**Designation: D6987/D6987M – 13a**

# Standard Test Method for Evaluation of Diesel Engine Oils in T-10 Exhaust Gas Recirculation Diesel Engine[1]

This standard is issued under the fixed designation D6987/D6987M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope*

1.1 This test method is commonly referred to as the Mack T-10.[2] This test method covers an engine test procedure for evaluating diesel engine oils for performance characteristics, including lead corrosion and wear of piston rings and cylinder liners.

1.2 This test method also provides the procedure for running an abbreviated length test, which is commonly referred to as the T-10A. The procedures for the T-10 and T-10A are identical with the exception of the items specifically listed in Annex A8. Additionally, the procedure modifications listed in Annex A8 refer to the corresponding section of the T-10 procedure.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* See Annex A7 for specific Safety Hazards.

## 2. Referenced Documents

2.1 *ASTM Standards:*[3]

D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure
D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
D97 Test Method for Pour Point of Petroleum Products
D129 Test Method for Sulfur in Petroleum Products (General High Pressure Decomposition Device Method)
D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D482 Test Method for Ash from Petroleum Products
D524 Test Method for Ramsbottom Carbon Residue of Petroleum Products
D613 Test Method for Cetane Number of Diesel Fuel Oil
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D976 Test Method for Calculated Cetane Index of Distillate Fuels
D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)
D2500 Test Method for Cloud Point of Petroleum Products
D2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge
D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D3338 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4485 Specification for Performance of Active API Service Category Engine Oils
D4739 Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricantsand is the direct responsibility of Subcommittee D02.B0 on Automotive Lubricants.

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[2] The ASTM Test Monitoring Center (TMC) will update changes in this test method by means of Information Letters. This edition includes all Information Letters through 13–1. Information Letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489, Attention: Administrator. www.astmtmc.cmu.edu

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D5186 Test Method for Determination of the Aromatic Content and Polynuclear Aromatic Content of Diesel Fuels and Aviation Turbine Fuels By Supercritical Fluid Chromatography
D5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions (Withdrawn 2003)[4]
D5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID) (Withdrawn 2003)[4]
D5967 Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine
D6078 Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE)
D6483 Test Method for Evaluation of Diesel Engine Oils in T-9 Diesel Engine (Withdrawn 2009)[4]
D6681 Test Method for Evaluation of Engine Oils in a High Speed, Single-Cylinder Diesel Engine—Caterpillar 1P Test Procedure
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E178 Practice for Dealing With Outlying Observations
E344 Terminology Relating to Thermometry and Hydrometry

## 3. Terminology

3.1 *Definitions:*

3.1.1 *blind reference oil, n*—a reference oil, the identity of which is unknown by the test facility.

3.1.1.1 *Discussion*—This is a coded reference oil that is submitted by a source independent from the test facility. **D5844**

3.1.2 *blowby, n—in internal combustion engines*, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **D5302**

3.1.3 *calibrate, v*—to determine the indication or output of a measuring device with respect to that of a standard. **E344**

3.1.4 *candidate oil, n*—an oil that is intended to have the performance characteristics necessary to satisfy a specification and is intended to be tested against that specification. **D5844**

3.1.5 *exhaust gas recirculation (EGR), n*—the mixing of exhaust gas with intake air to reduce the formation of nitrogen oxides ($NO_x$). **Automotive Handbook**[5]

3.1.6 *heavy-duty, adj— in internal combustion engine operation*, characterized by average speeds, power output, and internal temperatures that are close to the potential maximums. **D4485**

3.1.7 *heavy-duty engine, n*—in internal combustion engines, one that is designed to allow operation continuously at or close to its peak output. **D4485**

3.1.8 *non-reference oil, n*—any oil other than a reference oil, such as a research formulation, commercial oil, or candidate oil. **D5844**

3.1.9 *non-standard test, n*—a test that is not conducted in conformance with the requirements in the standard test method, such as running on an uncalibrated test stand, using different test equipment, applying different equipment assembly procedures, or using modified operating conditions. **D5844**

3.1.10 *oxidation, n*—of engine oil, the reaction of the oil with an electron acceptor, generally oxygen, which can produce deleterious acidic or resinous materials often manifested as sludge formation, varnish formation, viscosity increase, or corrosion, or a combination thereof. **Sub. B Glossary**[6]

3.1.11 *reference oil, n*—an oil of known performance characteristics and used as a basis for comparison.

3.1.11.1 *Discussion*—Reference oils are used to calibrate testing facilities, to compare the performance of other oils, or to evaluate other materials (such as seals) that interact with oils. **D5844**

3.1.12 *sludge, n—in internal combustion engines*, a deposit, principally composed of insoluble resins and oxidation products from fuel combustion and the lubricant, that does not drain from engine parts but can be removed by wiping with a cloth. **D5302**

3.1.13 *standard test, n*—a test on a calibrated test stand using the prescribed equipment according to the requirements in the test method, and conducted according to the specified operating conditions.

3.1.13.1 *Discussion*—The specified operating conditions in some test methods include requirements for determining a test's operational validity. These requirements are applied after a test is completed and can include (*1*) mid-limit ranges for the average values of primary and secondary parameters that are narrower than the specified control ranges for the individual values, (*2*) allowable deviations for individual primary and secondary parameters for the specified control ranges, (*3*) downtime limitations, and (*4*) special parameter limitations. **D5844**

3.1.14 *varnish, n—in internal combustion engines*, a hard, dry, generally lustrous deposit that can be removed by solvents but not by wiping with a cloth. **D5302**

3.1.15 *wear, n*—the loss of material from, or relocation of material on, a surface.

3.1.15.1 *Discussion*—Wear generally occurs between two surfaces moving relative to each other, and is the result of

[4] The last approved version of this historical standard is referenced on www.astm.org.

[5] Available from Robert Bosch GmbH, Postfach 50, D-7000 Stuttgart 1., Germany.

[6] Available from the ASTM Test Monitoring Center (TMC), 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

mechanical or chemical action or by a combination of mechanical and chemical action. **D5302**

## 4. Summary of Test Method

4.1 The test operation involves use of a Mack E-TECH V-MAC III diesel engine with exhaust gas recirculation (EGR). A warm-up and a 1 h break-in are followed by a two-phase test consisting of 75 h at 1800 r/min and 225 h at 1200 r/min, both at constant speed and torque.

4.2 Take oil samples periodically and analyze for viscosity increase and wear metals content.

4.3 Rebuild the engine prior to each test. Disassemble, solvent-clean (see 7.4), measure, and rebuild the engine power section using all new pistons, rings, cylinder liners, and connecting rod bearings in strict accordance with furnished specifications.

4.4 Solvent-clean (see 7.4) the engine crankcase and replace worn or defective parts.

4.5 Equip the test stand with appropriate accessories for controlling speed, torque, and various engine operating conditions.

## 5. Significance and Use

5.1 This test method was developed to evaluate the wear performance of engine oils in turbocharged and intercooled four-cycle diesel engines equipped with EGR. Obtain results from used oil analysis and component measurements before and after the test.

5.2 The test method may be used for engine oil specification acceptance when all details of the procedure are followed.

## 6. Apparatus

6.1 *General Description:*

6.1.1 The test engine is a Mack E-TECH V-MAC III, electronically controlled fuel injection with six electronic unit pumps, P/N 11GBA81025 (Annex A2). It is an open-chamber, in-line, six-cylinder, four-stroke, turbocharged, charge air-cooled, and compression ignition engine. The bore and stroke are 124 mm by 165 mm [4⅞ by 6½ in.], and the displacement is 12 L [728 in.$^3$].

6.1.2 The ambient laboratory atmosphere shall be relatively free of dirt and other contaminants as required by good laboratory standards. Filtering air, controlling temperature, and controlling humidity in the engine buildup area helps prevent accumulation of dirt and other contaminants on engine parts and aids in measuring and selecting parts for assembly.

6.2 *The Test Engine:*

6.2.1 *Mack T-10 Test Engine*—The engine is available from Mack Trucks, Inc. A complete parts list is shown in Table A2.1. Use test parts on a first-in/first-out basis.

6.2.2 *Engine Cooling System:*

6.2.2.1 Use a new Mack coolant conditioner shown in Table A2.1, for every test to limit scaling in the cooling system. Pressurize the system to 103 kPa [15 psi] at the expansion tank. Use the coolant shown in 7.3.1.

6.2.2.2 Use a closed-loop, pressurized external engine cooling system composed of a nonferrous core heat exchanger, reservoir, and water-out temperature control valve. The system shall prevent air entrainment and control jacket temperatures within the specified limit. Install a sight glass between the engine and the cooling tower to check for air entrainment and uniform flow in an effort to prevent localized boiling. Block the thermostat wide open.

6.2.2.3 Flow the coolant from the engine block fitting to the EGR coolers (see Fig. A1.3). Return the EGR coolant flow to the engine coolant-in line near the coolant pump inlet (see Fig. A1.7).

6.2.3 *Auxiliary Oil System*—To maintain a constant oil level in the pan, provide an additional 9.5 L [10 qt] sump by using a separate closed tank connected to the sump. Circulate oil through the tank at a rate of 5.7 L/min ± 1.9 L/min [1.5 ± 0.5 gal/min] with an auxiliary pump. The system schematic is shown in Fig. A1.1. The No. 6 and No. 8 lines are to have inside diameters of 10 mm [⅜ in.] and 13 mm [½ in.], respectively. Use a minimum No. 8 size vent line. Equivalent lines may be substituted for Aeroquip[7] lines provided they have the proper inside diameters.

6.2.3.1 Locate the auxiliary oil system suction line on the exhaust side of the oil pan, 127 mm [5.00 in.] down from the oil pan rail and 178 mm [7.00 in.] back from the front of the pan. This location is directly above the oil sump temperature thermocouple. Refer to Fig. A1.4. Connect the auxiliary oil system return line to the power steering pump cover on the front timing gear cover. Refer to Fig. A1.5. Connect the auxiliary oil scale vent line to the top of the auxiliary oil sump bucket and the dipstick tube opening.

6.2.3.2 Use a Viking pump Model No. SG053514 as the auxiliary oil pumps. Pump speed is specified as 1725 r/min.[8]

6.2.4 *Oil Cooling System:*

6.2.4.1 Use the oil cooler adapter blocks to mount the oil cooler to the engine. The adapter blocks are available from the supplier list in A2.7, Annex A2.

6.2.4.2 Use the oil filter housing (part no. 27GB525M) shown in Fig. A1.8.

6.2.5 *Blowby Meter*—Use a meter capable of providing data at a minimum frequency of 6 min. To prevent blowby condensate from draining back into the engine, the blowby line shall have a downward slope to a collection bucket. The collection bucket shall have a minimum volume of 18.9 L [5 gal]. Locate the blowby meter downstream of the collection bucket. The slope of the blowby line downstream of the collection bucket is unspecified.

6.2.6 *Air Supply and Filtration*—Use the Mack air filter element and the Mack filter housing shown in A2.3, Annex A2. Replace filter cartridge when 2.5 kPa [10 in. $H_2O$] $\Delta P$ is reached. Install an adjustable valve (flapper) in the inlet air system at least two pipe diameters before any temperature, pressure, and humidity measurement devices. Use the valve to maintain inlet air restriction within required specifications.

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[7] Aeroquip lines are available at local industrial hose suppliers.

[8] The sole source of supply of the apparatus known to the committee at this time is Viking Pump, Inc., A Unit of IDEX Corp., 406 State St., P.O. Box 8, Cedar Falls, IA 50613-0008. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

6.2.7 *Fuel Supply*—Heating or cooling, or both, of the fuel supply may be required, and a recommended system is shown in Fig. A1.2.

6.2.8 *Intake Manifold Temperature Control*—Use a Modine intercooler to control intake manifold temperature (refer to A2.4).

6.2.9 *Injection Timing Control*—Remove the engine intake manifold temperature sensor. Use the intake manifold temperature to control injection timing according to the temperature to injection timing correlation shown in Annex A5.

6.2.10 *Oil Pump*—Use a Mack P/N 315GC465BM oil pump. The oil pump is available from Mack Trucks, Inc. (see A2.2).

## 7. Engine Fluids

7.1 *Test Oil:*

7.1.1 Approximately 151 L [40 gal] of test oil is required for the test.

7.2 *Test Fuel:*

7.2.1 Obtain test fuel from the supplier shown in A2.6, Annex A2. The required fuel properties and tolerances are available from the TMC.[6]

7.3 *Engine Coolant:*

7.3.1 Use demineralized water with less than 0.03 g/L [2 grains/gal] of salts or distilled water (do not use antifreeze solutions). Use Pencool 3000 coolant additive at the manufacturer's recommended rate. Pencool 3000 may be obtained from the supplier shown in A2.8, Annex A2.

7.4 *Solvent*—Use only mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content (0-2% vol), Flash Point (142°F/61°C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning—**Combustible. Health hazard.) Obtain a Certificate of Analysis for each batch of solvent from the supplier.

## 8. Preparation of Apparatus at Rebuild

8.1 *Cleaning of Parts:*

8.1.1 *Engine Block*—Thoroughly spray the engine with solvent (see 7.4) to remove any oil remaining from the previous test and air-dry. Additionally, follow use of an engine parts washer by a solvent wash.

8.1.2 *Rocker Covers and Oil Pan*—Remove all sludge, varnish, and oil deposits. Rinse with solvent (see 7.4) and air-dry. Additionally, follow use of an engine parts washer by a solvent wash.

8.1.3 *Auxiliary Oil System*—Flush all oil lines, galleries, and external oil reservoirs first with a solvent (see 7.4) to remove any previous test oil and then air-dry.

8.1.4 *Oil Cooler and Oil Filter*—Flush the oil cooler and filter lines first with a solvent (see 7.4) to remove any previous test oil and then air-dry. Additionally, follow use of an engine parts washer by a solvent wash.

8.1.5 *Cylinder Head*—Clean the cylinder heads using a wire brush to remove deposits and rinse with a solvent (see 7.4) to remove any sludge and oil and then air-dry. Additionally, follow use of an engine parts washer by a solvent wash.

8.1.6 *Intake Manifold*—Clean the intake manifold before each test. Scrub the manifold using a nylon brush and a solvent, and then wash the manifold using an engine parts cleaner.

8.1.7 *EGR Coolers*—Clean the EGR coolers before each test by flushing with a solvent and then air-drying (see 7.4).

8.1.8 *EGR Venturi Unit*—Clean the venturi before each test. Spray with a solvent and scrub with a nylon brush.

8.2 *Valves, Seats, Guides, and Springs*—Visually inspect valves, seats, and springs for defects or heavy wear and replace if necessary. Replacement of the valves, guides, and seat inserts for each test is recommended, but not required.

8.2.1 Replace and ream guides to 0.9525 cm ± 0.0013 cm [0.3750 ± 0.0005 in.].

8.3 *Cylinder Liner, Piston, and Piston Ring Assembly:*

8.3.1 *Cylinder Liner Fitting*—For proper heat transfer, fit cylinder liners to the block according to the procedure outlined in the Mack Service Manual.[9]

8.3.2 *Piston and Rings*—Cylinder liners, pistons, and rings are provided as a set and should be used as a set. Examine piston rings for any handling damage. Record pre-test measurements as detailed in 11.1.

8.4 *Injectors and Injection Pumps:*

8.4.1 *Injectors*—Check the injector opening pressure at the start of each calibration period. Reset the injector opening pressure if it is outside the specification of 36 900 kPa to 37 900 kPa [5350 to 5500 psi].

8.4.2 *Injection Pumps*—The electronic unit pumps (EUP) may be changed at any time using the procedure specified in the Mack Service Manual. Be sure to enter the EUP's four digit calibration code into the engine control unit (ECU). The calibration code can be found on the EUP label.

8.5 *Assembly Instructions:*

8.5.1 *General*—The test parts specified for this test are intended to be used without material or dimensional modification. Exceptions, for example, is approval of a temporary parts supply problem by the TMC, and noting this approval in the test report. All replacement test engine parts shall be genuine Mack Truck Inc. parts. Assemble all parts as illustrated in the Mack Service Manual except where otherwise noted. Target all dimensions for the means of the specifications. Use Bulldog Premium EO-M+ Oil for lubricating parts during assembly; see A2.10, Annex A2.

8.5.1.1 *Thermostat*—Block the thermostat wide open.

8.5.1.2 *Rod Bearings*—Install new rod bearings for each test. See 10.1 for pre-test measurements to be recorded.

8.5.1.3 *Main Bearings*—Install new main bearings for each test.

8.5.1.4 *Piston Under Crown Cooling Nozzles*—Take particular care in assembling the piston under crown cooling nozzles to ensure proper piston cooling (as outlined in the Mack Service Manual).

NOTE 1—Proper oil pressure is also important to ensure sufficient oil volume for proper cooling.

[9] Mack Service Manuals are available from local Mack Trucks, Inc. distributors.

8.5.1.5 *Thrust Washers*—Install new thrust washers for each test.

8.5.2 *New Parts*—Use test parts on a first-in/first-out basis. Install the following new parts for each rebuild, see Table A2.1 for part numbers:

8.5.2.1 Cylinder liners.

8.5.2.2 Pistons.

8.5.2.3 Piston rings.

8.5.2.4 Overhaul gasket set.

8.5.2.5 Oil filters.

8.5.2.6 Engine coolant conditioner.

8.5.2.7 Primary fuel filter.

8.5.2.8 Secondary fuel filter.

8.5.2.9 Valve stem seals.

8.5.2.10 Valve guides.

8.5.2.11 Connecting rod bearings.

8.5.2.12 Main bearings.

8.5.2.13 Thrust washers.

8.6 *Measurements:*

8.6.1 *Calibrations:*

8.6.1.1 Calibrate thermocouples, pressure gages, speed, and fuel flow measuring equipment prior to each reference oil test or at any time readout data indicates a need. Conduct calibrations with at least two points that bracket the normal operating range. Make these calibrations part of the laboratory record. During calibration, connect leads, hoses, and read-out systems in the normally used manner and calibrate with necessary standards. For controlled temperatures, immerse thermocouples in calibration baths. Calibrate standards with instruments traceable to the National Institute of Standards and Technology on a yearly basis.

8.6.1.2 *Oxygen Sensor*—Calibrate the oxygen sensor prior to every test in accordance with Annex A4.

8.6.2 *Temperatures:*

8.6.2.1 *General*—Measure temperatures with thermocouples and conventional readout equipment or their equivalent. For temperatures in the 0 °C to 150 °C [32 to 300°F] range, calibrate temperature-measuring systems to ±0.5 °C for at least two temperatures that bracket the normal operating range. Insert all thermocouples so that the tips are located midstream of the flow unless otherwise indicated.

8.6.2.2 *Ambient Air*—Locate thermocouple in a convenient, well-ventilated position between 2 m and 3 m [approximately 6 and 10 ft] from the engine and hot accessories.

