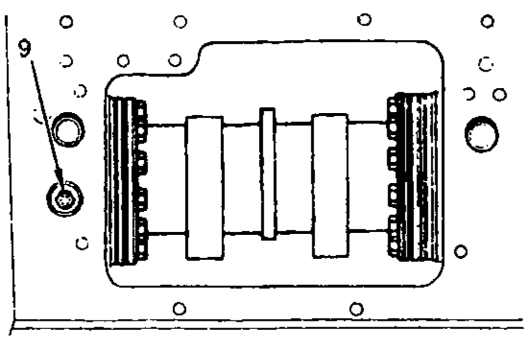


Illustration 84 g00311259

Installation of the camshaft timing pin

(9) Camshaft timing pin

5. Install the crankshaft timing pin. Remove camshaft timing pin (9) from the storage location.

6. Put camshaft timing pin (9) in the timing pin hole, and turn the camshaft until the timing pin goes into the hole in the camshaft.

7. After the camshaft is timed with the crankshaft, use the following procedure to tighten camshaft drive gear (4):

   a. Remove bolts (5) and (6), plate (8) and washer (7).

   b. Install washer (7) and bolt (6). Tighten bolt (6) by hand.

   c. Remove the crankshaft timing pin and the camshaft timing pin.

   d. Operate the prelube pump and turn the flywheel in the opposite direction of normal rotation for a minimum of 20 degrees.

   e. Operate the prelube pump and turn the flywheel in the direction of normal engine rotation until the crankshaft timing pin can be reinstalled in the crankshaft. This procedure holds the backlash in the timing gears in the direction of normal engine rotation.

NOTICE

If the crankshaft timing pin location is missed, do not turn the flywheel in the opposite direction in order to install the crankshaft timing pin.

Note: If the crankshaft timing pin location is missed, repeat Steps 7.d and 7.e.

   f. Install the camshaft timing pin in order to verify the camshaft position. To prevent damage to the timing pins, remove the crankshaft timing pin and the camshaft timing pin before tightening bolt (6).

   g. Use the 6V-6080 Torque Multiplier Gp and the 5P-1748 Socket to tighten bolt (6) to a torque of 2000 ± 275 N·m (1480 ± 200 lb ft).

   h. Use a hammer to strike the plate (8). Repeat Step 7.g.

   i. Repeat Step 7.h, until there is no movement of the gear on the shaft at full torque.

8. Repeat the "Camshaft Timing Check" procedure to verify the correct crankshaft to camshaft timing. If the camshaft timing is not correct, repeat the "Camshaft Timing Adjustment" procedure.

9. Remove the crankshaft timing pin and camshaft timing pin. Return the pins to the storage locations. Install the camshaft inspection covers on the side of the cylinder block.

10. Install camshaft drive gear covers (3) on the rear housing.

Note: For Vee engines, install the gas tubes on the rear of the engine.

11. Tighten the bolts that hold the rocker arm shafts in position, and adjust the valve lash.

12. Install the valve covers.

Valve Lash Check

Measure the valve lash between the rocker arm and the valve bridge. Perform checks and adjustments with the engine stopped. The valves must be fully closed. To determine whether the valves are fully closed, refer to "Finding the Top Center Compression Position for the No. 1 Cylinder" and "Crankshaft Position for Valve Lash Setting".

Adjustment is NOT NECESSARY if the measurements are within the tolerance that is listed in Table 15.

Table 15

Valve Lash Check with the Engine Stopped	
Valves	**Acceptable Range of Valve Lash**
Inlet	0.42 to 0.58 mm (.017 to .023 inch)
Exhaust	1.19 to 1.35 mm (.047 to .053 inch)

If the measurement is not within tolerance, adjust the valve bridge and then adjust the valve lash.

Valve Bridge Adjustment

Table 16

Tools Needed	Qty
1U-7133 Socket [1]	1
5P-0333 Wrench [1]	1

[1] To facilitate the use of a torque wrench, weld the jaw of the 5P-0333 Wrench around the top end of the 1U-7133 Socket.

The valve bridge must be adjusted before the valve lash is adjusted. The valve bridge can be adjusted without removal of the rocker arms and of the shafts. The valves must be fully closed. To determine whether the valves are fully closed, refer to "Finding the Top Center Compression Position for the No. 1 Cylinder" and "Crankshaft Position for Valve Lash Setting".

Note: If the cylinder head is disassembled, keep the bridges with the respective valves. Check that the bridge dowels are installed to the correct height. Lubricate the bridge dowel, the bore for the bridge dowel, and the top contact surface of the bridge. Install the bridge on the dowel.

Use the following procedure to adjust the valve bridges:

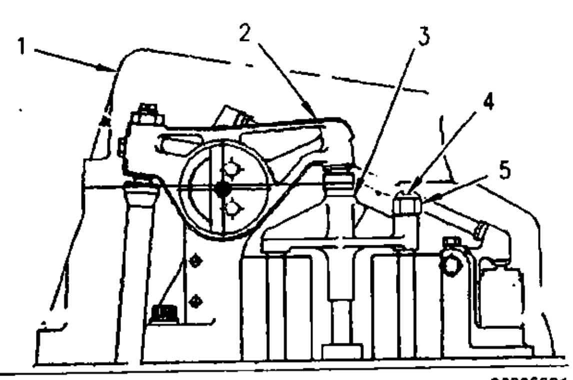


Illustration 85 g00825861

(1) Valve cover
(2) Rocker arm
(3) Valve bridge
(4) Adjusting screw
(5) Locknut

1. Remove valve cover (1).
2. Loosen the locknut (5) for adjusting screw (4). Loosen the adjusting screw for several turns.
3. Press straight down on rocker arm (2) at the point of contact for valve bridge (3). Turn adjusting screw (4) clockwise until the screw just contacts the valve stem.
4. Tighten adjusting screw (4) for an additional 45 ± 5 degrees in order to straighten the valve bridge onto the dowel.

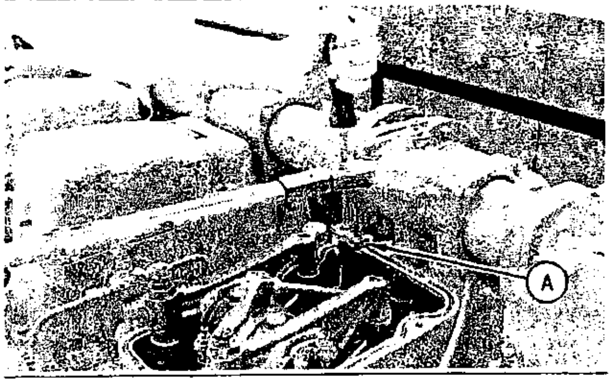


Illustration 86 g00801873

Tightening the locknut

(A) 1U-7133 Socket and 5P-0333 Wrench

5. Fit the 5P-0333 Wrench and 1U-7133 Socket (A) over locknut (5). Insert a screwdriver through the socket and hold adjusting screw (4) in position. Fit a torque wrench onto 5P-0333 Wrench (A) and tighten the locknut to a torque of 100 ± 15 N·m (75 ± 11 lb ft).
6. Ensure that the valve lash is correct.

Valve Lash Adjustment

Table 17

Tools Needed	Qty
4C-6593 Adjustment Tool [1]	1
6V-3075 Dial Indicator [1]	1
8S-3675 Indicator Contact Point [1]	1
1U-7133 Socket [2]	1
5P-0333 Wrench [2]	1

[1] Insert the contact point into the dial indicator. Insert the dial indicator into the adjustment tool. Tighten the retaining screw finger tight.
[2] To facilitate the use of a torque wrench, weld the jaw of the 5P-0333 Wrench around the top end of the 1U-7133 Socket.

1. Put the No. 1 piston at the Top Center position. Refer to "Finding the Top Center Compression Position for the No. 1 Cylinder" and "Crankshaft Position for Valve Lash Setting". Work on the appropriate cylinders.
2. Before you perform any adjustments, use a soft hammer to lightly tap each rocker arm at top of the adjusting screw. This will ensure that the lifter roller is seated against the camshaft.

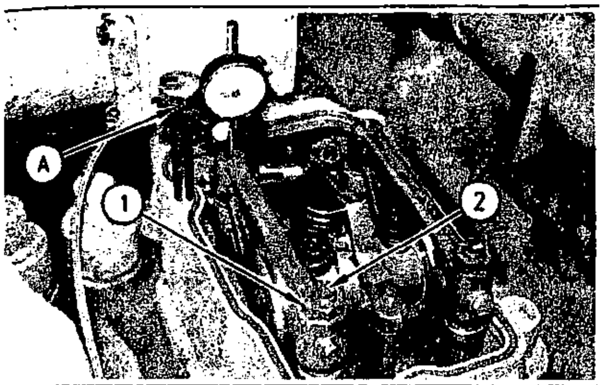


Illustration 87 g00801887

(A) 4C-6593 Adjustment Tool
(1) Locknut
(2) Adjusting screw

3. Install 4C-6593 Adjustment Tool (A) on the rocker base. Thread the adjustment tool into the hole that is nearest to the end of the rocker arm. Position the contact point of the dial indicator over the flat area on the end of the rocker arm. Tighten the knob. Rotate the dial indicator so the dial indicator can be easily read. Ensure that the tool is rigid and that the point of the dial indicator moves freely.

4. Loosen locknut (1). Turn adjusting screw (2) clockwise until resistance is felt. Slightly turn the adjusting screw in the counterclockwise direction in order to obtain a valve lash of zero. The valves must be fully closed.

5. Zero the dial indicator.

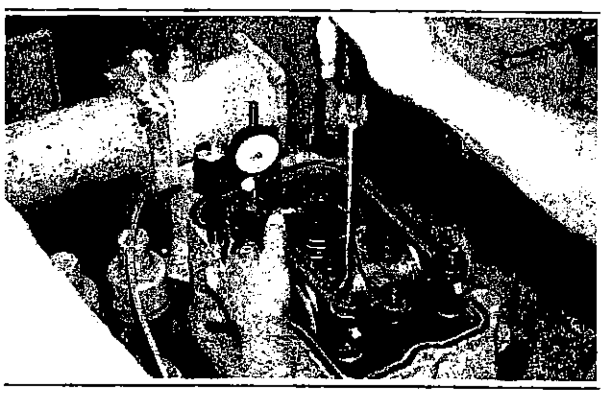


Illustration 88 g00311262

Valve lash adjustment

6. Lift up firmly on the valve end of the rocker arm. Turn the valve adjusting screw until you achieve the setting that is specified in Table 18.

Table 18

Valve Lash Setting With Engine	
Valves	Indicator Reading
Inlet	0.50 mm (0.020 inch)
Exhaust	1.27 mm (0.050 inch)

7. Try to move the rocker arm for a small amount while you lift the rocker arm. The dial indicator reading will vary. Read the dial indicator when the rocker arm fits in the groove for the rocker arm.

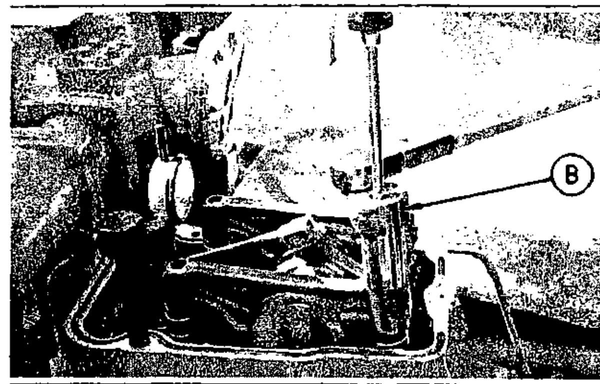


Illustration 89 g00801889

Tightening the locknut

(B) 1U-7133 Socket and 5P-0333 Wrench

8. Fit the 1U-7133 Socket and 5P-0333 Wrench (B) over the locknut. Insert a screwdriver through the socket and hold the adjusting screw in position. Fit a torque wrench onto the 5P-0333 Wrench and tighten the locknut to a torque of 200 ± 25 N·m (150 ± 18 lb ft). Check the adjustment again. Repeat the procedure, if necessary.

9. Perform the procedure for the remaining valves.

10. After all valves are adjusted for the Top Center Compression Stroke, remove the crankshaft timing pin. Operate the prelube pump and rotate the flywheel for 360 degrees in the direction of normal crankshaft rotation. This will put No. 1 piston at Top Center Exhaust Stroke. Install the timing pin. Complete the adjustments for the remaining cylinders.

Gas Admission Valve Lash

Table 19

Tools Needed	Qty
146-2742 Gas Inlet Valve Test Tool (1)	1
6V-3075 Dial Indicator (1)	1
8S-3675 Indicator Contact Point (1)	1

(1) Insert the contact point into the dial indicator. Insert the dial indicator into the test tool. Tighten the retaining screw finger tight.

1. Put the No. 1 piston at the Top Center position. Refer to "Finding The Top Center Compression Position Forthe No. 1 Cylinder" and "Crankshaft Position for Valve Lash Setting". Work on the appropriate cylinders.

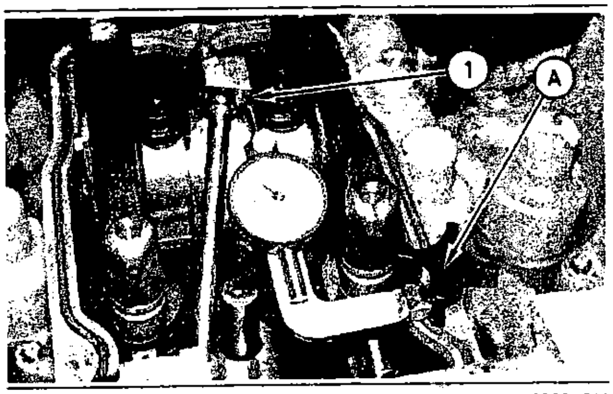


Illustration 90 g00801911

(1) Counterbore
(A) 146-2742 Gas Inlet Valve Test Tool

2. Install 146-2742 Gas Inlet Valve Test Tool (A) onto the rocker base. Align the point of the dial indicator into the center of counterbore (1).

Note: Make sure that the rocker arm is pressed to the left in order to indicate the maximum lash.

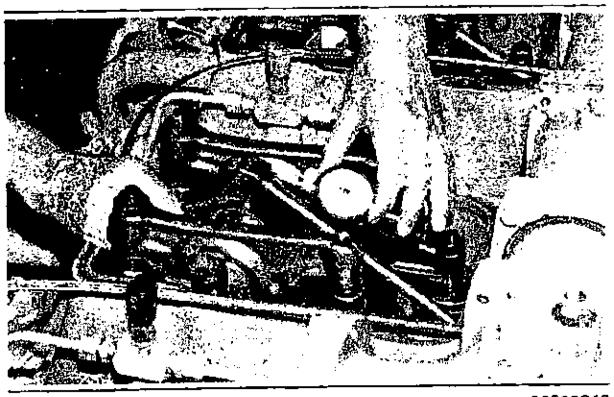


Illustration 91 g00500316

Lifting the rocker arm

3. Lift the end of the rocker arm that has the adjusting screw. Zero the dial indicator.

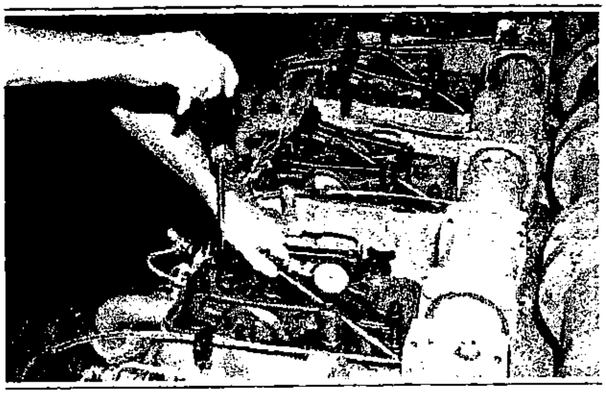


Illustration 92 g00500317

Adjusting the gas admission valve lash

4. Rotate the rocker arm away from the upper pushrod and push the rocker arm toward the exhaust valve's rocker arm. Read the dial indicator. The correct setting is listed in Table 20.

Table 20

Valve Lash Setting With Engine Stopped	
Valve	**Indicator Reading**
Gas admission valve	0.64 mm (.025 inch)

If the valve lash is correct, go to Step 6.

If the valve lash is not correct, loosen the locknut for the adjusting screw. Rotate the rocker arm away from the upper pushrod and push the rocker arm toward the exhaust valve's rocker arm. Turn the adjusting screw until the correct valve lash is obtained.

5. Tighten the locknut for the adjusting screw to a torque of 30 ± 4 N·m (22 ± 3 lb ft). Check the valve lash again. Repeat the procedure, if necessary.

6. Perform the procedure for the remaining valves.

7. After all valves are adjusted for the Top Center Compression Stroke, remove the crankshaft timing pin. Operate the prelube pump and rotate the flywheel for 360 degrees in the direction of the normal crankshaft rotation. This will put the No. 1 piston at the Top Center Exhaust Stroke. Install the timing pin. Complete the adjustments for the remaining cylinders.

Adjustment of the Speed-Timing Wheel

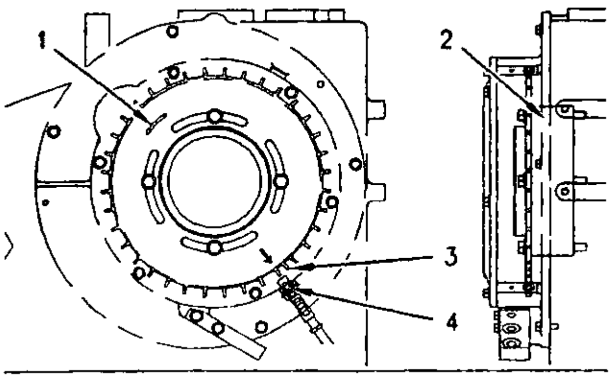


Illustration 93 g00896580

In-line engine

Position of the speed-timing wheel with the number one cylinder at the top center position on the compression stroke

(1) Arrow for the direction of the camshaft's rotation
(2) Spacer
(3) Extra tooth
(4) Engine speed/timing sensor

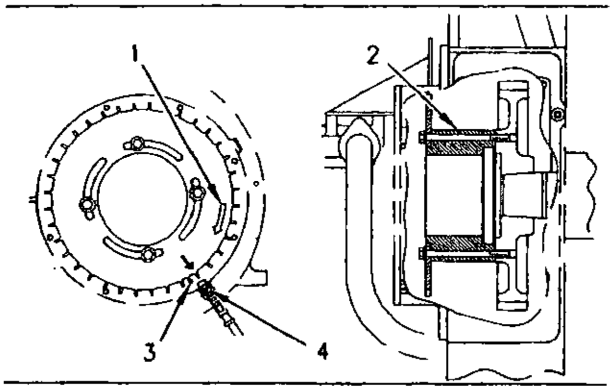


Illustration 94 g00896582

Vee engine

Position of the speed-timing wheel with the number one cylinder at the top center position on the compression stroke

(1) Arrow for the direction of the camshaft's rotation
(2) Spacer
(3) Extra tooth
(4) Engine speed/timing sensor

1. Put the No. 1 piston at the Top Center position on the compression stroke. Refer to "Finding The Top Center Compression Position Forthe No. 1 Cylinder" and "Crankshaft Position for Valve Lash Setting". Pin the camshaft.
2. Orient one of the camshaft drive gear's 1/2-13 threaded holes to the 12 o'clock position. The four 1/2-13 threaded holes form a diamond pattern.
3. Install spacer (2) and the speed-timing wheel. Orient extra tooth (3) near sensor (4). Loosely install the four bolts in order to enable speed-timing wheel to be moved.
4. Rotate the speed-timing wheel in the direction of the camshaft's rotation until the first tooth after the extra tooth is aligned with the centerline of the sensor.
5. Tighten the four bolts.
6. Install the cover for the speed-timing wheel.
7. Remove the camshaft timing pin from the camshaft. Install the timing pin in the storage position.

Adjusting the Engine Speed/Timing Sensor

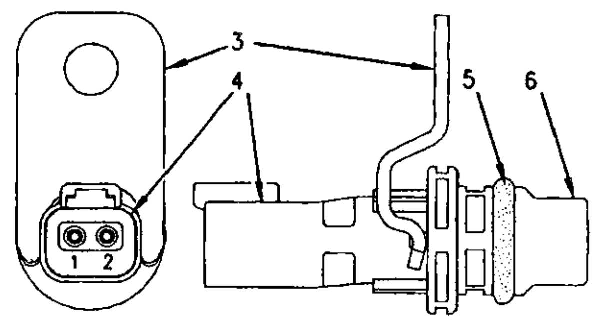


Illustration 95 g00850545

Engine speed/timing sensor

(1) Terminal for the - signal
(2) Terminal for the + signal
(3) Bracket
(4) Integral connector on the sensor
(5) O-ring seal
(6) Sensor

1. Clean the tip of sensor (6), the sensor's mounting flange and the counterbore for the sensor in the rear housing.
2. Lubricate O-ring seal (5) with clean engine oil.
3. Install the sensor into the counterbore in the rear housing. Make sure that the sensor is properly seated and that the bracket is flush with the mounting surface. Use the bolt to secure the bracket to the rear housing.
4. Measure the gap between the sensor's head and the speed-timing wheel's extra tooth. The distance must be between 0.6 mm (0.024 inches) and 1.4 mm (0.055 inch). If the gap is too large, remove material from the housing in order to attain the correct gap. If the gap is too small, use 119-9738 Shims in order to attain the correct gap.
5. Make sure that the connector on the engine harness is in good condition. Connect the engine harness to the sensor's connector. Make sure that the mating of the connection is secure.

i01860271

BTU and Precombustion Chamber Adjustments

SMCS Code: 1278; 1550

The control strategy for the air/fuel ratio is determined by the setting for the fuel quality, by the fuel flow, and by the combustion burn times. The setting for the fuel quality is the initial setting for the air/fuel ratio. The combustion burn time allows the control strategy to fine tune the air/fuel ratio. This is based on the quality of the fuel. Both of these adjustments are critical, and problems can arise if the adjustments are not properly set.

