



Standard Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low- Temperature, Light-Duty Conditions¹

This standard is issued under the fixed designation D6593; 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 covers and is commonly referred to as the Sequence VG test,² and it has been correlated with vehicles used in stop-and-go service prior to 1996, particularly with regard to sludge and varnish formation.³ It is one of the test methods required to evaluate oils intended to satisfy the API SL performance category.

1.2 The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.2.1 *Exception*—Where there is no direct SI equivalent such as screw threads, national pipe threads/diameters, tubing size, or specified single source equipment.

1.3 *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.* Specific hazard statements are given in 7.7, 7.10.2.2, 8.3.4.2, 8.4.4.3, 9.2.6, 9.3.4.5, 12.1.1.7, 12.2.1.4, and Annex A1.

1.4 A Table of Contents follows:

¹ This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.B0.01 on Passenger Car Engine Oils.

Current edition approved Oct. 1, 2013. Published October 2013. Originally approved in 2000. Last previous edition approved in 2013 as D6593 – 13a. DOI: 10.1520/D6593-13B.

² Until the next revision of this test method, the ASTM Test Monitoring Center will update changes in the test method by means of information letters. Information letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489. Attention: Administrator. This edition incorporates revisions in all information Letters through No. 13-1.

³ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1472.

	Section
Scope	1
Referenced Documents	2
Terminology	3
Summary of Test Method	4
Significance and Use	5
Apparatus (General Description)	6
Apparatus (The Test Engine)	7
Sequence VG Test Engine	7.1
Required New Engine Parts	7.2
Reusable Engine Parts	7.3
Specially Fabricated Engine Parts	7.4
Special Engine Measurement and Assembly Equipment	7.5
Miscellaneous Engine Components-Preparation	7.6
Solvents and Cleaners Required	7.7
Assembling the Test Engine-Preparations	7.8
Assembling the Test Engine-Installations	7.9
Engine Installation on the Test Stand	7.10
Engine Fluids (Supply/Discharge Systems)	8
Intake Air	8.1
Fuel and Fuel System	8.2
Engine Oil and Engine Oil System	8.3
Coolants	8.4
Measurement Instrumentation	9
Temperatures	9.1
Pressures	9.2
Flow Rates	9.3
Fuel Consumption	9.4
Speed and Load	9.5
Exhaust Gas	9.6
Humidity	9.7
Miscellaneous Laboratory Equipment	10
Test Stand Calibration	11
Test Procedure	12
Pre-Test Procedure	12.1
Engine Operating Procedure	12.2
Periodic Measurements and Functions	12.3
Special Maintenance Procedures	12.4
Diagnostic Data Review	12.5
End of Test Procedure	12.6
Interpretation of Test Results	13
Parts Rating Area-Environment	13.1
Sludge Ratings	13.2
Varnish Ratings	13.3
Clogging	13.4

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



Sticking	13.5
Used Oil Analyses	13.6
Additional Measurements	13.7
Assessment of Test Validity	14
General	14.1
Used Oil Analyses-Interpretation	14.2
Blowby Flow Rate	14.3
Manifold Absolute Pressure	14.4
Fuel Consumption Rate	14.5
Oil Consumption	14.6
Engine Parts Replacement	14.7
Quality Index and Deviation Percentage	14.8
Final Test Report	15
Report Forms	15.1
Precision and Bias	16
Keywords	17
ANNEXES	
Safety Hazards	Annex A1
Control and Data Acquisition Requirements	Annex A2
Detailed Specifications and Photographs of Apparatus	Annex A3
Special Service Tools for the Test Engine	Annex A4
Test Engine Part Number Listing	Annex A5
External Oil Heat Exchanger Cleaning Technique	Annex A6
Sequence VG Report Forms and Data Dictionary	Annex A7
Dipstick Calibration	Annex A8
Critical Part Supplier List	Annex A9
Operational Data Log-Engine Oil	Annex A10
Rating Worksheets	Annex A11
Fuel Injector Flow Measurements	Annex A12
APPENDIXES	
Piston and Ring Measurements Record Forms	Appendix X1
Sources of Materials and Information	Appendix X2
Description of Scott Quarterly Gas Audit Service	Appendix X3

2. Referenced Documents

2.1 ASTM Standards:⁴

- D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure
- 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)
- D323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)
- D381 Test Method for Gum Content in Fuels by Jet Evaporation
- D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
- D525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)
- D873 Test Method for Oxidation Stability of Aviation Fuels (Potential Residue Method)
- D1266 Test Method for Sulfur in Petroleum Products (Lamp Method)
- D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
- D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
- D2789 Test Method for Hydrocarbon Types in Low Olefinic Gasoline by Mass Spectrometry

- D3237 Test Method for Lead in Gasoline by Atomic Absorption Spectroscopy
- D3525 Test Method for Gasoline Diluent in Used Gasoline Engine Oils by Gas Chromatography
- D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
- D4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants
- D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
- D4485 Specification for Performance of Active API Service Category Engine Oils
- D5059 Test Methods for Lead in Gasoline by X-Ray Spectroscopy
- D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
- D5862 Test Method for Evaluation of Engine Oils in Two-Stroke Cycle Turbo-Supercharged 6V92TA Diesel Engine (Withdrawn 2009)⁵
- D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
- D7422 Test Method for Evaluation of Diesel Engine Oils in T-12 Exhaust Gas Recirculation Diesel Engine
- G40 Terminology Relating to Wear and Erosion

2.2 ANSI Standard:⁶

- ANSI MC96.1 Temperature Measurement-Thermocouples

2.3 Other ASTM Documents:

- ASTM Deposit Rating Manual 20 (Formerly CRC Manual 20)⁷

3. Terminology

3.1 Definitions:

3.1.1 *air-fuel ratio, n*—in internal combustion engines, the mass ratio of air-to-fuel in the mixture being inducted into the combustion chambers.

3.1.1.1 *Discussion*—In this test method, air-fuel ratio (AFR), is controlled by the EEC IV engine control module.

D4175

3.1.2 *blowby, n*—in internal combustion engines, that portion of the combustion products and unburned air/fuel mixture that leaks past piston rings into the engine crankcase during operation.

3.1.3 *cold-stuck piston ring, n*—in internal combustion engines, a piston ring that is stuck when the piston and ring are at room temperature, but inspection shows that it was free during engine operation.

⁵ The last approved version of this historical standard is referenced on www.astm.org.

⁶ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

⁷ For stock #TMCMLN20, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org.

⁴ 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.

3.1.3.1 *Discussion*—A cold-stuck piston ring cannot be moved with moderate finger pressure. It is characterized by a polished face over its entire circumference, indicating essentially no blowby passed over the ring face during engine operation. **D4175**

3.1.4 *debris, n—in internal combustion engines*, solid contaminant materials unintentionally introduced into the engine or resulting from wear.