8.6.2.3 *Coolant*—Locate the coolant-out thermocouple in the water manifold prior to the thermostat housing. Locate in center of water stream. Refer to Fig. A1.6. Locate the coolant-in thermocouple anywhere between the heat exchanger and the coolant pump inlet (upstream of the junction with the EGR coolant return). Refer to Fig. A1.7.

8.6.2.4 *Oil Gallery*—Locate thermocouple at the center port on the filter housing. Insertion depth shall be 98 mm [3.875 in.] Refer to Fig. A1.8.

8.6.2.5 *Oil Sump Temperature*—Using a front sump oil pan configuration, locate thermocouple on the exhaust side of the oil pan, 178 mm [7 in.] from the front and 178 mm [7 in.] from the top of the pan. Thermocouple length shall be 102 mm [4 in.]. Refer to Fig. A1.4.

8.6.2.6 *Intake Air Temperature*—Locate the intake air thermocouple in center of air stream at the turbocharger inlet as shown in Fig. A1.9. The temperature thermocouple is to be approximately 102 mm [4 in.] upstream of the compressor inlet connection. It is not necessary to control intake air humidity, but measurements are required.

8.6.2.7 *Fuel In*—Locate thermocouple at the fitting on the outlet side of the fuel transfer pump as shown in Fig. A1.10.

8.6.2.8 *Pre-Turbine Exhaust*—Locate one thermocouple in each side of exhaust manifold section; see Fig. A1.11. The thermocouple shall be downstream of the pre-turbine exhaust pressure sensor.

8.6.2.9 *Exhaust Tailpipe*—Locate thermocouple in exhaust pipe downstream of turbine in accordance with Fig. A1.12.

8.6.2.10 *Intake Manifold*—Locate thermocouple at tapped fitting on intake air manifold as shown in Fig. A1.13.

8.6.2.11 *EGR Cooler Inlet*—Distinct EGR cooler inlet temperature measurements are not necessary. Use the pre-turbine exhaust temperatures instead (see 8.6.2.8).

8.6.2.12 *EGR Cooler Outlet*—Locate thermocouple as shown in Fig. A1.14.

8.6.2.13 *EGR Pre-Venturi*—Locate thermocouple as shown in Fig. A1.15. Be aware that the EGR pre-venturi thermocouple shall be downstream of the pressure sensor.

8.6.2.14 *Additional*—Monitor any additional temperatures that the test laboratory regards as helpful in providing a consistent test procedure.

8.6.3 *Pressures:*

8.6.3.1 *Before Oil Filter*—Locate pickup at tapped hole on oil cooler fitting; see Fig. A1.16.

8.6.3.2 *After Oil Filter (Main Oil Gallery)*—Locate pickup at the left port of the filter housing; see Fig. A1.8.

NOTE 2—The E7 engine has only one oil gallery, and it serves as both a main gallery and piston-cooling gallery.

8.6.3.3 *Pre-Turbine Exhaust*—Locate pickup in each side of exhaust manifold section (tap shall be upstream of the pre-turbine temperature thermocouple); see Fig. A1.11. This measurement is not mandatory but is recommended for diagnostic and safety purposes.

8.6.3.4 *Intake Manifold (Air Boost)*—Take measurement at tapped fitting provided on intake manifold as illustrated in Fig. A1.17.

8.6.3.5 *Intake Air Pressure (Intake Air Restriction)*—Measure with a Keil probe (p/n KDF-8-W required) located approximately 203 mm [8 in.] upstream of the compressor inlet (see Fig. A1.9). The probes may be obtained from the supplier shown in A2.9.

8.6.3.6 *Exhaust Back*—Locate pickup in exhaust pipe after turbocharger in center of exhaust stream. Measure exhaust backpressure in a straight section of pipe, 30.5 cm to 40.6 cm [12 to 16 in.] downstream of the turbo with a pressure tap hole as shown in Fig. A1.12.

8.6.3.7 *Crankcase Pressure*—Locate pickup at any location in the auxiliary oil system vent line, such as between the dipstick tube fitting and the top of the auxiliary oil sump bucket.

8.6.3.8 *Compressor Discharge*—Locate pickup within 15.2 cm [6 in.] of the second compressor.

8.6.3.9 *Coolant System*—Locate pickup at the top of the coolant system expansion tank.

8.6.3.10 *Barometric Pressure*—Locate barometer approximately 1.2 m [4 ft] above ground level in convenient location in the laboratory.

8.6.4 *Exhaust Oxygen Sensor*—Locate the oxygen sensor at the 12 o'clock position, 35.6 cm to 43.2 cm [14 to 17 in.] downstream of the turbine. Countersink the sensor coupling and install the sensor so that the sensor threads are flush with the inside diameter of the exhaust pipe. Do not expose threads to the flow stream. Refer to Fig. A1.12.

8.6.5 *Intake Carbon Dioxide Sensor*—Measure intake $CO_2$. Locate the probe as shown in Fig. A1.8.

8.6.6 *Engine Blowby*—Connect the metering instrument to the filter element canister on the engine front cover.

8.6.7 *Fuel Consumption Measurements*—Place the measuring equipment in the fuel line before the primary fuel filter. Install the primary fuel filter before the fuel transfer pump and install the secondary filter before the unit injection pumps. Never plug fuel return lines. Accurate fuel consumption measurements require proper accounting of return fuel.

8.6.8 *Humidity*—Place the measurement equipment between the inlet air filter and compressor in such a manner as not to affect temperature and pressure measurements. Do not condition the intake air downstream of the humidity sensor. Report humidity on the appropriate form.

8.6.9 *System Time Responses*—The maximum allowable system time responses are shown in Table 1. Determine system time responses in accordance with the Data Acquisition and Control Automation II (DACA II) task force report.[6]

## 9. Procedure

9.1 *Pretest Procedure:*

9.1.1 *Initial Oil Fill for Pretest Break-In:*

9.1.1.1 The initial oil fill is 32.7 kg [72.0 lb] of test oil: 16.4 kg [36.0 lb] for the pan, 3.3 kg [7.2 lb] for the filters, 1.6 kg [3.6 lb] for the engine oil cooler, and 11.4 kg [25.2 lb] for the auxiliary oil reservoir and lines. Add the first 3.3 kg [7.2 lb] of fresh test oil to the oil filters (half in each filter), then turn on the auxiliary oil pumps and add an additional 29.4 kg [64.8 78lb] of test oil to the engine. This oil may be added directly through the engine oil fill tube.

9.1.2 *Pretest Break-In:*

9.1.2.1 Run the break-in sequence described in Annex A6.

9.1.2.2 Drain the oil within 1 h after the break-in is completed. Replace all oil filters. Refill the engine with test oil and conduct the test in accordance with 9.4. When performing the pre-test oil charge, do not account for any hang up oil left in the oil system.

9.2 *Engine Start-Up:*

**TABLE 1 Maximum Allowable System Time Responses**

| Measurement Type | Time Response(s) |
|---|---|
| Speed | 2.0 |
| Temperature | 3.0 |
| Pressure | 3.0 |
| Flow | 45.0 |

9.2.1 Perform all engine start-ups in accordance with Annex A6. Start-ups are not included as test time. Test time starts as soon as the engine returns to the test cycle. The start date and time of a test is defined as when the engine first reaches test conditions as shown in Table 2. (**Warning**—Crank the engine prior to start-up to fill the engine oil passages. This practice will enhance engine durability significantly.)

9.3 *Engine Shutdown:*

9.3.1 Perform all non-emergency shutdowns in accordance with Annex A6. The shutdown operation does not count as test time. Record the length and reason of each shutdown on the appropriate form.

9.3.2 All operationally valid tests should not exceed 10 shutdowns. Additionally, all operationally valid tests should not exceed 150 h of downtime. Conduct an engineering review if either condition is exceeded.

9.4 *Test Cycle:*

9.4.1 The test cycle includes a 1 h break-in followed by a 300 h test. Operating conditions are shown in Table 2. Conduct the break-in by operating at Phase II conditions for 30 min, followed by Phase I conditions for 30 min. Conduct the test by operating for 75 h at Phase I conditions, followed by 225 h at Phase II conditions. Conduct the transition from Phase I to Phase II in accordance with Annex A6.

9.4.1.1 Based upon oil analysis, injection timing may be changed within the first 75 h of the test (Phase I) to ensure meeting the 75 h soot window of 5.0 % ± 0.3 % (see 11.7).

9.4.2 *Operational Validity:*

9.4.2.1 Determine operational validity in accordance with Annex A3.

9.5 *Oil Samples:*

9.5.1 Take 120 mL [4-oz] oil samples at every 25 h interval except the 75 h sample. At 75 h, take a 240 mL [8-oz] sample. Take the EOT oil sample within 30 min of test completion. Obtain oil samples through a drain petcock located in the oilrig return line (oil pan return pump); see Fig. A1.1. Always take oil samples before new oil is added.

9.6 *Oil Addition/Drain:*

9.6.1 Initially establish the full mark as the oil weight after 1 h of running at Phase II test conditions, but do not add any new oil until test hour 100 (25 h into Phase II). At 100 h test and each 50 h period thereafter, perform a forced drain. Drain a sufficient amount of oil to obtain an oil mass, which is 2.27 kg [5.0 lb] below the full mark, and add 2.27 kg [5.0 lb] of new oil to the engine. After a shutdown, use the drain level of the previous period to determine the forced drain quantity. For any period, if the oil mass is already more than 2.27 kg [5.0 lb] below the full mark, do not perform a forced drain.

9.6.2 If the auxiliary oil sump goes dry after 250 h, continue running the test to 300 h. Do not take a 275 h oil sample. Take the EOT oil sample from the engine sump within 30 min of test completion.

9.6.3 If the auxiliary oil sump goes dry at or before 250 h, declare the test non-interpretable.

9.7 *Oil MassMeasurements:*

9.7.1 Record the oil mass every 6 min and compute the oil consumption (see 10.5) from these readings.

**TABLE 2 Test Conditions**

| Parameters | Limits | |
|---|---|---|
| | Phase I | Phase II |
| Time, h | 75 | 225[A] |
| Injection timing, °BTDC | Variable | 18 |
| | Controlled Parameters[B] | |
| Speed, r/min | 1800 | 1200 |
| Fuel flow, kg/h [lb/h] | 59.2 [130.5] | 63.5 [140.0] |
| Intake $CO_2$ level, % | 1.5 ± 0.05 | 0.2 ± 0.05 |
| Inlet manifold temperature, °C [°F] | 70 [158] | 66 [150] |
| Coolant out temperature, °C [°F] | 66 [150] | 85 [185] |
| Fuel in temperature, °C [°F] | 40 [104] | 40 [104] |
| Oil gallery temperature, °C [°F] | 88 [190] | 113 [235] |
| Intake air temperature, °C [°F] | 25 [77] | 25 [77] |
| | Ranged Parameters[C] | |
| Inlet air restriction, kPa [in. $H_2O$] | 3.5-4.0 [14-16] | 3.5-4.0 [14-16] |
| Inlet manifold pressure, kPa [in. Hg], min | 160 [47.4] | 210 [62.2] |
| Exhaust back pressure, kPa [in. $H_2O$] | 2.7-3.5 [11-14] | 2.7-3.5 [11-14] |
| Crankcase pressure, kPa [in. $H_2O$] | 0.25-0.75 [1-3] | 0.25-0.75 [1-3] |
| | Uncontrolled Parameters | |
| Power, kW [bhp] | ~257 [~345] | ~324 [~434] |
| Torque, N·m [lbf·ft]C | record[D] | record[D] |
| Exhaust $O_2$ level, % | record | record |
| Exhaust temperature, °C [°F] | | |
| Pre-turbine | record | record |
| Tailpipe | record | record |
| Oil sump temperature, °C [°F] | record | record |
| Coolant in temperature, °C [°F] | record | record |
| EGR cooler inlet temperature front, °C [°F] | record | record |
| EGR cooler outlet temperature rear, °C [°F] | record | record |
| EGR pre-venturi temperature, °C [°F] | record | record |
| Inlet air dew point, °C [°F] | record | record |
| Inlet air humidity, g/kg [gr/lb] | record | record |
| Blowby, L/min [$ft^3$/min] | record | record |
| Pre-turbine exhaust pressure, kPa [in. Hg] | record | record |
| Main gallery oil pressure, kPa [psi] | record | record |
| Oil filter DP, kPa [psi] | Not to exceed 138 [20][E] | Not to exceed 138 [20][E] |

[A] Check valve lash after break-in.
[B] All control parameters shall be targeted at the mean indicated.
[C] All ranged parameters shall fall within the specified ranges.
[D] At 98.2 kPa [29 in. Hg] and 29.5 °C [85°F] dry air.
[E] If oil filter $\Delta P$ exceeds 138 kPa [20 psi], change the two full flow filters. If the filters are changed, attempt to recover as much oil as possible by draining the filters. No new oil is to be added. The test report shall indicate if the filters are changed.

9.8 *Fuel Samples:*

9.8.1 Take two 1 L [1-qt] fuel samples prior to the start of test and at EOT.

9.9 *Periodic Measurements:*

9.9.1 Make measurements at 6 min intervals on the parameters listed in 9.9.2 and record statistics on the appropriate form. Automatic data acquisition is required. Recorded values shall have minimum resolution as shown in Table 3. Characterize the procedure used to calculate the data averages on the appropriate form.

9.9.2 *Parameters:*

9.9.2.1 Speed, r/min,

9.9.2.2 Torque, N·m [lbf·ft],

9.9.2.3 Oil gallery temperature, °C [°F],

9.9.2.4 Oil sump temperature, °C [°F],

9.9.2.5 Coolant out temperature, °C [°F],

9.9.2.6 Coolant in temperature, °C [°F],

9.9.2.7 Intake air temperature, °C [°F],

9.9.2.8 Intake manifold temperature, °C [°F],

9.9.2.9 Intake manifold pressure, kPa [in. Hg],

9.9.2.10 Fuel flow, s/kg or kg/h [s/lb or lb/h],

9.9.2.11 Fuel inlet temperature, °C [°F],

9.9.2.12 Tailpipe exhaust back pressure, kPa [in. $H_2O$],

9.9.2.13 Before filter oil pressure, kPa [psi],

9.9.2.14 Main gallery oil pressure, kPa [psi],

9.9.2.15 Crankcase pressure, kPa [in. $H_2O$],

9.9.2.16 Pre-turbine exhaust temperature, front manifold, °C [°F],

9.9.2.17 Pre-turbine exhaust temperature, rear manifold, °C [°F],

9.9.2.18 Inlet air restriction, kPa [in. $H_2O$],

9.9.2.19 Tailpipe exhaust temperature, °C [°F],

9.9.2.20 Crankcase blowby, L/min [$ft^3$/min] (see 9.10),

9.9.2.21 Pre-turbine exhaust pressure, front manifold, kPa [in. Hg],

9.9.2.22 Pre-turbine exhaust pressure, rear manifold, kPa [in. Hg],

9.9.2.23 Inlet air humidity, g/kg [grains/lb],

9.9.2.24 Tailpipe oxygen level, %,

9.9.2.25 EGR cooler outlet temperature, °C [°F],

9.9.2.26 EGR pre-venturi temperature, °C [°F],

9.9.2.27 Inlet air dew point, °C [°F], and

9.9.2.28 Oil weight, kg [lbf].

9.10 *Blowby:*

**TABLE 3 Minimum Resolution of Recorded Measurements**

| Parameter | Record Data to Nearest | Parameter | Record Data to Nearest |
|---|---|---|---|
| Speed | 1 r/min | Blowby | 1 L/min |
| Fuel flow | 0.1 kg/h | Inlet air dew point | 1 °C |
| Coolant temperatures | 0.1 °C | Oil temperatures | 0.1 °C |
| Fuel in temperature | 0.1 °C | Exhaust temperatures | 1 °C |
| Intake air temperature | 0.1 °C | EGR temperatures | 1 °C |
| Intake manifold temperature | 0.1 °C | Oil pressures | 1 kPa |
| Exhaust back pressure | 0.1 kPa | Crankcase pressure | 0.1 kPa |
| Inlet air restriction | 0.1 kPa | Intake manifold pressure | 1 kPa |
| Torque | 1 N·m | Oxygen | 0.1 % |
| Power | 1 kW | Oil mass | 0.001 kg |
| Humidity | 0.1 g/kg | | |

9.10.1 Record the crankcase blowby on the appropriate form. Exercise care to prevent oil traps from occurring in the blowby line at any time during operation.

9.11 *Centrifugal Oil Filter Mass Gain:*

9.11.1 Prior to the start of test, determine the mass of the centrifugal oil filter canister. At EOT, remove the centrifugal oil filter canister from the engine and drain upside down for 30 min. After draining, determine the mass of the canister and record on the appropriate form. Determine the centrifugal oil filter mass gain for each test.

9.12 *Oil Filter $\Delta P$ Calculation:*

9.12.1 The reported oil filter $\Delta P$ is the maximum oil filter $\Delta P$ that occurs as a result of the test. Calculate the oil filter $\Delta P$ as follows:

$$\Delta P = \Delta P max - \Delta P\ initial \quad (1)$$

where:

$\Delta P$ *max* = the maximum $\Delta P$ across the oil filter, and
$\Delta P$ *initial* = the $\Delta P$ across the oil filter at the start of test conditions.

If an oil filter change is made, add the oil filter $\Delta P$ value obtained after the filter change to the oil filter $\Delta P$ obtained prior to the filter change. If a shutdown occurs, add the oil filter $\Delta P$ value obtained after the shutdown to the oil filter $\Delta P$ obtained prior to the shutdown. Change the oil filter if the $\Delta P$ exceeds 138 kPa [20 psi]. Report oil filter $\Delta P$ on the appropriate form.

## 10. Inspection of Engine, Fuel, and Oil

10.1 *Pre-Test Measurements:*

10.1.1 *Pistons:*

10.1.1.1 No piston measurements are required.

10.1.2 *Cylinder Sleeves Inside Diameter Surface Finish*—Measure in accordance with 10.1.2 of Test Method D6483. Report results on the appropriate form.

10.1.3 *Piston Rings*—Clean and measure according to the Mack Test Ring Cleaning and Measuring Procedure, available from the TMC.[6] Report results on the appropriate form.

10.1.4 *Connecting Rod Bearings*—Clean and measure in accordance with 10.1.4 of Test Method D6483. Report results on the appropriate form.

10.2 *Post Test Engine Measurements:*

10.2.1 *Pistons*—Before removing pistons, carefully remove carbon from top of cylinder sleeve. Do not remove any metal.

10.2.1.1 Rate all six pistons for deposits in accordance with Test Method D6681. Use the 1P piston rating method. Report the results on the appropriate forms.

10.2.2 *Cylinder Sleeves*—Measure in accordance with Instructions for Measuring Cylinder Sleeves, available from the TMC.[6] Report the results on the appropriate form.

10.2.3 *Piston Rings*—Clean and measure in accordance with the Mack Test Ring Cleaning and Measuring Procedure, available from the TMC.[6] Report results on the appropriate form.