Setting of the Fuel Quality

Note: Use the Caterpillar Electronic Technician (Cat ET) to adjust the setting for the fuel quality.

The setting for the fuel quality is typically defined during the engine commissioning. The setting of the fuel quality does not require further adjustment unless the fuel's average lower heating value (LHV) changes. To establish the setting for the fuel quality, a gas analysis and a measurement of the exhaust emissions are required.

A current gas analysis is required before making any adjustments to the value for the fuel quality. Obtain the analysis and enter the data into Caterpillar Software, LEKQ6378, "Methane Number Program". This program establishes the LHV through a calculation that weighs the effect of the various contents of the gas. This calculation is based on the percentage of the total gas. Set the fuel quality to this LHV.

Note: It is very important to use the Caterpillar Software, LEKQ6378, "Methane Number Program". Use of only the data from the gas analysis can result in incorrect settings.

A measurement of the exhaust emissions verify that the engine is properly set. The emission levels for the fuel quality can be compared to the levels of these emissions that were recorded during the engine commissioning: NO, NO_x, CO, CO_2, and O_2.

If the amount of NO_x and CO in the exhaust are not within ± 10 ppm of the engine commissioning, determine whether the setting for the fuel quality should be adjusted. A leaner air/fuel ratio will reduce NO_x and a leaner air/fuel ratio will increase CO. A richer air/fuel ratio will increase NO_x and a richer air/fuel ratio will reduce CO. Two basic concepts of the control strategy must be understood before making an adjustment to the fuel quality.

Basic Engine Speed and Governing Control

The engine's control strategy adjusts fuel flow. This is based on the differential between the actual engine speed and the desired engine speed setting.

If the actual engine speed is lower than the desired engine speed, the control will increase the amount of fuel flow. If the actual engine speed is higher than the desired engine speed, the control will decrease the amount of fuel flow. The application of load to the engine will result in a higher fuel flow in order to maintain the same desired speed. This is due to a decrease of the actual engine speed as the load increases.

Basic Air/Fuel Ratio Control

The control strategy uses the volume of fuel and the fuel's heating value to determine the amount of air that is required for maintaining the proper air/fuel ratio.

The volume of fuel that is consumed by combustion is calculated by measuring the following conditions:

- Pressure differential between the fuel manifold and the inlet air manifold
- Temperature of the fuel to the cylinder
- Engine rpm

The setting of the fuel quality and the combustion burn times are evaluated in order to determine the heating value of the fuel. The volume of inlet air will increase as the volume of fuel and the heating value increase. The volume of inlet air will decrease as the volume of fuel and the heating value decrease. The control strategy regulates the volume of air by adjusting positions of the wastegate and of the air choke.

Adjustments to the setting of the fuel quality will affect the air/fuel ratio during tuning of the engine. To obtain a leaner air/fuel ratio, increase the setting of the fuel quality when the engine is tuned again. This will increase the volume of air for combustion. The control will interpret the higher fuel quality as a hotter fuel. The actual heating value of the fuel does not change. To obtain a richer air/fuel ratio, decrease the setting of the fuel quality when the engine is tuned again. This will reduce the volume of air for combustion. The control will interpret the lower fuel quality as a cooler fuel. The actual heating value of the fuel does not change.

The control also uses the fuel quality in order to calculate the percentage of engine load. This calculated load is used by the control strategy to determine the timing, the air/fuel ratio, and the operating limits. Adjusting the fuel quality will directly affect the operation of the engine.

NOTICE

The BTU setting will directly affect the air/fuel ratio during tuning which in turn will alter the emission level of the engine. Improper settings of the BTU during tuning will lead to engine performance problems and have a negative impact on the site emission permits.

Do not use the fuel quality as an adjustment for improving starting and/or acceptance of a load. If there are problems with engine start-up and/or loads at a particular setting for the fuel quality, another gas analysis and/or adjustments to the engine are required.

Note: Normally, the engine will operate with different fuels that have a broad range of heating values. If the heating value of the fuel changes significantly, an adjustment to the setting of the fuel quality may be necessary in order to operate the engine.

If the setting of the fuel quality is not within ± 25 fuel quality of the fuel's actual LHV, the engine is not considered to be properly set. Additional gas analysis and/or engine adjustments are required.

The setting of the fuel quality will directly affect the performance of the engine. If the setting is too low, the air/fuel mixture will be too rich. This will result in higher exhaust temperatures, in detonation, and in possible damage to the precombustion chambers. If the setting is too high, the air/fuel mixture will be too lean. This will result in poor engine performance, in false detonation, in misfire, and in shutdowns.

Do not adjust the setting for the fuel quality while the control strategy is running in the feedback mode. The control strategy for the engine will automatically compensate for any variation in the heating value of the fuel. Adjusting the setting of the fuel quality during feedback mode will not change the operating condition of the engine. If the setting is adjusted, the adjustment could lead to operational problems.

Tuning the Engine

The setting of the fuel quality establishes a reference point. If the LHV of the gas does not change, the engine's performance will probably be consistent. However, it is likely that the LHV will change over time.

Note: Before you tune the engine, determine whether misfire is present. Also, determine the load and speed for the application.

Modes of Air/Fuel Ratio Control

Start-Up

During start-up, the air/fuel ratio is controlled with the air choke. The starting position depends on the number of cylinders. Typically, the starting position is closed 60 to 80 percent.

The air choke is maintained at a fixed position until ten seconds after the engine achieves the desired speed. If the starting position is set too high, the engine will not get enough combustion air. In this case, the programming in the software opens the air choke in steps until the engine speed increases. This enables a steady increase of the engine speed until the desired speed is achieved.

The starting position is programmed in the Cat ET configuration screen.

Exhaust Port Temperature Feedback

In this mode of operation, the air/fuel ratio is controlled in order to achieve a desired exhaust port temperature. This mode of operation is normally activated after the start-up is complete.

The Integrated Combustion Sensing Module (ICSM) calculates the difference between the average exhaust port temperature and the desired exhaust port temperature. The ICSM sends a fuel correction factor to the ECM. The ECM uses the fuel correction factor to control the air choke actuator in order to maintain the desired exhaust temperature.

If the average exhaust temperature is too low, the ECM commands the air choke actuator to move toward the closed position in order to richen the air/fuel mixture. Combustion of the richer air/fuel mixture increases the exhaust port temperatures.

The "Desired Engine Exhaust Port Temp" parameter is set in the Cat ET configuration screen. This is the desired exhaust port temperature for a load of 25 percent.

Combustion Feedback

During normal operation at loads that are greater than approximately 40 percent, the engine operates with combustion feedback. In this mode, the Electronic Control Module (ECM) adjusts the inlet manifold air pressure according to these factors: fuel flow, setting of the fuel quality, and combustion burn times. During this mode, the control automatically adjusts for any variations in the LHV of the fuel. The inlet manifold air pressure and the fuel correction factor can be monitored in order to observe the adjustments for the air/fuel ratio.

The inlet manifold pressure and the fuel correction factor can be observed with Cat ET. If the heating value of the fuel increases, the combustion burn time will decrease. The engine will be operating with a richer air/fuel ratio. The ECM increases the inlet air in order to increase the combustion burn time. If the heating value of the fuel decreases, the combustion burn time will increase because the engine will be operating with a leaner air/fuel ratio. The ECM decreases the inlet air in order to reduce the combustion burn time. In both cases, the ECM works in order to restore the desired combustion burn time.

Prechamber Calibration Mode

The prechamber calibration mode is enabled by selecting the screen with Cat ET. This will allow the engine to be tuned for the performance characteristics of the fuel.

When the engine is operating in the prechamber calibration mode, the ECM does not automatically adjust the inlet air. The combustion burn times are eliminated in the calculation of the air/fuel ratio. Primarily, the fuel flow and the setting for the fuel quality determine the amount of inlet air that is required for combustion. This allows the adjustment of the air/fuel ratio via the setting for the fuel quality. If the setting for the fuel quality is increased in this mode, the inlet air is also increased. This will result in a leaner air/fuel ratio. If the setting for the fuel quality is reduced in this mode, the inlet air is also reduced. This will result in a richer air/fuel ratio. The combustion burn time can be set to these conditions by adjusting the amount of fuel that is delivered to the precombustion chamber. Each cylinder has a needle valve that controls the amount of gas to the precombustion chamber.

Detection of Misfire

Before adjusting the engine, determine whether misfire is present. If misfire is present, the combustion burn time will not be accurate. The misfire will falsely increase the average combustion burn time.

Note: Failure to correct the misfire will result in an improper engine setting that will lead to problems.

Under normal operating conditions, the combustion burn time is an average value that is displayed by the Machine Information Display System (MIDS) on the remote control panel in milliseconds (0.01 seconds). The combustion burn time begins when the spark plug ignites. The combustion burn time ends when the flame front reaches the combustion sensor. When a cylinder misfires, the combustion sensor does not detect the flame front. The combustion burn time does not stop until the next cylinder is about to fire. This results in a long combustion burn time. The displayed combustion burn time increases because the time is an average of several ignitions in the cylinder.

Adjusting the fuel supply in the precombustion chamber on a misfiring cylinder will result in an incorrect setting on the engine that will lead to operational problems.

There are two forms of misfire: actual misfire and false misfire.

Note: Actual misfire can occur without significantly affecting the exhaust port temperature.

The exhaust port temperatures can help to differentiate between actual misfire and false misfire. A low exhaust port temperature probably indicates actual misfire. Troubleshooting can be concentrated on those components that are likely to be causing the misfire. The following components are included:

- Check valve for the precombustion chamber
- Spark plug
- Spark plug extender
- Ignition coil
- Integrated combustion sensing module (ICSM)
- Needle valve for the precombustion chamber
- Gas supply line for the precombustion chamber
- Gas admission valve

False misfire occurs when the combustion burn time is not measured correctly but the exhaust port temperatures are normal. This indicates a problem with one of the following components: combustion sensor, extender for the combustion sensor, wiring for the combustion sensor, and ICSM. These components are also susceptible to electrical noise.

Electrical noise in the feedback system can cause the combustion burn time to be incorrectly measured. This results in combustion burn times that are too fast. The electrical noise stops the timer before the flame front passes by the combustion sensor. Electrical noise can be detected by eliminating the averaging of combustion burn time during operation in the prechamber calibration mode.

Excessive oil in the cylinder will also cause fast combustion burn times.

If the wiring from the combustion sensors to the ICSM is not connected correctly, false misfire can be indicated. The exhaust temperatures will be normal but the combustion burn times can be excessive because the ICSM is not monitoring the correct firing order.

To isolate the component that is affecting the combustion burn times, components from a suspect cylinder can be exchanged with components from other cylinders. Operate the engine in order to locate the component. The misfire will follow the component to one of the other cylinders.

Adjusting Fuel Supply To The Precombustion Chamber

Before you tune the engine, define the operating load and the speed for the application. This can be different for different applications.

If the engine will be operated continuously at a certain load and speed, tune the engine at that load and speed. If the engine is expected to run continuously above 850 rpm and 75 percent of the rated load, tune the engine at the expected condition.

If the engine load and speed will vary, tune the engine at the midpoint of the defined range.

After the preliminary steps are completed, the needle valves for the precombustion chamber can be adjusted.

1. Before you start the engine, install an emissions analyzer.

Note: For initial start-up and start-up after major work, use the prechamber calibration mode. This will prevent the engine's control strategy from switching into the combustion feedback mode when the load is greater than approximately 40 percent. This also allows direct control of the air/fuel ratio with the setting for the fuel quality. The engine can be started and loaded prior to the tuning. Skip Step 3 and review Step 4.

2. Start the engine and operate the engine at the desired load and speed until the water temperatures and oil temperatures are stable. Approximately one hour is required for the warm-up.

3. Operate in the feedback mode and refer to the value of the fuel correction factor.

   If the fuel correction factor is 100 percent, no special consideration is required.

   If the fuel correction factor is less than 99 percent or if the factor is greater than 101 percent, the LHV of the fuel may have changed since the last tuning. A gas analysis is required to determine the new LHV. Before the engine is tuned, adjust the setting of the fuel quality to the new value.

4. Use Cat ET to switch the engine's control to the prechamber calibration mode.

Note: Do not exit the prechamber calibration mode while you tune the engine. This could result in adjusting the engine for an improper air/fuel ratio. This will lead to poor engine performance. When the engine's control is in the prechamber calibration mode, the fuel correction factor is automatically set to 100 percent.

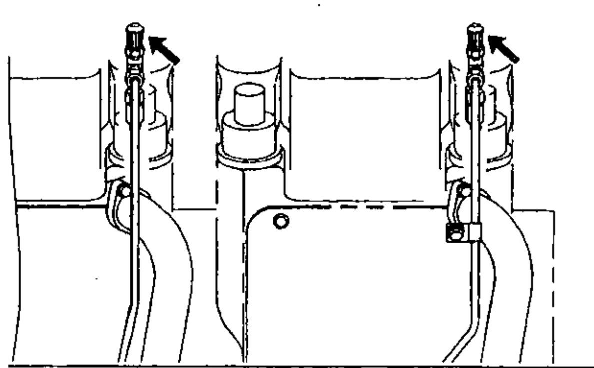


Illustration 96 g00815515

Needle valves

5. Monitor all of the combustion burn times that are observed on Cat ET or on the MIDS. Compare the combustion burn times to the desired combustion burn time. Adjust all of the needle valves for the precombustion chamber sequentially. Allow a minimum of five minutes for the combustion burn time to stabilize. Repeat this process until all of the actual combustion burn times are within ± 0.20 milliseconds of the desired combustion burn time.

   Opening the needle valve will increase the fuel flow to the precombustion chamber. This decreases the combustion burn time for the cylinder.

Closing the needle valve will decrease fuel flow to the precombustion chamber. This increases the combustion burn time.

Adjusting the needle valves too far will result in rich misfire or in lean misfire. This will be reflected by combustion burn times that are long and unstable.

6. Measure the levels of the exhaust emissions. Compare the data to the data from the engine commissioning and/or from the history of the engine's performance.

7. Observe the data for the engine performance on Cat ET or on the MIDS. Pay particular attention to the fuel correction factor and to the inlet manifold air pressure.

   Look for any variations and determine the root cause. If the exhaust emissions are not correct, adjust the setting for the fuel quality.

   Make sure that the current fuel analysis is correct. Make sure that the emissions analyzer is accurate.

8. After the exhaust emissions are correct, record the inlet manifold air pressure and the fuel correction factor. Switch the engine's control to the feedback mode.

9. After the engine is operating in the feedback mode, observe the inlet manifold air pressure and the fuel correction factor. Determine whether these parameters remain stable.

   If these values shift then the engine is not properly tuned. Repeat the process.

10. Record exhaust emissions for the feedback mode. Compare the exhaust emissions to the data from the engine commissioning.

    The levels of NO_x and CO should be within ± 10 ppm of the original levels.

11. Record all of the parameters for the engine operation. Record the settings of the needle valves. Save this data for future reference.

NOTICE

Adjustments to the precombustion chamber needle valves should not be made when the engine's control strategy is operating in the "feedback" mode. The engine's control strategy adjusts the air fuel ratio to maintain the actual combustion burns equal to the desired burn times. Therefore, adjusting the needle valves will not result in different burn times. Adjusting the needle valve will, instead, set the air/fuel ratio to an unknown value, because the engine's control strategy will attempt to correct for this change.

When an engine is initially started and when an engine is started after major work, open the needle valves for four to five turns. Changing the settings of the needle valves on an engine that has been tuned will cause problems with starting and loading.

If the settings for the needle valves increase over time, problems may be occurring in the precombustion chamber. Inspect the precombustion chambers with a borescope in order to determine the root cause of the increased settings of the needle valves.

If the needle valves have continuous problems, the fuel may be contaminated. If the contamination is in the form of small particles, a fuel filter that has a 0.01 micron filter is recommended. If the fuel is contaminated by liquids, the system that supplies the gas must be improved in order to remove the contamination.

If the LHV of the fuel changes during tuning, the tuning will be more difficult. The settings will be improper. Check the exhaust emissions after the engine is tuned in order to verify that the engine was properly tuned.

Operation of the engine at an air/fuel ratio that is too rich will increase the exhaust port and exhaust stack temperatures. This operation could result in a shutdown for high exhaust stack temperature. An air/fuel mixture that is too rich can also cause detonation.

Damage may occur to a precombustion chamber if the engine is operated at an air/fuel ratio that is too rich. This can occur if misfire is not corrected before adjustment of the needle valves.

Air Inlet and Exhaust System

i01753108

General Information (Air Inlet and Exhaust System)

SMCS Code: 1050

These engines use three actuators with adjustable linkages to control the fuel inlet, the exhaust bypass (wastegate), and the inlet air (choke). The Electronic Control Module (ECM) controls these functions.
If there is a complaint about poor performance or operational problems, check for correct adjustment of the actuators and of the needle valves for the precombustion chambers.

Restriction of Air Inlet and Exhaust

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

The air flow through the air cleaner may have a restriction. The restriction must not be more than 3.74 kPa (15 inches of H_2O).

Back pressure is the difference in the pressure between the exhaust at the outlet elbow and the atmospheric air. Back pressure from the exhaust must not be more than 2.49 kPa (10 inches of H_2O).

Lubrication System

i01753807

General Information (Lubrication System)

SMCS Code: 1300

One of the problems in the list that follows will generally be an indication of a problem in the engine's lubrication system.

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

Excessive Consumption of Engine Oil

Incorrect Engine Oil Level

Overfilling the crankcase will increase the consumption of engine oil. Make sure that the engine oil level is correct.

When the engine crankcase is full, engine oil will be initially consumed at a relatively rapid rate. The rate of consumption is reduced as the engine oil level decreases. A crankcase that is always maintained at the full level will have a faster rate of consumption.

If the engine has a system for automatically filling the crankcase with engine oil, check the level for the system. Adjust the system in order to provide engine oil to a level that is less than the full level. Make sure that the supply of engine oil is adequate.

External Leak

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

Measure the crankcase blowby according to the engine's Operation and Maintenance Manual, "Crankcase Blowby - Measure/Record".

Internal Leak

There are several possible ways for engine oil to leak into the combustion chambers:

- Leakage between worn valve guides and valve stems
- Worn components or damaged components (pistons, piston rings, or dirty passages for engine oil)
- Incorrect installation of the compression ring and/or the intermediate ring
- Leakage past the seal rings in the turbocharger
- Overfilling of the crankcase
- Incorrect dipstick or guide tube

Signs of internal leaks include high consumption of engine oil, blue smoke, and excessive detonation.

If the pistons are suspected, check the cylinder compression. Refer to the engine's Operation and Maintenance Manual, "Cylinder Pressure - Measure/Record".

Worn Components

Excessively worn engine components and damaged engine components can result from the following conditions:

- Contaminated engine oil
- Incorrect fuel system settings
- Contamination from the inlet air

Extended Operation with Low Loads

Extended operation at low idle or extended operation at a reduced load will cause increased oil consumption and carbon buildup in the cylinders. This will occur if the engine is usually operated at a torque that is significantly below the rated power.

The engine can be operated at a low load. However, engine operation at a low load is limited. For information on operation with a low load, refer to the engine's Operation and Maintenance Manual, "Engine Operation".

Measuring Engine Oil Pressure

A faulty indicator or a faulty sensor for engine oil pressure can provide a false indication of the engine oil pressure.

The 1U-5470 Engine Pressure Group can be used to compare the indicator on the instrument panel and the engine oil pressure that is displayed on the Caterpillar Electronic Technician (Cat ET).

⚠ WARNING

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

Check the engine oil pressure to the camshaft and main bearings on the side of the cylinder block at a plug for the main engine oil gallery. With the engine at operating temperature, the minimum engine oil pressure at full load rpm is approximately 280 kPa (40 psi). The minimum engine oil pressure at low idle rpm is approximately 140 kPa (20 psi).

Low Engine Oil Pressure

Engine Oil Level

Check the level of the engine oil in the crankcase. Add engine oil, if necessary.

It is possible for the engine oil level to be too far below the supply tube for the engine oil pump and the pump cannot supply enough lubrication to the engine components.

Contaminated Engine Oil

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

Improper Circulation of the Engine Oil

Several factors could cause improper circulation of the engine oil:

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

Oil Filter Bypass Valve

If the bypass valve for one or more of the engine oil filters is held in the open position due to a restriction, a reduction in the pressure can be the result. Remove each bypass valve and clean each bypass valve in order to correct this problem. You must also clean each bypass valve bore. Install new Caterpillar engine oil filters. New filters will prevent more debris from causing this problem.

Worn Components

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

Obtain an analysis of the engine oil. Check the analysis for the level of wear metals in the engine oil.

High Engine Oil Pressure

Engine oil pressure will be high if the bypass valve for the engine oil pump can not move from the closed position.

Excessive Bearing Wear

If an engine component shows premature bearing wear, the cause can be a restriction in a passage for engine oil. An indicator may show that there is enough oil pressure, but a component is worn due to a lack of lubrication. In such a case, look at the passage for the engine oil supply to the component.