3.1.4.1 *Discussion*—Examples include such things as gasket material, silicone sealer, towel threads, and metal particles. **D5862**

3.1.5 *filtering, n—in data acquisition*, a means of attenuating signals in a given frequency range. They can be mechanical (volume tank, spring, mass) or electrical (capacitance, inductance) or digital (mathematical formulas), or a combination thereof. Typically, a low-pass filter attenuates the unwanted high frequency noise.

3.1.6 *hot-stuck piston ring, n—in internal combustion engines*, a piston ring that is stuck when the piston and ring are at room temperature, and inspection shows that it was stuck during engine operation.

3.1.6.1 *Discussion*—The portion of the ring that is stuck cannot be moved with moderate finger pressure. A hot-stuck piston ring is characterized by varnish or carbon across some portion of its face, indicating that portion of the ring was not contacting the cylinder wall during engine operation. **D4175**

3.1.7 *knock, n—in a spark ignition engine*, abnormal combustion, often producing audible sound, caused by autoignition of the air/fuel mixture. **D4175**

3.1.8 *out of specification data, n—in data acquisition*, sampled value of a monitored test parameter that has deviated beyond the procedural limits.

3.1.9 *reading, n—in data acquisition*, the reduction of data points that represent the operating conditions observed in the time period as defined in the test procedure.

3.1.10 *scoring, n—in tribology*, a severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding. **G40**

3.1.11 *scuffing, n—in lubrication*, damage caused by instantaneous localized welding between surfaces in relative motion that does not result in immobilization of the parts.

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. **D4175**

3.1.13 *time constant, n—in data acquisition*, A value which represents a measure of the time response of a system. For a first order system responding to a step change input, it is the time required for the output to reach 63.2 % of its final value.

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. **D4175**

3.1.15 *wear, n—loss of material from a surface*, generally occurring between two surfaces in relative motion, and result-

ing from mechanical or chemical action, or a combination of both. **D7422**

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *clogging, n*—the restriction of a flow path due to the accumulation of material along the flow path boundaries.

3.2.2 *enrichment, n—in internal combustion engine operation*, a fuel consumption rate in excess of that which would achieve a stoichiometric air-to-fuel ratio.

3.2.2.1 *Discussion*—Enrichment is usually indicated by elevated CO levels and can also be detected with an extended range air/fuel ratio sensor.

3.2.3 *Lambda, n*—the ratio of actual air mass induced, during engine operation, divided by the theoretical air mass requirement at the stoichiometric air-fuel ratio for the given fuel.

3.2.3.1 *Discussion*—A Lambda value of 1.0 denotes a stoichiometric air-fuel ratio.

3.2.4 *low-temperature, light-duty conditions, n*—indicative of engine oil and coolant temperatures that average below normal warmed-up temperatures, and engine speeds and power outputs that average below those encountered in typical highway driving.

3.2.5 *ramping, n*—the prescribed rate of change of a variable when one set of operating conditions is changed to another set of operating conditions.

4. Summary of Test Method

4.1 Each test engine is assembled with many new parts and essentially all aspects of assembly are specified in detail.

4.2 The test stand is equipped to control speed, torque, AFR, and various other operating parameters.

4.3 The test is run for a total of 216 h, consisting of 54 cycles of 4 h each. Each cycle consists of three stages.

4.4 While the operating conditions are varied within each cycle, overall they can be characterized as a mixture of low-temperature and moderate-temperature, light and medium duty operating conditions.

4.5 To accelerate deposit formation, the level of oxides of nitrogen in the blowby and the rate of blowby into the crankcase are significantly increased. The fresh air breathing of the crankcase is eliminated and the oil and coolant temperatures are lowered to induce condensation of water and fuel.

4.6 The performance of the test engine oil is evaluated at the end of the test by dismantling the engine and measuring the level of deposit formation.

5. Significance and Use

5.1 This test method is used to evaluate an automotive engine oil's control of engine deposits under operating conditions deliberately selected to accelerate deposit formation. This test method was correlated with field service data, determined from side-by-side comparisons of two or more oils in police, taxi fleets, and delivery van services. The same field service oils were then used in developing the operating conditions of this test procedure.



with the accelerated operating conditions, should be considered when interpreting test results.

6.1 The test engine is a Ford, spark ignition, four stroke, eight-cylinder V configuration engine with a displacement of 4.6 L. Features of this engine include an overhead camshaft, a

6.1 The test engine is a Ford, spark ignition, four stroke, eight-cylinder V configuration engine with a displacement of 4.6 L. Features of this engine include an overhead camshaft, a

cross-flow fast-burn cylinder head design, two valves per cylinder and electronic port fuel injection. It is based on the Ford Motor Co. EFI Crown Victoria⁸ passenger car engine with a displacement of 4.6 L.

6.2 Configure the test stand to accept a Ford engine, two valves per cylinder, with a displacement of 4.6 L. All special equipment necessary for conducting this test is listed herein.

6.3 Use the appropriate air conditioning apparatus to control the temperature, pressure, and humidity of the intake air.

6.4 Use an appropriate fuel supply system (Fig. 1).

6.5 The control and data acquisition system shall meet the requirements listed in Annex A2.

7. Apparatus (The Test Engine)

7.1 *Sequence VG Test Engine*—The test engine kit is available from the Ford Motor Co. (A9.1). Parts from the engine may be used for as many as four tests. A detailed listing of all parts included in the kit is given in Annex A5.

7.1.1 Non-rated parts can be replaced during the test, provided the reason for replacement was not oil related.

7.2 *Required New Engine Parts*—Use the parts listed in the engine kit (see A5.1). Use a new gasket kit for each test. Do not modify or alter test parts without the approval of Sequence V Surveillance Panel.

7.3 *Reusable Engine Parts*—The parts listed in the test stand set up kit, supplemental stand set up kit, engine dress kit, and engine finish and fastener kit can be reused (all of these can be used in numerous engine assemblies as long as they remain serviceable). See Annex A5. Crankshaft, connecting rods, timing chain covers and cylinder heads may be used for multiple engine assemblies as long as they remain serviceable. Camshafts can be used for as many as four tests as long as they remain serviceable. As the block can be used for as many as four tests, damaged threads in the block can be corrected with commercially available thread inserts.