10.2.4 *Connecting Rod Bearings*—Clean and measure in accordance with 10.2.4 of Test Method D6483. Report the results on the appropriate form.

10.3 *Oil Inspection:*

10.3.1 Analyze oil samples for viscosity at 100 °C [212°F] in accordance with either Test Method D445 or Test Method D5967, Annex A3. Base viscosity increase on the minimum viscosity. In addition to the viscosity measurements, conduct soot analysis in accordance with Test Method D5967, Annex A4. Conduct the 75 h soot measurement twice and report the average (round the result in accordance with Practice E29). To maintain accuracy and precision, conduct all soot measurements at a TMC-calibrated laboratory. Determine wear metals content (iron, lead, copper, chromium, aluminum), additive metals content, silicon, and sodium levels in accordance with Test Method D5185 every 25 h from 0 h to EOT. Conduct EOT lead content measurements at least twice and report the average value. Conduct oil analysis as soon as possible after sampling. Determine base number every 25 h, including EOT, in accordance with Test Method D4739. Determine acid number every 25 h, including EOT, in accordance with Test Method D664. Determine oxidation using integrated IR every 25 h, including EOT. Report all results on the appropriate form.

10.4 *Fuel Inspections:*

10.4.1 Use fuel purchase inspection records to ensure conformance to the specifications (see 7.2.1) and to complete the appropriate form for the last batch of fuel used during the test. In addition, perform the following inspections on new (0 h) and EOT (300 h) fuel samples:

10.4.1.1 API gravity at 15.6 °C [60°F], Test Method D287 or D4052.

10.4.1.2 Total Sulfur, % mass, Test Method D129 or D2622.

10.4.1.3 Use one 1 L [1-qt] sample for inspections.

10.5 *Oil Consumption Calculation:*

10.5.1 Using the 6 min oil weight measurements (see 9.7), determine the oil consumption in grams per hour by performing linear regression on the data for each of the nine 25 h periods from 75 to 300 h. The oil consumption for a 25 h period is the slope of the regression line for that same period. The reported oil consumption is the average of the nine results.

10.5.1.1 Following any shutdowns, oil samples, oil additions, or phase transitions, exclude 1 h of oil mass data from the regression to account for the stabilizing of the oil scale.

10.5.1.2 If any shutdowns occur during a 25 h period, the result for that 25 h period shall be the weighted average of all the regression slope that apply to that period. The weighting of a regression slopes is the length of run time associated with it. An example with two shutdowns, one at 84 h and one at 93.5 h are shown in Table 4.

10.5.1.3 Report the average oil consumption for the test on the appropriate form.

## 11. Laboratory and Engine Test Stand Calibration/Non-Reference Oil Test Requirements

11.1 *Calibration Frequency:*

11.1.1 To maintain test consistency and severity levels, calibrate the engine and test stand at regular intervals.

11.2 *Calibration Reference Oils:*

**TABLE 4 25 h Period Oil Consumption Sample Calculation**

| Oil Scale Data | Time Start (hh:mm) | Time Stop (hh:mm) | Run Time | Regression Slope (g/h) |
|---|---|---|---|---|
| Stabilizing | 75:00 | 76:00 | 1:00 | n/a |
| Collecting | 76:00 | 84:00 | 8:00 | 40.0 |
| Stabilizing | 84:00 | 85:00 | 1:00 | n/a |
| Collecting | 85:00 | 93:30 | 8:30 | 45.0 |
| Stabilizing | 93:30 | 94:30 | 1:00 | n/a |
| Collecting | 94:30 | 100:00 | 5:30 | 48.5 |

Oil consumption 75 h –100 h = [(8 x 40.0) + (8.5 x 45.0) + (5.5 x 48.5)] / 22 =
44.1 g/h

11.2.1 The reference oils used to calibrate T-10 test stands have been formulated or selected to represent specific chemical types or performance levels, or both. They can be obtained from the TMC. The TMC will assign reference oils for calibration tests. These oils are supplied under code numbers (blind reference oils).

11.2.2 *Reference Oils Analysis:*

11.2.2.1 Do not submit reference oils to physical or chemical analyses for identification purposes. Identifying the oils by analyses could undermine the confidentiality required to operate an effective blind reference oil system. Therefore, reference oils are supplied with the explicit understanding that they will not be subjected to analyses other than those specified within this procedure unless specifically authorized by the TMC. In such cases where analyses are authorized, supply written confirmation of the circumstances involved, the data obtained, and the name of the person authorizing the analysis to the TMC.

11.3 *Test Numbering:*

11.3.1 Number each T-10 test to identify the test stand number, the test stand run number, engine serial number, and engine hours at the start of the test. The sequential stand run number remains unchanged for reruns of aborted, invalid, or unacceptable calibration tests. However, follow the sequential stand run number by the letter A for the first rerun, B for the second, and so forth. For calibration tests, engine hours shall be zero. For non-reference oil tests, engine hours are the test hours accumulated since last calibration. For example, 58-12A-2H0380-0 defines a test on stand 58 and stand run 12 as a calibration test that was run twice on engine 2H0380 (serial number). A test number of 58-14-2H0380-300 defines a test on stand 58 and stand run 14 as a non-reference oil test on engine 2H0380, which has run 300 hours since the last reference.

11.4 *New Laboratories and New Test Stands:*

11.4.1 A new laboratory is any laboratory that has never previously calibrated a test stand under this test method, or has not calibrated a test stand within one year from the end of the last successful calibration test. All stands at a new laboratory are considered new stands.

11.4.2 A new stand is a test cell and support hardware, which has never previously been calibrated under this test method, or has not been calibrated within a year from the end of the last successful calibration test on that stand.

11.4.2.1 A new complete engine with EGR kit requires a successful calibration test.

11.4.3 Calibrate a new test stand in accordance with the Lubricant Test Monitoring System (LTMS).[6]

11.5 *Test Stand Calibration:*

11.5.1 *Test Stand Calibration*—Perform a calibration test on a reference oil assigned by the TMC after six months have elapsed since the completion of the last successful calibration test. A non-reference test may be started provided at least 1 h remains in the calibration period. An unsuccessful calibration test voids any current calibration on the test stand.

11.5.2 *Test Stand/Engine Combination*—For reference and non-reference tests, any engine may be used in any stand. However, the engines shall be used in the test stands on a first available engine basis (FIFO). In other words, there shall be no attempt on the part of the test laboratory to match a particular test stand and engine combination for any given test.

11.5.2.1 A new complete engine setup with EGR kit requires a calibration test.

11.5.3 If non-standard tests are conducted on a calibrated test stand, the TMC may require the test stand to be recalibrated prior to running standard tests.

11.6 *Test Results*—The reference oil test specified test results are average top ring weight loss [milligrams], average cylinder liner wear [micrometers], Δlead [milligrams per kilogram] at EOT, Δlead [milligrams per kilogram] 250 h to 300 h, and average oil consumption (grams per hour). The non-reference oil test specified test result is the Mack Merit Rating.

11.6.1 *Average Top Ring Weight Loss*—Screen the data for outliers in accordance with Annex A9. Calculate the average top ring weight loss, excluding any outliers, and report the data on the appropriate forms.

11.6.2 *Average Cylinder Liner Wear*—Screen the data for outliers in accordance with Annex A9. Calculate the average cylinder liner wear step, excluding any outliers, and report the data on the appropriate forms.

11.6.3 *ΔLead at EOT*—Δ Lead at EOT results are adjusted to account for any upper rod bearing weight loss outliers.

11.6.3.1 Calculate the measured average upper rod bearing weight loss and report the value on the appropriate form.

11.6.3.2 Use Practice E178, two-sided test at a 95 % significance level, to determine if any rod bearing weight loss values are outliers. Report the outlier screened average upper rod bearing weight loss on the appropriate form. If no outliers were identified, this value will be identical to the measured value calculated in 11.6.3.1.

11.6.3.3 For connecting rod bearing batch codes A through G, calculate Δlead according to the following:

$$\Delta lead = \left(lead_{300} - lead_{NEW}\right) \times \left(OABWLU/ABWLU\right) \quad (2)$$

where:

$lead_{300}$ = lead content of the 300 h oil sample, mg/kg,
$lead_{NEW}$ = lead content of the new oil sample, mg/kg,
$ABWLU$ = as measured upper rod bearing weight loss, mg, and
$OABWLU$ = outlier screened upper rod bearing weight loss, mg.

Report the calculated Δlead at EOT value on the appropriate forms.

11.6.3.4 For connecting rod bearing batch code J, calculate Δlead according to the following:

$$if\ OABWLU \leq 245\ mg \tag{3}$$

$$\Delta lead = e^{(0.603 + 0.024\ OABWLU - 0.000043\ (OABWLU)^2)}$$

$$if\ OABWLU > 245\ mg \tag{4}$$

$$\Delta lead = 58$$

where:

$OABWLU$ = outlier screened upper rod bearing weight loss, mg.

11.6.3.5 Report the calculated Δlead at EOT value on the appropriate forms.

11.6.4 *ΔLead 250 h to 300 h:*

11.6.4.1 For connecting rod bearing batch codes A through G, calculate the ΔLead 250 h to 300 h by subtracting the lead value at 250 h from the lead value at 300 h.

11.6.4.2 For connecting rod bearing batch code J, calculate the ΔLead 250 h to 300 h according to the following:

$$\Delta Lead\ 250\ h\ \ to\ 300\ h = -5.9 + 0.044(ir_{300} - ir_{250}) + 0.070\ OABWLU \tag{5}$$

where:

$ir_{300}$ = oxidation value of the 300 h oil sample
$ir_{250}$ = oxidation value of the 250 h oil sample
$OABWLU$ = outlier screened upper rod bearing weight loss, mg.

11.6.4.3 Report the results on the appropriate forms.

11.6.5 *Oil Consumption:*

11.6.5.1 Report the oil consumption, as calculated in 10.5, on the appropriate form.

11.6.6 *Mack Merit Rating:*

11.6.6.1 Report the Mack Merit Rating as calculated in Annex A10.

11.7 *Reference and Non-Reference Oil Test Requirements:*

11.7.1 All operationally valid tests shall produce a TGA soot level of 5.0 % ± 0.3 % at 75 h. Any test that misses the 75 h soot window is considered operationally invalid. A laboratory should terminate a test that has missed the 75 h soot window.

11.7.1.1 Injection timing can be adjusted anytime within the first 75 h to meet the 75 h soot window. However, during the first 75 h, do not adjust injection timing more than ±5° from the initial injection timing.

11.7.2 Calibration acceptance is determined in accordance with the LTMS as administered by the TMC.

11.8 *Non-Reference Oil Test Result Severity Adjustments:*

11.8.1 This test method incorporates the use of a severity adjustment (SA) for non-reference oil test results. A control chart technique, described in the LTMS, has been selected for identifying when a bias becomes significant for average top ring weight loss, average cylinder liner wear, Δlead at EOT, Δlead 250 h to 300 h, and oil consumption. When calibration test results identify a significant bias, determine an SA according to LTMS. Report the SA value on the appropriate form, Test Results Summary, in the space for SA. Add this SA value to non-reference oil test results, and enter the adjusted result in the appropriate space. The SA remains in effect until a new SA is determined from subsequent calibration test results, or the test results indicate the bias is no longer significant. Calculate and apply SA on a laboratory basis.

11.9 *Donated Reference Oil Test Programs*—The surveillance panel is charged with maintaining effective reference oil test severity and precision monitoring. During times of new parts introductions, new or re-blended reference oil additions, and procedural revisions, it may be necessary to evaluate the possible effects on severity and precision levels. The surveillance panel may choose to conduct a program of donated reference oil tests in those laboratories participating in the monitoring system, in order to quantify the effect of a particular change on severity and precision. Typically, the surveillance panel requests its panel members to volunteer enough reference oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The surveillance panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

11.10 *Adjustments to Reference Oil Calibration Periods:*

11.10.1 *Procedural Deviations*—On occasions when a laboratory becomes aware of a significant deviation from the test method, such as might arise during an in-house review or a TMC inspection, the laboratory and the TMC shall agree on an appropriate course of action to remedy the deviation. This action may include the shortening of existing reference oil calibration periods.

11.10.2 *Parts and Fuel Shortages*—Under special circumstances, such as industry-wide parts or fuel shortages, the surveillance panel may direct the TMC to extend the time intervals between reference oil tests. These extensions shall not exceed one regular calibration period.

11.10.3 *Reference Oil Test Data Flow*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. There may be occasions when laboratories conduct a large portion of calibration tests in a short period of time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss (or gain) in calibration status.

11.10.4 *Special Use of the Reference Oil Calibration System*— The surveillance panel has the option to use the reference oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The surveillance panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration is left in an excessively long pending status. In order to maintain the integrity of the reference oil monitoring system, each reference oil test is conducted so as to be interpretable for stand calibration. To facilitate the required test scheduling, the surveillance panel may direct the TMC to lengthen and shorten reference oil calibration periods within laboratories such that the laboratories incur no net loss (or gain) in calibration status.

## 12. Report

12.1 *Reporting Reference Oil Test Results*—For reference oil tests, the standardized report form set and data dictionary for reporting test results and for summarizing operational data are required. Report forms and the Data Dictionary are available from the TMC. Fill out the report forms according to the formats shown in the Data Dictionary. When transmitting data electronically, a Header Data Dictionary shall precede the Data Dictionary. The latest version of this Header Data Dictionary can be obtained from the TMC either by ftp (internet) or by calling the test engineer responsible for this particular test. Round the data in accordance with Practice E29.

12.1.1 During the test, if the engine is shut down or operated out of test limits, record the test hours, time, and date on the appropriate form. In addition, note all prior reference oil tests that were deemed operationally or statistically invalid in the comment section.

12.1.2 When reporting reference oil test results, transmit the test data electronically by utilizing the ASTM Data Communications Committee Test Report Transmission Model (see Section 2, Flat File Transmission Format), which is available from the TMC. Transmit the data within five working days of test completion. Mail a copy of the final test report within 30 days of test completion to the TMC.

12.2 *Deviations from Test Operational Limits*—Report all deviations from specified test operational limits on the appropriate form under Other Comments.

## 13. Precision and Bias

13.1 *Precision:*

**TABLE 5 Test Precision**

| Test Result | Measured Units | |
|---|---|---|
| | Intermediate Precision, (i.p.) | Reproducibility, (R) |
| Adjusted liner wear, mm | 11.84 | 11.84 |
| Top ring weight loss, mg | 65.5 | 65.5 |
| Δlead at EOT, ln mg/kg[A] | 1.68 | 1.70 |
| Oil consumption, g/h | 19.4 | 24.8 |
| Δlead 250–300 h, mg/kg | 10.6 | 12.0 |

[A] This parameter is transformed using a natural log. When comparing two test results on this parameter, first apply this transformation to each test result. Compare the absolute difference between the transformed results with the appropriate (intermediate or reproducibility) precision limit.

13.1.1 Test precision is established on the basis of operationally valid reference oil test results monitored by the TMC. A research report[10] contains industry data developed prior to establishment of this test method.

13.1.1.1 *Intermediate Precision Conditions*—Conditions where test results are obtained with the same test method using the same oil, with changing conditions such as operators, measuring equipment, test stands, test engines, and time.

NOTE 3—*Intermediate precision* is the appropriate term for this test method, rather than *repeatability*, which defines more rigorous within-laboratory conditions.

13.1.1.2 *Intermediate Precision Limit* (i.p.)—The difference between two results obtained under intermediate precision conditions that would in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 5 in only one case in twenty. When only a single test result is available, the Intermediate Precision Limit can be used to calculate a range (test result ± Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time in twenty.

13.1.1.3 *Reproducibility Conditions*—Conditions where test results are obtained with the same test method using the same test oil in different laboratories with different operators using different equipment.

13.1.1.4 *Reproducibility Limit* (R)—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 5 in only one case in twenty. When only a single test result is available, the Reproducibility Limit can be used to calculate a range (test result ± Reproducibility Limit) outside of which a second test result would be expected to fall about one time in twenty.

13.1.2 The test precision, as of Dec. 1, 2004, is shown in Table 5.

13.1.3 The TMC updates precision data as it becomes available.

13.2 *Bias*—Bias is determined by applying an accepted statistical technique to reference oil test results and when a significant bias is determined, a severity adjustment is permitted for non-reference oil test results (see 11.8).

## 14. Keywords

14.1 cylinder liner wear; diesel engine oil; exhaust gas recirculation; lead; lubricants; oil consumption; oxidation; soot; top ring weight loss; T-10 Diesel Engine

[10] The T-10 research report is available from the ASTM Test Monitoring Center (TMC), ftp://ftp.astmtmc.cmu.edu/docs/diesel/mack/misc/T-10_Research_Report/.

# ANNEXES

## (Mandatory Information)

## A1. SYSTEM SCHEMATICS AND SENSOR LOCATIONS

A1.1 Properly locating the sensor devices is important to this test. Figs. A1.1-A1.17 indicate the sensor locations for the T-10 engine components.