Increased Engine Oil Temperature

The temperature may be higher than normal when the engine is operating. In such a case, the engine oil cooler may have a restriction. Look for a restriction in the passages of the engine oil cooler. The engine oil pressure will be reduced just because the engine oil cooler has a restriction.

Determine whether the bypass valve for the engine oil cooler is held in the open position. This condition will allow the engine oil through the valve instead of the engine oil cooler. The temperature will increase.

Cooling System

i01753559

General Information (Cooling System)

SMCS Code: 1350

This engine has a pressurized cooling system. A pressurized cooling system has two advantages.

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

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

If the cooling system is not properly maintained, solids such as scale and deposits reduce the ability of the cooling system to transfer heat. The engine operating temperature will increase. Overheated coolant can be lost through the cooling system's pressure relief valve. Lower coolant levels contribute to additional overheating. Overheating can result in scuffing or in seizing of parts due to reduced lubrication and clearances.

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

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

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

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

Visual Inspection Of The Cooling System

⚠ WARNING

Personal injury can result from escaping fluid under pressure.

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

1. Check the coolant level in the cooling system.
2. Look for leaks in the cooling system. After the engine is stopped, look for coolant or for steam from the filler cap's pressure relief valve. Inspect the coolant lines and connections.
3. After the engine is cool, remove the filler cap slowly in order to relieve any pressure. Inspect the filler cap and the sealing surface for the cap. This surface must be clean and the seal must not be damaged.
4. Look for signs of air or of combustion gas in the cooling system.

   Air and/or gas in the coolant results in foaming of the coolant.

Testing The Cooling System

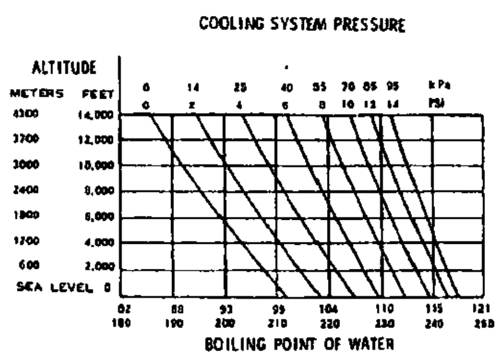


Illustration 97 g00286266

Atmospheric pressure and the boiling point of water

Remember that temperature and pressure work together. To help diagnose a cooling system problem, check the temperature and the pressure. The cooling system pressure has an effect on the cooling system temperature. Illustration 97 demonstrates the effect of pressure on the boiling point (steam) of water.

Test Tools For Cooling System

Table 21

Tools Needed	Quantity
4C-6500 Digital Thermometer	1
1U-5470 Engine Pressure Group	1
8T-5296 Coolant Conditioner Test Kit	1
9S-8140 Pressurizing Pump	1

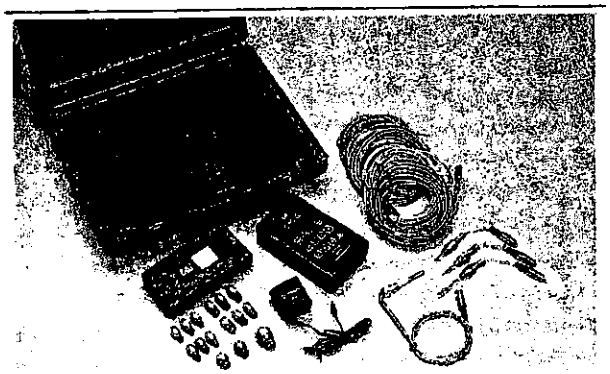


Illustration 98 g00286267

4C-6500 Digital Thermometer

The 4C-6500 Digital Thermometer is used in the diagnosis of overheating conditions and of overcooling conditions. This group can be used to check temperatures in several different parts of the cooling system. The Operating Manual, NEHS0554 is provided with the thermometer.

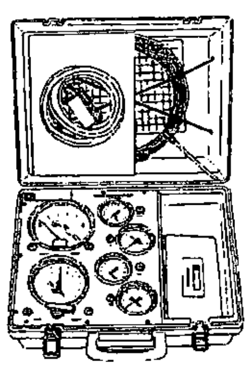


Illustration 99 g00295554

1U-5470 Engine Pressure Group

The 1U-5470 Engine Pressure Group can be used to measure the pressures in different parts of the cooling system.

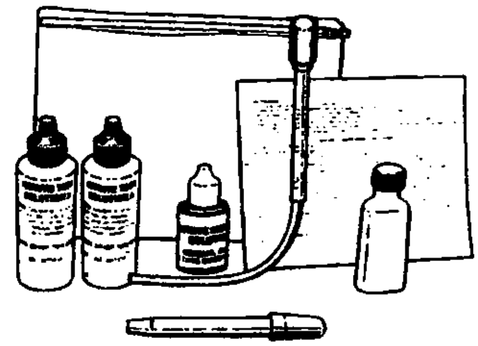


Illustration 100 g00768793

8T-5296 Coolant Conditioner Test Kit

The 8T-5296 Coolant Conditioner Test Kit is used to measure the concentration of Caterpillar Supplemental Coolant Additive. Insufficient concentrations or excessive concentrations can lead to engine damage. Instructions are provided with the kit.

Note: The 8T-5296 Coolant Conditioner Test Kit tests the concentration of nitrites in the coolant. Some types of coolant additives have phosphates rather than nitrites. If the additive in the cooling system has phosphates, test the coolant according to the instructions that are provided by the OEM of the additive.

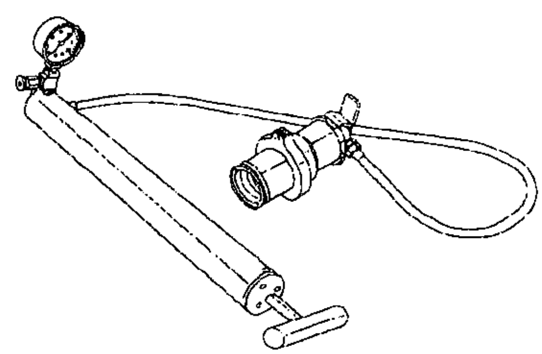


Illustration 101 g00286369

9S-8140 Pressurizing Pump

The 9S-8140 Pressurizing Pump is used to test the filler cap, the pressure relief valve, and the pressure gauge.

Testing the Filler Cap

Table 22

Tools Needed		Quantity
9S-8140	Pressurizing Pump	1

⚠ WARNING

Steam or hot coolant can cause severe burns.

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

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

One cause for a pressure loss from the cooling system can be a damaged seal on the filler cap.

To check for the amount of pressure that opens the filler cap, use the following procedure:

1. After the engine cools, carefully loosen the filler cap in order to release the pressure from the cooling system. Remove the filler cap.
2. Carefully inspect the filler cap. Look for any damage to the seals and to the sealing surface.

   Remove any deposits that are found.

   If the filler cap is damaged, obtain a new cap.
3. Install the filler cap on the 9S-8140 Pressurizing Pump.

   The opening pressure for the filler cap's pressure relief valve is stamped on the filler cap.
4. Apply pressure to the filler cap. Compare the gauge reading with the opening pressure that is listed on the filler cap.

   If the cap cannot sustain the correct pressure, obtain a new cap.

   If the filler cap's pressure relief valve does not open within approximately 7 kPa (1 psi) of the pressure that is stamped on the filler cap, obtain a new cap.

Testing the Water Temperature Indicator

Table 23

Tools Needed	Quantity
4C-6500 Digital Thermometer (1)	1

(1) A temperature indicator of known accuracy can also be used.

Check the accuracy of the water temperature indicator and/or water temperature sensor if you find either of the following conditions:

- The engine runs at a temperature that is too hot, but a normal temperature is indicated. A loss of coolant is found.
- The engine runs at a normal temperature, but a hot temperature is indicated. No loss of coolant is found.

⚠ WARNING

Personal injury can result from escaping fluid under pressure.

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

⚠ WARNING

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

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

1. Install a probe for the test thermometer into a suitable location near the suspect indicator's water temperature sensor.
2. Start the engine. Run the engine until the temperature reaches the desired range according to the test thermometer.
3. Compare the reading on the water temperature indicator with the reading on the test thermometer.

   If the readings are within the tolerance for the range of the water temperature indicator, the indicator and the sensor are OK.

   If the readings are not within the tolerance for the range of the water temperature indicator, obtain a new indicator and/or a sensor.

Testing the Water Temperature Regulator

1. Drain the cooling system to a level below the water temperature regulator housing.
2. Remove the water temperature regulator from the water temperature regulator housing.

Note: Refer to the literature that is supplied by the OEM of the water temperature regulator for the water temperature regulator's opening temperature and opening distance.

3. Heat water in a pan until the temperature is equal to the opening temperature for the water temperature regulator.

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

5. Keep the water at the correct temperature for ten minutes.

6. After ten minutes, remove the water temperature regulator. Immediately measure the opening in the water temperature regulator.

   If the opening agrees with the distance that is specified by the OEM of the water temperature regulator, the water temperature regulator is operating properly.

   If the distance is less than the distance that is specified by the OEM of the water temperature regulator, obtain a new water temperature regulator.

Basic Engine

i00669880

Basic Block

SMCS Code: 1200

Connecting Rod Bearings

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

Connecting rod bearings are available with 0.50 mm (.020 inch) and 1.00 mm (.040 inch) smaller inside diameter than the original size bearing. These bearings are for crankshafts that have been ground.

Main Bearings

Main bearings are available with a larger outside diameter than the original size bearings. These bearings are available for the cylinder blocks with the main bearing bore that is made larger than the bores' original size. Main bearings are available with 1.00 mm (.040 inch) and 2.00 mm (.080 inch) larger outside diameter than the original size bearings.

Cylinder Block

If the main bearing caps are installed without bearings, the bore in the block for the main bearings can be checked. Tighten the nuts that hold the caps to the torque that is shown in the Specifications. Alignment error in the bores must not be more than 0.040 mm (.0016 inch). Refer to the Special Instruction, SMHS7606 for the use of the 1P-4000 Line Boring Tool Group for the alignment of the main bearing bores. The 1P-3537 Dial Bore Gauge Group can be used to check the size of the bores. The Special Instruction, GMGO0981 is with the group.

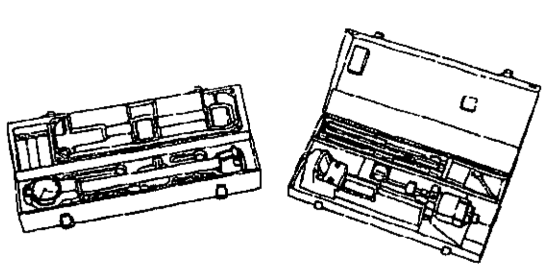


Illustration 102 g00285686

1P-3537 Dial Bore Gauge Group

Flywheel And Flywheel Housing

Table 24

Tools Needed		Quantity
8T-5096	Dial Indicator Group	1

Face Runout (axial eccentricity) of the Flywheel Housing

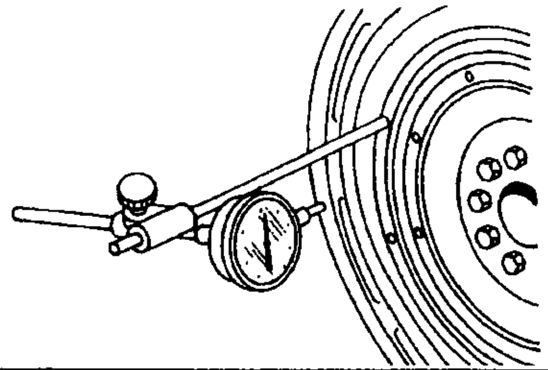


Illustration 103 g00285931

8T-5096 Dial Indicator Group

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

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

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

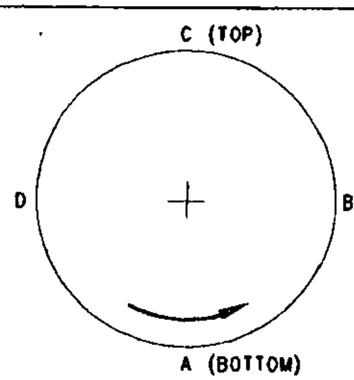


Illustration 104 g00285932

Checking Face Runout Of The Flywheel Housing

3. Turn the flywheel while the dial indicator is set at 0.0 mm (.00 inch) at location (A). Read the dial indicator at locations (B), (C) and (D).

4. The difference between the lower measurements and the higher measurements that are performed at all four points must not be more than 0.38 mm (.015 inch), which is the maximum permissible face runout (axial eccentricity) of the flywheel housing.

Bore Runout (radial eccentricity) of the Flywheel Housing

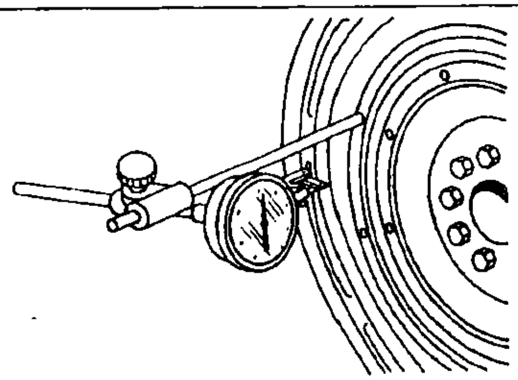


Illustration 105 g00285934

8T-5096 Dial Indicator

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

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

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

Illustration 106 g00285936

2. While the dial indicator is in the position at location (C) adjust the dial indicator to 0.0 mm (.00 inch). Push the crankshaft upward against the top of the bearing. Refer to the illustration 106. Write the measurement for bearing clearance on line 1 in column (C).

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

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

4. Turn the flywheel in order to put the dial indicator at (A). Adjust the dial indicator to 0.0 mm (.00 inch).

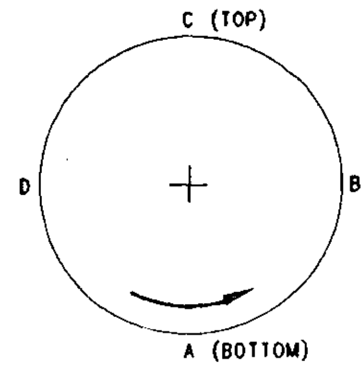


Illustration 107 g00285932

Checking Bore Runout Of The Flywheel Housing

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

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

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

8. Add the lines together in each column.

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

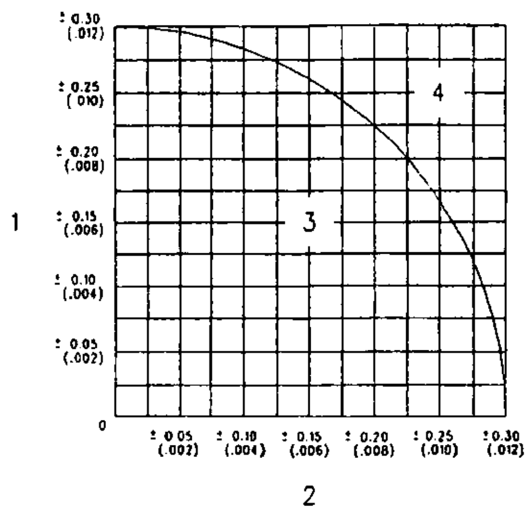


Illustration 108 g00286046

Graph For Total Eccentricity

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

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

11. If the point of intersection is in the range marked "Acceptable", the bore is in alignment. If the point of intersection is in the range marked "Not acceptable", the flywheel housing must be changed.

Face Runout (axial eccentricity) of the Flywheel

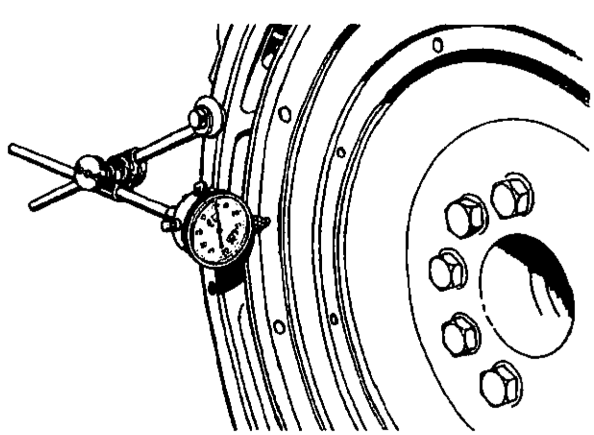


Illustration 109 g00286049

Checking Face Runout Of The Flywheel

1. Refer to illustration 109 and install the dial indicator. Always put a force on the crankshaft in the same direction before the dial indicator is read. This will remove any crankshaft end clearance.
2. Set the dial indicator to read 0.0 mm (.00 inch).
3. Turn the flywheel at intervals of 90 degrees and read the dial indicator.
4. Take the measurements at all four points. Find the difference between the lower measurements and the higher measurements. This value must not exceed the maximum permissible face runout (axial eccentricity) of the flywheel.

Bore Runout (radial eccentricity) of the Flywheel

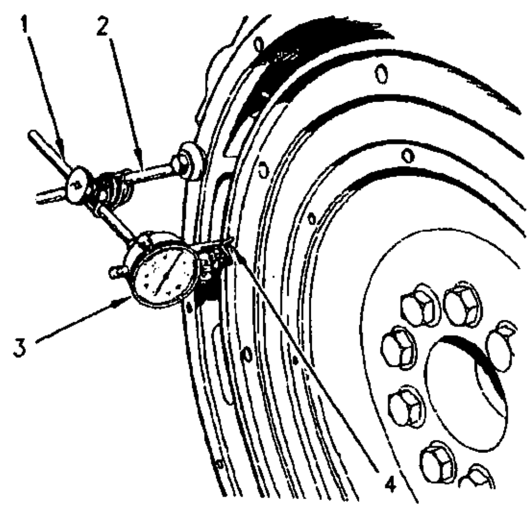


Illustration 110 g00286054

Checking Bore Runout Of The Flywheel

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

1. Install the 7H-1942 Dial Indicator (3). Make an adjustment of the 7H-1940 Universal Attachment (4) so that the dial indicator makes contact on the flywheel.
2. Set the dial indicator to read 0.0 mm (.00 inch).
3. Turn the flywheel at intervals of 90 degrees and read the dial indicator.
4. Take the measurements at all four points. Find the difference between the lower measurements and the higher measurements. This value must not exceed the maximum permissible bore runout (radial eccentricity) of the flywheel.

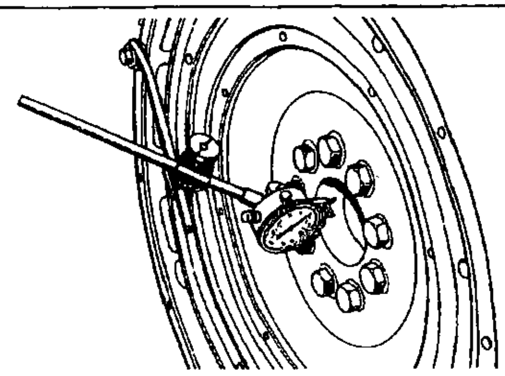


Illustration 111 g00286058

Flywheel Clutch Pilot Bearing Bore

5. Take the measurements at all four points. Find the difference between the lower measurements and the higher measurements. This value must not exceed the maximum permissible pilot bore runout of the flywheel.

Checking The Crankshaft Deflection (Bend)

The crankshaft can be deflected if the engine was not installed correctly. If the engine mounting rail is not fastened correctly to the foundation mounting rail, the cylinder block can twist or the cylinder block can bend. This will cause the crankshaft to deflect. This deflection can cause crankshaft failure and bearing failure.

The crankshaft deflection must be checked after the final installation of the engine. The check must be made with the engine cold. The following procedure can be used to check the crankshaft deflection.

1. Remove an inspection cover from the cylinder block that will give access to the connecting rod journal. This inspection cover should be nearest to the center of the engine. This check must be made at No. 4 and No. 1 connecting rod journals.

2. Turn the crankshaft in the direction of normal rotation until the center of the counterweights barely go beyond the connecting rod.

3. When the counterweight is not available on both sides, install a 2B-7218 Bolt with a 1B-4333 Nut or 2J-3507 Full Nut in the crankshaft. Tighten the nut against the crankshaft. The bolt and the nut are used to provide a locating face.

4. Install a Starrett Crankshaft Distortion Dial Gauge No. 696 with a Starrett No. 696B between the bolt and the counterweight. Put the dial indicator within 10 mm (.39 inch) of the end of the counterweight. Turn the dial of the dial indicator in order to align the zero with the pointer. Turn the dial indicator on the end points until the pointer of the dial indicator will not move from zero.

5. Turn the crankshaft in the direction of the normal rotation until the dial indicator almost makes contact with the connecting rod. This connecting rod is on the other side of the crankshaft.

Note: Do NOT allow the dial indicator to make contact with the connecting rod.

6. The dial indicator reading must not change more than 0.080 mm (.0032 inch) for the approximate 300 degrees of crankshaft rotation. Now turn the crankshaft in the opposite direction to the starting position. The dial indicator must now read zero. If the dial indicator does not read zero, do the procedure again.

If the dial indicator read more than 0.080 mm (.0032 inch), the cylinder block is distorted. Loosen the bolts that hold the engine mounting rails to the foundation mounting rails. Adjust the shims in order to make the engine straight again. Ensure that the engine mounting bolts have enough clearance in order to allow the engine to expand as the engine gets hot.

Vibration Damper

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

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

Air Starting System

i01753629

General Information (Air Starting System)

SMCS Code: 1450

To protect the starting motor and other components, use a supply of pressurized air that is clean and dry.