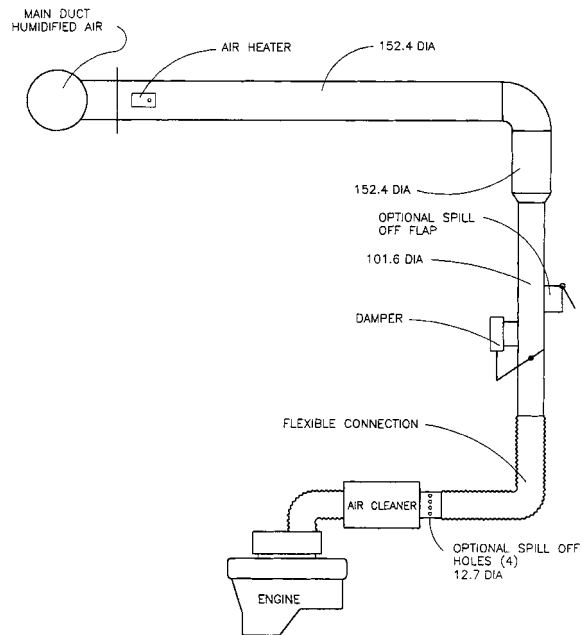
7.4 *Specially Fabricated Engine Parts*—The following subsections detail the specially fabricated engine parts required in this test method:

7.4.1 *Intake Air System* (see Fig. 2 and Figs. A3.1 and A3.2)—Intake air system shall use the stock Crown Victoria configuration with the air horn removed from the air cleaner.

7.4.2 *Camshaft Baffles* (see Fig. A3.3)—These are fabricated for attachment to the under side of the rocker cover. The clearance between the edges of the baffle and the (rocker arm cover) RAC permits a limited splash flow of oil to the top of the baffle and the RAC. Therefore, the dimensional accuracy of the baffle is important to minimize the influence on test severity. The camshaft baffle is available from the supplier listed in A9.2.

7.4.3 *Crankcase Oil Fill Port*—The crankcase oil fill port is located towards the rear of the left rocker cover. See item 8 and 9 on Fig. A3.4.

7.4.4 *Dipstick and Dipstick Tube* (see Fig. A3.6)—The dipstick has been modified for accurate oil level measurements.



NOTE 1—Dimensions are in millimetres.

FIG. 2 Typical Test Stand Intake Air Supply System

The dipstick and dipstick tube are calibrated as a pair. If either part is replaced, recalibrate the pair. Use the dipstick and dipstick tube available from the supplier listed in A9.2.

7.4.5 *Oil Pan*—Use a modified oil pan with removable baffles as shown in Fig. A3.7 from the supplier listed in A9.2.

7.4.6 *Exhaust Manifold*—The required exhaust manifolds (see A9.4), transition plates (see A9.3) and exhaust system are shown in Figs. A3.15 and A3.16. A heated exhaust gas oxygen (HEGO) sensor is installed in the exhaust system after each exhaust manifold.

7.4.7 *Flywheel*—Use the flywheel listed in Annex A5.

7.4.8 *Rocker Arm Cover (RAC)*—The RAC is fabricated from stainless steel and incorporates a water jacket and bolt bosses for the camshaft baffle (see Figs. A3.3-A3.5). The RAC, bolts, and washers supplier is listed in A9.2. As the RAC is used for multiple tests, leaks to the external cooling jacket may be repaired by welding or other suitable means. Do not modify the rated surfaces of the RAC.

7.4.9 *Oil Filter*—Use a 60 µm screen type oil filter with a bypass (see Fig. A3.8) available from the supplier listed in X2.1.20.

7.4.10 *Oil Pan Insulation*—The oil pan is covered with a fiberglass insulation to reduce the effects of ambient temperature variations. The insulation supplier is listed in A9.2.

7.5 *Special Engine Measurement and Assembly Equipment*—Items routinely used in laboratory and workshop are not included. Use any special tools or equipment shown in the 1994 and 2000 Crown Victoria Service Manual⁹ for assembly. A list of these tools is shown in Annex A4. Complete any assembly instructions not detailed in Section 7 according to the instructions in the 1994 and 2000 Crown Victoria Service Manual.

⁸ Ford Crown Victoria is a product of the Ford Motor Co., Dearborn, MI 48121.

⁹ Available from Ford and Lincoln-Mercury Dealerships.

7.5.1 Piston Ring Positioner—Use the piston ring positioner to locate the piston rings from the cylinder block deck surface by 28.5 mm. This allows the compression rings to be positioned in a consistent location in the cylinder bore before measurement. Fabricate the positioner according to the details shown in [Fig. A3.9](#).

7.5.2 Piston Ring Grinder—A ring grinder is required for adjusting ring gaps. A suitable ring grinder is noted in [7.8.5.1](#).

7.5.3 PCV Valve Flow Rate Device:

7.5.3.1 Use this device to verify the flow rate of the PCV valve before the test and measure the degree of clogging after the test. Fabricate the device according to the details shown in [Fig. A3.10](#). The device shall have a full scale accuracy of 5 % and a resolution of 0.05 L/s (see [7.6.7](#)).

7.5.3.2 Calibrate the flow rate device once every six months against a standard traceable to NIST.

7.5.4 Engine Service Tools—A complete list of special tools for the test engine is shown in [Annex A4](#). The tools are available from a Ford dealership. These are designed to aid in performing several service items, in addition to the following specific service items that require special tools to perform the functions indicated (if not self-explanatory).

7.5.5 A total of four master bores are required for verifying the cylinder bore measurement device, for determining ring gap increase for the rings in cylinders 1 and 8, and for determining piston to bore clearance. Master bores are sized according to piston oversize as follows:

For 0.125 mm piston	90.345 mm
For 0.25 mm piston	90.470 mm
For 0.375 mm piston	90.595 mm
For 0.50 mm piston	90.700 mm

7.5.5.1 Maintain the master bores in a temperature controlled room.

7.5.6 Oil Screen Blowdown Device—Use the device available from the supplier listed in [A9.3](#) to blow a controlled amount of compressed air across the oil screen to remove any oil that is retained on the oil screen after allowing it to drain.

7.5.7 Engine Parts Cleaning—Clean the engine block and cylinder heads using Model Number 300 LX-P-2x dishwasher type parts cleaning machine or similar apparatus. See [X2.1.12](#).

7.5.8 Cylinder Hone—Use a Sunnen CV-616 for cylinder bore resizing and finishing.^{10,11}

7.5.9 Connecting Rod Heater—The piston pins are fixed to the connecting rods with an interference fit. A connecting rod heater^{12,11} is required to facilitate installation of the piston pins and prevent piston distortion.

7.6 Miscellaneous Engine Components-Preparation:

7.6.1 Engine Build-Up and Measurement Area-Environment—The ambient atmosphere of the engine buildup and measurement areas shall be reasonably free of contaminants. A relatively constant temperature (within $\pm 3^\circ\text{C}$) is

necessary to ensure acceptable repeatability in the measurement of parts dimensions. To prevent moisture forming on cold engine parts that are brought into the buildup or measurement areas, maintain the relative humidity at a nominal maximum of 50 %.