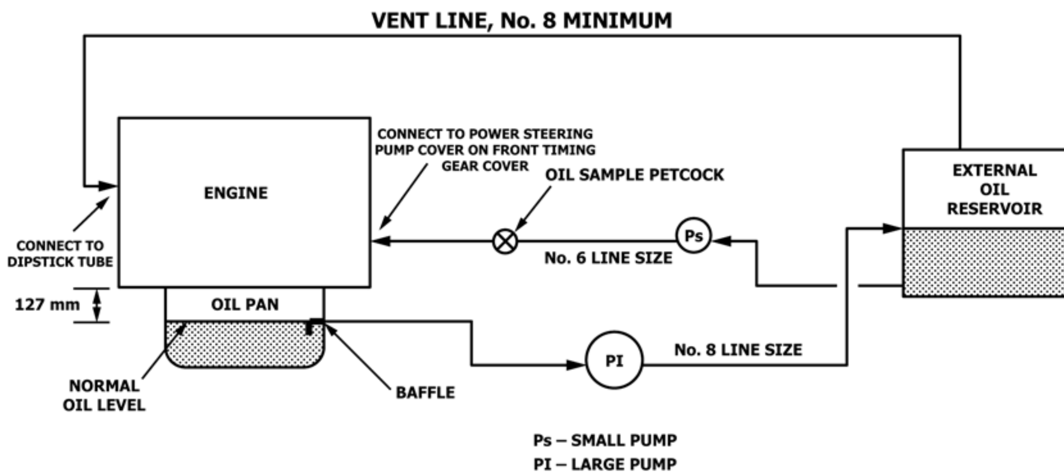


FIG. A1.1 Auxiliary Oil System

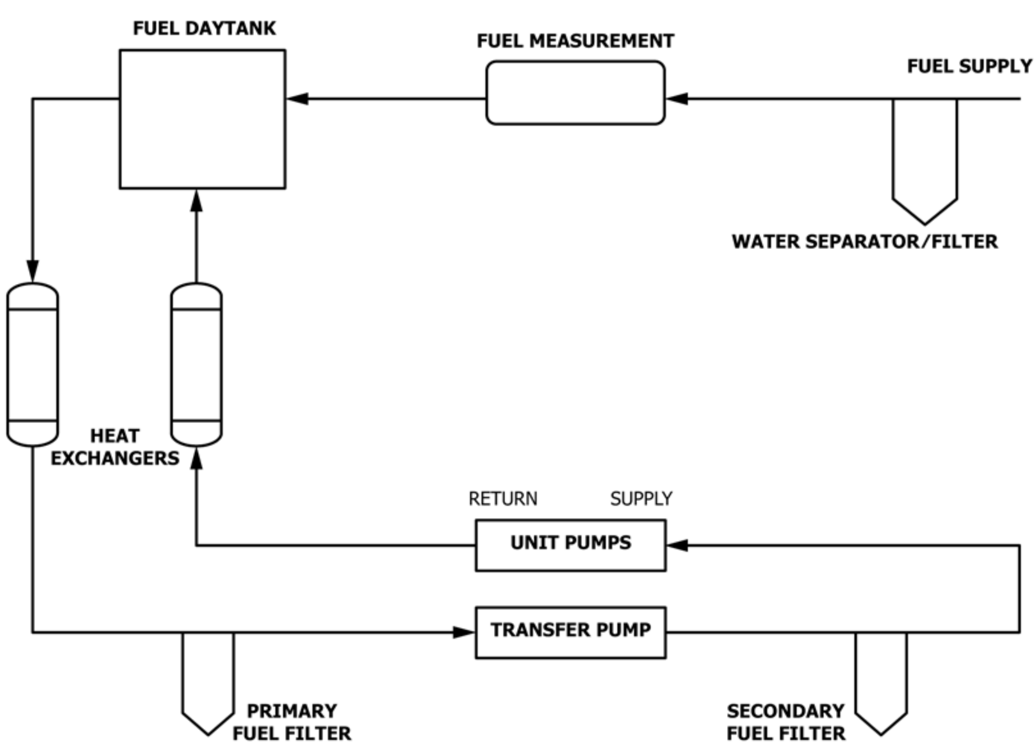


FIG. A1.2 Test Cell Fuel Schematic

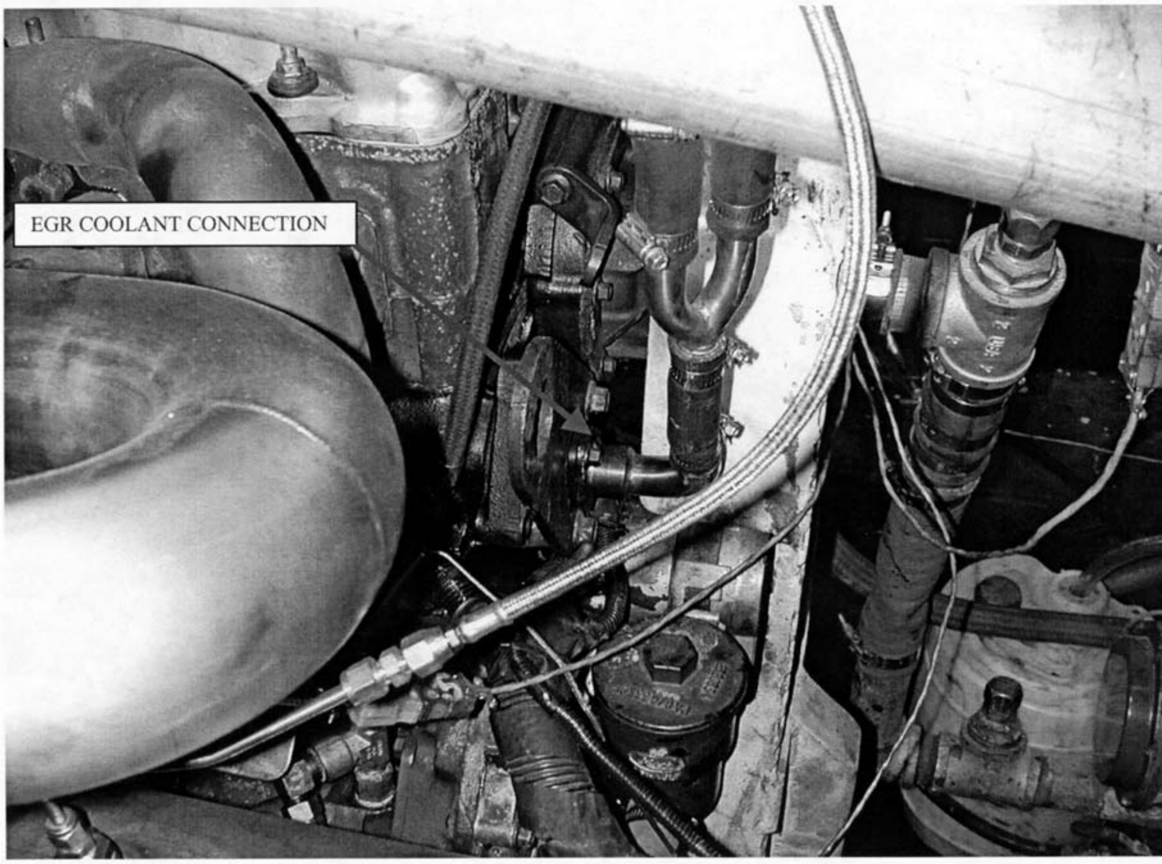


FIG. A1.3 Coolant Supply to EGR Cooler

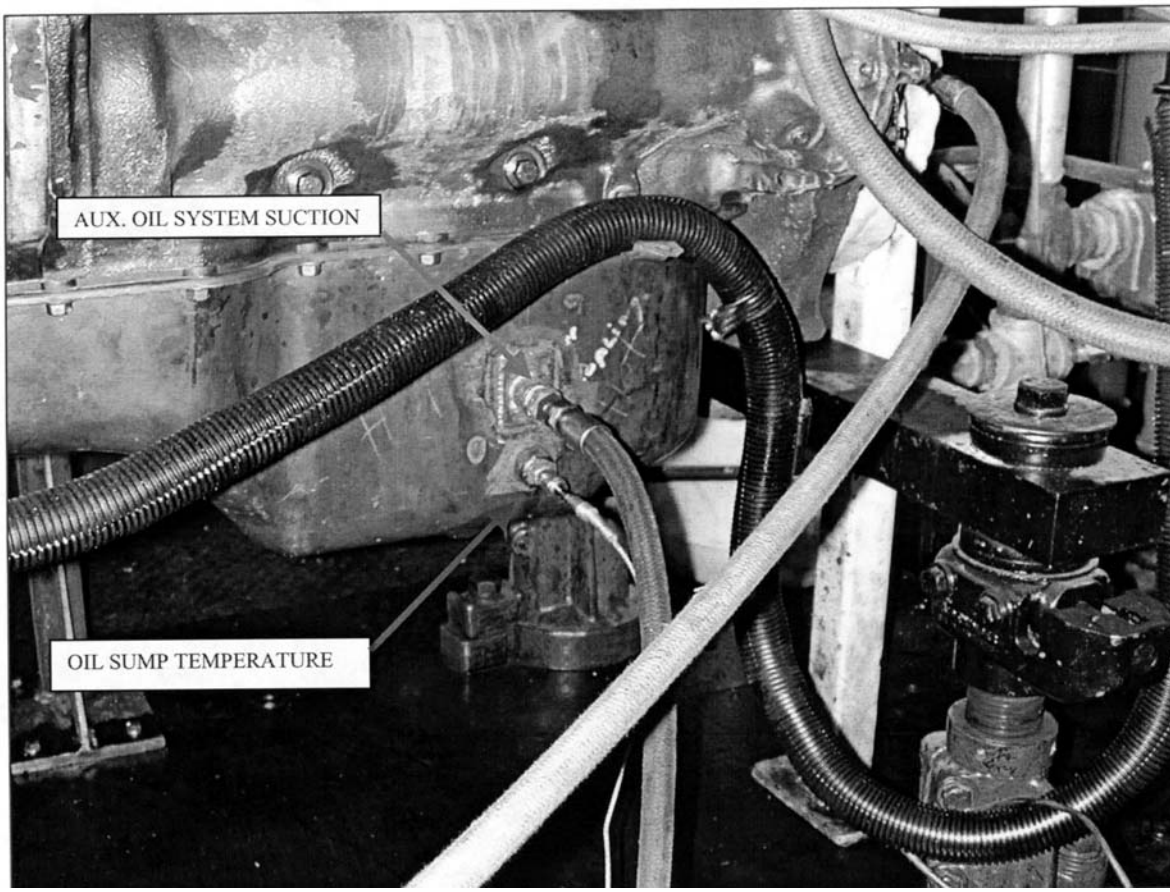


FIG. A1.4 Auxiliary Oil System Suction Line and Oil Sump Temperature Thermocouple