To start the engine at colder temperatures, a larger volume of starting air and/or a higher air pressure is necessary. Ensure a sufficient supply of air pressure for cold weather starting. Do not exceed the maximum air pressure for the starting motor. Refer to the engine's Application and Installation Guide for information on cranking torque and air starting motors at various temperatures.

Condensation of vapor in the air supply can freeze in cold weather. Ice that forms in the supply lines will restrict the air supply. If particles of ice enter the inlet of the starting motor, the starting motor can be damaged.

Dry air is required for cold weather in order to help prevent ice from forming in the supply lines. A water separator is recommended in order to remove vapor from compressed air prior to the air storage tank.

If the engine operates in a humid environment with temperatures that are below 0 °C (32 °F), an air dryer is needed in order to prevent condensation from freezing in the piping. If the starting air is also used for pneumatic controls, an air dryer is essential.

Lubrication

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

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

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

To maintain the efficiency of the starting motor, flush the starting motor at regular intervals. Pour approximately 0.5 L (.53 qt) of diesel fuel into the air inlet of the starting motor and operate the starting motor. This procedure will remove the dirt, the water and the mixture of oil from the vanes of the air starting motor.

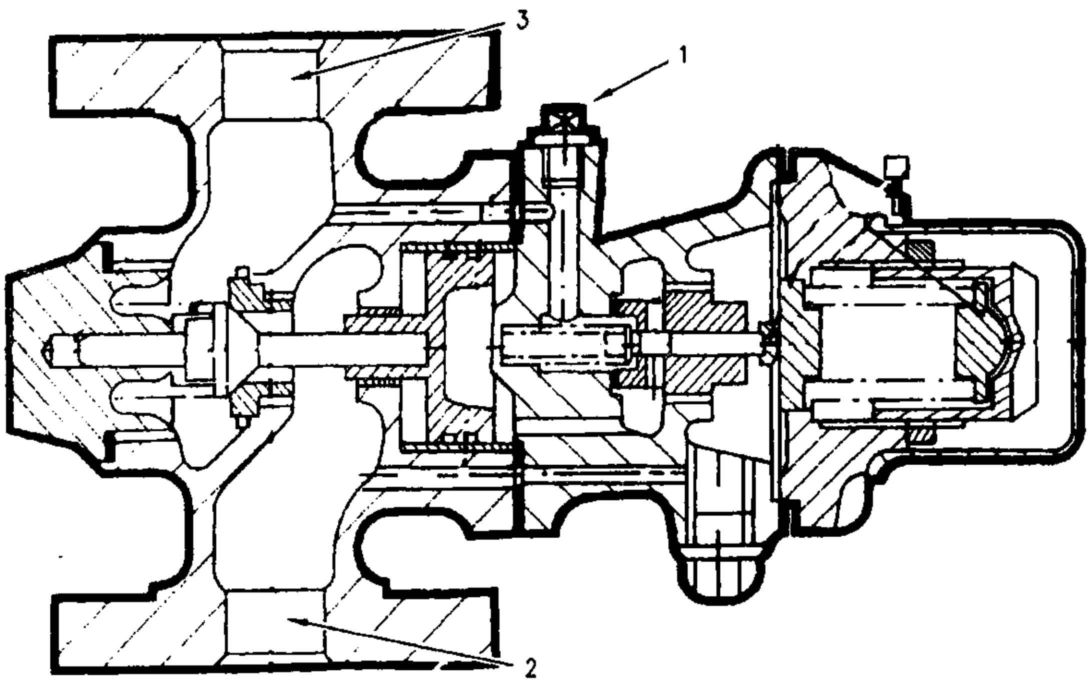
i01753644

Pressure Regulating Valve

SMCS Code: 1462-025

Table 25

Tools Needed	Quantity
8T-0849 Pressure Gauge Group	1



g00692961

Illustration 112

Section view of a typical pressure regulating valve

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

Use the following procedure for checking and for adjusting the pressure regulating valve:

1. Relieve the air pressure to the pressure regulating valve.
2. Disconnect the pressure regulating valve from the starting motor's control valve.
3. Connect an 8T-0849 Pressure Gauge Group to regulator outlet (3).
4. Apply air pressure to regulator inlet (2) and measure the pressure.
5. Adjust the pressure regulating valve to the value that is shown for the recommended air pressure setting.
6. Relieve the air pressure to the pressure regulating valve.
7. Remove the 8T-0849 Pressure Gauge Group. Connect the air pressure regulator to the line to the air starting motor.

Each engine application must be inspected in order to determine the most advantageous starting conditions. The settings for the pressure regulating valve are affected by the following factors:

- Loads from attachments that are pulled by the engine during the start-up
- Ambient temperature conditions
- Oil viscosity
- Capacity of air reservoir
- Condition of the engine

The minimum recommended air pressure is 1034 kPa (150 psi).

The maximum allowable air pressure is 1724 kPa (250 psi).

The advantage of setting the valve at the higher pressures is the increased torque for the starting motor and the faster rotation of the engine. The advantage of setting the valve at the lower pressures is the longer time of the engine rotation for the given reservoir capacity of the supply air. Additionally, a lower air pressure reduces wear on the starting motor.

Electrical System

i01753693

General Information (Electrical System)

SMCS Code: 1400

Test Tools for the Electrical System

Table 26

Tools Needed		Quantity
4C-4911	Battery Load Tester	1
8T-0900	Ammeter	1
9U-7330	Multimeter	1

Most of the tests of the electrical system can be done on the engine. The wiring insulation must be in good condition. The wire and cable connections must be clean and tight. The battery must be fully charged. If the on-engine test shows a defect in a component, remove the component for more testing.

The service manual Testing And Adjusting Electrical Components, REG00636 has complete specifications and procedures for the components of the starting circuit and of the charging circuit.

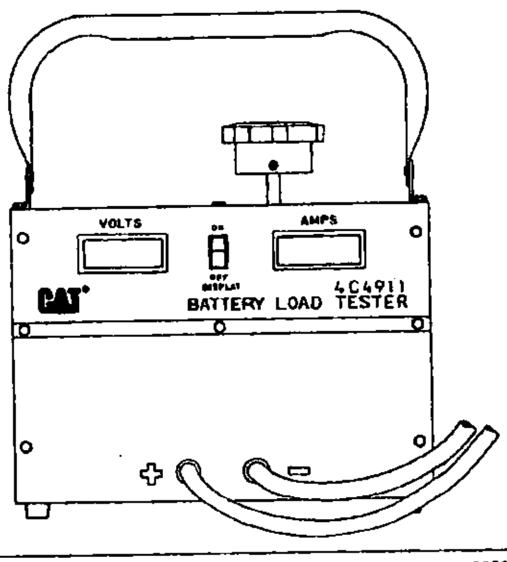


Illustration 113 g00283565

4C-4911 Battery Load Tester

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

The tester is a digital voltmeter with a built-in LCD that displays the amperage. The tester accurately measures the battery voltage at the battery through tracer wires that are inside of the load cables. The tester accurately displays the amperage that is drawn from the battery.

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

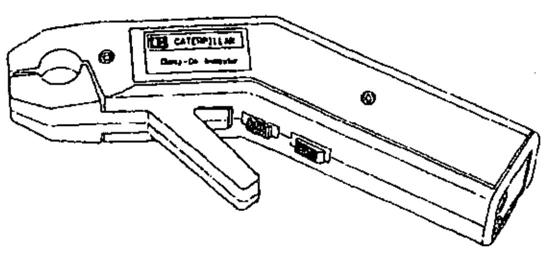


Illustration 114 g00293221

8T-0900 Ammeter

The 8T-0900 Ammeter is a completely portable, self-contained instrument that allows electrical current measurements to be made without breaking the circuit or without disturbing the insulation on the conductors. A digital display is located on the ammeter for reading current directly in a range from 1 to 1200 amperes. If an optional 6V-6014 Cable is connected between this ammeter and one of the digital multimeters, current reading of less than 1 ampere can be read directly from the display of the multimeter.

A lever is used to open the jaws over the conductor up to a diameter of 19 mm (3/4 inch). The spring loaded jaws are closed around the conductor for the measurement of current. A trigger switch that can be locked on the ON or OFF position is used to turn on the ammeter. When the trigger is released, the last current is displayed for five seconds. This allows accurate measurements in limited access areas when the digital display may not be immediately visible to the operator. A zero control is provided for DC operation. The power for the ammeter is supplied by the batteries which are located inside the handle.

Note: Refer to Special Instruction, SEHS8420 for more complete information for the use of the 8T-0900 Ammeter.

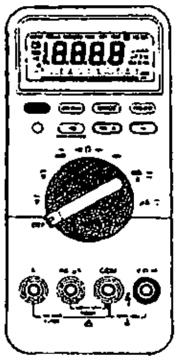


Illustration 115 g00293224

9U-7330 Multimeter

The 9U-7330 Digital Multimeter is a completely portable, hand held instrument with a digital display. This multimeter is built with extra protection against damage in field applications. The multimeter can display Pulse Width Modulation (PWM). G3600 Engines use PWM signals for an increased resistance to static that may interfere with the correct operation of the electronic components. The multimeter has an instant ohms indicator that permits the checking of continuity for fast circuit inspection. The multimeter can also be used for troubleshooting capacitors that have small values.

Note: Refer to Special Instruction for complete information for the use of the 9U-7330 Multimeter. The Special Instruction is packaged with the unit.

Battery

⚠ WARNING

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

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

NOTICE

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

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

Charging System

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

When possible, use the wiring and the components that are a permanent part of the system to test the charging unit and the voltage regulator. The components can also be bench tested in order to determine whether repair is necessary. After repairs are made, perform a test in order to verify that the repair has restored the components to good condition.

To check for correct output of the alternator, refer to the engine's Specifications.

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

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

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

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

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

Alternator Regulator

If an alternator is under charging the battery or overcharging the battery, check the charging rate of the alternator. Refer to the engine's Specifications for the alternator's specifications.

No adjustment can change the rate of charge on the alternator regulators. If the rate of charge is not correct, replace the regulator.

Tightening The Alternator Pulley Nut

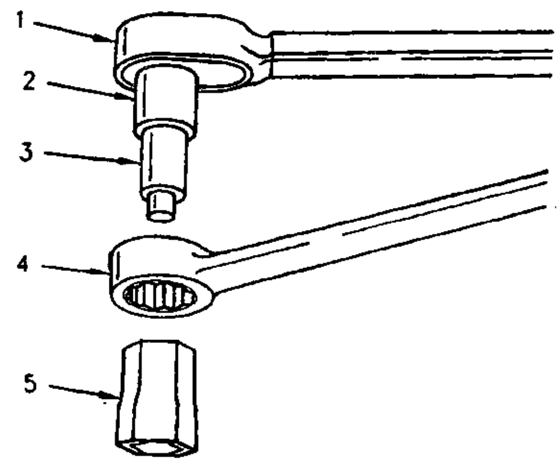


Illustration 116 g00283568

Tools for tightening the alternator's pulley nut

(1) 8T-9293 Torque Wrench
(2) 8S-1588 Adapter
(3) 2P-8267 Hex Bit Socket
(4) 8H-8517 Combination Wrench
(5) 8T-5314 Adapter Socket

Tighten the nut that holds the pulley with the above tools. Refer to the engine's Specifications for the torque.

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Printed in U.S.A.

APPENDIX C - TROUBLESHOOTING MANUAL

CATERPILLAR®

RENR5910-02
October 2002

Troubleshooting

G3600 Engines

BLB1-Up (Engine)
BKE1-Up (Engine)
BEN1-Up (Engine)
4ZS1-Up (Engine)

i01658146

Important Safety Information

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

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

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

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

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

⚠ WARNING

The meaning of this safety alert symbol is as follows:

Attention! Become Alert! Your Safety is Involved.

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

Operations that may cause product damage are identified by "NOTICE" labels on the product and in this publication.

Caterpillar cannot anticipate every possible circumstance that might involve a potential hazard. The warnings in this publication and on the product are, therefore, not all inclusive. If a tool, procedure, work method or operating technique that is not specifically recommended by Caterpillar is used, you must satisfy yourself that it is safe for you and for others. You should also ensure that the product will not be damaged or be made unsafe by the operation, lubrication, maintenance or repair procedures that you choose.

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

⚠ WARNING

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

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

Table of Contents

Troubleshooting Section

Diagnostic Functional Tests

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Troubleshooting Section

Electronic Troubleshooting

i01754066

System Overview

SMCS Code: 1901-038

Control System

The following components are included in the control system:

- An Electronic Control Module (ECM) and an emergency stop button in an engine mounted junction box
- Optional remote control panel with a Machine Information Display System (MIDS)
- Integrated Combustion Sensing Module (ICSM)
- Gas Shutoff Valve (GSOV)
- Ignition system that is controlled by the ECM
- Detonation sensor for each two cylinders
- A system for prelube that includes the solenoid and prelube pump
- Actuators that are hydraulically actuated and electronically controlled for the fuel, for the air choke, and for the exhaust bypass (wastegate)
- A system for cranking that includes the solenoid and starting motor

The ECM controls most of the functions of the engine. The module is an environmentally sealed unit that is in an engine mounted junction box. The ECM monitors various inputs from sensors in order to activate relays, solenoids, etc at the appropriate levels. The ECM supports the following five primary functions:

- Governing of the engine
- Control of ignition
- Air/fuel ratio control
- Start/stop control
- Monitoring of engine operation

The ECM does not have a removable personality module. The software and maps are changed with the Caterpillar Electronic Technician (Cat ET) by flash programming of a file.

Governing of the Engine RPM

Desired engine speed is determined by the status of the idle/rated switch, of the desired speed input (analog voltage or 4 to 20 mA), and of parameters that are programmed into the software. Actual engine speed is detected via a signal from the engine speed/timing sensor. Parameters such as idle speed and governor gain can be programmed with Cat ET.

The ECM monitors the actual engine speed. The ECM calculates the difference between the actual engine speed and the desired engine speed. The ECM controls the fuel actuator in order to maintain the desired engine speed. The fuel actuator is located at the flange of the inlet air manifold.

If the actual engine speed is less than the desired engine speed, the ECM commands the fuel actuator to move toward the open position in order to increase the fuel flow. The increase of fuel accelerates the engine speed.

Control of Ignition

Each cylinder has an ignition transformer. To initiate combustion, the ECM sends a pulse of approximately 108 volts to the primary coil of each ignition transformer at the appropriate time and for the appropriate duration. The transformer increases the voltage which creates a spark across the spark plug electrode.

The ECM provides variable ignition timing that is sensitive to detonation. Detonation sensors monitor the engine for excessive detonation. The engine has one detonation sensor for each two adjacent cylinders. The sensors generate data on vibration that is processed by the ECM in order to determine detonation levels. If detonation reaches an unacceptable level, the ECM retards the ignition timing of the affected cylinder or cylinders. If retarding the timing does not limit detonation to an acceptable level, the ECM shuts down the engine.

Levels of detonation can be displayed by the Machine Information Display System (MIDS) on the optional control panel. Alternatively, the "Cylinder X Detonation Level" screen of Cat ET can also be used. The "X" represents the cylinder number.

The ECM provides extensive diagnostics for the ignition system.

Air/Fuel Ratio Control

The ECM provides control of the air/fuel mixture for performance and for efficiency at low emission levels. The system includes the following components: maps in the ECM, output drivers in the ECM, fuel actuator, air choke actuator, exhaust bypass actuator (wastegate), ICSM, thermocouples, and combustion sensors. Illustration 1 is a diagram of the system's main components and of the system's lines of communication.

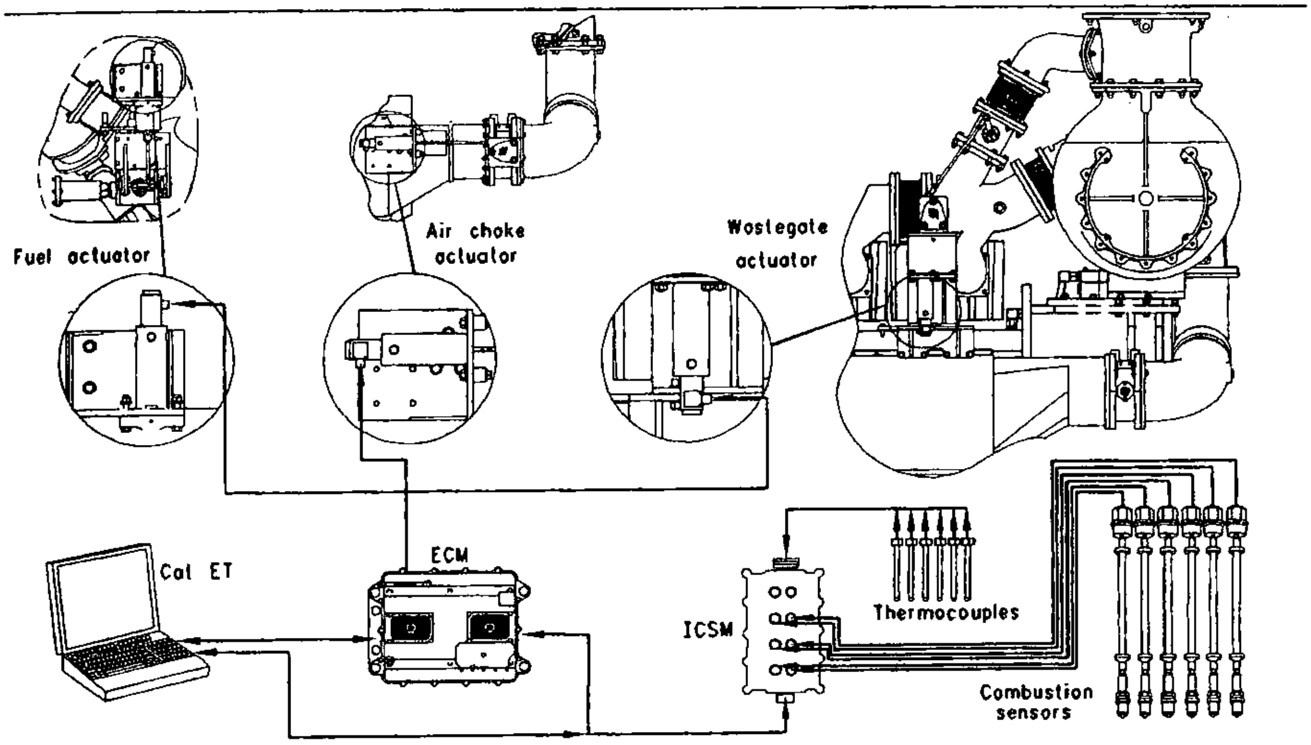

Illustration 1

g00910538

The desired air/fuel ratio is based on maps that are stored in the ECM. The maps are specific for different applications, for engine speeds, and for engine loads.

The engine load is calculated from the fuel flow. For example, zero fuel flow is zero load and fuel flow of 100 cfm might be 50 percent of the rated load.

Note: The calculated engine load varies. Several variables affect the calculated engine load, including timing, settings for emissions, fuel quality, and specific gravity of the fuel.

The system has five modes of operation for the air/fuel ratio:

- Start-up
- No feedback
- Exhaust port temperature feedback
- Combustion feedback
- Prechamber calibration

Error for the inlet manifold air pressure – This is the absolute difference between the actual inlet manifold air pressure and the desired inlet manifold air pressure.

In each of these modes, the air/fuel ratio is controlled by either the air choke actuator or the wastegate actuator: only one of the actuators operates at any time. The active actuator is determined by the ability to provide the desired inlet manifold air pressure. Both of the actuators regulate the air flow. The regulation is based on an error that is calculated for the inlet manifold air pressure. Both of the actuators are controlled by a map for the air/fuel ratio.

The software is also programmed to correct the fuel flow according to the temperature of the jacket water and the engine speed. This occurs when the coolant temperature is not at the water temperature regulator's rated temperature. If the temperature is cooler than the rating, the fuel in the cylinder head is also cooler and more dense. Because the denser fuel provides an air/fuel mixture that is richer than the desired mixture, the calculation of the fuel flow is corrected for the lower temperature. This tends to lean the actual air/fuel ratio. If the temperature is warmer than the rating, the fuel in the cylinder head is less dense. Because the warmer fuel provides a leaner air/fuel mixture, the calculation of the fuel flow is corrected for the higher temperature. This tends to richen the air/fuel ratio.

Note: When the engine is operating in combustion feedback mode, the temperature of the jacket water only affects the fuel correction factor.

The relationship of the modes of operation to the engine load and the transitions between the modes are represented in Illustration 2. The modes of operation are explained in more detail below.