7.6.2 Intake Manifold and Throttle Body:

7.6.2.1 The required intake manifold modifications entail blocking off the EGR port (block off plate shown in [Fig. A3.11](#)) and the coolant bypass port. Block coolant bypass port in intake manifold by tapping the hole and installing a ½ in. NPT pipe plug. Replace the idle air bypass motor with the idle load control system. A schematic of the system and the idle air block off plate are shown in [Fig. A3.12](#) and [Fig. A3.13](#), respectively.

7.6.2.2 Clean the butterfly and bore of the throttle body with solvent ([7.7.1](#)) and air-dry before each test. Do not disassemble the throttle body as this will cause excessive wear on the components. The idle air screw can be removed for the cleaning process. Fully close the idle air screw during test operation.

7.6.2.3 There is no specific life for the throttle body. However, the clearance between the bore and the butterfly will eventually increase and render the body unserviceable. When the clearance becomes too great to allow control of speed, torque, and air-fuel ratio during Stage III, discard the throttle body.

7.6.2.4 If throttle assembly F8ZU-9E926-AD is used, perform the following modifications:

(1) Remove the throttle position sensor from the throttle assembly, retaining the two attaching screws.

(2) Install throttle position sensor with part number F2AF-9B989-AA.

(3) Close the bleed air hole by either soldering shut or filling with an epoxy.

7.6.3 Rocker Arm Cover:

7.6.3.1 Before each test, inspect the coolant jacket. If a deposit or film is present, then clean the RAC coolant jacket with a commercially available de-scaling cleaner, neutralizer, and inhibitor ([8.4.4.1](#)). An example of an acceptable cleaner is detailed in [7.7.3](#).

7.6.3.2 Submerge the RAC in agitated organic solvent (see [7.7.2](#)) until clean (approximately 1 h). Rinse the parts thoroughly with hot water ($> 60^\circ\text{C}$). Rinse the RAC with degreasing solvent ([7.7.1](#)) and allow to air-dry. Inspect the appearance of the inside of the RAC. If the before test rating is less than ten on the ASTM varnish rating scale (ASTM Deposit Rating Manual 20), polish the RAC with Scotch Brite General Purpose Hand Pad #7447^{13,11} to achieve a dull finish. Rinse with degreasing solvent ([7.7.1](#)) and allow to air-dry before use.

7.6.4 Camshaft Baffle—Submerge the camshaft baffles in agitated organic solvent (see [7.7.2](#)) until clean (approximately 1 h). Rinse the parts thoroughly with hot water ($> 60^\circ\text{C}$). Rinse the camshaft baffles with degreasing solvent ([7.7.1](#)) and allow to air-dry. Inspect the appearance of the top surface of the camshaft baffle. If the before test rating is less than ten on the ASTM varnish rating scale (ASTM Deposit Rating Manual

¹⁰ The sole source of supply of the Sunnen CV-616 honing machine known to the committee at this time is Sunnen Inc., 7910 Manchester, St. Louis, MO 63143.

¹¹ 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.

¹² The sole source of supply of the connecting rod heater (Sunnen Model CRH-50) and pin installation tool known to the committee at this time is Sunnen, Inc., 7910 Manchester, St. Louis, MO 63143.

¹³ Scotch Brite is a trademark of 3M Corporate Headquarters, 3M Center, St. Paul, MN 55144-1000.

20), polish the camshaft baffle with Scotch Brite General Purpose Hand Pad #7447^{13,11} to achieve a dull finish. Rinse with degreasing solvent (7.7.1) and allow to air-dry before use.

7.6.5 Oil Pan—Submerge the oil pan in agitated organic solvent (see 7.7.2) until clean (approximately 1 h). Rinse the part thoroughly with hot water (> 60 °C). Rinse the oil pan with degreasing solvent (7.7.1) and allow to air-dry.

7.6.6 Oil Pan Baffle—Submerge the oil pan baffle in agitated organic solvent (see 7.7.2) until clean (approximately 1 h). Rinse the part thoroughly with hot water (> 60 °C). Rinse the oil pan baffle with degreasing solvent (7.7.1) and allow to air-dry.

7.6.7 PCV Valve—Measure and record the flow rates of the PCV valve with the calibrated flow device described in 7.5.3 and Fig. A3.10. Measure the flow rate at (25 and 60) kPa vacuum. Because of the hysteresis in the PCV valve spring, make the vacuum adjustments in one direction only. Measure the flow rate twice and average the readings. Reject any PCV valve that does not exhibit an average flow rate of (90 to 140) L/min at 25 kPa and (30 to 50) L/min at 60 kPa.

7.6.8 Water Pump Drive System—Use only the pulleys provided in the Sequence VG test stand set-up kit (see Annex A5), crankshaft, water pump, grooved idler and tensioner, and a five or six groove belt, 956 mm in length to ensure that the water pump rotates at the proper speed and direction.

7.6.9 Engine Coolant Temperature Sensor—Modify engine coolant temperature sensor by attaching a relay and a resistor of 13 kΩ between the ECT sensor and the EEC as shown in Fig. A3.14.

7.6.10 Front Cover—Modify front cover to facilitate installation of tensioner, idler, and water pump drive belt. Since the belt is routed differently from the stock location some bolt bosses may need to be altered to clear the shorter belt and the tensioner. These bolt bosses are used to attach the front end accessory drive components that are not used for this test.

7.6.11 Oil Separators—Clean with degreasing solvent (7.7.1) and allow to air-dry.

7.6.12 Timing Chain Cover—Submerge the timing chain cover in agitated organic solvent (see 7.7.2) until clean (approximately 1 h). Rinse the part thoroughly with hot water (> 60 °C). Clean with degreasing solvent (7.7.1) and allow to air-dry.

7.7 Solvents and Cleaners Required—No substitutions for 7.7.1 – 7.7.5 are allowed. (**Warning**—Use adequate safety provisions with all solvents and cleaners. See Annex A1.)

7.7.1 Solvent—Use only mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content (0 to 2) vol %, Flash Point (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.

7.7.2 Organic Solvent, Penmul L460. (**Warning**—Combustible. Health hazard.)^{14,11}

7.7.3 Dearsol 134 Acidic Cleaner^{15,11} with Inhibitor, RAC cooling jacket internal cleaner. (**Warning**—Combustible. Health hazard.)

7.7.4 Cooling System Cleaner, Dupont or equivalent, for cleaning cooling system components external to the engine. (**Warning**—Caustic. Health hazard.)