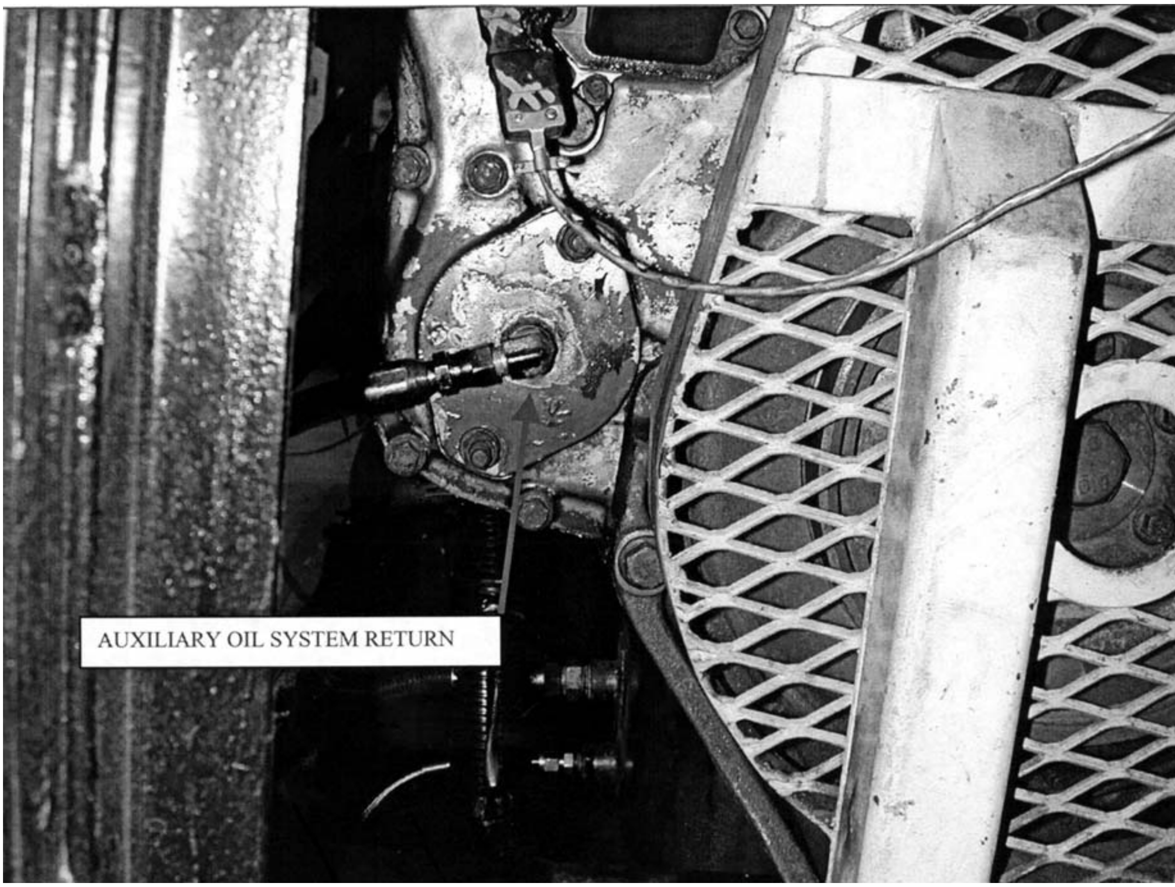


FIG. A1.5 Auxiliary Oil System Return

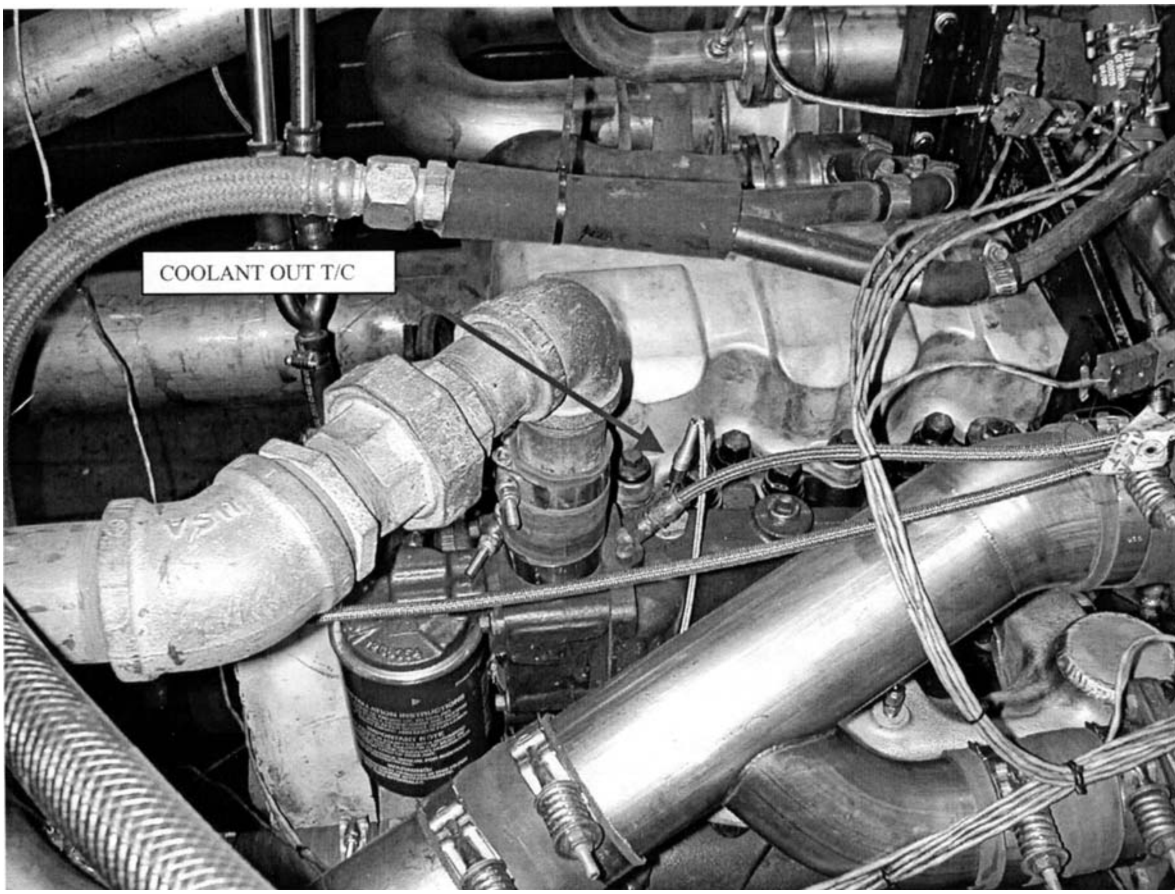


FIG. A1.6 Coolant Out Temperature

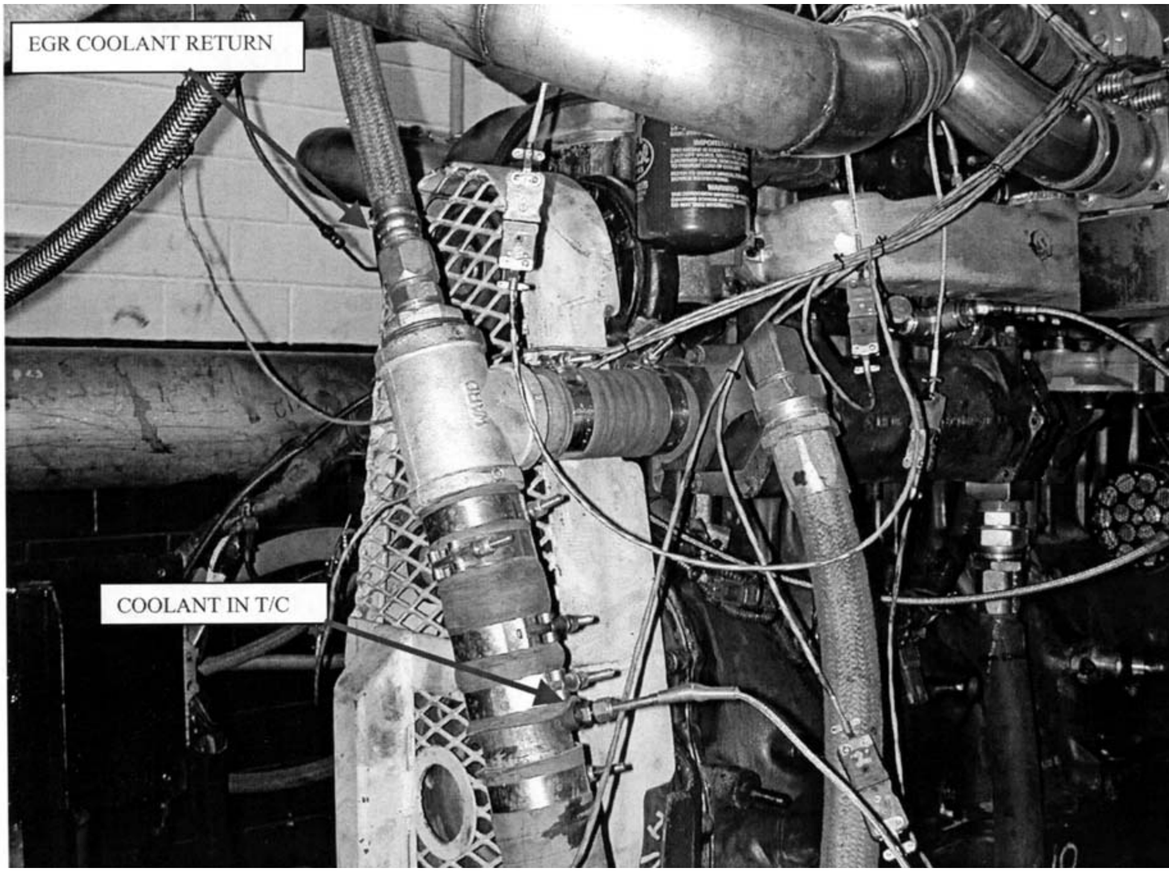


FIG. A1.7 Engine Coolant In Temperature and EGR Coolant Return

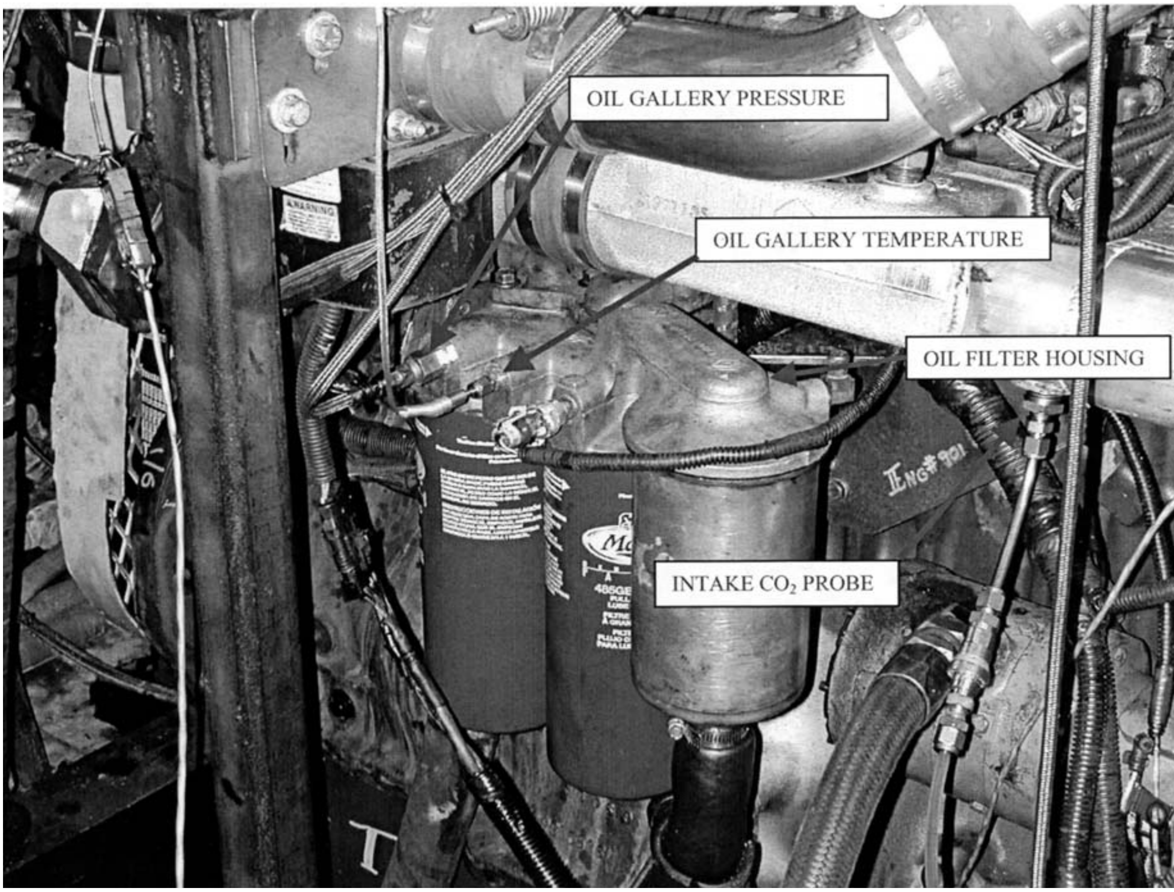


**FIG. A1.8 Oil Gallery Temperature and Pressure (After-Filter Pressure) and Intake $CO_2$ Probe**

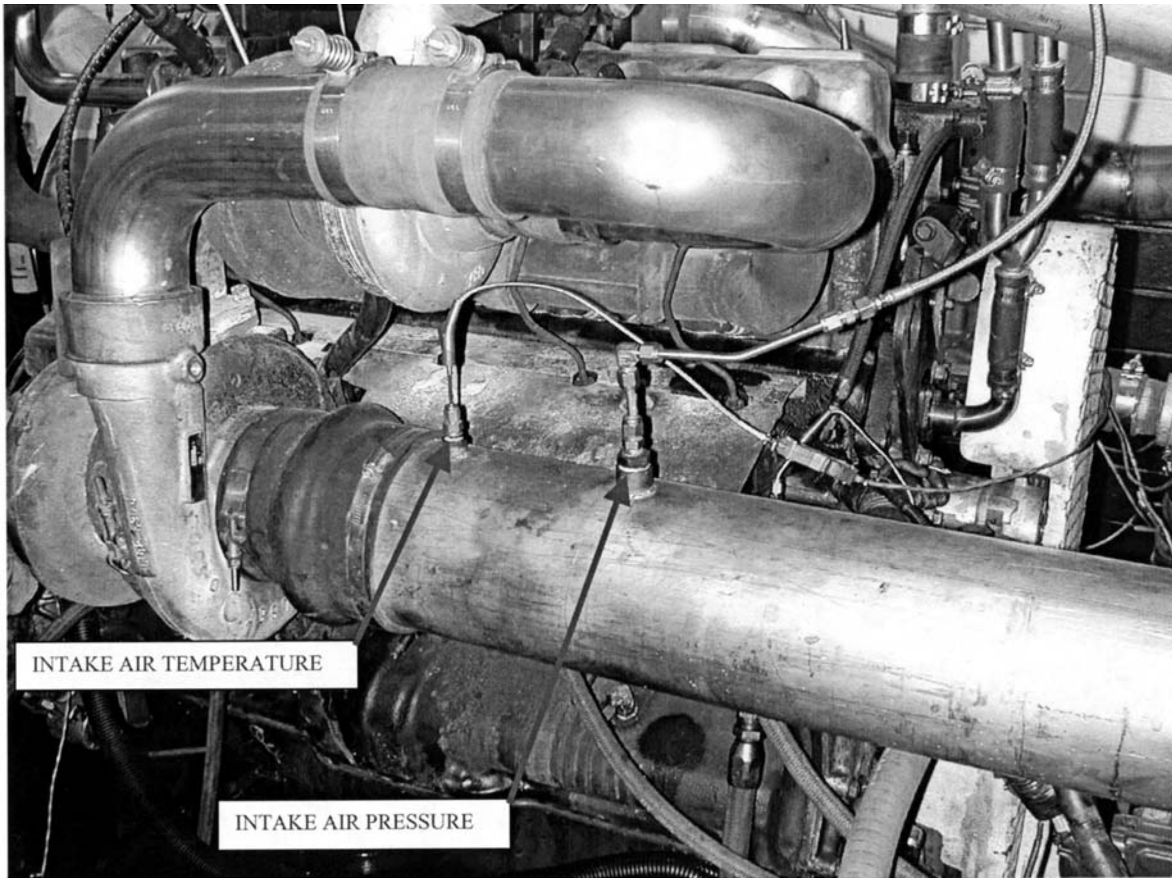


FIG. A1.9 Intake Air Temperature and Pressure

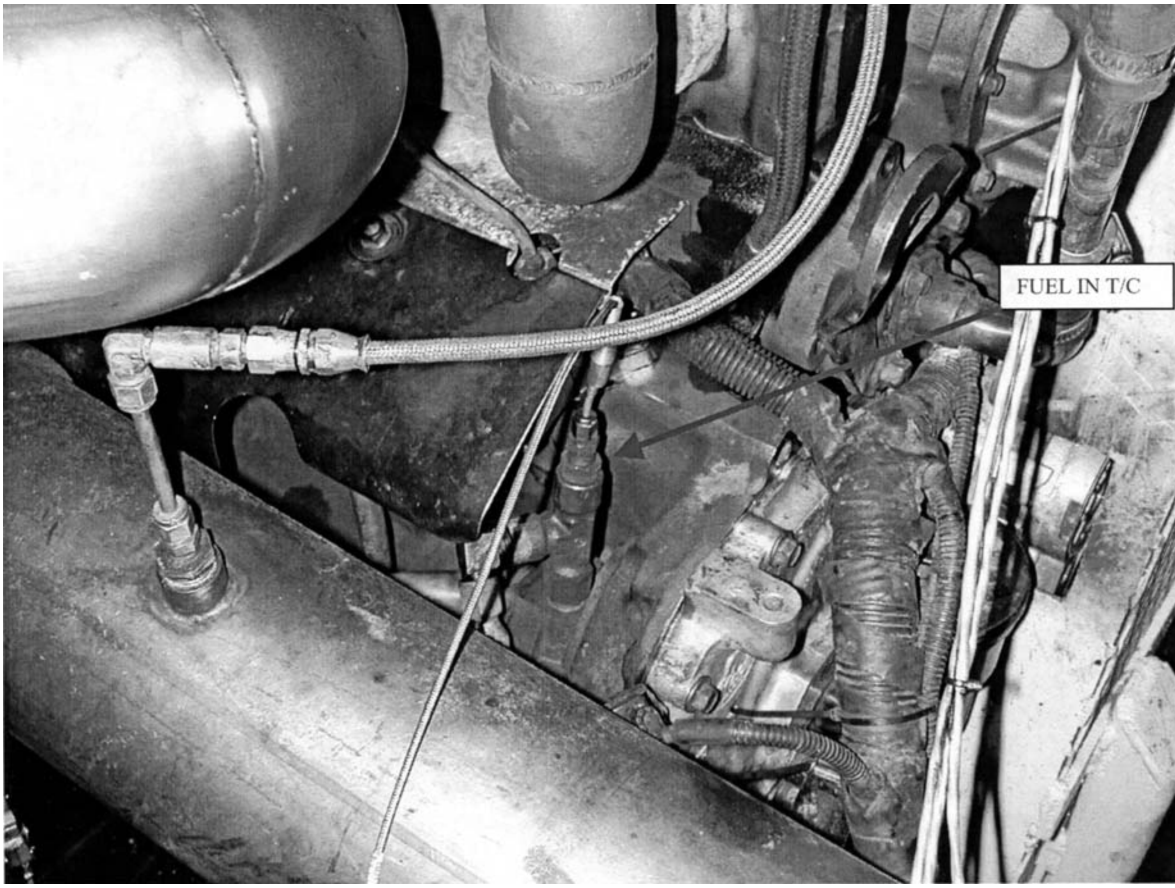


FIG. A1.10 Fuel In Temperature

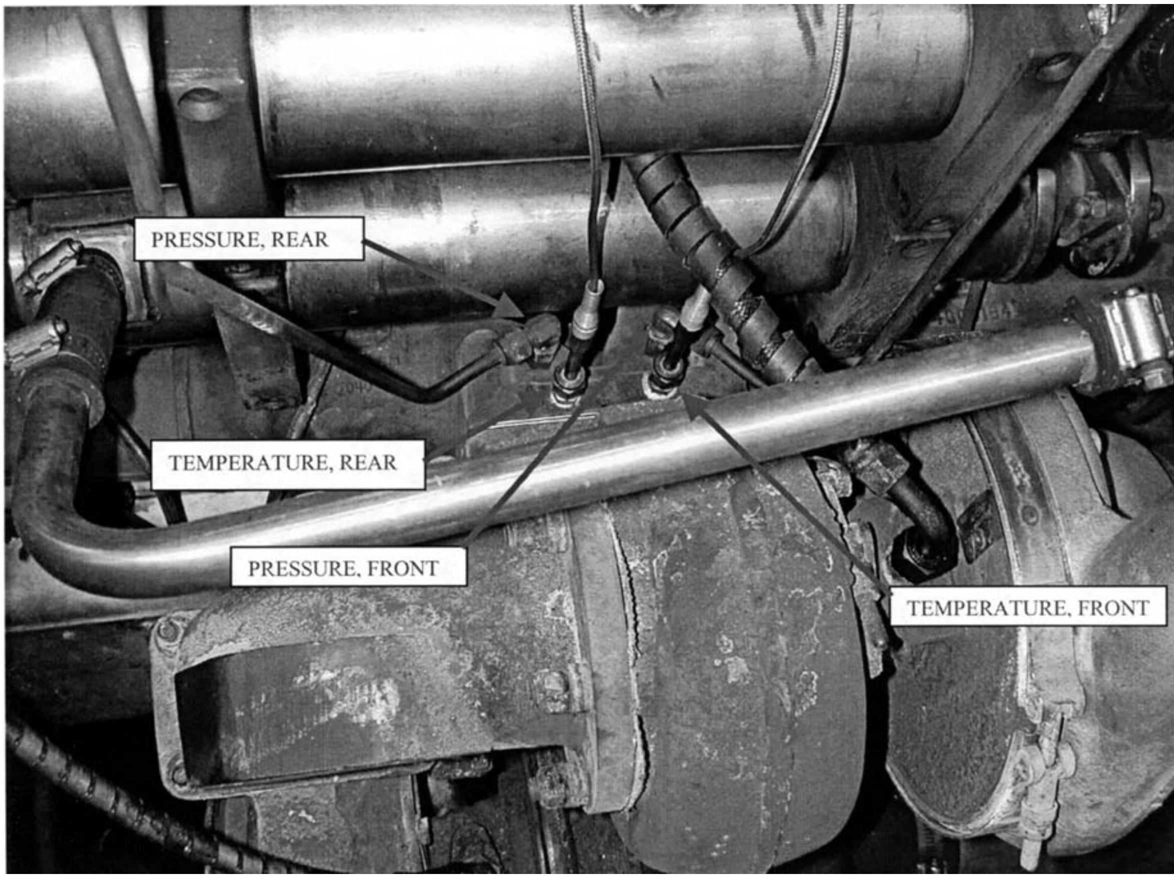


FIG. A1.11 Exhaust Pre-Turbine Temperature and Pressure, Front and Rear

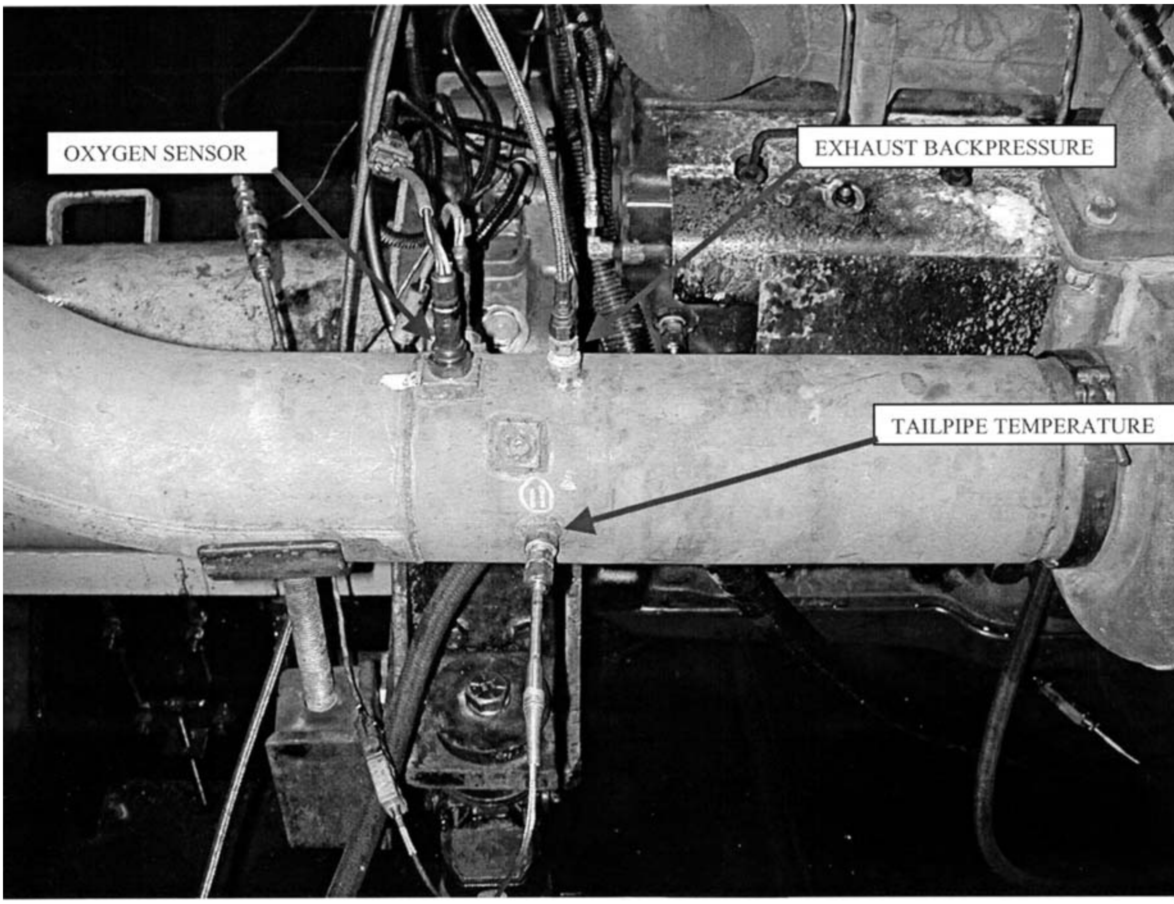


FIG. A1.12 Exhaust Backpressure, Tailpipe Temperature, and Oxygen Sensor

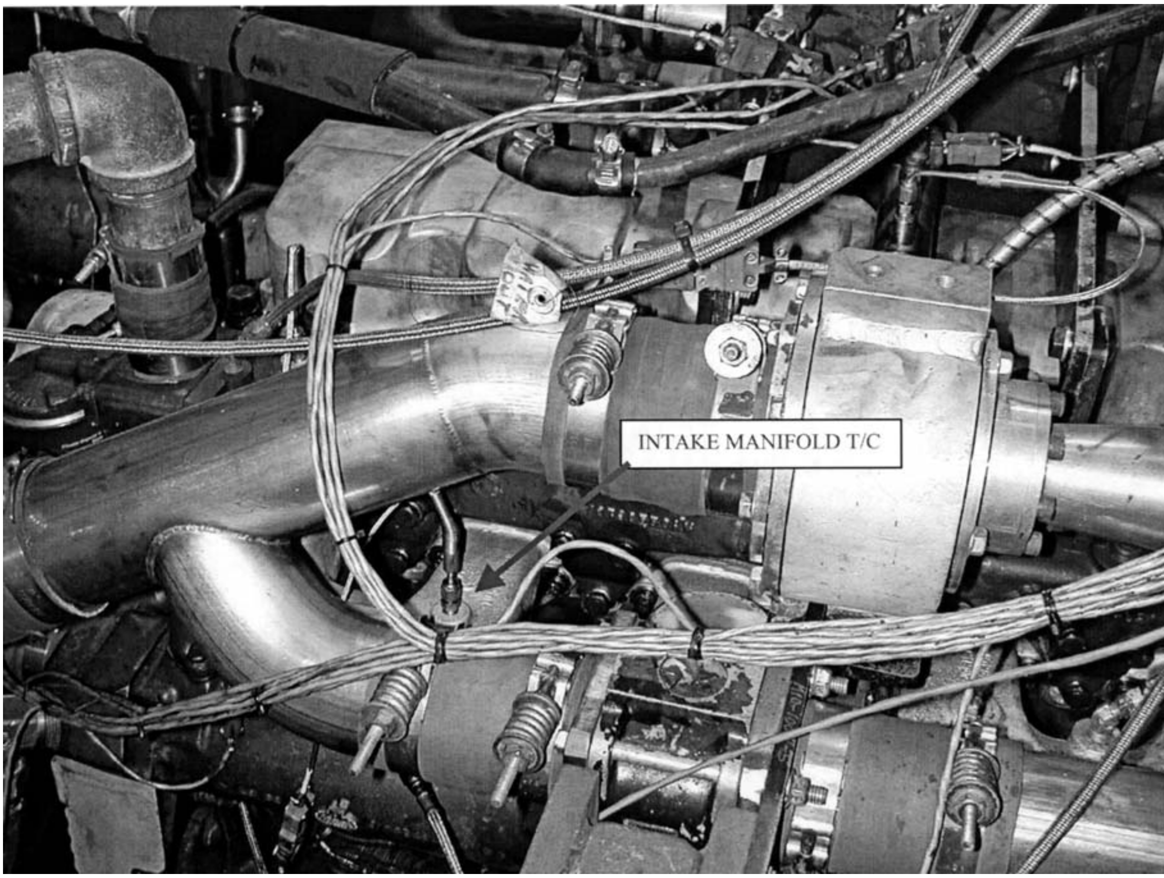


FIG. A1.13 Intake Manifold Temperature

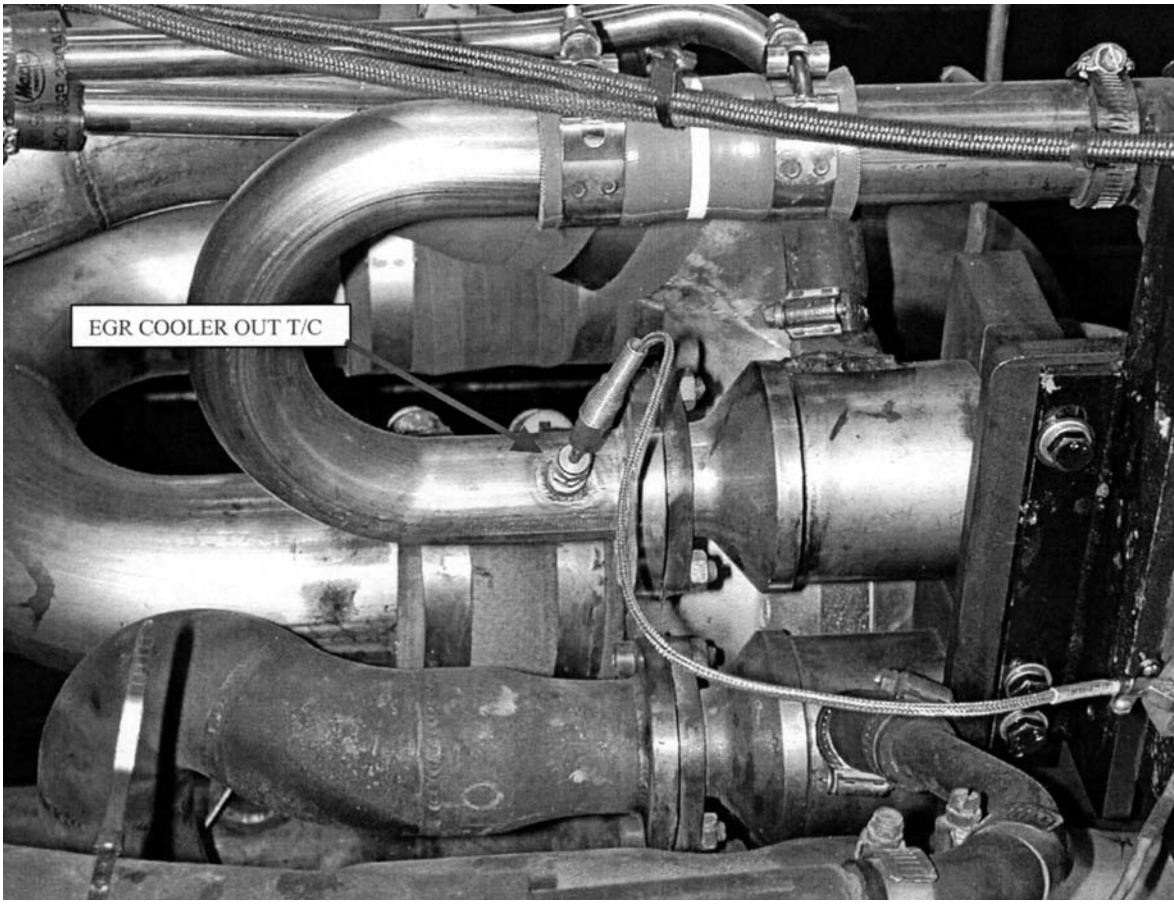


FIG. A1.14 EGR Cooler Out Temperature

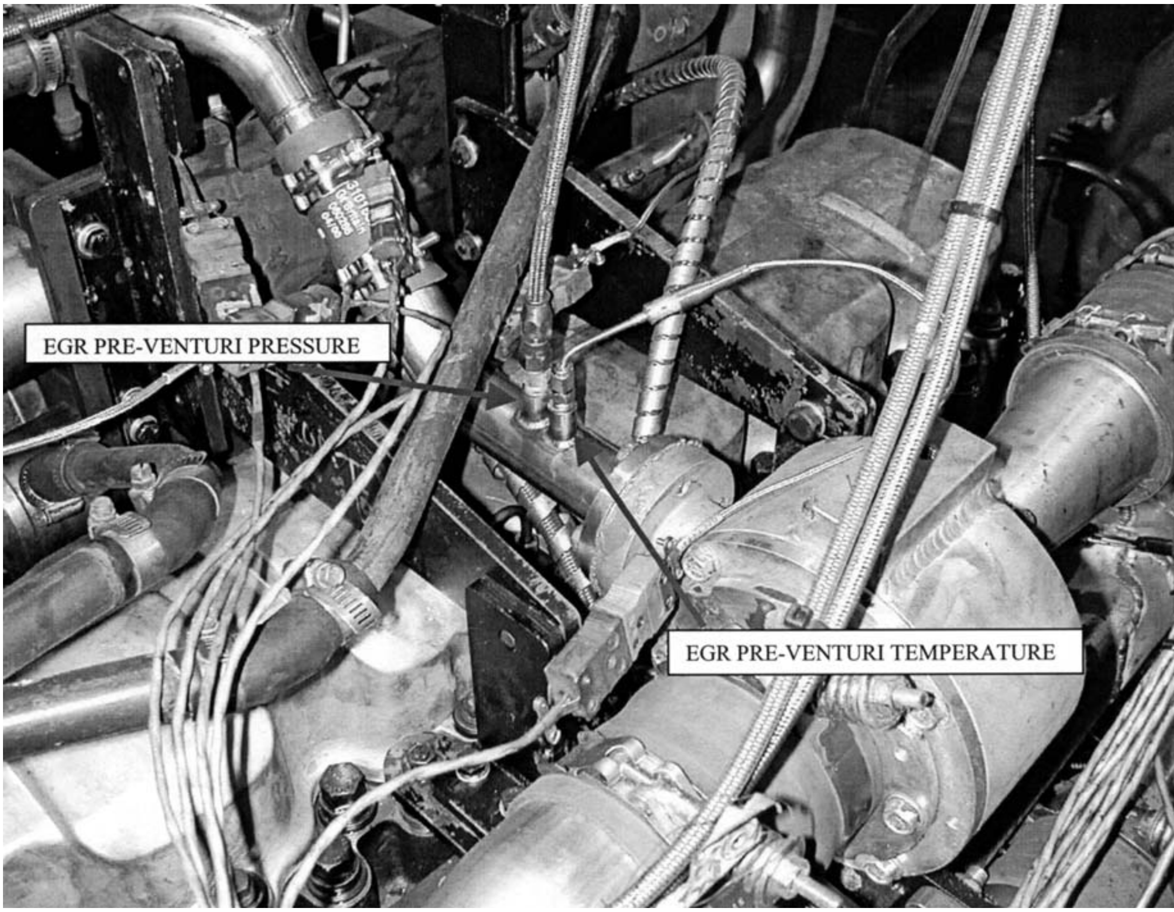


FIG. A1.15 EGR Pre-Venturi Temperature and Pressure

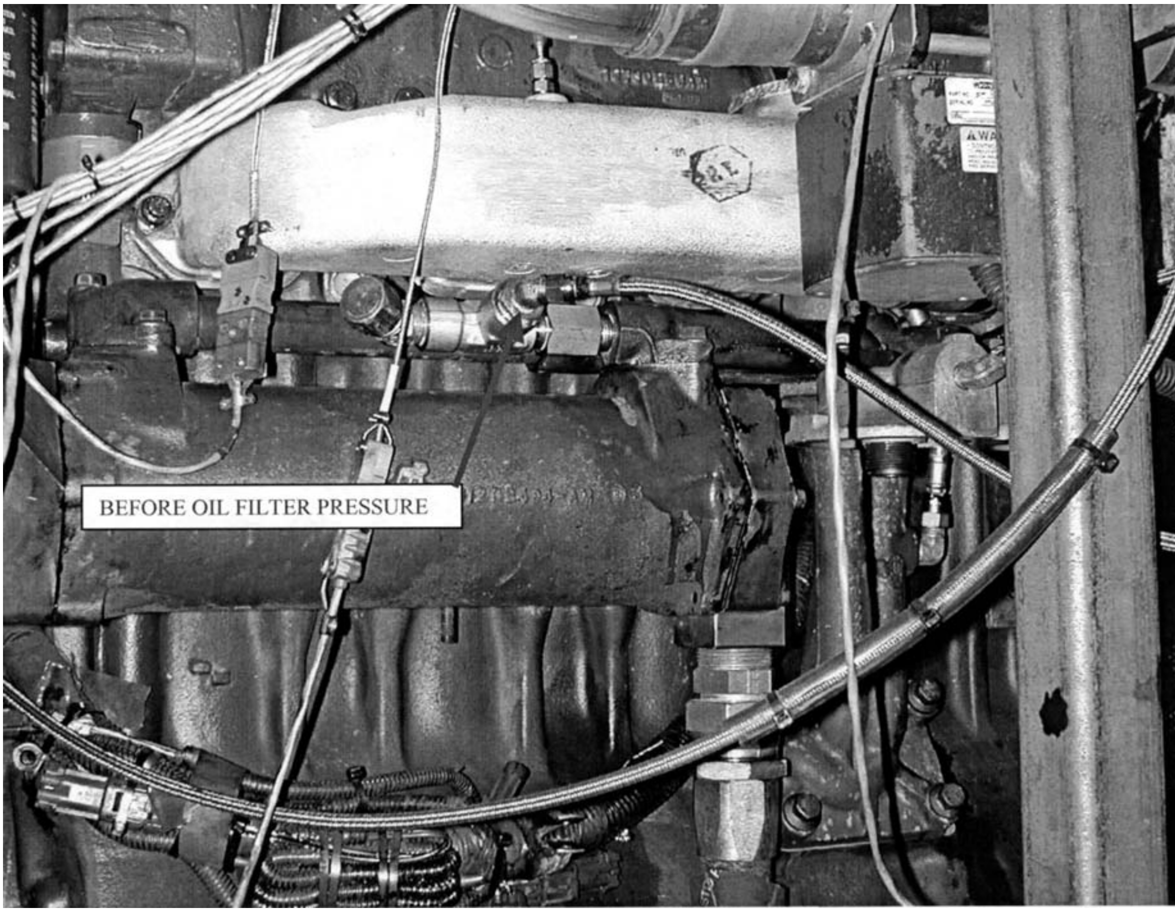


FIG. A1.16 Before Oil Filter Pressure

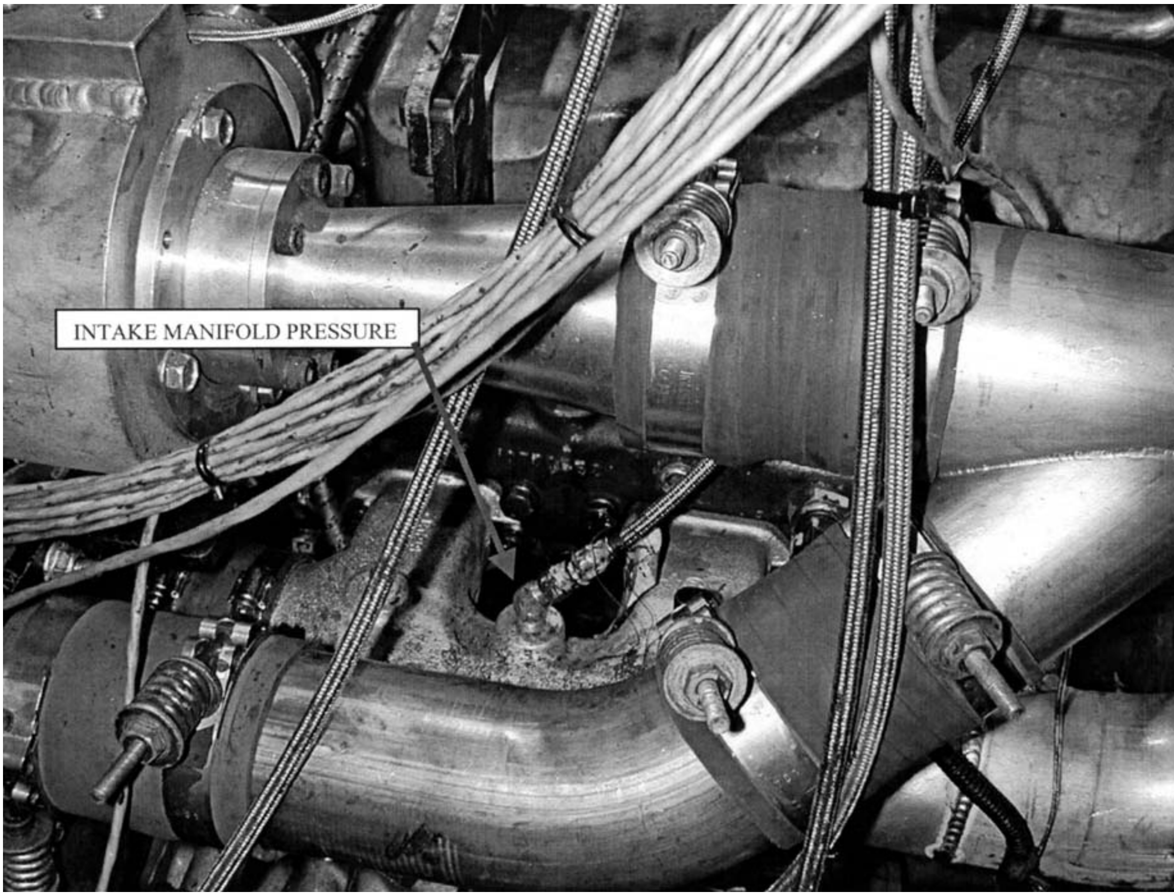


**FIG. A1.17 Intake Manifold Pressure**

## A2. PROCUREMENT OF TEST MATERIALS

A2.1 Throughout the text, references are made to necessary hardware, reagents, materials, and apparatus. In many cases, for the sake of uniformity and ease of acquisition, certain suppliers are named. If substitutions are deemed appropriate for the specified suppliers, obtain permission to substitute in writing from the TMC before such substitutions will be considered to be equivalent. The following entries represent a consolidated listing of the ordering information necessary to complete the references found in the text.

A2.2 The test engine (P/N 11GBA81025) is available from Mack Trucks, Inc., 13302 Pennsylvania Ave., Hagerstown, MD 21742. The oil pump and the parts shown in Table A2.1 are available from Test Engineering, Inc., 12718 Cimarron Path, San Antonio, TX 78249-3423.

A2.3 *Air Filtration*—Mack air filter element (p/n 57MD33) and Mack air filter housing (p/n 2MD3183) are available from Mack Trucks, Inc.

A2.4 *Intercooler* —When ordering the Modine cooler from Mack Trucks Inc., instruct the dealers to use P/N 5424 03 928 031. Because it is a non-stocked part in the Mack parts distribution system, it will appear as an invalid P/N. Explain that the P/N is valid and that you want to have it expedited on a Ship Direct purchase order. It will then be shipped from Modine to you, bypassing the normal parts distribution system.