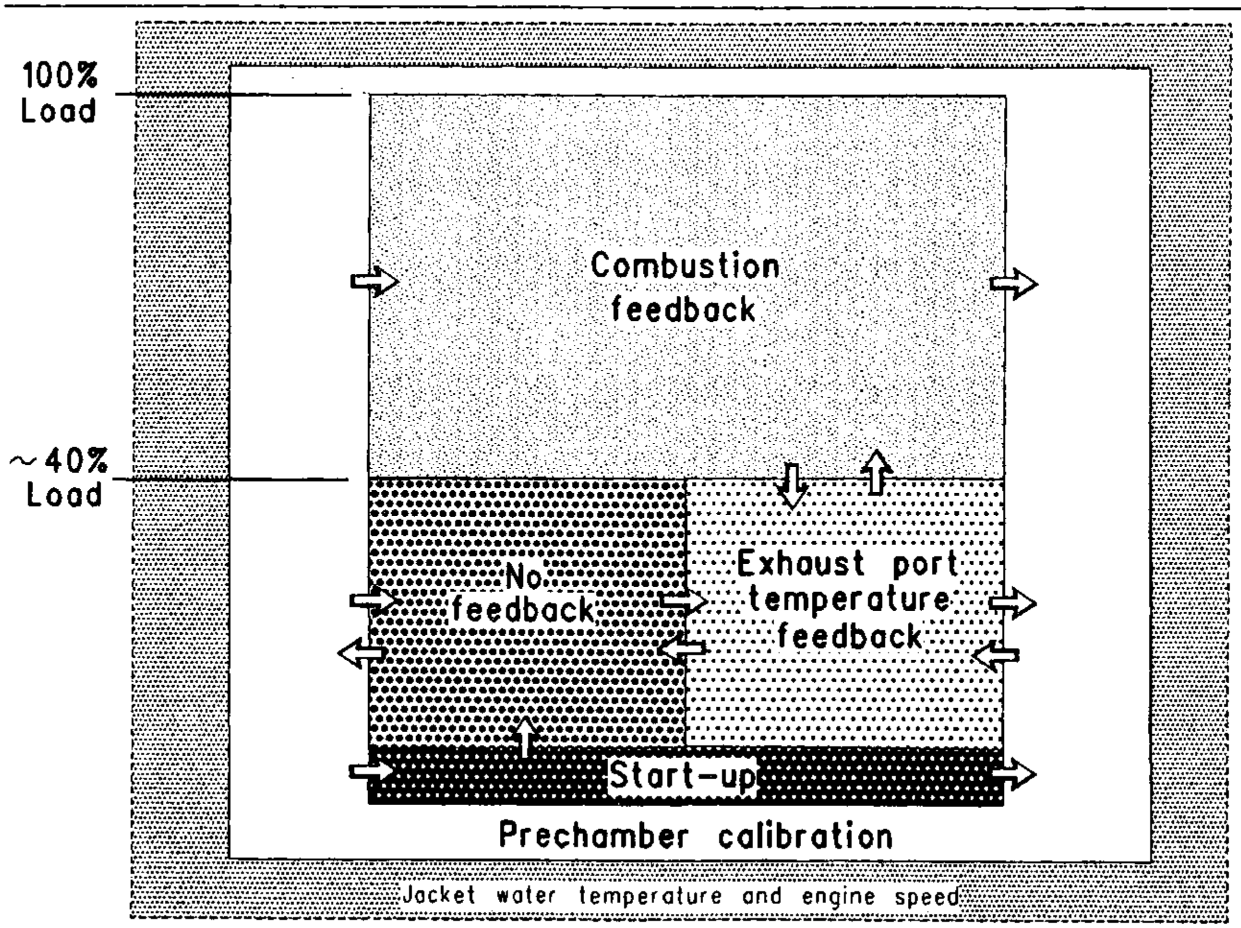

Illustration 2 g00910198

Schematic of the modes of operation, of transitions, and of the engine load

Note: Control of the inlet manifold air pressure is not determined directly by the engine load. The active actuator is determined by the ability to provide the desired inlet manifold air pressure.

At loads that are less than approximately 40 percent, the air/fuel ratio is controlled by the air choke actuator. The air choke controls the flow of air during engine start-up. The air choke continues to control the air flow during the increase in the engine speed and in load. As the engine speed and load are increased, the required inlet manifold air pressure increases. The air choke opens in order to provide more combustion air. When the air choke becomes fully open, the air choke cannot further increase the air flow. Then, the wastegate becomes active.

Conversely, the required inlet manifold air pressure is reduced as the engine speed and load are reduced. As the requirement for combustion air is reduced, the wastegate opens. When the wastegate is fully open, the wastegate cannot regulate a smaller quantity of combustion air. Then, the air choke becomes active again.

During start-up, the air choke is maintained at a fixed position until ten seconds after the engine achieves the desired speed. This enables a correction of the excessive error for inlet manifold air pressure. The starting position for the air choke is set in the Cat ET configuration screen. The starting position depends on the number of cylinders. Typically, the starting position is closed 60 to 80 percent. If the starting position is set too high, the engine will not get enough combustion air.

If the starting position is set too high and the engine speed does not increase to the desired speed, the programming in the software opens the air choke in steps until the engine speed increases. This enables a steady increase of the engine speed until the desired speed is achieved.

The maximum position for the air choke can also be set in the Cat ET configuration screen. The maximum position is set in order to enable a sufficient flow of air for combustion when the engine is running at no load. Typically, the maximum position is closed 75 to 85 percent.

At ten seconds after the engine reaches the desired speed, the air/fuel ratio is controlled directly by the map for the air/fuel ratio. No correction factors are related to any feedback: this is a correction factor of 100 percent. This mode of operation uses no feedback.

Normally, the map is calculated in order to provide a low air/fuel ratio for loads up to approximately 40 percent. This provides a mixture that is sufficiently rich for operation at low temperatures. The air/fuel ratio will continue to be controlled by the map until the conditions allow operation in one of the feedback modes or in the prechamber calibration mode.

A low air/fuel ratio is critical for operation after start-up in order to keep the air choke partially closed. Otherwise, the air choke may open fully and the wastegate will control the inlet manifold air pressure. This results in a period of misfire and of excessive fuel flow. Because of the excessive fuel flow, the calculated engine load is excessive.

Programmable "Desired Engine Exhaust Port Temp" parameter – This parameter is set in the Cat ET configuration screen. This is the desired exhaust port temperature for a load of 25 percent. The control uses this parameter during operation in the exhaust port temperature feedback mode.

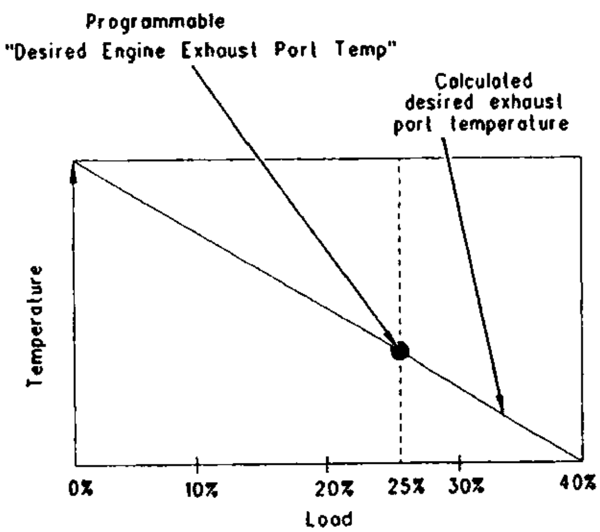

Illustration 3 g00914203

Graph of the calculated desired exhaust port temperature

The calculated desired exhaust port temperature varies from the programmable "Desired Engine Exhaust Port Temp" by 1 °C (1.8 °F) per 1 percent of engine load. For each 1 percent of engine load below 25 percent, the calculated desired exhaust port temperature increases by 1 °C (1.8 °F). For each 1 percent of engine load above 25 percent, the calculated desired exhaust port temperature decreases by 1 °C (1.8 °F).

Control's average exhaust port temperature – The ICSM continuously calculates the average exhaust port temperature. If the actual temperature of any cylinder exhaust port is less than 273 °C (523 °F), the ICSM substitutes a temperature of 273 °C (523 °F) for that cylinder. This temperature is substituted for any number of cylinders with an exhaust port temperature that is less than 273 °C (523 °F). The temperature is used in the calculation of the average for all of the monitored cylinders.

Exhaust port temperature feedback – In this mode of operation, the air/fuel ratio is controlled in order to achieve a desired exhaust port temperature. Each cylinder exhaust port has a thermocouple that is monitored by an ICSM. The ICSM monitors the actual exhaust port temperatures for one bank of cylinders. The ICSM calculates an average exhaust port temperature for the bank of cylinders. The ECM calculates the desired exhaust port temperature for the load. The ECM sends the desired exhaust port temperature to the ICSM. The ICSM calculates the difference between the average exhaust port temperature and the desired exhaust port temperature. The ICSM sends a fuel correction factor to the ECM. The ECM uses the fuel correction factor to control the air choke actuator in order to maintain the desired exhaust temperature.

After start-up, the exhaust port temperature feedback mode is activated for the following conditions:

- The calculated control's average exhaust port temperature exceeds the desired exhaust port temperature.
- The calculated control's average exhaust port temperature ceases to increase. The engine load is less than approximately 40 percent.
- The timer for operation with no feedback expires.

The transition to the exhaust port temperature feedback mode can also occur for the following circumstances:

- The air/fuel ratio is controlled by combustion feedback. The engine load is reduced to approximately 40 percent or less than 40 percent. The transition occurs in a 15 second period.
- The engine operation exits the prechamber calibration mode. The engine load is approximately 40 percent or less than 40 percent. In this case, the fuel correction factor begins at 100 percent. Then, the fuel correction factor is adjusted in order to achieve the desired exhaust port temperature.

The programmed air/fuel ratio control begins to use a correction factor in order to modify the air/fuel ratio that is specified in the map for the air/fuel ratio. The correction factor is based on an error for the exhaust port temperature.

If the average exhaust temperature is too low, the ECM commands the air choke actuator to move toward the closed position in order to richen the air/fuel mixture. Combustion of the richer air/fuel mixture increases the exhaust port temperatures.

Combustion feedback – In this mode of operation, the air/fuel ratio is controlled in order to achieve the desired combustion burn time.

When the load reaches approximately 40 percent, the air/fuel ratio is controlled by the wastegate actuator which is trimmed by the combustion burn time.

Combustion burn time – The combustion burn time is measured in each cylinder. Each cylinder has a combustion sensor. The pulse of the ignition starts a timer in the ICSM. The flame travels in the cylinder from the spark plug to the combustion sensor. The ICSM monitors the voltage across the combustion sensor. When the flame reaches the combustion sensor, the ionization that surrounds the sensor changes the voltage. When the ICSM detects the change of the sensor's voltage, the ICSM stops the timer. The combustion burn time is a method of measuring the air/fuel ratio. A rich air/fuel mixture provides a faster combustion burn time. A lean air/fuel mixture provides a slower combustion burn time.

Each ICSM calculates an average combustion burn time for all of the cylinders in one bank. The ECM sends a point from the map of the desired combustion burn time to the ICSM. The ICSM calculates the difference between the average combustion burn time and the desired combustion burn time. The ICSM sends a fuel correction factor to the ECM. The ECM controls the wastegate actuator in order to maintain the desired combustion burn time.

A command for the desired inlet manifold air pressure is sent from the ECM to the wastegate actuator. The actuator adjusts the inlet manifold air pressure in order to correct the combustion burn time.

If the average desired combustion burn time is too fast, the ECM commands the wastegate actuator to move toward the closed position in order to provide more air for a leaner air/fuel mixture. This provides a slower combustion burn time. If the average desired combustion burn time is too slow, the ECM commands the wastegate actuator to move toward the open position in order to provide less air for a richer air/fuel mixture. The richer air/fuel mixture burns faster. This is a continuous process during operation at loads that are greater than approximately 40 percent.

The combustion feedback mode is activated for either of the following conditions:

- The air/fuel ratio is in the exhaust port temperature feedback mode. The engine load exceeds approximately 40 percent. The average exhaust port temperature is stable and the desired exhaust port temperature is established. The transition occurs in a 15 second period.

- The engine operation exits the prechamber calibration mode and the engine load is greater than approximately 40 percent.

Prechamber calibration mode – This mode can be activated with Cat ET. This mode can be activated during operation at any load. The mode is used for adjustment of the precombustion chambers' needle valves in order to achieve the desired exhaust emissions. In the prechamber calibration mode, the fuel correction factor is maintained at 100 percent. After an exit from this mode, the fuel correction factor is adjusted in order to achieve the desired air/fuel ratio.

Start/Stop Control

The ECM contains the logic and the outputs for control of engine prelubrication, of starting, of shutdown, and of postlube. The customer programmable logic responds to signals from the following components: engine control switch, emergency stop switch, remote start switch, data link, and other inputs.

To control the engine at the appropriate times, the ECM provides +Battery voltage to the solenoids that control the prelube pump, the starting motor, and the gas shutoff valve.

When the programmable logic determines that the prelubrication function is necessary, the ECM supplies +Battery voltage to the solenoid for the prelube pump. The prelubrication must develop sufficient engine oil pressure before the engine will crank. The engine has a pressure switch for the prelube. When the engine oil pressure is sufficient, the pressure switch closes and the engine can be cranked.

When the programmable logic determines that it is necessary to crank the engine, the ECM supplies +Battery voltage to the solenoid for the starting motor. Rotation of the crankshaft also operates the pump for the electrohydraulic actuators. The pump develops hydraulic oil pressure for operation of the fuel actuator, the air choke actuator, and the wastegate actuator.

The engine has an energize-to-run type of Gas Shutoff Valve (GSOV). When the programmable logic determines that fuel is required to start the engine or to run the engine, the ECM supplies +Battery voltage to the valve's solenoid.

At one second after the GSOV is energized, the pressure differential between the fuel and the air is monitored. This parameter is monitored in order to ensure that no fuel is entering the fuel manifold before the ECM issues a command to the fuel actuator. If the differential pressure for fuel to air is less than 0.5 kPa (0.073 psi), the ECM supplies +Battery voltage to the fuel actuator's solenoid.

The ECM controls the fuel actuator by adjusting the current flow through the actuator's solenoid. During start-up, the combustion chambers are usually filled with excessive combustion air. The ECM operates the fuel actuator in order to supply sufficient fuel for a combustible air/fuel mixture.

The ECM removes the voltage from the starting motor's solenoid when the programmable crank terminate speed is reached or when a programmable cycle crank time has expired. The starter motor pinion disengages from the flywheel ring gear.

When the programmable logic determines that an engine shutdown is necessary, the ECM removes +Battery voltage from the solenoids for the fuel actuator and for the GSOV. The fuel is shut off.

The prelube system is programmed to perform a postlube cycle during engine shutdown. This supplies the turbocharger with adequate lubrication during shutdown.

Monitoring Engine Operation

The ECM monitors both the engine operation and the electronic system.

Problems with engine operation cause the ECM to generate an event code. The ECM can issue a warning or a shutdown for events. This depends on the severity of the condition.

For example, a high pressure pump provides hydraulic pressure with oil for the electrohydraulic system. The oil supply is separate from the engine oil. The high pressure oil supply is monitored by a pressure switch. If the pressure drops below an acceptable level, the ECM generates an event code and the ECM shuts down the engine.

The ICSM monitors the combustion sensors and the thermocouples for the cylinders and for the turbocharger. The ICSM sends signals regarding the parameters to the ECM over the CAT Data Link. If any parameter exceeds the acceptable range, the ECM can initiate a warning or a shutdown.

For more information on event codes, refer to Troubleshooting, "Troubleshooting with an Event Code".

Problems with the electronic system such as an open circuit produce a diagnostic code. For more information, refer to Troubleshooting, "Troubleshooting with a Diagnostic Code".

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Self-Diagnostics

SMCS Code: 1901-038

The Electronic Control Module (ECM) and the Integrated Combustion Sensing Module (ICSM) have the ability to detect problems with the electronic system and with engine operation. When a problem is detected, a code is generated. An alarm may also be generated. There are two types of codes:

- Diagnostic
- Event

Diagnostic Code – When a problem with the electronic system is detected, the appropriate module generates a diagnostic code. This indicates the specific problem with the circuitry.

Event Code – An event code is generated by the detection of an abnormal engine operating condition. For example, an event code will be generated if the oil pressure is too low. In this case, the event code indicates the symptom of a problem.

The codes can have two different states:

- Active
- Logged

Active Code – An active code indicates that an active problem has been detected. Active codes require immediate attention. Always service active codes prior to servicing logged codes.

Logged Code – Every generated code is stored in the permanent memory of the appropriate module. The codes are logged.

Logged codes may not indicate that a repair is needed. The problem may have been temporary. The problem may have been resolved since the logging of the code. If the system is powered, it is possible to generate an active diagnostic code whenever a component is disconnected. When the component is reconnected, the code is no longer active. Logged codes may be useful to help troubleshoot intermittent problems. Logged codes can also be used to review the performance of the engine and of the electronic system.

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Electrical Connectors and Functions

SMCS Code: 1408-038

Harness Wire Identification

Caterpillar identifies different wires with eleven different solid colors. Table 1 lists the color codes of the wiring.

Table 1

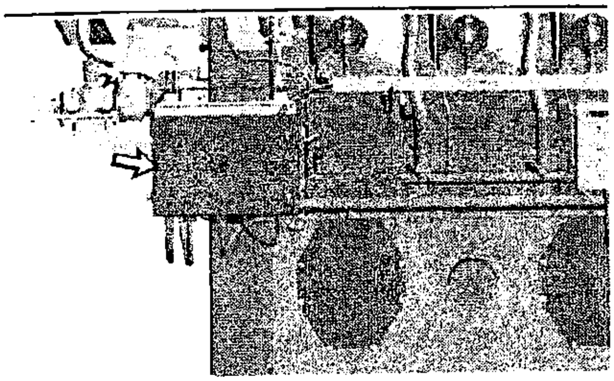
Color Codes for Wiring	
Code	**Color**
BK	Black
BR	Brown
BU	Blue
GN	Green
GY	Gray
OR	Orange
PK	Pink
PU	Purple
RD	Red
WH	White
YL	Yellow

In addition to the color, the entire length of each wire is stamped with a specific circuit number that is repeated on every 25 mm (1 inch) of the wire. The actual wires are identified on the engine's Schematic.

For example, a code of J011-RD on the Schematic identifies a red wire that is stamped with the circuit number J011. This particular wire is the engine harness wire for the primary signal of the transformer in the number one cylinder.

The Schematic also identifies the size of the wire. The size or gauge of the wire is called the American Wire Gauge (AWG). Unless the schematic specifies a different size, the wire is 16 AWG.

Terminal Box



g00891827

Illustration 4

Terminal box

The engine mounted terminal box is located on the rear right side of the engine. The Electronic Control Module (ECM) is inside the terminal box. The terminal box provides the point of termination for all of the wiring that is related to the engine's sensors and for the ignition system. The terminal box's components are identified in Illustrations 5 and 6.

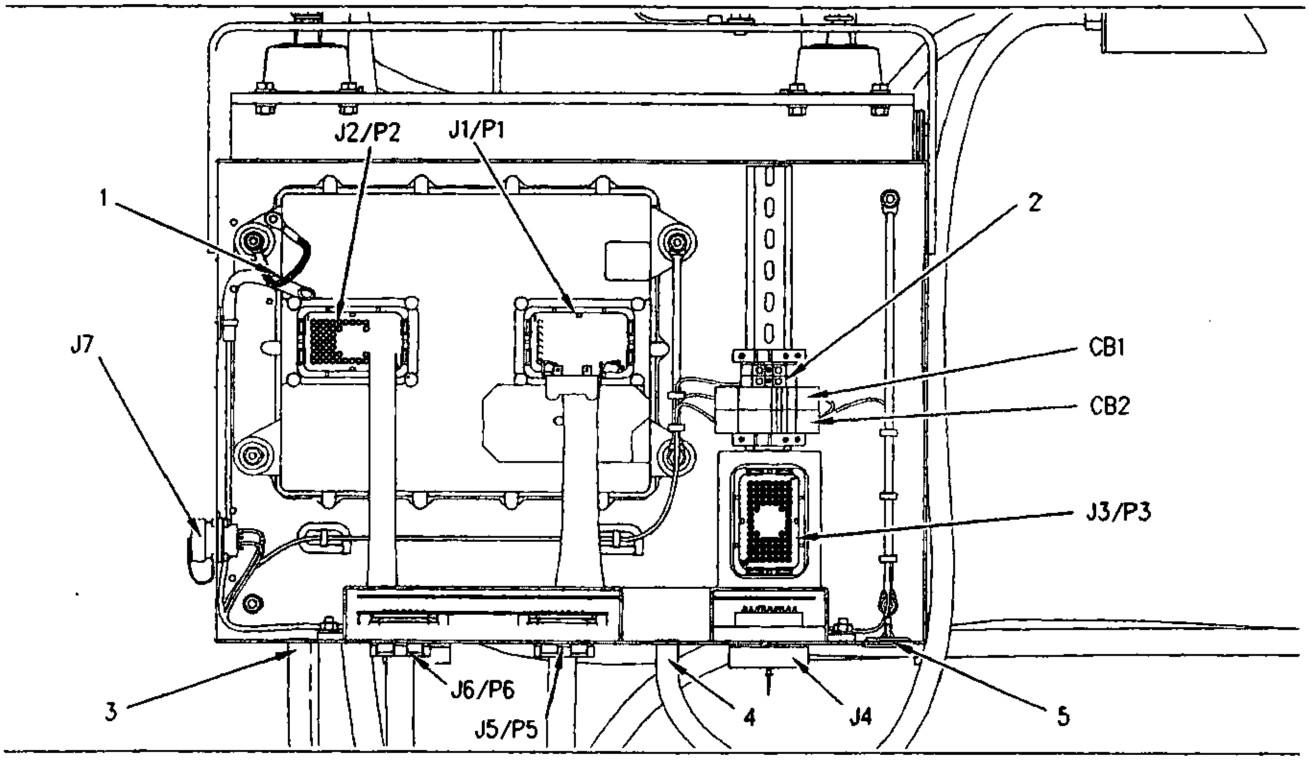


Illustration 5 g00892898

Inside of the terminal box

(J2/P2) 70-pin connectors for the ECM
(J1/P1) 70-pin connectors for the ECM
(1) Ground strap
(2) Terminal for the 24 VDC power supply
(J7) 9-pin service tool connector
(CB1) 16 amp circuit breaker
(CB2) 6 amp circuit breaker
(J3/P3) 70-pin connectors for the customer's wiring
(3) Ignition wiring for the left side of the vee engine
(J6/P6) 70-pin connectors for the sensors on the left side of the engine
(J5/P5) 70-pin connectors for the sensors on the right side of the engine
(4) Ignition wiring for the right side of the vee engine
(J4) 47-pin connector for the optional control panel or for a customer connector
(5) Wiring for the electrical power

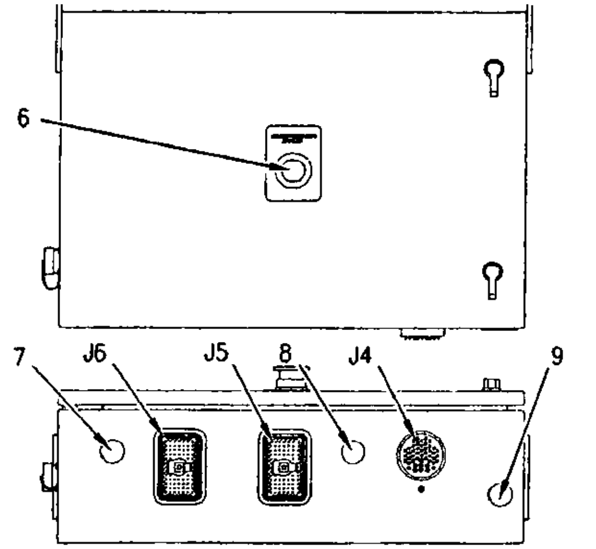


Illustration 6 g00891953

Front and bottom of the terminal box

(J6) 70-pin connector for the sensors on the left side of the engine
(J5) 70-pin connector for the sensors on the right side of the engine
(J4) 47-pin connector for the optional control panel or for a customer connector
(6) Emergency stop button
(7) Hole for the ignition wiring on the left side of the vee engine
(8) Hole for the ignition wiring on the right side of the vee engine
(9) Hole for the electrical power supply and/or for the customer's wiring to the 70-pin connector (P3)

Sensors

Sensors provide information to the engine control module and to the integrated combustion sensing modules. The information is used for monitoring engine operation. The information enables the modules to control the engine as efficiently as possible over a wide range of operating conditions.