7.7.5 Parts Cleaning Soap,^{16,11} NAT-50 or PDN-50 have been found to be acceptable. (**Warning**—Health hazard.)

7.8 Assembling the Test Engine-Preparations—Use the test engine obtained from the supplier in 7.1. If this is the first test on a new engine, disassemble the engine in accordance with the 1994 and 2000 Crown Victoria Shop Manuals. Number the connecting rod bearing caps to the corresponding cylinders. Retain the following parts from the new engine: oil pump, main bearings, connecting rod bearings, thrust washer, oil screen spacer, oil filter gasket, oil pan gasket, exhaust manifold gasket, roller followers, valve lash adjusters, rear seal housing, crankshaft gear, timing chains, tensioners, chain rails, plus the following parts that can be used for multiple tests: cylinder block, crankshaft, connecting rods, ignition ring sensor, crankshaft and camshaft timing sensors, crankshaft vibration damper, crankshaft bolt and washer, oil filter adapter and the water pump and pulley.

7.8.1 Parts Selection—Instructions concerning the use of new or used parts are detailed in 7.1.1, 7.2, and 7.3.

7.8.2 Sealing Compounds—Use a silicon-based sealer as needed between the rear seal housing-cylinder block, the cylinder block-cylinder head-front cover interfaces, cylinder head-front cover-rocker cover interfaces, and cylinder block-front cover-oil pan interfaces.

7.8.2.1 Use silicon-based sealer sparingly since it can elevate the indicated silicon content of the used oil.

NOTE 1—Non-silicon liquid or tape thread sealers can be used on bolts and plugs.

7.8.3 Gaskets and Seals—Install new gaskets and seals during engine assembly.

7.8.4 Block Preparations—Inspect block, including oil galleries for debris and rust. Remove any debris or rust that is found. Remove oil gallery plugs. Removal of coolant jacket plugs is left to the discretion of the laboratory. Enlarge the chamfers around the top of the cylinder bore. Spray the block with degreasing solvent (see 7.7.1). Spray block with a 50/50 mixture of degreasing solvent (see 7.7.1) and EF-411.^{17,11} Install the stress plates with cylinder heads and torque to (37 to 43) N·m with an additional 180° in two 90° rotation increments. Head bolts may be used for a maximum of five times. Install the main bearing caps and torque to 40 N·m, with an additional 90° rotation. Install the jackscrews and torque to (8 to 11) N·m.

7.8.4.1 Honing:

¹⁵ The sole source of supply of Dearsol 134 Acidic Cleaner known to the committee at this time is Dearborn Div., subsidiary of W. R. Grace and Co., 300 Genesee St., Lake Zurich, IL 60047.

¹⁶ The sole source of supply of the soap (NAT-50 or PDN-50) known to the committee at this time is Better Engineering Manufacturing, 8361 Town Court, Baltimore, MD 21236.

¹⁷ The sole source of supply of Mobil EF-411 oil known to the committee at this time is Mobil Oil Corp., 3225 Gallows, Fairfax, VA 22037.

¹⁴ The sole source of supply of Penmul L460 known to the committee at this time is Penetone Corp., P.O. Box 22006, Los Angeles, CA 90022.



(1) Install the block in the honing machine. Use a Sunnen CV-616 honing machine to hone the block. Install the block with the right cylinder bank on the outside and the front of the block to the right. Verify the honing oil has been changed within the past 15 h, and change if necessary.

(2) Set the honing machine to flow Sunnen LP8X fluid at a nominal rate of 7 L/min. Set the feed rate to 4 with 57 strokes per minute and spindle speed of 170 r/min. Set the stroke for 133.35 mm and lower the block for 10 mm overstroke.

(3) Install EHU512 stones. Typical pressures of 25 to 40 units have found to be acceptable. Hone the right bank in the following order, cylinder 1, 3, 4 and 2. Hone the left bank in the following order, Cylinder 7, 5, 8 and 6. Following this order will minimize the possibility of over heating one area of the block. The block may be rotated in the honing machine and does not have to be removed to hone the other bank.

(4) Install JHU725 stones and hone for approximately five strokes at 20 to 25 units of pressure in the order described in 7.8.4.1(3).

(5) Install a plateau hone brush and hone at 25 to 30 units of pressure to obtain a surface finish of (8 to 13) μm . Typically 45 strokes have provided acceptable results.

(6) Measure the cylinder bore using a bore ladder shown in Fig. A3.28. Measure bore both longitudinally and transversely. Determine the bore diameter for piston clearance purposes by adding the middle and bottom transverse bore measurements and dividing by two. Measure the piston skirt 42 mm from the top of the piston. Subtract this value from the bore measurement and verify that the piston-to-bore clearance is within (0.020 to 0.046) mm. Re-hone the block or choose a different diameter piston to obtain this clearance.

(7) Determine bore taper by measuring the difference between top-to-bottom, top-to-middle and middle-to-bottom, transversely. Record the maximum value of the readings. Verify that the maximum taper does not exceed 0.006 mm. Determine out-of-round by subtracting the difference between the transverse and longitudinal bore measurements at the top, middle and bottom. Record the maximum value. Verify that the cylinder bore out-of-round does not exceed 0.020 mm.

7.8.4.2 Post Honing Cleaning:

(1) Remove the block from the honing machine. Remove the stress plates, jackscrews, main bearing bolts and caps. Remove jackscrews from the main bearing caps.

(2) Clean with degreasing solvent (see 7.7.1).

(3) Place block in dishwasher type cleaning machine (see 7.5.7) and wash using soap (7.7.5) for 30 min at 60 °C.

(4) Spray block with 50/50 solution of EF-411 and degreasing solvent (see 7.7.1).

7.8.4.3 Crankshaft Installation:

(1) If the crankshaft has been used previously, soak the crankshaft in organic solvent (see 7.7.2) for a minimum of 24 h.

(2) Spray the crankshaft with degreasing solvent.

(3) Measure the main journals and verify that the diameters are (67.483 to 67.503) mm.

(4) Measure the connecting rods journals and verify that the diameters are (52.988 to 53.003) mm.

(5) Install the main bearings.

TABLE 1 Required Piston and Piston Ring Dimensions

Ring side clearance, avg	0.0508–0.1016 mm
Ring gap delta	0.045–0.055 mm

(6) Install the main bearing caps and torque to 40 N·m, with an additional 90° rotation.

(7) Install the jack screws and torque to (9 to 11) N·m.

(8) Install the jack screw bolts and torque to (19 to 23) N·m.

7.8.4.4 Piston Installation:

(1) Examine the skirt surfaces for discoloration. Remove any discoloration by rubbing the piston with a Scotch Brite #7445 pad.^{13,11} Reject any pistons from which staining cannot be removed.

(2) Install the piston on the connecting rod using Sunnen Model CRH-50 connecting rod heater.^{12,11}

7.8.5 Piston Rings:

7.8.5.1 Ring Gap Adjustment:

(1) Cut the top and second compression ring gaps as required to obtain the specified blowby flow rate, using the Sanford Piston Ring Grinder.^{18,11} Record the ring side clearance(s) and new ring gap(s) on any ring(s) adjusted. Enter the new dimension(s) on the Supplemental Operational Data sheets. Typical forms for recording these dimensions are shown in Appendix X1. Ensure that the required ring gap delta and ring side clearance are attained (Table 1). Replace rings if smaller ring gaps are required. Measure the rings for cylinders 1 and 8 in the master bore. These measurements are required to determine the ring gap increase.