A2.5 Cleaning solvent that meets the requirements of 7.4 is available from local petroleum product suppliers.

A2.6 PC-9-HS reference diesel fuel is available from Chevron Phillips, Phillips 66 Co. Marketing Services Ctr., P.O. Box 968, Borger, TX 79008-0968.

A2.7 Oil cooler adapter blocks are available from Southwest Research Institute, 6220 Culebra Road, P.O. Drawer 28510, San Antonio, TX 78228-0510.

**TABLE A2.1 New Parts for Each Rebuild**

| Part Name | Mack Part Number | Quantity |
|---|---|---|
| 1. Cylinder liners | 509GC471 | 6 |
| 2. Piston Assembly | 240GC2256M | |
| Piston Crown | 240GC5114M | 6 |
| Piston Skirt | 240GC5119M | 6 |
| 3. Piston Ring Set | 353GC2141 | 6 |
| No. 1 Compression ring | 349GC3107 | 6 |
| No. 2 Compression ring | 349GC3108 | 6 |
| Oil ring | 350GC343 | 6 |
| 4. Overhaul gasket sets | 57GC2176 | 2 |
| | 57GC2178A | 1 |
| | 57GC2179 | 1 |
| 5. Spin-on filters | 485GB3191C | 2 |
| Centrifugal filter cartridge | 239GB244B | 1 |
| 6. Engine coolant conditioner | 25MF435B | 1 |
| 7. Primary fuel filter | 483GB470AM | 1 |
| 8. Secondary fuel filter | 483GB471M | 1 |
| 9. Valve guides | 714GB3103 | 24 |
| 10. Valve stem seals | 446GC328 | |
| 11. Connecting rod bearings | | 6 |
| Upper | 62GB327 | 6 |
| Lower | 62GB328 | 6 |
| 12. Main Bearings | 57GC387 | 7 |
| 13. Thrust Washers | 714GC45 | 2 |
| | 714GC46 | 2 |

NOTE 1—A P/N 57GC3116 cylinder rebuild kit contains items 1, 2, and 3. Six kits are required per engine rebuild. A P/N 57GC2177B filter kit contains items 5, 6, 7, and 8. A P/N 62GB2396A Service Bearing Pair contains one each of the upper and lower connecting rod bearings (item 11).

A2.8 Pencool 3000 is available from The Penray Companies, Inc., 100 Crescent Center Pkwy., Suite 104, Tucker, GA 30084.

A2.9 Keil Probes are available from United Sensor Corp., 3 Northern Blvd., Amherst, NH 03031.

A2.10 Bulldog Premium EO-M+ oil is available from local Mack truck dealers.

## A3. DETERMINATION OF OPERATIONAL VALIDITY

A3.1 *Quality Index Calculation*:

A3.1.1 Calculate quality index (QI) for all control parameters according to the DACA II Report. In addition, account for missing or bad quality data according to the DACA II Report.