Vee Engines

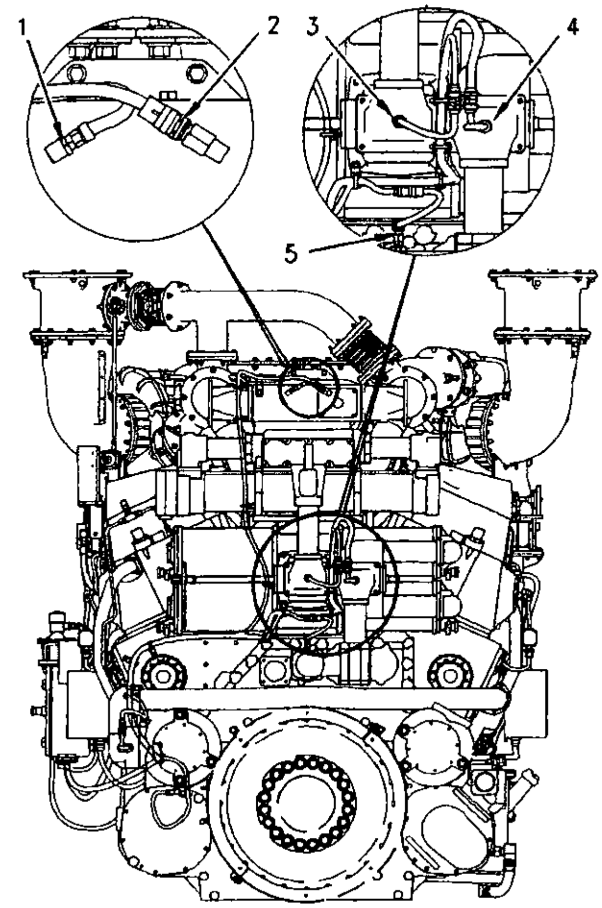


Illustration 7 g00803846

Front view of a Vee engine

(1) Sensor for the outlet pressure of the jacket water
(2) Sensor for the jacket water coolant temperature
(3) Unfiltered engine oil pressure sensor
(4) Engine oil temperature sensor
(5) Filtered engine oil pressure sensor

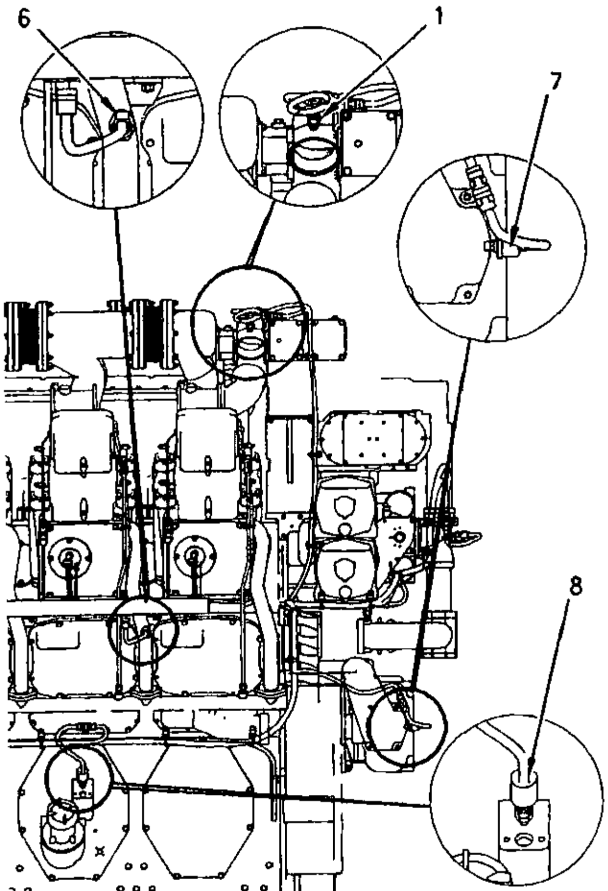


Illustration 8 g00825637

Right side view near the front of a Vee engine

(1) Sensor for the outlet pressure of the jacket water
(6) Detonation sensor
(7) Switch for the inlet pressure of the jacket water
(8) Crankcase pressure sensor

Note: There is one detonation sensor between each pair or cylinders.

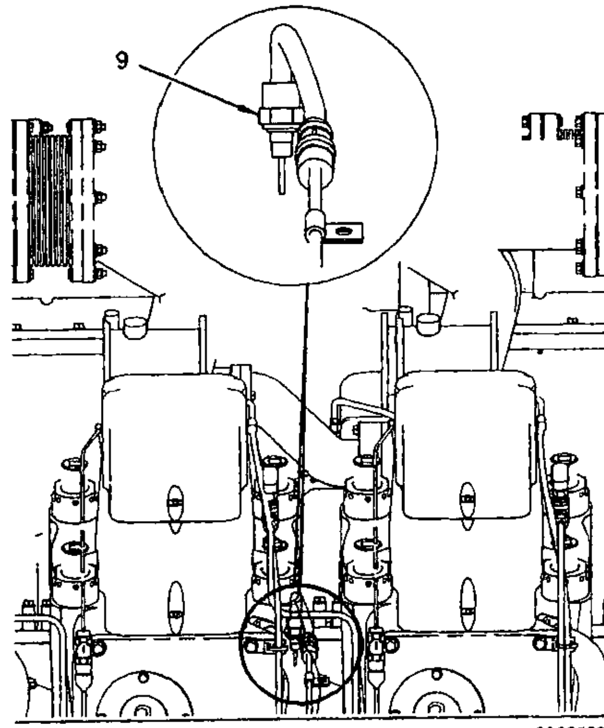


Illustration 9 g00825893

The sensor for the inlet manifold air temperature is installed in the inlet air manifold between the two center cylinder heads on the right side of the Vee engine.

(9) Sensor for inlet manifold air temperature

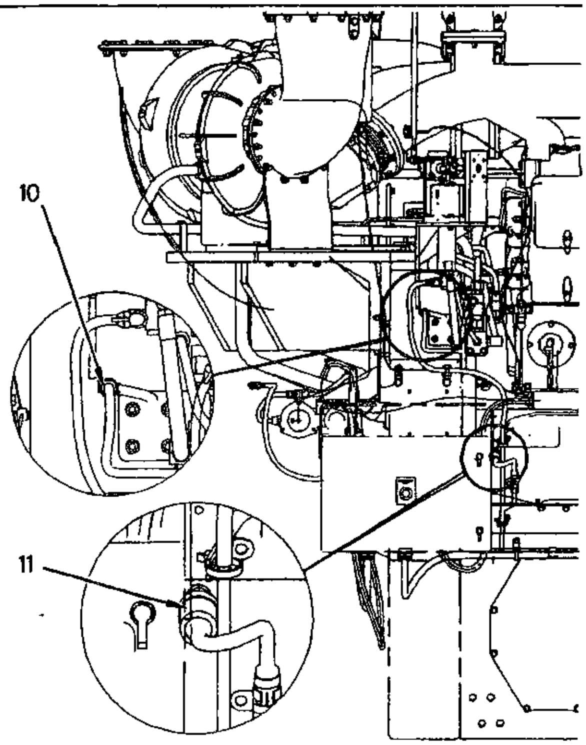


Illustration 10 g00825717

Right side view near the rear of a Vee engine

(10) Connector for the electrohydraulic actuators' pressure switch
(11) Switch for prelube oil pressure

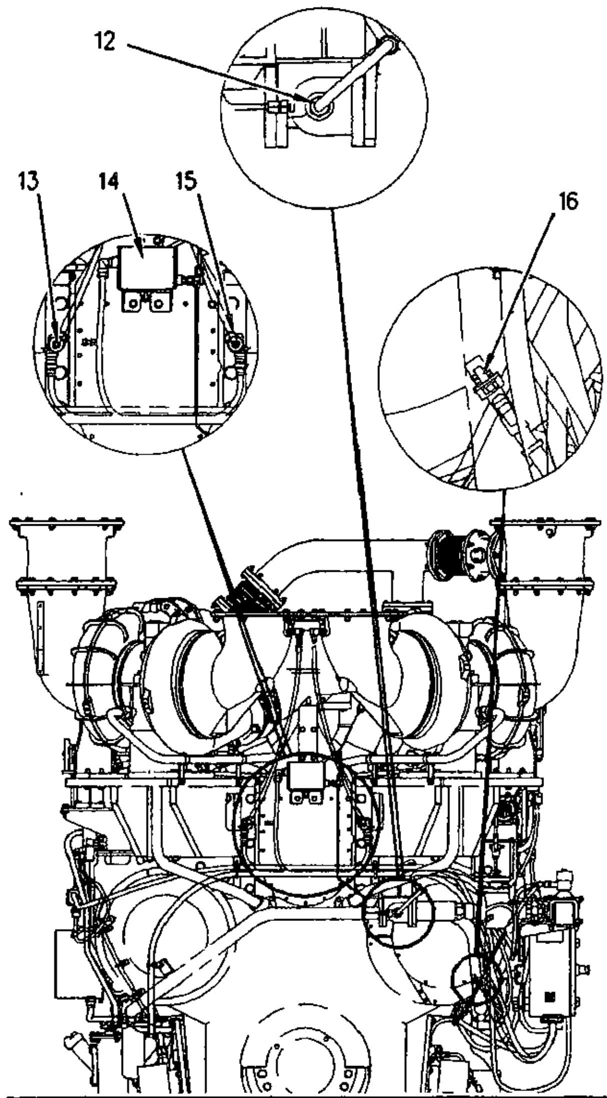


Illustration 11 g00825638

Rear view of a Vee engine

(12) Fuel temperature sensor
(13) Switch for inlet air restriction (left)
(14) Pressure module for inlet air and fuel
(15) Switch for inlet air restriction (right)
(16) Engine speed/timing sensor

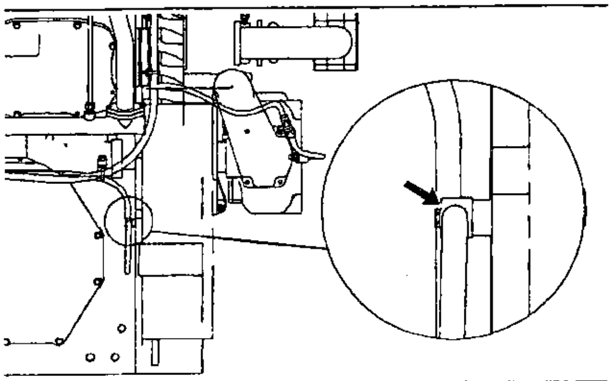


Illustration 12 g00902969

Right view of a Vee engine

Engine harness connector for the engine oil level switch and the coolant level switch

In-Line Engines

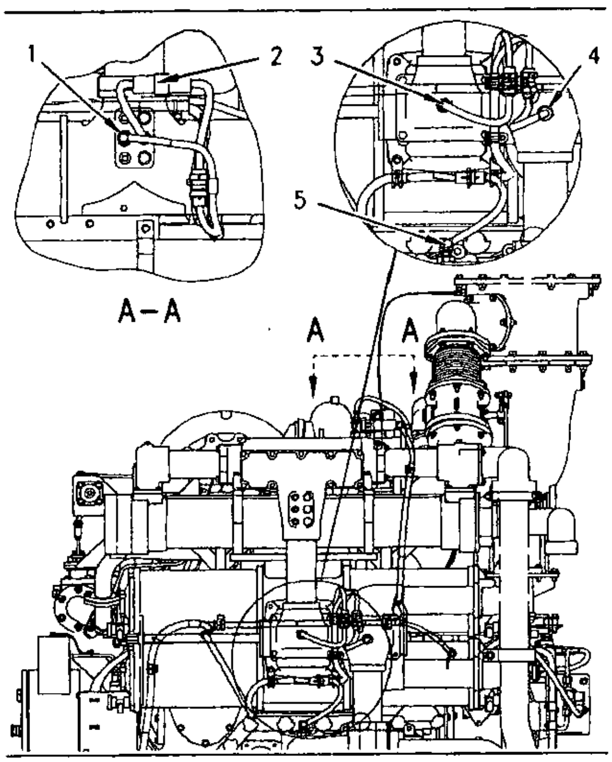


Illustration 13 g00895272

Front view of an In-line engine

(1) Sensor for jacket water coolant temperature
(2) Sensor for outlet pressure of the jacket water
(3) Unfiltered engine oil pressure sensor
(4) Engine oil temperature sensor
(5) Filtered engine oil pressure sensor

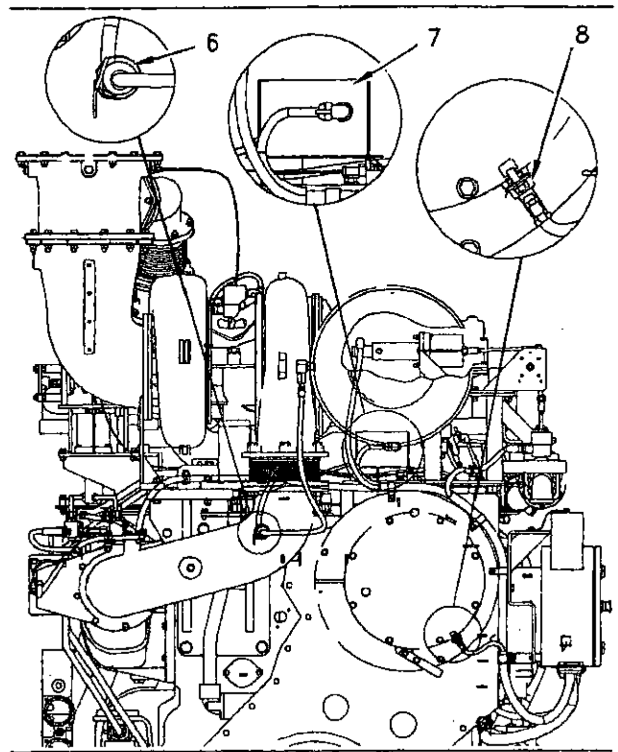


Illustration 14 g00895316

Right side view near the front of an In-line engine

(6) Inlet air restriction's switch
(7) Air/fuel pressure module
(8) Engine speed/timing sensor

Note: There is one detonation sensor between each pair or cylinders.

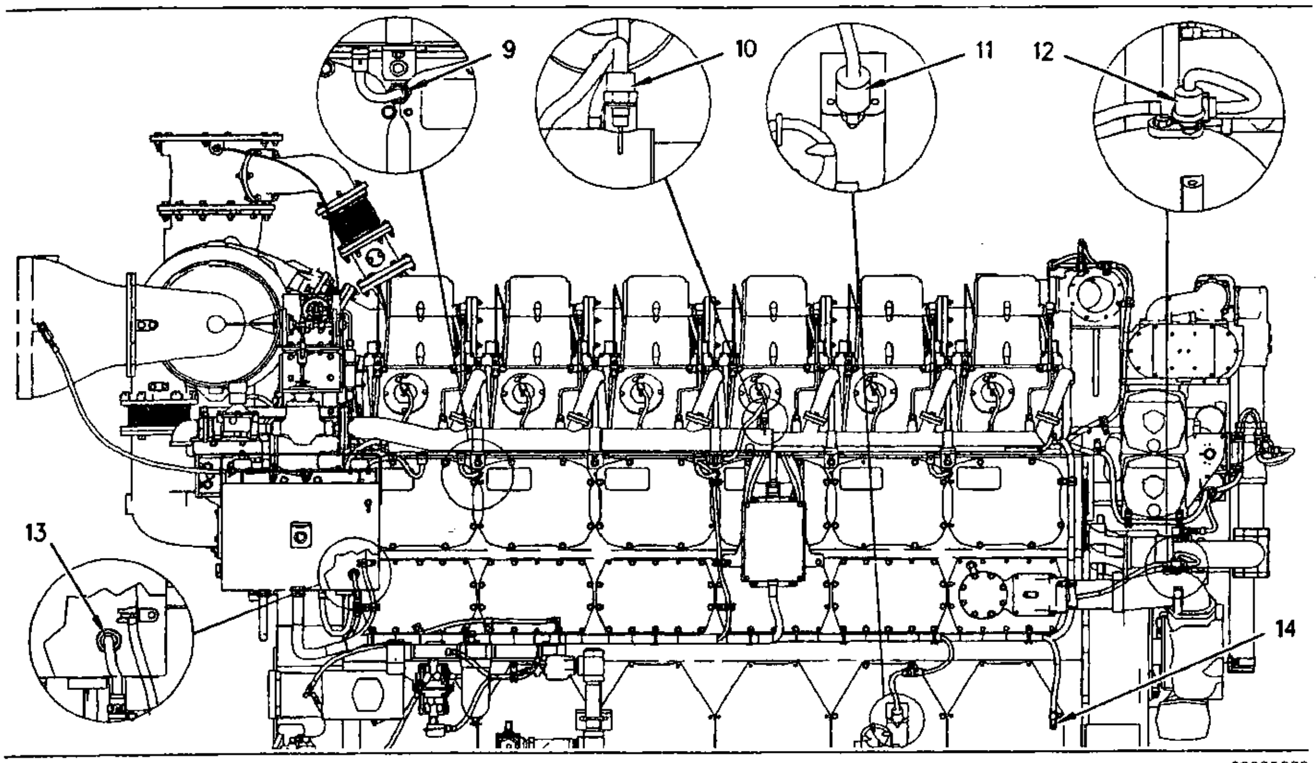


Illustration 15 g00895279

Right side view near the front of an In-line engine

(9) Detonation sensor
(10) Fuel temperature sensor
(11) Crankcase pressure sensor
(12) Switch for the inlet pressure of the jacket water
(13) Switch for the prelube oil pressure
(14) Connector for the switches for low engine oil level and for low coolant level

Note: The switches for connector (14) can be supplied by the customer or by the factory.