(2) Using the master bore, measure the ring gaps for the top rings in cylinders 1 and 8 prior to the start of the test.

7.8.5.2 Piston Ring Cutting Procedure:

(1) Cut the ring to the required gap using the ring cutting burr^{19,11} rotated at a rated speed of 3450 r/min. Remove equal amounts from both sides of the gap. Make final cuts on the down stroke only. The ring is cut with a maximum increment of 0.125 mm until the desired ring gap is achieved.

(2) After the rings are cut remove the ring from the cutting tool, debur using a Sunnen soft stone^{20,11} and wipe with a dry towel.

7.8.5.3 Installation:

(1) Install the oil control rings and the compression rings on the pistons with the gaps located over the piston pin. Position the gaps at approximately 180° intervals, with the top compression ring gap toward the rear. Install the rings using a ring spreader tool, keeping the rings' surfaces parallel to the ring groove in the piston.

(2) If any rings require replacement, then measure and record the new ring gap(s) and ring side clearance(s). Calculate ring side clearance by determining the difference between the ring groove width and the associated ring width.

¹⁸ The sole source of supply of the Sanford Piston Ring Grinder known to the committee at this time is Sanford Mfg. Co., 300 Cox St., P.O. Box 318, Roselle, NJ 07203.

¹⁹ The sole source of supply of the 3/16 in. carbide ring cutting burr, No. 74010020 known to the committee at this time is M. A. Ford.

²⁰ The sole source of supply of Sunnen soft stone, No. JHU-820 known to the committee at this time is Sunnen, Inc., 7910 Manchester, St. Louis, MO 63143.

7.8.6 Cylinder Bore Measurements—Measure the cylinder 1 and 8 cylinder bores with the bearing caps in place. Clean the bores with a dry rag. The bores shall be clean and dry when they are measured. Use a bore gage micrometer to determine the diameter of cylinder 1 and 8 at the top, middle and bottom of the second ring travel in the transverse direction.

7.9 Assembling the Test Engine-Installations—Assemble the engine according to the instructions in the service manual unless specified herein.

7.9.1 Intake Manifold—Block the coolant bypass port in the intake manifold at the thermostat housing (7.6.2.1).

7.9.2 Piston Installation—Install pistons in proper cylinders, taking care to ensure rings are not damaged during installation. Wipe the cylinders with EF-411. Install the pistons and connecting rods with the notches facing the rear. Install the rod bearing caps and torque to (40 to 45) N·m with an additional 90° rotation.

7.9.3 Oil System Components—All oil system components in the engine are production configuration with the exception of the oil pan that contains removable baffles.

7.9.4 Cylinder Head Installation—Cylinder heads are obtained from the supplier in A9.3. Heads may be used for multiple tests, as long as they remain serviceable.

(1) Disassemble heads and inspect for any debris or other deleterious materials and remove as necessary.

(2) If the cylinder heads have not been previously used, spray the cylinder heads with degreasing solvent (see 7.7.1). If the cylinder heads have been used previously, soak in organic solvent (see 7.7.2) for 24 h, place the cylinder heads in the dishwasher type cleaning machine (7.5.7) using soap (7.7.5) at 60 °C for 30 min. Promptly remove the cylinder head from the cleaning machine and spray with a 50/50 mixture of EF-411 and degreasing solvent (7.7.1).

(3) Determine valve guide clearance at the top and middle of the heads on the transverse side of the guide. Reject any heads that exceed (0.020 to 0.069) mm for intake and (0.046 to 0.095) mm for exhaust.

(4) Assemble the cylinder heads in accordance with the manual. Verify valves are properly seated. The method is left at the discretion of the laboratory.

(5) Install cam bearings. Camshafts can be installed at this time.

7.9.4.1 Heads may also be procured from the source listed in A9.5. Modify heads from this source to accept cam bearings, and have new valve guides installed, by the source listed in A9.6.

(1) Conduct a successful reference oil test prior to using these heads for all testing.

7.9.5 Camshaft and Related Components—The camshafts used in this test are for a Ford truck engine with a displacement of 4.6 L and are different than what is shown in the service manual. The camshaft sprocket is an integral part of the camshaft. Install the camshaft in the same manner as described in the service manual with the exception of the sprocket installation.

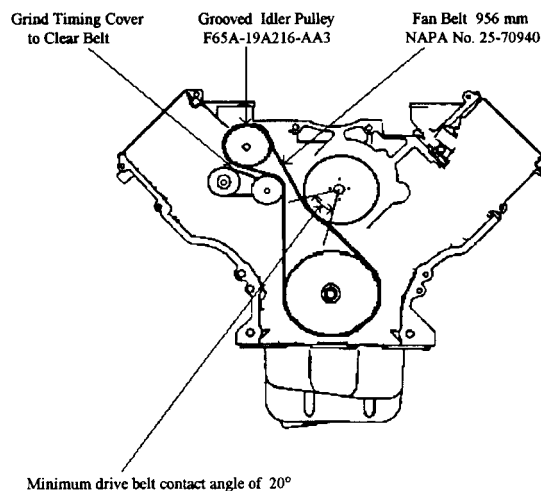


FIG. 3 4.6 L Water Pump Drive Arrangement

7.9.5.1 Prior to the timing chain installation, clock the crankshaft keyway at 315° of crankshaft angle (TDC of piston No. 1) as described in the service manual.⁹ Rotate the crankshaft clockwise only, when viewed from the front.

7.9.5.2 When viewed from the rear, maintain the camshaft D-slot shall at a 90° clocked position relative to the cam cover rail.

7.9.5.3 When installing the timing chains ensure that the timing marks (mentioned above) remain aligned. Install L.H. crankshaft sprocket with timing chain on the crankshaft. Drape the L.H. timing chain over camshaft sprocket. The timing chain shall hang below the tensioner dowel.

7.9.5.4 Repeat the procedure in 7.9.5.3 for the right hand timing chain. After installation, the timing chain shall hang between the chain guide and the tensioner dowel.

NOTE 2—There should be a minimum of chain slack on the tension side between the two sprockets.

7.9.6 Rocker Arm Cover and Baffle—Fasten the camshaft baffle to the rocker cover. Cut off the tabs from the rocker cover gasket and install it in the gasket groove on cover rail. Install rocker arm cover on the cylinder head and confirm that the baffle does not contact any valve train components. Using new rubber washers on the bolts, torque the bolts to (8 to 12) N·m (the rubber washers are not reusable). The two rocker covers are different, ensure that the correct cover is installed on the correct head (Figs. A3.4 and A3.5).