A3.1.2 Use the U, L, Over Range, and Under Range values shown in Table A3.1 for the QI calculations.

A3.1.3 Do not use the data from the first 6 min of Phase II. This is considered transition time and the data is not to be used to calculate QI.

A3.1.4 Round the calculated QI values to the nearest 0.001.

A3.1.5 Report the QI values on Form 5.

A3.2 *Averages* :

A3.2.1 Calculate averages for all control, ranged, and non-control parameters and report the values on Form 5.

A3.2.2 The averages for control and non-control parameters are not directly used to determine operational validity but they may be helpful when an engineering review is required (see A3.4).

A3.3 *Determining Operational Validity*:

A3.3.1 QI threshold values for operational validity are shown in Table A3.1. Specifications for all ranged parameters are shown in Table A3.1.

A3.3.1.1 A test with EOT QI values for all control parameters equal to or above the threshold values and with averages for all ranged parameters within specifications is operationally valid, provided that no other operational deviations exist that may cause the test to be declared invalid.

A3.3.1.2 A test with any control parameter QI value less than the threshold value requires an engineering review to determine operational validity (see A3.4).

A3.3.1.3 With the exception of crankcase pressure, a test with a ranged parameter average value outside the specification is invalid. A test with crankcase pressure outside the specification requires an engineering review to determine operational validity.

A3.4 *Engineering Review*:

A3.4.1 Conduct an engineering review when a control parameter QI value is below the threshold value. A typical engineering review involves investigation of the test data to determine the cause of the below threshold QI. Other affected parameters may also be included in the engineering review. This can be helpful in determining if a real control problem existed and the possible extent to which it may have impacted the test. For example, a test runs with a low QI for fuel flow. An examination of the fuel flow data may show that it contains several over range values. At this point, an examination of exhaust temperatures may help determine whether the instrumentation problem affected real fuel flow versus affecting only the data acquisition.

A3.4.2 For reference oil tests, conduct the engineering review jointly with the TMC. For non-reference oil tests, optional input is available from the TMC for the engineering review.

A3.4.3 Determine operational validity based upon the engineering review and summarize the decision in the comment section on Form 11. It may be helpful to include any supporting documentation at the end of the test report. The final decision regarding operational validity rests with the laboratory.

**TABLE A3.1 Quality Index and Average Calculation Values**

| Control Parameter | Units | Quality Index Threshold | Quality Index *U* and *L* Values | | | | Over and Under Range Values | |
|---|---|---|---|---|---|---|---|---|
| | | | *U* | | *L* | | Low | High |
| Speed$^{A}$ | r/min | 0.000 | 1802.5 | 1202.5 | 1797.5 | 1197.5 | 1063 | 1937 |
| Fuel flow$^{A}$ | kg/h | 0.000 | 60.20 | 64.50 | 58.20 | 62.50 | 4.4 | 118.3 |
| Inlet manifold temperature | °C | 0.000 | 70.8 | 66.8 | 69.2 | 65.2 | 22.2 | 113.8 |
| Coolant out temperature | °C | 0.000 | 66.9 | 85.9 | 65.1 | 84.1 | 16.7 | 134.3 |
| Fuel in temperature | °C | 0.000 | 40.5 | | 39.5 | | 12.6 | 67.4 |
| Oil gallery temperature | °C | 0.000 | 88.6 | 113.6 | 87.4 | 112.4 | 55.1 | 145.9 |
| Intake air temperature | °C | 0.000 | 26.0 | | 24.0 | | –29.8 | 79.8 |

| Ranged parameter | Units | Range | | Over and Under Range Values | |
|---|---|---|---|---|---|
| | | | | Low | High |
| Inlet air restriction | kPa | 3.5-4.0 | | 0 | 14 |
| Inlet manifold pressure | kPa | min 160 | min 210 | 0 | 400 |
| Exhaust back pressure | kPa | 2.7-3.5 | | 0 | 16 |
| Crankcase pressure | kPa | 0.25-0.75 | | 0 | 3 |
| Intake $CO_2$ | % | 1.5 ± 0.05 | 0.2 ± 0.05 | 0 | 5 |

$^{A}$ *U* and *L* values for speed, fuel flow, coolant out temperature, and oil gallery temperature are split by test phase.

## A4. $O_2$ SENSOR CALIBRATION

A4.1 *Order*:

A4.1.1 Run the calibration procedure in the order prescribed. Running in the wrong order will affect the final calibration.

A4.2 *Equipment* :

A4.2.1 The following equipment shall be available for the calibration procedure:

A4.2.1.1 The $O_2$ sensor and the readout instrumentation to be used on the engine installation.

A4.2.1.2 The $O_2$ calibration chamber is shown in Fig. A4.1. This chamber is a steel cylinder in which the sensor is mounted perpendicular to the gas flow. The chamber has a calibration gas supply line and a small vent hole that allows continuous flow of calibration gas across the sensor. To regulate the gas flow, the gas supply line shall include a ball and tube flow meter and a valve. The layout of the $O_2$ calibration system is shown in Fig. A4.2.

A4.2.1.3 The various tubing and quick-connects needed to direct gas flow through the calibration chamber.

A4.3 *Calibration Gases*:

A4.3.1 The following pressure regulated calibration gases shall be available:

A4.3.1.1 Nitrogen, 100 (100.0/99.8 %).

A4.3.1.2 Oxygen, 5.0 % ± 0.2 %.

A4.3.1.3 Oxygen, 9.0 % ± 0.2 %.

A4.4 *Calibration Procedure*:

A4.4.1 *Sensor Installation:*

A4.4.1.1 Screw the $O_2$ sensor into the calibration chamber and secure to minimize leaks. Do not over tighten. Plug the sensor into the readout and then power up the readout. Allow the sensor element to reach operating temperature; this warm-up takes a minimum of 15 min.

NOTE A4.1—The sensing element and body are both very hot when plugged in. Take all precautions necessary to avoid burns. Avoid splashing liquids or directing air from an air hose across the sensor. These conditions can cause sudden cooling of the sensor, which will cause instant failure of the crystal element.

A4.4.2 *Pre-Calibration Measurements:*

A4.4.2.1 Record the actual calibration gas concentration that is certified on each gas bottle.

A4.4.2.2 Attach the nitrogen bottle to the calibration chamber and adjust the gas flow across the chamber to 3 L/min. Regulate flow using the pressure regulator valve on the gas bottle, not the control valve on the flow meter. Wait 5 min and record the percent oxygen. Do not adjust the $O_2$ meter.

A4.4.2.3 Attach the 5 % $O_2$ bottle to the calibration chamber and adjust the gas flow across the chamber to 3 L/min. Regulate flow using the pressure regulator valve on the gas bottle, not the control valve on the flow meter. Wait 5 min and record the percent oxygen. Do not adjust the $O_2$ meter.

A4.4.2.4 Attach the 9 % $O_2$ bottle to the calibration chamber and adjust the gas flow across the chamber to 3 L/min. Regulate flow using the pressure regulator valve on the gas bottle, not the control valve on the flow meter. Wait 5 min and record the percent oxygen. Do not adjust the $O_2$ meter.

A4.4.3 *Calibration Measurements:*

A4.4.3.1 Reattach the nitrogen bottle and adjust flow to 3 L/min. Wait 5 min for stabilization and adjust the readout to achieve the correct $O_2$ gas concentration. Record the corrected reading.

A4.4.3.2 Reattach the 5 % oxygen bottle and adjust flow to 3 L/min. Wait 5 min for stabilization and adjust the readout to achieve the correct $O_2$ gas concentration. Record the corrected reading.

A4.4.3.3 Reattach the 9 % oxygen bottle and adjust flow to 3 L/min. Wait 5 min for stabilization and adjust the readout to achieve the correct $O_2$ gas concentration. Record the corrected reading.

A4.4.3.4 Recheck the 5 % $O_2$ reading. If it has not changed, reconnect the 9 % $O_2$ bottle and confirm the reading is still correct.

A4.4.3.5 Once the 5 % and 9 % readings are stable, measure the 0 % $O_2$ and record. Do not readjust the readout. This reading is only done to confirm the fitness of the sensor and to provide a level of confidence in precision in the $O_2$ measuring system.

A4.5 *Records* :

A4.5.1 File all measurements with the permanent laboratory calibration records. A sample $O_2$ calibration sheet is shown in Table A4.1.

A4.5.2 When re-installing the $O_2$ sensor in the engine exhaust tube, use an anti-seize compound specifically approved for $O_2$ sensors (contains no lead).

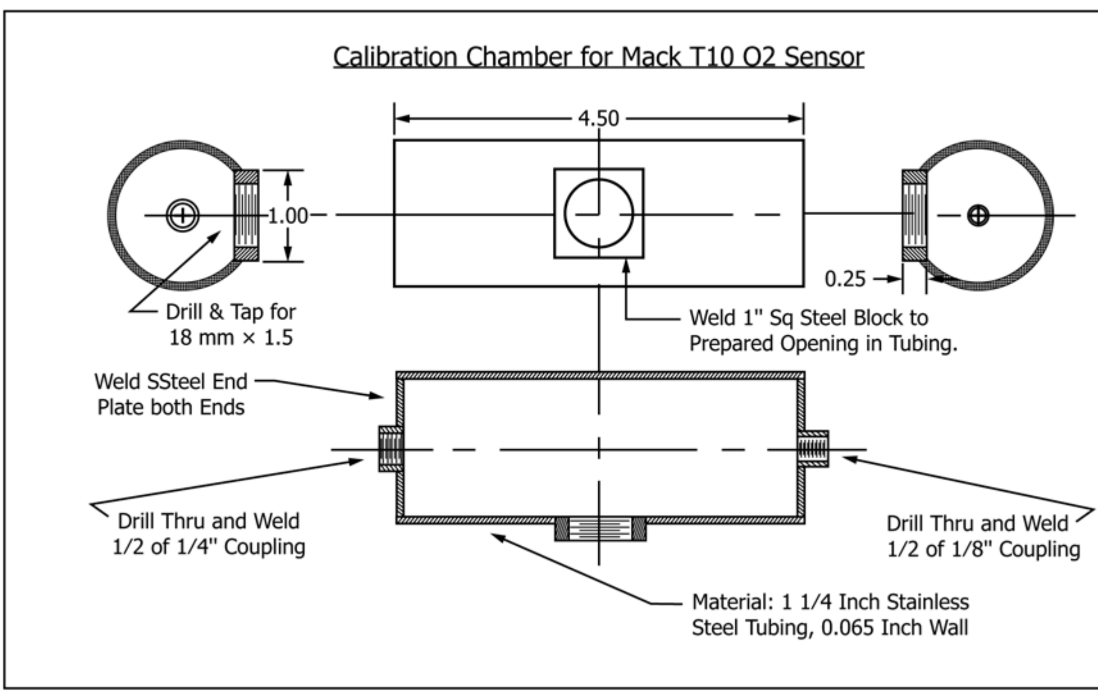


**FIG. A4.1 Oxygen Sensor Calibration Chamber**

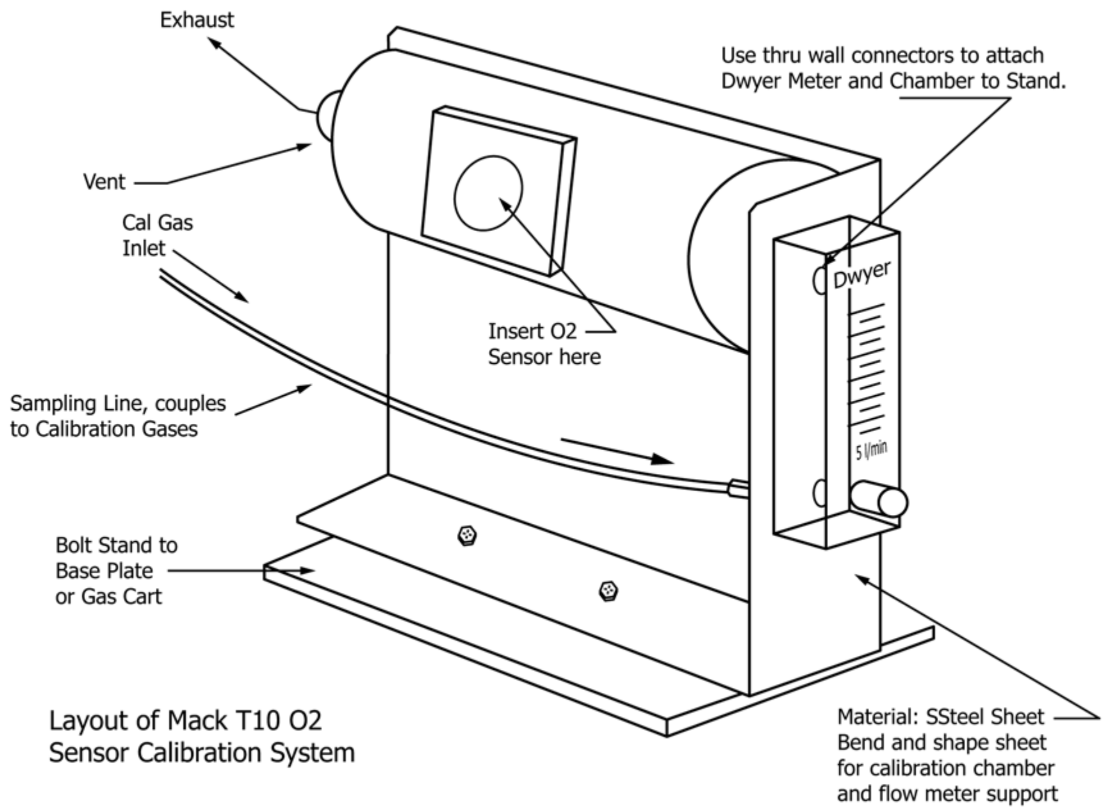


**FIG. A4.2 Oxygen Sensor Calibration System**

**TABLE A4.1 Sample Oxygen Sensor Calibration Sheet**

T-10 Oxygen Sensor Calibration Sheet

Laboratory:
Date:
Test Stand:
Stand Run Number:
Engine Serial Number:
Engine Hours:

Calibration Gas Information and Calibration Results

| Calibration Gas | Identification | Required Calibration Gas Concentration | Certified Concentration % | Pre-Calibration Oxygen % | Post Calibration Oxygen % |
|---|---|---|---|---|---|
| 0 % Oxygen (nitrogen 100 %) | | 100.0 ± 0.2 % Nitrogen | | | |
| 5 % Oxygen | | 5.0 ± 0.2 % Oxygen | | | |
| 9 % Oxygen | | 9.0 ± 0.2 % Oxygen | | | |

## A5. TEMPERATURE TO INJECTION TIMING CORRELATION

A5.1 See Table A5.1.

**TABLE A5.1**

| Intake Manifold Temperature | Injection Timing (°BTDC) |
|---|---|
| 30 | 21 |
| 40 | 18 |
| 50 | 15 |
| 60 | 12 |
| 70 | 9 |
| 80 | 6 |
| 90 | 3 |

## A6. BREAK-IN, START-UP, SHUTDOWN, AND TRANSITION PROCEDURES

A6.1 The break-in sequence is shown is Table A6.1.

A6.2 The Phase I start-up sequence is shown in Table A6.2.

A6.3 The Phase II start-up sequence is shown in Table A6.3.

A6.4 The shutdown sequence for Phases I and II is shown in Table A6.4.

A6.5 The transition sequence from Phase I to Phase II is shown in Table A6.5.

A6.6 Emergency (or hard) shutdowns are considered a laboratory safety procedure and are not specified by this test method.

A6.7 The torque values in Tables A6.1-A6.5 are nominal values. Run the appropriate fuel rates to achieve the nominal torque values.

**TABLE A6.1 Break-In Sequence**

| Step | Time (h:mm:ss) | Speed (r/min) | Torque (N·m) | Comments |
|---|---|---|---|---|
| | | Prior to start | | set injection timing to 18° BTDC and full EGR bypass |
| 1 | 0:00:00 | idle | 0 | engine idle, waiting for oil pressure |
| | 0:00:10 | idle | 0 | proceed if oil pressure >138 kPa |
| 2 | 0:00:11 | idle | 245 | engine idle; set torque to 245; hold conditions for 4 min 50 s |
| 3 | 0:05:00 | 1200 | 245 | set speed to 1200; linearly ramp torque to 815 in 4 min |
| | 0:09:00 | 1200 | 815 | end of torque ramp; hold conditions for 2 min 30 s |
| 4 | 0:11:30 | 1200 | 815 | linearly ramp torque to 1085 in 2 min |
| | 0:13:30 | 1200 | 1085 | end of torque ramp; hold conditions for 2 min 30 s |
| 5 | 0:16:00 | 1200 | 1085 | linearly ramp torque to 2440 in 10 min |
| | 0:26:00 | 1200 | 2440 | end of torque ramp, hold conditions for 2 min 30 s |
| | 0:28:30 | 1200 | 2440 | set EGR, hold conditions for 30 min |
| 6 | 0:58:30 | 1200 | 2440 | linearly ramp torque to 1300 in 2 min |
| | 0:59:00 | 1200 | ramping | linearly ramp speed to 1800 in 2 min |
| | 1:00:30 | ramping | 1300 | end of torque ramp |
| | 1:01:00 | 1800 | 1300 | end of speed ramp; hold conditions for 2 min 30 s |
| | 1:03:30 | 1800 | 1300 | set injection timing and EGR, hold conditions for 30 min |
| 7 | 1:33:30 | 1800 | 1300 | proceed to shutdown sequence |

TABLE A6.2 Phase I Start-Up Sequence

| Step | Time (h:mm:ss) | Speed (r/min) | Torque (N·m) | Comments |
|---|---|---|---|---|
| | Prior to start | | | set injection timing to 18° BTDC and full EGR bypass |
| 1 | 0:00:00 | idle | 0 | engine idle, waiting for oil pressure |
| | 0:00:10 | idle | 0 | proceed if oil pressure >138 kPa |
| 2 | 0:00:11 | idle | 245 | engine idle; set torque to 245, hold conditions for 4 min 50 s |
| 3 | 0:05:00 | 1200 | 245 | set speed to 1200; linearly ramp torque to 815 in 4 min |
| | 0:09:00 | 1200 | 815 | end of torque ramp; hold conditions for 2 min 30 s |
| 4 | 0:11:30 | 1800 | 815 | set speed to 1800; linearly ramp torque to 1085 in 2 min |
| | 0:13:30 | 1800 | 1085 | end of torque ramp, hold conditions for 2 min 30 s |
| 5 | 0:16:00 | 1800 | 1085 | linearly ramp torque to 1300 in 2 min |
| | 0:18:00 | 1800 | 1300 | end of torque ramp; hold conditions for 2 min 30 s |
| | 0:20:30 | 1800 | 1300 | set injection timing and EGR; proceed to Phase I, set fuel rate |