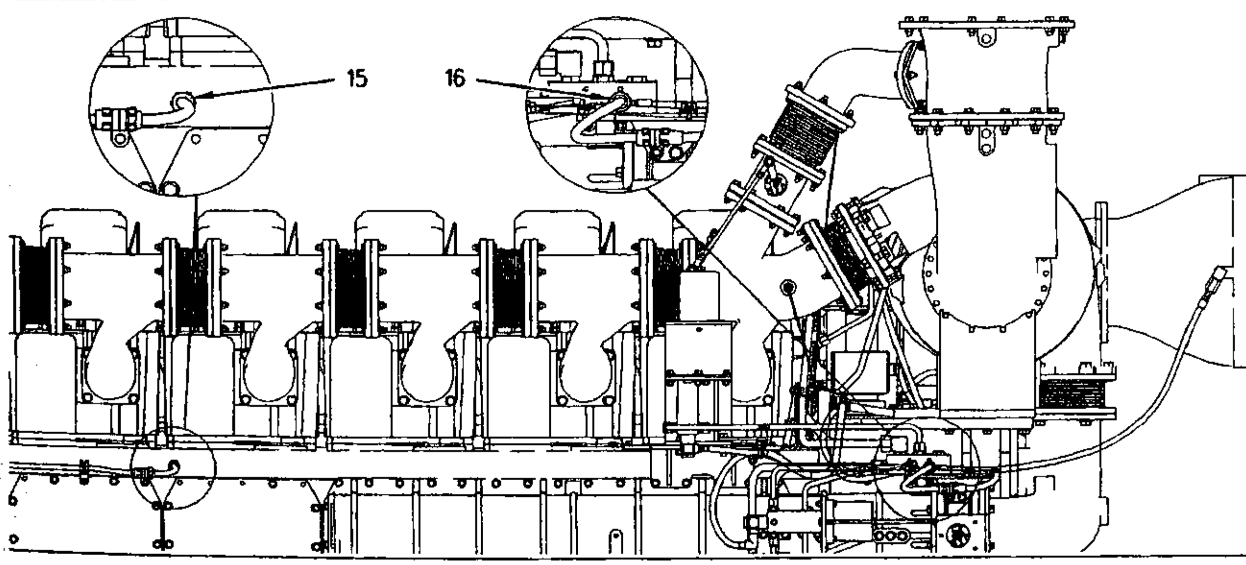


Illustration 16 g00895328

In-line engine

(15) Inlet manifold air temperature's sensor
(16) Electrohydraulic actuator's pressure switch

Integrated Combustion Sensing Module (ICSM)

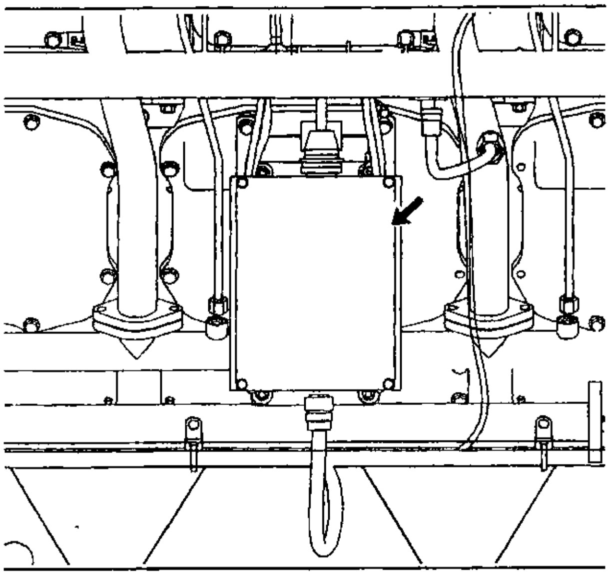


Illustration 17 g00843952

Integrated Combustion Sensing Module (ICSM)

The engine has an Integrated Combustion Sensing Module (ICSM) for each bank of cylinders. The ICSM monitors exhaust temperature sensors and combustion sensors. The ICSM performs calculations with the data. The ICSM communicates with the ECM via the CAT Data Link.

Exhaust temperatures are monitored for each cylinder exhaust port, for the inlet of the turbocharger turbine, and for the outlet of the turbocharger turbine.

Vee Engines

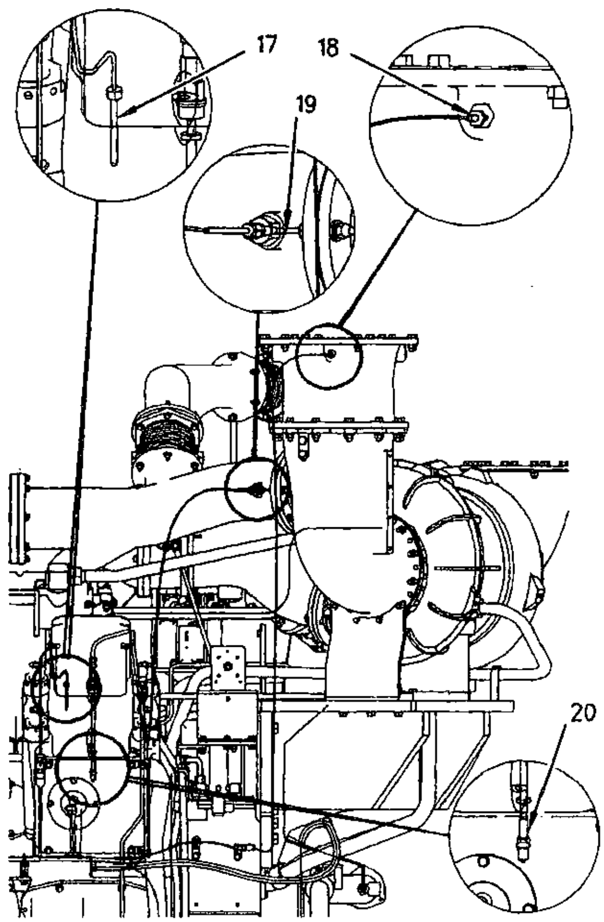


Illustration 18 g00825730

Vee engine

(17) Temperature sensor for the cylinder exhaust port
(18) Temperature sensor for the exhaust after the turbocharger
(19) Temperature sensor for the exhaust before the turbocharger
(20) Combustion sensor

Note: For each cylinder, there is one temperature sensor for the exhaust port (17) and one combustion sensor (20). For each turbocharger, there is one temperature sensor for the exhaust after the turbocharger (18) and one temperature sensor for the exhaust before the turbocharger (19).

In-Line Engines

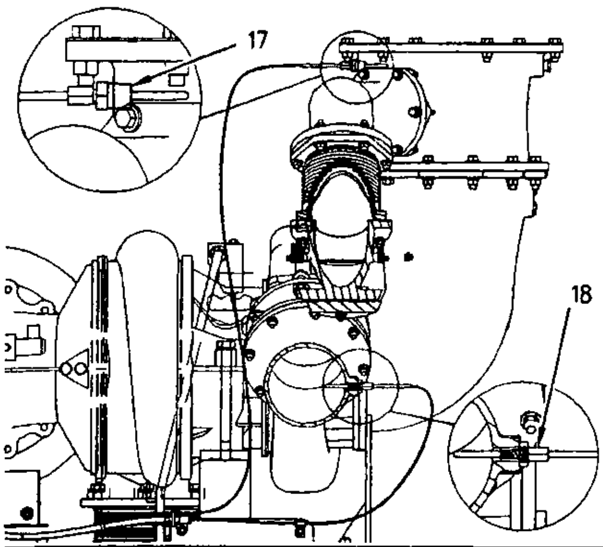


Illustration 19 g00895336

In-line engine

(17) Temperature sensor for the exhaust after the turbocharger
(18) Temperature sensor for the exhaust before the turbocharger

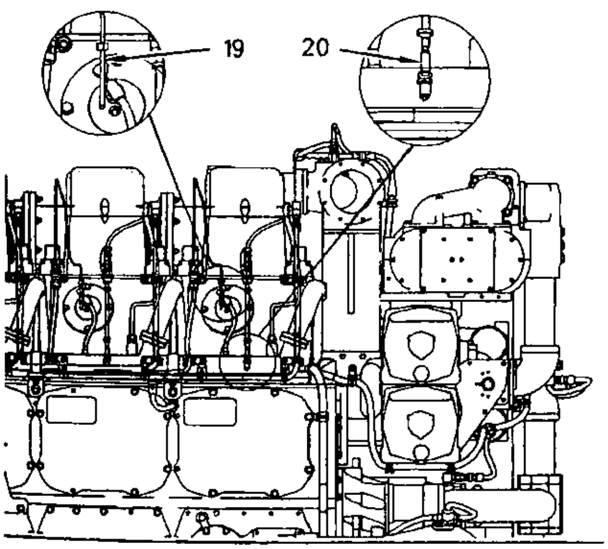


Illustration 20 g00895356

In-line engine

(19) Temperature sensor for the cylinder exhaust port
(20) Combustion sensor

Note: For each cylinder, there is one temperature sensor for the exhaust port (19) and one combustion sensor (20).

i01775381

Electronic Service Tools

SMCS Code: 1901-038

Caterpillar Electronic Service Tools are designed to help the service technician:

- Obtain data.
- Diagnose problems.
- Read parameters.
- Program parameters.
- Calibrate sensors.

The tools that are listed in Table 2 are required in order to enable a service technician to perform the procedures.

Table 2

Service Tools		
Pt. No.	Description	Functions
N/A	Personal Computer (PC)	This PC configuration is recommended: Intel Pentium II 333 mHz processor 64 megabyte of RAM 4.3 GB hard drive 14X speed CD-ROM drive
N/A	Personal Computer (PC)	This PC configuration has the minimum requirements: IBM PC compatible 100 MHz processor 32 megabyte of RAM 10 MB of available hard drive space CD-ROM drive 3.5 inch 1.44-MB floppy disk drive Windows NT or Windows 95 RS232 port with 16550AF UART VGA monitor or display
"JERD2124"	Software	Single user license for Cat ET Use the most recent version of the software.
"JERD2129"	Software	Data subscription for all engines
171-4401	Communication Adapter II (1)	The communication adapter is connected between the PC (Cat ET) and the Electronic Control Module (ECM).
196-0055	Serial Cable As (1)(2)	This cable connects the PC to the 171-4401 Communication Adapter II.
160-0141	Serial Cable As (2)	This cable connects the PC to the 171-4401 Communication Adapter II.
207-6845	Adapter Cable As (1)(3)	This cable connects the 171-4401 Communication Adapter II to the 7X-1414 Data Link Cable As.
7X-1701	Communication Adapter	The communication adapter is connected between the PC (Cat ET) and the ECM.
7X-1425	Serial Cable As	This cable connects the PC (Cat ET) to the 7X-1701 Communication Adapter.
139-4166	Adapter Cable As	This cable connects the 7X-1701 Communication Adapter to the 7X-1414 Data Link Cable As.
7X-1414	Data Link Cable As	This cable connects the service tool connector on the engine mounted terminal box to the 139-4166 Adapter Cable As.
8T-8726	Adapter Cable As	This breakout harness is for use between the jacks and the plugs of the sensors.
151-6320	Wire Removal Tool	This tool is used for the removal of pins and sockets from Deutsch connectors and AMP connectors.
1U-5804	Crimp Tool	This tool is used for work with CE electrical connectors.
9U-7330	Digital Multimeter	The multimeter is used for the testing and the adjusting of electronic circuits.
7X-1710	Multimeter Probes	The probes are used with the multimeter to measure voltage in wiring harnesses without disconnecting the harnesses.
5P-7277	Voltage Tester	The tester is used to test for voltage in circuits, relays, bulbs, wires, and switches.

(1) This item is included in the 171-4400 Communication Adapter Gp.
(2) Either the 160-0141 or the 196-0055 cable may be used.
(3) Either the 160-0133 or the 207-6845 cable may be used.

Note: Either the 171-4401 Communication Adapter II or the 7X-1700 Communication Adapter Gp can be used. However, the 7X-1700 Communication Adapter Gp is no longer serviced.

Caterpillar Electronic Technician (ET)

The Caterpillar Electronic Technician (ET) is designed to run on a personal computer. Cat ET can display the following information:

- Parameters
- Diagnostic codes
- Event codes
- Engine configuration
- Status of the monitoring system

Cat ET can perform the following functions:

- Diagnostic tests
- Sensor calibration
- Flash downloading
- Set parameters

Connecting Cat ET with the 171-4401 Communication Adapter II

The battery supplies the communication adapter with 24 VDC. Use the following procedure to connect Cat ET and the communication adapter to the engine.

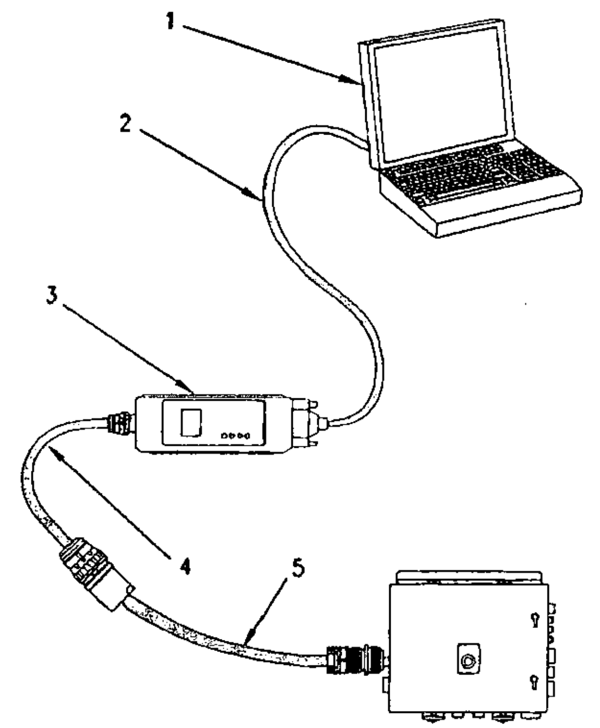


Illustration 21 g00694774

(1) PC
(2) 196-0055 Serial Cable or the 160-0141 Serial Cable
(3) 171-4401 Communication Adapter II
(4) 207-6845 Adapter Cable
(5) 7X-1414 Data Link Cable

1. Connect cable (2) to the RS232 serial port of PC (1).
2. Connect cable (2) to communication adapter (3).
3. Connect cable (4) to communication adapter (3).
4. Connect cable (4) to cable (5).
5. Connect cable (5) to the service tool connector of the terminal box.
6. Make sure that the engine control switch is in the ON position. If Cat ET and the communication adapter do not communicate with the ECM, refer to Troubleshooting, "Electronic Service Tool Will Not Communicate with ECM or ICSM".

Connecting Cat ET with the 7X-1701 Communication Adapter

The battery supplies the communication adapter with 24 VDC. Use the following procedure to connect Cat ET and the communication adapter to the engine.

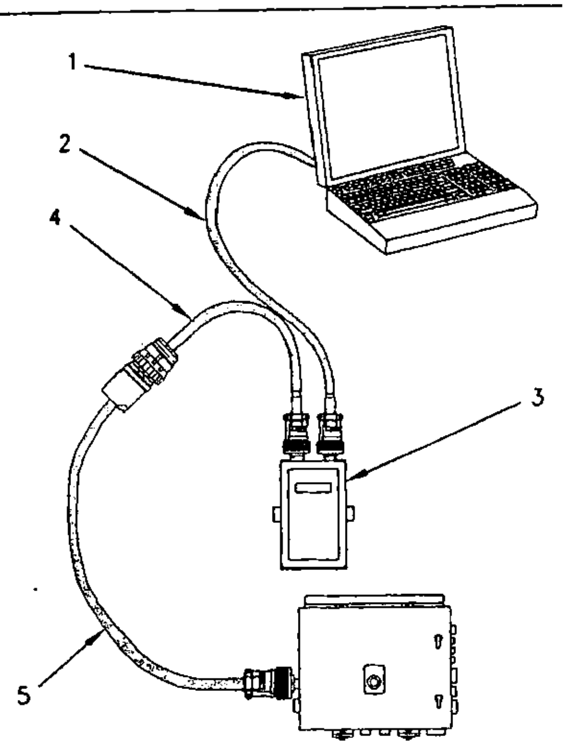


Illustration 22 g00694776

(1) PC
(2) 7X-1425 Serial Cable
(3) 7X-1701 Communication Adapter
(4) 139-4166 Adapter Cable
(5) 7X-1414 Data Link Cable

1. Connect cable (2) to the RS232 serial port of PC (1).
2. Connect cable (2) to communication adapter (3).
3. Connect cable (4) to communication adapter (3).
4. Connect cable (4) to cable (5).
5. Connect cable (5) to the service tool connector of the terminal box.
6. Make sure that the engine control switch is in the ON position. If Cat ET and the communication adapter do not communicate with the ECM, refer to Troubleshooting, "Electronic Service Tool Will Not Communicate with ECM or ICSM".

i01754145

Engine Monitoring System

SMCS Code: 1901-038

The Electronic Control Module (ECM) monitors the operating parameters of the engine. The ECM can initiate a warning or a shutdown if a specific engine parameter exceeds an acceptable range. The default settings for the parameters are programmed at the factory.

The status of the parameters can be viewed on the "Service/Monitoring System" screen of the Caterpillar Electronic Technician (Cat ET). This screen is also used to change the settings.

To accommodate unique applications and sites, some parameters may be reprogrammed with Cat ET. The screens of Cat ET provide guidance for changing trip points. Use Cat ET to perform the following activities:

- Select the available responses.
- Program the level for monitoring.
- Program delay times for each response.

Note: Some parameters are protected by factory passwords. Other parameters can be changed with customer passwords.

For instructions on using Cat ET, refer to the User's Manual that is supplied with the software.

For information on the warnings and shutdowns, refer to Troubleshooting, "Troubleshooting with an Event Code".

For detailed information on system parameters that can be programmed and for recommendations for programming parameters, refer to Systems Operation/Testing and Adjusting, "Engine Monitoring System".

NOTICE

Changing the parameters during engine operation can cause the engine to operate erratically. This can cause engine damage.

Unless the instructions are different, only change the settings of the parameters when the engine is STOPPED.

Programming Parameters

i01754149

Programming Parameters

SMCS Code: 1901-038

Programmable parameters enable the engine to be configured to meet the requirements of the application. Two types of parameters can be programmed into the Electronic Control Module (ECM): system configuration parameters and monitoring system parameters.

The Caterpillar Electronic Technician (Cat ET) is used for viewing the status of parameters and for programming parameters.

For more information on parameters, refer to Troubleshooting, "Sytem Configuration Parameters" and Troubleshooting, "Engine Monitoring System".

i01726982

Customer Passwords

SMCS Code: 1901

Certain monitoring system parameters and system configuration parameters may be protected with customer passwords. Use of the passwords helps to prevent free access to the modification of the parameters. If the customer passwords are not programmed, all of the parameters are unprotected.

The customer passwords can be changed, if necessary. The customer passwords or a factory password is needed in order to change the customer passwords. If the customer passwords are forgotten, factory passwords can be acquired from Caterpillar.

After the customer passwords are entered, the passwords are required in order to change certain parameters. Once the passwords are entered successfully, the passwords are not requested again until another screen is accessed or the data link is interrupted.

This feature is enabled by programming two customer passwords. Use the following procedure to program the passwords. The same procedure is used to change the passwords:

1. Access the "Service/Configuration" screen of the Caterpillar Electronic Technician (ET).

2. Highlight the "Customer Password #1" parameter. Click on the "Change" button in the lower right corner of the screen.

Note: Be sure to record the customer passwords. Store the passwords securely. The passwords can have a maximum of eight characters. Alphanumeric characters may be used. The passwords are case sensitive.

3. Enter the password in the "Change Parameter Value" dialog box and click on the "OK" button.

4. Highlight the "Customer Password #2" parameter. Click on the "Change" button in the lower right corner of the screen.

5. Enter the password in the "Change Parameter Value" dialog box and click on the "OK" button.

   The passwords are now programmed into the memory of the Electronic Control Module (ECM).

Make a copy of Table 3 and record your passwords. Store the passwords securely.

Table 3

Customer Passwords
Customer Password #1
Customer Password #2

i01727009

Factory Passwords

SMCS Code: 1901-038

Factory level security passwords are required for clearing certain logged events and for changing certain programmable parameters. Because of the passwords, only authorized personnel can make changes to some of the programmable items in the Electronic Control Module (ECM). When the correct passwords are entered, the changes are programmed into the ECM.

Factory passwords are required to program the following shutdowns:

- "Engine Overspeed"
- "High Engine Oil Temperature"
- "High Oil Filter Differential Pressure"
- "Low Oil Filter Differential"
- "High Jacket Water to Engine Oil Temperature Differential"

The "Enter Factory Passwords" screen on Cat ET will display the following parameters. To obtain the proper passwords, the information must be given to an authorized Caterpillar dealer:

- Current ECM
- Serial number of the service tool
- Serial number of the engine
- Serial number of the ECM
- Diagnostic clock
- Total Tattletale
- Reason

The old interlock code is required to change the interlock code on a used ECM. The passwords are controlled by Caterpillar. The passwords may only be obtained by an authorized Caterpillar dealer.

The passwords may only be used for one programming session. After you exit the "Enter Factory Passwords" screen on Cat ET, a different set of passwords will be required before you can program the ECM.

Factory passwords are not required for the first hour of operation for a new ECM. After the hour expires, factory passwords are required for some of the programming.

i01727016

Factory Passwords Worksheet

SMCS Code: 1901-038

Note: A mistake in recording this information will result in incorrect passwords.

Table 4

Factory Passwords Worksheet
Dealer Code
Customer's Name
Address
Telephone Number
Information from the "Enter Factory Passwords" Screen on the Caterpillar Electronic Technician (ET)
Serial Number for Cat ET
Engine Serial Number
ECM Serial Number
Diagnostic Clock(1)
Total Tattletale
Reason Code
Factory Passwords
Factory Password (No. 1)
Factory Password (No. 2)

(1) Do not obtain this information from the service meter.

i01754150

Flash Programming

SMCS Code: 1901-038

Software is located in the flash memory of the Electronic Control Module (ECM) and in the Integrated Combustion Sensing Module (ICSM). The Caterpillar Electronic Technician (Cat ET) can be used to flash new software into the ECM and into the ICSM. The flash is accomplished by transferring the data from Cat ET to the module via data link wiring. The Software, JERD2124 or Software, JERD2129 is used.

Flash Programming

If the slowest baud rate of Cat ET is selected, flash programming can last up to 15 minutes. Be sure to set the baud rate to the fastest rate for your PC.

To select the baud rate, use the ET "Utilities/Preferences". Select the "Communications" tab and click on "Advanced...". Then select the baud rate from the "Advanced Communication Settings" menu and click the "OK" button.

If a communication error occurs, select a slower baud rate in order to improve the reliability.

1. Connect Cat ET to the service tool connector.

2. Turn the engine control switch to the STOP position.

   Cat ET will not flash if the engine control switch is in the OFF position or in the START position.

3. Select "WinFlash" from the "Utilities" menu on Cat ET.

   "WinFlash" will try to detect an ECM.

4. When an ECM has been detected, the "ECM Selector" window will appear. Select the appropriate ECM and then select "OK".

   The "Flash File Selection" window will appear.

5. The flash files are located on a disk drive and in a directory. Select the correct disk drive and the directory from "Drives" and "Directories" on Cat ET.