7.9.7 Oil Pan, Baffles, and Insulation—Install front and rear oil pan baffles to the oil pan as shown in Fig. A3.7. Install front baffle first. Install the oil pan according to the procedure in the service manual. Install the oil pan insulation over the oil pan.

7.9.8 Water Pump, Water Pump Drive—Install the water pump and pulley, the crankshaft pulley, and the idler and tensioner according to the service manual. These are the only components needed to drive the water pump. All other production front end accessory drive components can be discarded. Pull back tensioner and install water pump drive belt as shown in Fig. 3. Ensure that there is a minimum contact angle of 20° between the drive belt and the water pump pulley.

7.10 *Engine Installation on the Test Stand*—Functions that are to be performed in a specific manner or at a specific time in the assembly process are noted.

7.10.1 *Mounting the Engine on the Test Stand*—Mount the engine on the test stand so that the flywheel friction face is $(4.0 \pm 0.5)^\circ$ from vertical, with the front of the engine higher than the rear. The engine mounting system should be designed to minimize engine vibration at (700 to 2900) r/min. Couple the engine directly to the dynamometer through a driveshaft. The engine cannot be used to drive any external engine accessory other than the water pump.

7.10.2 *Exhaust System and Gas Sampling Fittings*:

7.10.2.1 The required exhaust manifold, a typical exhaust system, and fittings for exhaust gas sampling are illustrated in **Figs. A3.15 and A3.16**. Exhaust components should be constructed of either solid or bellows pipe/tubing. Other type flexible pipe is not acceptable.

7.10.2.2 The exhaust gas sample probes can be used until they become unserviceable. If the existing probes are not cracked, brittle, or deformed, clean the outer surface and clear all port holes. Check the probes for possible internal obstruction and reinstall the probes in the exhaust pipe. Stainless steel probes are generally serviceable for several tests; mild steel probes tend to become brittle after one test. Exhaust gas is noxious. (**Warning**—Any leaks in the connections to the sample probe will result in erroneous readings and incorrect air-fuel ratio adjustment.)

7.10.3 *Oil Dipstick and Tube*—Install modified oil dipstick and dipstick tube, described in 7.4.4, in the engine block at the production location and attachment points.

NOTE 3—The intake manifold, the rocker arm covers, and the exhaust manifolds can be installed after the engine is installed on the test stand.

7.10.4 *Fuel Management System*:

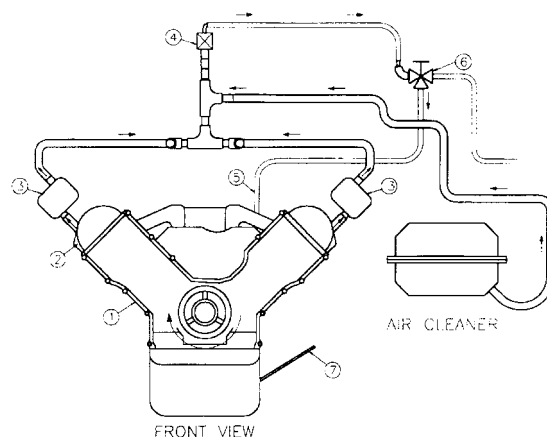
7.10.4.1 *Fuel Rail Injectors*:

(1) The fuel injectors can be used for multiple tests providing they meet the requirements delineated in **Annex A12**. Fuel injectors that have caused misfires in previous tests should be cleaned before reuse. Commercial injector cleaning fluids and flow benches are available from various manufacturers. *Do not use injector cleaning fluids while operating the engine.*

(2) Inspect the O-rings to ensure they are in good condition and will not allow fuel leaks. Install the fuel injectors into the fuel rail and into the intake manifold.

7.10.4.2 *Electronic Engine Control (EEC) System*—The fuel injector operation, cylinder firing, pulse width, ignition timing, and so forth, are controlled by the specified EEC. The EEC module is available from the supplier listed in **A9.2**.

(1) The EEC power shall come from a battery (13.5 ± 1.5) V or a power supply that does not interrupt/interfere with proper EEC operation. Connect the EEC battery/power supply to the engine wire harness with an appropriate gage wire of the shortest practical length so as to maintain a dc voltage of (12 to 15) V on the STAR tester and minimize EEC electrical noise problems. Ground the EEC ground wire to the engine. From the same ground point, run a minimum two gage wire back to the battery negative to prevent interruption/interference of the EEC operation. The power supply can also be used for the Lambda measuring devices.



- NOTE—Legend
- (1) Blowby flows through 6 oil drain back passages in cylinder block and head and through the front cover.
 - (2) Cam baffle shields cover from oil.
 - (3) Oil separator prevents loss of oil into PCV valve.
 - (4) PCV valve flows approximately 120 L/min. Blowby rate is (60 to 70) L/min.
 - (5) Air vent provides balance of flow by PCV valve. When excessive plugging of the PCV valve occurs excess blowby is vented to the engine air intake.
 - (6) Three-way ball valve routes blowby to the intake manifold and provides a connection point for blowby measurement apparatus.
 - (7) Dipstick tube is location for crankcase pressure measurement.

FIG. 4 Functional Description of Closed Crankcase Ventilation System

7.10.5 *Spark Plugs*—Install new Motorcraft AWSF-32PP spark plugs that have been gapped to 1.37 mm. Torque the spark plugs to (9 to 12) N·m. Install the spark plug wiring harness. Do not use anti-seize compounds on spark plug threads.

NOTE 4—The components used in the ignition system do not require modification.

7.10.6 *Crankcase Ventilation System*—The crankcase ventilation system is a closed system allowing blowby to be vented from the crankcase and drawn into the intake manifold. A description of the system operation is shown in **Fig. 4**. Install PCV system components and hoses as shown in **Fig. A3.17**.

7.10.6.1 *Oil Separator and PCV Valve*—Use two clean oil separators and a new PCV valve listed in the parts list **Annex A5**. Oil separators can be reused as long as they remain serviceable.

7.10.6.2 *Three-Way Valve*—Install a clean three-way valve and attach the PCV valve hose. Install the remaining PCV valve hose between the three-way valve and the intake manifold (see **Fig. A3.17**). Do not allow the hose to flatten at the bend after installation.

7.10.7 *Intake Air Components*—Install the throttle body, air cleaner assembly, and new air cleaner. Modify the air cleaner assembly to accept fittings for inlet air temperature thermocouple, pressure tap and fresh air, as shown in **Fig. A3.1**.

7.10.8 *External Hose Replacement*—Inspect all external hoses used on the test stand and replace any hoses that have become unserviceable. Check for internal wall separations that could cause flow restrictions. Check all connections to ensure security.