TABLE A6.3 Phase II Start-Up Sequence

| Step | Time (h:mm:ss) | Speed (r/min) | Torque (N·m) | Comments |
|---|---|---|---|---|
| | Prior to start | | | set injection timing to 18° BTDC and full EGR bypass |
| 1 | 0:00:00 | idle | 0 | engine idle, waiting for oil pressure |
| | 0:00:10 | idle | 0 | proceed if oil pressure >138 kPa |
| 2 | 0:00:11 | idle | 245 | engine idle; set torque to 245; hold conditions for 4 min 50 s |
| 3 | 0:05:00 | 1200 | 245 | set speed to 1200; linearly ramp torque to 815 in 4 min |
| | 0:09:00 | 1200 | 815 | end of torque ramp; hold conditions for 2 min 30 s |
| 4 | 0:11:30 | 1200 | 815 | linearly ramp torque to 2440 in 10 min |
| | 0:21:30 | 1200 | 2440 | end of torque ramp; hold conditions for 2 min 30 s |
| 5 | 0:24:00 | 1200 | 2440 | set EGR; proceed to Phase II; set fuel rate |

TABLE A6.4 Shutdown Sequence, Phases I and II

| Step | Time (h:mm:ss) | Speed (r/min) | Torque (N·m) | Comments |
|---|---|---|---|---|
| | Prior to start of shutdown sequence | | | engine running at test conditions, either Phase I or II |
| 1 | 0:00:00 | 1800/ 1200 | 1300/2440 | set EGR to full bypass; linearly ramp torque to 815 in 1 min |
| | 0:01:00 | 1800/ 1200 | 815 | end of torque ramp; hold conditions for 1 min |
| 2 | 0:02:00 | 1800/ 1200 | 815 | linearly ramp torque to 270 in 1 min 30 s |
| | 0:03:30 | 1800/ 1200 | 270 | end of torque ramp; hold conditions for 3 min 30 s |
| 3 | 0:07:00 | 1800/ 1200 | 270 | linearly ramp torque to 0 in 1 min; linearly ramp speed to idle in 2 min |
| | 0:08:00 | ramping | 0 | end of torque ramp |
| | 0:09:00 | idle | 0 | end of speed ramp; hold conditions for 1 min |
| 4 | 0:10:00 | idle | 0 | stop engine in 1 s |
| | 0:10:01 | 0 | 0 | end of shutdown |

TABLE A6.5 Transition Sequence from Phase I to Phase II

| Step | Time (h:mm:ss) | Speed (r/min) | Torque (N·m) | Comments |
|---|---|---|---|---|
| | Prior to start of sequence | | | phase I has completed; set injection timing to 18° BTDC |
| 1 | 0:00:00 | 1800 | 1300 | linearly ramp speed to 1200 in 2 min 30 s |
| | 0:02:00 | ramping | 1300 | linearly ramp torque to 2440 in 2 min 30 s |
| | 0:02:30 | 1200 | ramping | end of speed ramp |
| | 0:04:30 | 1200 | 2440 | end of torque ramp; hold conditions for 2 min 30 s |
| 2 | 0:07:00 | 1200 | 2440 | set EGR and fuel rate; proceed to Phase II |

## A7. SAFETY HAZARDS

A7.1 *General* :

A7.1.1 Operating engine tests can expose personnel and facilities to a number of safety hazards. It is recommended that only personnel who are thoroughly trained and experienced in engine testing should undertake the design, installation, and operation of engine test stands.

A7.1.2 Each laboratory conducting engine tests should have their test installation inspected and approved by their Safety Department. Personnel working on the engines should be provided with proper tools, be alert to common sense safety practices, and avoid contact with moving or hot engine parts, or both. Guards should be installed around all external moving or hot parts. When engines are operating at high speeds, heavy-duty guards are required and personnel should be cautioned against working alongside the engine and coupling shaft. Barrier protection should be provided for personnel. All fuel lines, oil lines, and electrical wiring should be properly routed, guarded, and kept in good order. Scraped knuckles, minor burns, and cuts are common if proper safety precautions are not taken. Safety masks or glasses should always be worn by personnel working on the engines and no loose or flowing clothing, including long hair or other accessory to dress which could become entangled, should be worn near running engines.

A7.1.3 The external parts of the engines and the floor area around the engines should be kept clean and free of oil and fuel spills. In addition, all working areas should be free of tripping hazards. Personnel should be alert for leaking fuel or exhaust gas. Leaking fuel represents a fire hazard and exhaust gas fumes are noxious. Containers of oil or fuel cannot be permitted to accumulate in the testing area.

A7.1.4 The test installation should be equipped with a fuel shut-off valve, which is designed to automatically cutoff the fuel supply to an engine when the engine is not running. A remote station for cutting off fuel from the test stand is recommended. Suitable interlocks should be provided so that the engine is automatically shutdown when any of the following events occur: *(1)* engine or dynamometer water temperature becomes excessive; *(2)* engine loses oil pressure; *(3)* dynamometer loses field current; *(4)* engine over-speeds; *(5)* exhaust system fails; *(6)* room ventilation fails; or *(7)* the fire protection system is activated.

A7.1.5 Consider an excessive vibration pickup interlock, if equipment operates unattended. Fixed fire protection equipment should be provided.

A7.1.6 Normal precautions should be observed when using flammable solvents for cleaning purposes. Ensure adequate fire fighting equipment is immediately accessible.

## A8. T-10A ABBREVIATED LENGTH TEST REQUIREMENTS

A8.1 *Overview* —The purpose of the T-10A is to provide the low temperature viscosity result for used oil. The low temperature result in question is the MRV viscosity after 75 h at Stage I T-10 conditions. This result may be obtained two different ways. First, it may be obtained from an operationally valid standard T-10 test. Second, it may be obtained from a test stand setup that runs only the first 75 h of T-10 conditions. Unlike the standard T-10 test, this form of the T-10A does not require a new engine build with each test. Instead, it is a flush-and-run setup. With the exception of A8.4, A8.5.2, A8.5.3, and A8.6, no special instructions are necessary to obtain a T-10A result from a standard T-10. The special instructions necessary to obtain a T-10A result from a flush-and-run setup are contained in the remainder of this annex.

A8.2 *Preparation of Apparatus at Rebuild (refer to Section 8)*—The timing and frequency of engine rebuild is left to the discretion of the laboratory.

A8.2.1 *Injectors (refer to 8.4.1)*—Check the injector opening pressure at rebuild. Reset the injector opening pressure if it is outside the specification of 36 900 kPa to 37 900 kPa [5350 to 5500 psi].

A8.3 *Procedure (refer to Section 9)*:

A8.3.1 *Pretest Oil Flush*—The pre-test flush is not performed on a new engine build. For new engine builds, run the break-in sequence according to A8.3.2. For existing engine builds, flush the engine and auxiliary oil system with test oil for 15 min. Drain the oil. Repeat the flush and drain sequence two more times. Use the same set of oil filters for all three flushes. At the completion of the third flush, drain the oil, change the oil filters, and charge the engine and auxiliary oil system with test oil. Proceed with the test according to A8.3.3.

A8.3.2 *Pretest Break-In (see 9.1.2)*—The pre-test break-in is not necessary for every test; it is only necessary for a new engine build. For a new engine build, run a 30 min break-in at Phase I conditions. To do this, follow the Phase I start-up sequence shown in Table A6.2, and once the start-up sequence is complete, hold the conditions for 30 min. Change all oil filters at the completion of the break-in.

A8.3.3 *Test Cycle (see 9.4)*—Conduct the test by operating for 75 h at Phase I conditions, which are shown in Table 2.

A8.3.4 *Post-Test Oil Flush*—At the completion of the test, drain the oil and change the oil filters. Hot flush the engine and auxiliary oil system with Bulldog Premium Oil for 15 min. Drain the oil. Repeat the flush and drain sequence two more times. Use the same set of oil filters for all three flushes.

A8.4 *Oil Inspection (see 10.3)*—Analyze the 75 h oil sample for MRV viscosity according to a research report[11] on mini-rotary viscosity and yield stress of highly sooted diesel engine oils. As part of the MRV measurement procedure, be sure to prepare the sample in accordance with A4.3 (Annex A4) of Test Method D5967.

A8.5 *Laboratory and Engine Test Stand Calibration/Non-Reference Oil Requirements (Section 11)*:

A8.5.1 *Test Stand/Engine Calibration (refer to 11.5)*—The calibration period for a flush-and-run T-10A is fifteen operationally valid non-reference oil tests or nine months from completion of the last successful calibration test.

A8.5.1.1 A T-10A flush-and-run stand may be installed in a stand that originally calibrated as a standard T-10 without impacting the standard T-10 calibration status. However, the flush-and-run setup will only be calibrated for the first non-reference oil test. To re-establish calibration, a reference oil test shall be run following the first test on the flush-and-run engine.

A8.5.1.2 A newly rebuilt engine requires a reference oil test to establish test stand calibration. Additionally, a T-10A cannot be run on an engine build that has seen Phase II test conditions (break-in conditions are excluded for a T-10A obtained as part of a standard T-10).

[11] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1517.

A8.5.2 *Test Result (see 11.6)*—The specified test result is MRV viscosity at 75 h. Report the result on Forms 4 and 8.

A8.5.3 *Non-Reference Oil Test Result Severity Adjustments (see 11.8)*—This test method incorporates the use of an SA for non-reference oil test results. A control chart technique, described in the LTMS, has been selected for identifying when a bias becomes significant for MRV viscosity at 75 h. When calibration test results identify a significant bias, an SA is determined according to LTMS. Report the SA on Form 4 in the space for SA. Add this SA value to non-reference oil test results, and enter the SA adjusted result in the appropriate space. The SA remains in effect until a new SA is determined from subsequent calibration test results, or the test results indicate the bias is no longer significant. Calculate and apply SA on a laboratory basis. Be aware that the SA applied to non-reference results is the laboratory SA that is in place at the completion of the 75th hour of the test (that is, for T-10A results that are obtained through a standard length T-10, do not use the SA at EOT of the T-10, instead use the SA that is in place at 75 h).

A8.6 *Precision and Bias (refer to Section 13)*:

A8.6.1 *Precision*—The test precision for MRV Viscosity at 75 h, as of December 23, 2003, is shown in Table A8.1.

A8.6.2 *Bias*—Bias is determined by applying the LTMS control chart technique (see A8.5.3) and when a significant bias is determined, a severity adjustment is permitted for non-reference oil test results.

**TABLE A8.1 Test Precision**

| Test Result | Intermediate Precision (*i.p.*) | Reproducibility (*R*) |
|---|---|---|
| MRV viscosity at 75 h (cP) | 2108 | 2139 |

## A9. T-10 RING AND LINER OUTLIER SCREENING CRITERIA

A9.1 Average Top Ring Weight Loss:

A9.1.1 Calculate the average top ring weight loss using all rings and report the data on the appropriate forms.

A9.1.2 For each cylinder, calculate the top ring weight loss relative offset as:Table A9.1

$$TRWLOffset_{cylinder} = (TRWL_{cylinder} - ATRWL - RRPTRWL_{cylinder})/RSDTRWL \qquad (A9.1)$$

where:

$TRWL_{cylinder}$ = top ring weight loss for the cylinder, mg,
$ATRWL$ = average top ring weight loss from A9.1.1, mg,
$RRPTRWL$ = reference relative top ring weight loss profile from Table A9.1,
$RSDTRWL$ = reference top ring weight loss standard deviation from Table A9.1, and
$Cylinder$ = 1,2,3,4,5,6.

**TABLE A9.1 Relative Profiles**[A]

| Cylinder | Cylinder Liner Wear RRPCLW | Middle Ring Weight Loss RRPTRWL |
|---|---|---|
| 1 | 4.5 | 39 |
| 2 | -0.6 | -1 |
| 3 | -0.6 | 8 |
| 4 | -1.2 | -17 |
| 5 | -1.6 | -2 |
| 6 | -0.6 | -27 |
| | RSDCLW | RRPTRWL |
| Standard Deviation. | 5.9 | 45 |

[A] Contact the TMC to obtain a history of cylinder liner wear and top ring weight loss relative profiles.

A9.1.2.1 If maximum |TRWLOffsetcylinder| > 2.20, the outlier screened average top ring weight loss is the average of the top ring weight losses for the five cylinders for which |TRWLOffsetcylinder| is not maximized plus $RRPTRWL_{cylinder}/6$ for the cylinder where it is maximized.

A9.1.2.2 If max |TRWLOffsetcylinder| ≤ 2.20, the outlier screened average top ring weight loss is identical to the average top ring weight loss.

A9.2 *Average Cylinder Liner Wear*:

A9.2.1 Calculate the average cylinder liner wear step using all cylinder liners. Report the data on Forms 4 and 10.

A9.2.2 For each cylinder, calculate the cylinder liner wear step relative offset as:

$$CLWOffset_{cylinder} = (CLW_{cylinder} - ACLW - RRPCLW_{cylinder})/RSDCLW \tag{A9.2}$$

where:

$CLW_{cylinder}$ = cylinder liner wear step for the cylinder, µm,
$ACLW$ = average cylinder liner wear step from A9.2.1, µm,
$RRPCLW_{cylinder}$ = reference relative cylinder liner wear step profile from Table A9.1,
$RSDCLW$ = reference cylinder liner wear step standard deviation from Table A9.1, and
$Cylinder$ = 1,2,3,4,5,6.

A9.2.2.1 If maximum $|CLWOffset_{cylinder}| > 2.20$, the outlier screened average cylinder liner wear step is the average of the cylinder liner wear steps for the five cylinders for which $|CLWOffset_{cylinder}|$ is not maximized plus $RRPCLW_{cylinder}/6$ for the cylinder where it is maximized.

A9.2.2.2 If maximum $|CLWOffset_{cylinder}| \leq 2.20$, the outlier screened average cylinder liner wear step is identical to the average cylinder liner wear step.

## A10. T-10 MACK MERIT CALCULATION METHODOLOGY

A10.1 *Merit System Components*:

A10.1.1 *Targets*—Target performance level based on one test.

A10.1.2 *Maximums*—Limit of acceptable performance.

A10.1.3 *Minimums*—Best achievable result.

A10.1.4 *Weights*—Relative contribution to total merit.

A10.1.5 *Multipliers*—Using Table A10.1, determine the multiplier for each parameter as follows:

A10.1.5.1 If a result is at the target, multiplier is one (for example, liner wear = 30 yields multiplier = 1).

A10.1.5.2 If a result is at or below the minimum, multiplier is two (for example, liner wear = 10 yields multiplier = 2).

A10.1.5.3 If a result is at the maximum, multiplier is zero (for example, liner wear = 32.0 yields multiplier = 0).

**TABLE A10.1**

| Criterion | 0-300 Hour Delta Pb | 250-300 Hour Delta Pb | Cylinder Liner Wear | Top Ring Weight Loss | Oil Consumption |
|---|---|---|---|---|---|
| Weight | 225 | 225 | 250 | 150 | 150 |
| Maximum | 35 | 14 | 32.0 | 158 | 65.0 |
| Target | 30 | 10 | 30 | 140 | 57 |
| Minimum | 5 | 0 | 12 | 50 | 25 |

A10.1.5.4 If a result is between minimum and target, linearly interpolate multiplier between 2 and 1 (for example, liner wear = 24 yields multiplier = 1 + (24 – 30)/(12 – 30) = 1.33).

A10.1.5.5 If a result is between target and maximum, linearly interpolate multiplier between 1 and 0 (for example, liner wear = 31.0 yields multiplier = 1 – (31.0 – 30)/(32.0 – 30) = 0.5).

A10.1.5.6 If a result is above the maximum, linearly extrapolate multiplier on the same line as between 1 and 0 (for example, liner wear = 33.0 yields multiplier = 1 – (33.0 – 30)/(32.0 – 30) = -0.5).

A10.2 *Calculated Merit Result*—Sum the products of weights and multipliers across the five results. This is the calculated merit result. In equation form:

$$\text{calculated Merit} = \sum_{i=1}^{5} weight_i \tag{A10.1}$$

$$x \left\{ \begin{array}{l} \delta(result_i > target_i) \times (max_i - result_i)/(max_i - target_i) \\ +\delta(min_i < result_i \leq target_i) \times [1 + (target_i - result_i)/(target_i - min_i)] \\ +\delta(result_i \leq min_i) \times 2 \end{array} \right\}$$

where:

$\delta(x)$ = 1 if $x$ is true; 0 if $x$ is false.

A10.2.1 Report the results of the merit calculations on Form 4.

## APPENDIX

### (Nonmandatory Information)

### X1. T-10 WITH ULTRA-LOW SULFUR DIESEL FUEL (ULSD)

X1.1 The European Automobile Manufacturers Association (ACEA) uses results from T-10 tests run on ultra-low sulfur diesel fuel, designated by ACEA as the T-10 ULSD. Ranges for such a fuel are provided in Table X1.1. This test method makes no attempt to quantify precision or discrimination between results for T-10 tests run with this or any other alternate fuel.

**TABLE X1.1 ULSD Fuel Specification**

| Property | Specification | ASTM Test Method |
|---|---|---|
| Additives | Lubricity additive only | . . . |
| Distillation Range, °C 90 % | 293 – 332 | D86 |
| Specific Gravity | 0.840 – 0.855 | D4052 |
| API Gravity | 34 – 37 | D4052 |
| Corrosion, 3 h at 50 °C | 1 max | D130 |
| Sulfur, mass, mg/kg | 7 – 15 | D5844 |
| Flash Point, °C | 54 min | D93 |
| Pour Point, °C | -18 max | D97 |
| Cloud Point, °C | Report | D2500 |
| Viscosity at 40 °C, cSt | 2.0 – 2.6 | D445 |
| Ash, weight % | 0.005 max | D482 |
| Carbon Residue on 10 % Bottoms | 0.35 max | D524 |
| Net Heat of Combustion | Report | D3338 |
| Water and Sediment, volume % | 0.05 max | D2709 |
| Total Acid Number | 0.05 max | D664 |
| Strong Acid Number | 0 max | D664 |
| Cetane Index | Report | D976 |
| Cetane Number | 43 – 47 | D613 |
| Accelerated Stability, mg/100 mL | 1.5 max | D2274 |
| Composition: | | |
| Aromatics, wt % | 26 – 31.5 | D5186 |
| Olefins, vol % | Report | D1319 |
| Saturates, vol % | Report | D1319 |
| SLBOCLE, g | 3100 min[A] | D6078[A] |

[A] May be altered to be consistent with CARB or ASTM diesel fuel specifications.

## SUMMARY OF CHANGES

Subcommittee D02.B0 has identified the location of selected changes to this standard since the last issue (D6987 – 13) that may impact the use of this standard. (Approved Oct. 1, 2013.)

*(1)* Subsection A8.5.1 has a revised test stand/engine calibration schedule.

Subcommittee D02.B0 has identified the location of selected changes to this standard since the last issue (D6987 – 11) that may impact the use of this standard.

*(1)* Subsection A2.6 has a revised fuel designation.
*(2)* Editorial changes were made, applying Form and Style (including SI 10) guidelines.