   A list of flash files will appear.

6. Select the correct file from the list of flash files. Read the "Description" and the "File Info" in order to verify that the correct file is selected. Select "Open".

7. Select the "Begin Flash" button in order to program the personality module.

   When the flash is completed, this message will appear: "Flash Completed Successfully".

8. Program the configuration parameters and the monitoring system parameters.

   The parameters must be programmed in order to ensure proper engine operation. Refer to Troubleshooting, "Programming Parameters".

9. Start the engine and check for proper operation.

   a. If a diagnostic code of 268-02 "Check Programmable Parameters" is generated, program any parameters that were not in the original software.

   b. Access the "Configuration" screen under the "Service" menu in order to determine the parameters that require programming. Look under the "Tattletale" column. All of the parameters should have a tattletale of 1 or more. If a parameter has a tattletale of 0, program that parameter.

"WinFlash" Error Messages

If you receive any error messages during flash programming, click on the "Cancel" button in order to stop the process. Access the information about the "ECM Summary" under the "Information" menu. Make sure that you are flashing the correct file for your engine.

i01754153

System Configuration Parameters

SMCS Code: 1901-038

The system configuration parameters must be programmed when the application is installed. Perform this programming before the initial engine start-up. Incorrect programming of parameters may lead to complaints about performance and/or to engine damage.

Data from a gas analysis is required for determining the correct settings for the fuel quality and for the specific gravity of the gas. The data must be entered into the Caterpillar Software, LEKQ6378, "Methane Number Program".

The status of the parameters can be viewed on the "Configuration" screen of the Caterpillar Electronic Technician (Cat ET).

If the Electronic Control Module (ECM) is replaced, the appropriate parameters must be copied from the original ECM. This can be done with the "Copy Configuration" feature of Cat ET. Alternatively, the settings can be recorded on paper and then programmed into the new module.

Table 5 is a list of the parameters that can be configured for G3600 Engines.

Table 5

Configuration Parameters for G3600 Engines
Air/Fuel Ratio Control
"Fuel Quality"
"Gas Specific Gravity"
"Desired Engine Exhaust Port Temp"
"Maximum Choke Position"
"Engine Start Choke Position"
"Wastegate (Proportional) Gain Percentage"
"Wastegate (Integral) Stability Percentage"
"Wastegate (Derivative) Compensation Percentage"
"Choke (Proportional) Gain Percentage"

(continued)

(Table 5, contd)

Configuration Parameters for G3600 Engines
"Choke (Integral) Stability Percentage"
"Choke (Derivative) Compensation Percentage"
Speed Control
"Low Idle Speed"
"Minimum Engine High Idle Speed"
"Maximum Engine High Idle Speed"
"Engine Accel. Rate"
"Desired Speed Input Configuration"
"Governor Type Setting"
"Engine Speed Droop"
"Governor (Proportional) Gain Percentage"
"Governor (Integral) Stability Percentage"
"Governor (Derivative) Compensation Percentage"
"Governor Auxiliary 1 (Proportional) Gain Percentage"
"Governor Auxiliary 1 (Integral) Stability Percentage"
"Governor Auxiliary 1 (Derivative) Compensation Percentage"
Start/Stop Control
"Driven Equipment Delay Time"
"Crank Terminate Speed"
"Engine Purge Cycle Time"
"Engine Cooldown Duration"
"Cycle Crank Time"
"Engine Overcrank Time"
"Engine Speed Drop Time"
"Engine Pre-lube Time Out Period"
Monitoring and Protection
"High Inlet Air Temp Engine Load Set Point"
Information for the Electronic Control Module (ECM)
"Engine Serial Number"
"Equipment ID"
"Customer Password #1"
"Customer Password #2"
"Total Tattletale"

For detailed information on the configuration parameters and for recommendations on programming of the parameters, refer to Systems Operation/Testing and Adjusting, "Electronic Control System Parameters".

For instructions on using Cat ET, refer to the User's Manual that is supplied with the software.

NOTICE

Changing the parameters during engine operation can cause the engine to operate erratically. This can cause engine damage.

Unless the instructions are different, only change the settings of the parameters when the engine is STOPPED.

i01754158

Replacing the ECM

SMCS Code: 1901-038

The Electronic Control Module (ECM) contains no moving parts. Failure of the ECM is unlikely. Before you replace an ECM, follow the troubleshooting procedures in this manual in order to be sure that replacement of the ECM will correct the problem.

Verify that the suspect ECM is the cause of the problem. Install a test ECM in place of the suspect ECM. Transfer the software from the suspect ECM to the test ECM. Program all the parameters for the test ECM in order to match the parameters of the suspect ECM. **The parameters must match.** Refer to the following test steps for details on programming the parameters.

If the test ECM resolves the problem, reconnect the suspect ECM. Verify that the problem recurs. If the problem recurs, replace the suspect ECM with the test ECM.

Note: If the parameters cannot be read from the suspect ECM, the parameters must be obtained from records or from the factory.

Perform the following procedure to replace the ECM.

1. Use the "Service/Copy Configuration/ECM Replacement" function of the Caterpillar Electronic Technician (Cat ET).

   Save the file. You can select "Load from ECM". You may also select the "Print" function in order to obtain a paper copy of the parameter settings.

Note: Before you replace an ECM, record all of the logged events.

   a. Connect Cat ET with the communications adapter. Select the "Service/Copy Configuration/ECM Replacement" screen from the pull-down menu.

Cat ET will load the configuration parameters and the monitoring system parameters of the suspect ECM.

b. Select "Load from ECM" from the Cat ET screen. Select the suspect ECM and select "OK".

After the loading is complete, Cat ET will display this message: "The data has been successfully loaded from the ECM". Select "OK".

c. Select "File/Disconnect F8" from the pull-down menu.

Note: Do not terminate Cat ET.

2. Replace the ECM.

a. Turn the engine control switch to the "OFF/RESET" position.

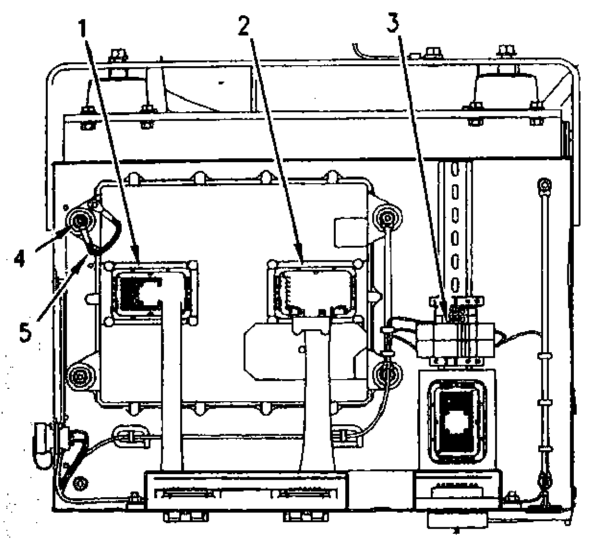


Illustration 23 g00842215

(1) ECM Connector P2
(2) ECM Connector P1
(3) 16 Amp Circuit Breaker
(4) Mounting nut
(5) Ground Strap

b. Switch the 16 amp circuit breaker (1) for the ECM to the OFF position.

c. Use a 4 mm Allen wrench to disconnect connectors (P1) and (P2).

d. Remove mounting nut (2) in order to disconnect the ground strap (3). Remove the three remaining mounting nuts.

Note: Rubber grommets behind the ECM are held in place by the mounting studs. The grommets help to reduce vibration. The grommets may fall when the ECM is removed. Be sure not to lose the grommets.

e. Remove the ECM from the terminal box.

3. Install the replacement ECM.

a. Use the mounting hardware to install the new ECM. Use a mounting nut to fasten the ground strap for the ECM to the upper left mounting stud. Then install the other three mounting nuts.

Check the mounting hardware and the ECM for correct installation. A correctly installed ECM will move slightly on the rubber grommets. If the ECM cannot move slightly on the grommets, check that the washers, spacers, and grommets are positioned correctly.

b. Use a 4 mm Allen wrench to connect the P1 and P2 connectors to the ECM. Tighten the screws to a torque of 6 ± 1 N·m (55 ± 9 lb in).

4. Program the configuration parameters and the monitoring system parameters into the replacement ECM.

a. Switch circuit breaker (1) to the ON position.

b. Turn the engine control switch to the "STOP" position.

c. Select "File/Select ECM" from the pull-down menu.

d. Select the replacement ECM and click "OK".

e. Select "Service/Copy Configuration/ECM Replacement" from the pull-down menu. Click "OK" on the window.

f. Select "Program ECM" from the screen. Select the replacement ECM and click "OK". If the correct ECM is shown, select "Yes".

g. After the loading is complete, a window with the message "Programming Conflict Warning" will appear. Select "OK".

h. A window with the message "Program ECM Results" will appear. Select "OK".

Note: When you program a new ECM, factory passwords are not required for the first hour of operation. After one hour, factory passwords are required for changing the parameters that are normally protected with factory passwords.

i01754163

Replacing the ICSM

SMCS Code: 1901-038

The Integrated Combustion Sensing Module (ICSM) contains no moving parts. Failure of the ICSM is unlikely. Replacement of the ICSM can consume much time. Before you replace an ICSM, follow the troubleshooting procedures in this manual in order to be sure that replacement of the ICSM will correct the problem.

Use the following guidelines to verify that the suspect ICSM is the cause of the problem:

Install a test ICSM in place of the suspect ICSM. Transfer the software from the suspect ICSM to the test ICSM. Program all the parameters for the test ICSM in order to match the parameters of the suspect ICSM. **The parameters must match.** Refer to the following steps for details on programming the parameters.

If the test ICSM resolves the problem, reconnect the suspect ICSM. Verify that the problem recurs. If the problem recurs, replace the suspect ICSM with the test ICSM.

Use the following procedure to replace the ICSM:

Note: If the parameters cannot be read from the suspect ICSM, the parameters must be obtained from records or from the factory.

1. Use the "Service/Copy Configuration/ECM Replacement" function of the Caterpillar Electronic Technician (Cat ET) in order to transfer the software from the suspect ICSM.

   You may also select the "Print" function in order to obtain a paper copy of the parameter settings.

Note: Before you replace an ICSM, record all of the logged events.

   a. Connect Cat ET with the communications adapter. Select "Service/Copy Configuration/ECM Replacement" from the pull-down menu.

      Cat ET will load the configuration parameters and the monitoring parameters from the ECM.

   b. Select "Load from ECM" in the lower left corner of the screen. Select the suspect ICSM and select "OK".

      After the loading is complete, Cat ET will display this message: "The data has been successfully loaded from the ECM". Select "OK".

   c. Select "File/Disconnect F8" from the pull-down menu.

Note: Do not exit from Cat ET.

2. Replace the ICSM.

   a. Turn the engine control switch to the "OFF/RESET" position.

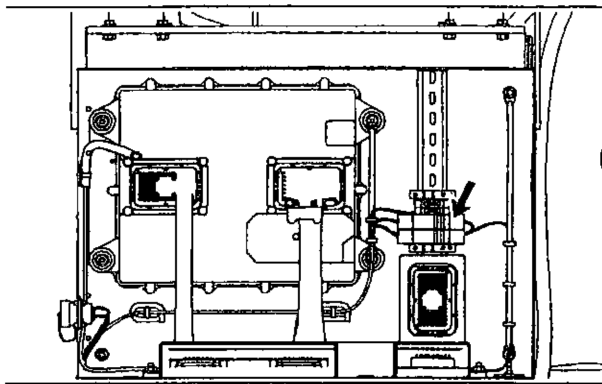


Illustration 24 g00842289

16 amp circuit breaker for the ECM

   b. Switch the 16 amp circuit breaker for the ECM to the OFF position.

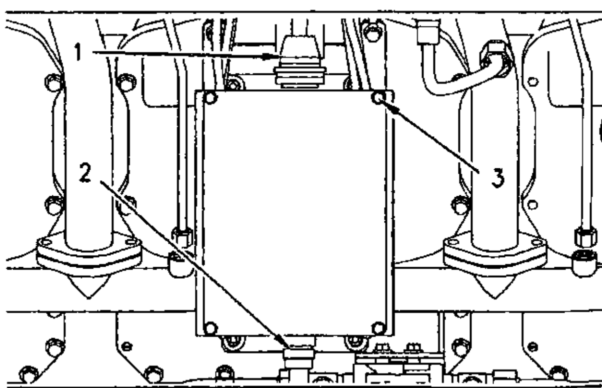


Illustration 25 g00842252

(1) 20 pin P72 connector
(2) 14 pin P73 connector
(3) Bolt

   c. Disconnect P72 connector (1) and P73 connector (2) from the ICSM. Remove four bolts (3) in order to remove the cover.

Note: Rubber grommets for the ICSM are held in place on the mounting studs. The grommets help to reduce vibration. The grommets may fall when the ICSM is removed. Be sure not to lose the grommets.

Note: A ground strap is connected with one of the mounting bolts.

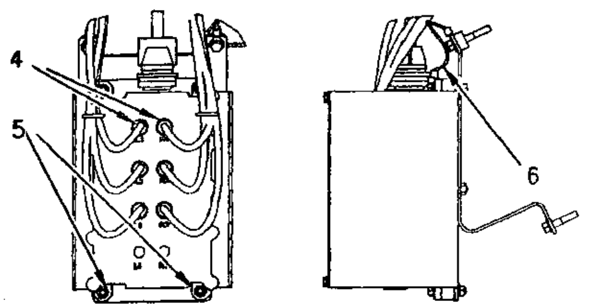


Illustration 26 g00842267

(4) Connectors for the sensors
(5) Mounting bolts
(6) Ground strap

d. Disconnect connectors (4) for the sensors from the ICSM. Remove four mounting bolts (5). Detach ground strap (6).

3. Install the replacement ICSM. Orient the 20 pin J72 connector to the upward position.

a. Use the mounting hardware to install the new ICSM. Be sure to install ground strap (6).

Check the mounting hardware and the ICSM for correct installation. A properly installed ICSM will move slightly on the rubber grommets. If the ICSM cannot move slightly on the grommets, check that the washers and grommets are positioned correctly.

b. Connect connectors (4) for the sensors to the ICSM.

c. Connect P72 connector (1) and P73 connector (2) to the ICSM.

d. Install the cover and four bolts (3).

4. Program the configuration parameters and the monitoring system parameters into the replacement ICSM.

a. Switch the 16 amp circuit breaker for the ECM ON.

b. Turn the engine control switch to the "STOP" position.

c. Select "File/Select ECM" from the pull-down menu of Cat ET.

d. Select the "Replacement ICSM" and click "OK".

e. Select "Service/Copy Configuration/ECM Replacement" from the pull-down menu. Click "OK" on the window.

f. Select "Program ECM" from the lower left corner of the screen. Select the replacement ICSM and click "OK".

g. After the loading is complete, a window with the message "Programming Complete" will appear. Select "OK".

Note: When you program a new ICSM, factory passwords are not required. Also, the ICSM does not require calibration.

i01794002

Troubleshooting Data Sheet

SMCS Code: 1901-038

To help troubleshoot a gas engine, complete the information in Table 6. Be sure to include the units of measurement.

Table 6

Data Sheet for Troubleshooting								
Customer and installation								
Engine model and driven equipment								
Engine serial number			Application					
Service hours	Compression ratio			Altitude		"Fuel Quality" setting (LHV)		
Fuel LHV	Fuel methane number			Fuel rate		Pressure to the gas regulator		
Fuel flow	Air flow		Brand of oil type of oil					
Engine rpm		Percent load			Detonation level		Air restriction	
Inlet manifold air pressure Desired inlet manifold air pressure		Inlet manifold air temperature			Actual air/fuel ratio Desired air/fuel ratio Desired combustion burn time			
Engine oil pressure			Turbocharger exhaust temperature		left		Exhaust stack pressure	
					right			
Fuel command		Air choke command			Wastegate command			
Exhaust stack temperature	$\% \ O_2$		PPM of NO_x		PPM of CO		Brand of exhaust analyzer	
Cylinder exhaust port temperatures	(1)	(3)	(5)	(7)	(9)	(11)	(13)	(15)
	(2)	(4)	(6)	(8)	(10)	(12)	(14)	(16)
Needle valve setting	(1)	(3)	(5)	(7)	(9)	(11)	(13)	(15)
	(2)	(4)	(6)	(8)	(10)	(12)	(14)	(16
Cylinder combustion burn time	(1)	(3)	(5)	(7)	(9)	(11)	(13)	(15)
	(2)	(4)	(6)	(8)	(10)	(12)	(14)	(16)
Aftercooler water temperature	in	Jacket water temperature		in	Engine oil temperature		in	
	out			out			out	
Comments								

Report the Service Information

After you have successfully repaired the engine, it is important to provide good information about the repair. The following topics are recommended for your report:

Complaint – Include a description of the customer's complaint in the report.

Cause – Provide a specific description of the cause of the failure. Include the method that was used in order to diagnose the problem. If diagnostic codes or event codes were generated, include all of the codes and the status of the codes. Indicate your determination of the problem. For example, if you performed a diagnostic functional test, identify the test procedure. For example, a visual inspection revealed abrasion of a wire in a harness. Be specific: dynamometer testing of the engine produced power below specifications at 1000 rpm due to the loss of an ignition transformer.

Repair – Explain your repair of the problem. For example, you may have installed a new wiring harness. You may have replaced the ignition transformer per instructions from the factory.

The providing of complete, accurate information will help Caterpillar to provide better service to you and to the customer.

APPENDIX D - SERVICE SCHEUDULE

SERVICE SCHEDULE
CATERPILLAR GS3600
ICE PLANT
PUENTE HILLS LANDFILL

Maintaining the engine in proper running condition is essential in meeting emissions limits. LACSD maintains our G3616 engines according to the recommended service intervals found in the Caterpillar service manual. A summary of the maintenance is listed below.

When Required

Actuator Control Linkage - Replace
Barring Device - Lubricate
Cooling System Coolant Sample (Level 2) - Obtain
Engine Air Cleaner Element (Single Element) – Clean/Replace
Engine Air Pre-cleaner - Clean
Engine Oil - Change
Engine Oil Filter - Change
Overhaul Considerations
Valve Stem Projection – Measure/Record

Daily

Control Panel - Inspect
Cooling System Coolant Level - Check
Driven Equipment - Inspect/Replace/Lubricate
Electro-hydraulic System - Inspect
Engine Air Cleaner Service Indicator - Inspect
Engine Oil Level - Check
Fuel System Fuel Filter Differential Pressure - Check
Walk-Around Inspection

Every 125 Service Hours

Engine Oil Sample - Obtain

Every 250 Service Hours

Battery Electrolyte Level - Check
Cooling System Coolant Sample (Level 1) - Obtain
Cooling System Supplemental Coolant Additive (SCA) – Test/Add

Initial 1000 Service Hours

Crankcase Blow-by - Measure/Record
Cylinder Pressure - Measure/Record
Electro-hydraulic System Oil Filter - Change
Engine Crankcase Breather - Clean
Engine Protective Device Connections - Inspect
Engine Speed/Timing Sensor – Clean/Inspect
Engine Valve Lash - Inspect/Adjust
Engine Valve Rotators - Inspect
Valve Stem Projection - Measure/Record

Every 1000 Service Hours

Actuator Control Linkage -Lubricate
Combustion Sensor – Clean/Inspect/Replace
Hoses and Clamps - Inspect/Replace
Ignition System Spark Plugs - Replace
Pre-chamber Check Valves - Clean

Every 2000 Service Hours

After-cooler Condensation - Drain
Cooling System Coolant Sample (Level 2) - Obtain
Crankshaft Vibration Damper - Inspect
Cylinders - Inspect
Engine Crankcase Breather - Clean
Engine Mounts - Check
Engine Valve Lash – Inspect/Adjust
Engine Valve Rotators - Inspect
Valve Stem Projection – Measure/Record

Every 5000 Service Hours

Cooling System Level Switch - Inspect
Crankcase Blow-by – Measure/Record
Cylinder Pressure – Measure/Record
Driven Equipment - Check
Electro-hydraulic System - Check/Adjust
Electro-hydraulic System Oil - Change
Electro-hydraulic System Oil Filter - Change
Engine Protective Device Connections - Inspect
Engine Protective Device - Check
Exhaust Bypass - Recondition
Gas Shutoff Valve - Inspect
Inlet Air System - Inspect
Inlet Gas Manifold and Piping - Inspect/Replace
Pre-chamber Check Valves - Replace
Starting Motor - Inspect
Turbocharger - Inspect

Between 10 000 and 14 000 Service Hours

Gas Admission Valve Seals – Inspect/Replace
Overhaul (Top End)
Pre-chamber - Clean/Inspect

Every 10 000 Service Hours

Cooling System Water Temperature Regulator - Replace
Electro-hydraulic Actuator - Inspect
Engine Oil Temperature Regulator - Replace
Engine Speed/Timing Sensor – Clean/Inspect
Exhaust Shields - Inspect
Gas Pressure Regulator – Inspect/Replace
Pre-lube Pump - Inspect
Water Pump - Inspect

Every 20 000 Service Hours or 3 Years

Cooling System Coolant (NGEC) - Change

Between 27 000 and 33 000 Service Hours

Electro-hydraulic Actuator - Recondition
Gas Admission Valve - Recondition
Overhaul (In-Frame)

Between 36 000 and 44 000 Service Hours

Gas Admission Valve Seals – Inspect/Replace
Overhaul (Top End)

Between 52 000 and 54 000 Service Hours

Overhaul (Major)

Overhaul

Connecting Rod Bearings - Inspect/Replace