TABLE 2 Sequence VG Operating Specification

Condition	Stage I	Stage II	Stage III
Duration, min	120	75	45
Engine speed, r/min	1200 ± 5	2900 ± 5	700 ± 15
Engine power, kW	record	record	1.30 ± 0.2
Manifold abs press, kPa (abs)	69 ± 0.2	66 ± 0.2	record
Engine oil in, °C	68 ± 0.5	100 ± 0.5	45 ± 1
Engine coolant out, °C	57 ± 0.5	85 ± 0.5	45 ± 1
Engine coolant flow, L/min	48 ± 2	record	record
Engine coolant pressure, kPa (gage)	70 ± 10	70 ± 10	70 ± 10
RAC coolant in, °C	29 ± 0.5	85 ± 0.5	29 ± 1
Rocker cover flow, L/min	15 ± 1	15 ± 1	15 ± 1
Intake air, °C	30 ± 0.5	30 ± 0.5	30 ± 0.5
Intake air press, kPa (gage)	0.05 ± 0.02	0.05 ± 0.02	0.05 ± 0.02
Lambda	1.00 ± 0.05	1.0 ± 0.05	0.75 ± 0.03
Blowby flow rate, avg, L/min	record	60-70	—
Intake air humidity, g/kg	11.4 ± 0.8	11.4 ± 0.8	11.4 ± 0.8
Exhaust back pressure, kPa abs	104 ± 2	107 ± 2	record
Fuel flow, kg/min	record	record	record

7.10.9 Wiring Harness—There are two wiring harnesses used on the test stand, a dynamometer harness and an engine harness. Obtain the dynamometer wiring harness from the supplier listed in [A9.2](#). The engine harness is listed in [Annex A5](#).

8. Engine Fluids (Supply/Discharge Systems)

8.1 Intake Air—Condition the intake air to (30 ± 0.5) °C, (11.4 ± 0.8) g/kg humidity, and pressurized to (0.05 ± 0.02) kPa.

8.1.1 Capacity—The supply system shall be capable of delivering 110 L/s of conditioned air, while maintaining the intake/air parameters detailed in [Table 2](#). The test stand intake air duct system is shown in [Fig. 2](#).

8.1.2 Dew Point—The dew point may be measured in the main system duct or at the test stand. If the dew point is measured in the main system duct, verify the dew point periodically at the test stand. Maintain the duct surface temperature above the dew point temperature at all points downstream of the humidity measurement point to prevent condensation and loss of humidity level.

8.2 Fuel and Fuel System:

8.2.1 System Description—A schematic diagram of a typical fuel supply system is shown in [Fig. 1](#). Supply an excess volume of fuel to the fuel rail at all times. Introduce make-up fuel (fuel used by the engine) into the loop from an external source. Mix the make-up fuel with fuel that is returned from the fuel rail (fuel not used by the engine). Pump the fuel through a mixing chamber, or small heat exchanger that is used to mix the two streams and provide fuel of consistent temperature to the engine. Deliver the fuel to a high-pressure pump (Ford P/N E7TF-9C407 or E7TC-9C407), that boosts the pressure and supplies the fuel to the fuel rail.

8.2.2 Controls—Maintain the fuel temperature to the fuel rail below 50 °C. To ensure good atomization of the fuel, maintain the fuel pressure to the fuel rail above 185 kPa. In addition, the fuel pressure should be constant at all steady-state conditions to ensure good speed, power, and air-fuel ratio control.

8.2.3 Fuel Volume Required—Approximately 3300 L of sequence VG unleaded gasoline are required for each test.

TABLE 3 VG Fuel Analysis

NOTE 1—Appearance, water, lead, and oxidation stability are analyzed on an absolute basis.

Parameter	Specification Band
API gravity ^A	58.7–61.2
RVP ^B	60.7–63.4 kPa
Total sulfur ^C	(0.01–0.04) mass %
Existent gum ^D	5 mg/100 mL, max
Distillation ^E	
IBP	(22.2–35.0) °C
10 %	(48.9–57.2) °C
50 %	(98.9–115.2) °C
90 %	(162.8–176.7) °C
EP	(196.1–212.8) °C
Appearance	clear and bright
Water ^F	0.01 vol %, max
Lead ^G	10 mg/L max
Oxidation stability ^H	1440 minutes, min

^A In accordance with Test Method [D1298](#) or [D287](#).

^B In accordance with Test Method [D323](#) or Automatic Reid Vapor Pressure.

^C In accordance with Test Method [D4294](#), [D1266](#), or [D2622](#).

^D In accordance with Test Method [D381](#).

^E In accordance with Test Method [D86](#).

^F In accordance with Test Method [D6304](#).

^G In accordance with Test Method [D3237](#) or [D5059](#).

^H In accordance with Test Method [D525](#).

8.2.4 Fuel Batch Approval Process—Obtain fuel from the supplier listed in [X2.1.5](#). Each new batch of fuel is approved by the following process:

8.2.4.1 Before initial blending, typical samples of the fuel blend components are analyzed, and the data are compared with predetermined physical specifications. A small amount of fuel mixture is then blended, analyzed, and compared to predetermined specifications. The ASTM Test Monitoring Center (TMC) confirms the acceptability of the fuel mixture analytical data and authorizes blending of the entire batch for engine testing. After the entire batch is blended, the TMC confirms the acceptability of the analytical data of the entire fuel batch, and authorizes the engine test fuel approval program.

8.2.4.2 A sample of the fuel is shipped to two designated independent laboratories. A designed program involving more than one calibration test is completed using reference oils selected by the TMC. (The Sequence V Reference Oils and Fuels Sub Panel, ASTM D02.B0.01.05, is involved in the design of the program.) The TMC reviews the test results and if acceptable, authorizes the fuel supplier to notify potential purchasers of the approval status of the fuel batch.

8.2.5 Fuel Batch Analysis—Upon receipt from the supplier, it is the responsibility of the laboratory to analyze each fuel shipment to determine the value of the parameters shown in [Table 3](#) (except sulfur, oxidation stability, and distillation). Compare the results to the values obtained by the supplier on that particular batch. The results should be within the specification band shown in [Table 3](#) beside each parameter. This provides a method to determine if the fuel batch is contaminated or has aged prematurely. If any results fall outside the tolerances shown in [Table 3](#), the laboratory should contact the TMC for help in resolving the problem. One potential method for resolving the problem is to obtain an analysis at the fuel supplier's laboratory of the *as received* fuel sample.

8.2.6 Laboratory Storage Tank Fuel Analysis—Analyze the contents of each fuel storage tank that contains fuel used for calibrated Sequence VG tests bimonthly. Analyze fuel in run tanks, those with a direct feed line to test engines, every month. Laboratories should take composite samples using [Table 1](#) in Practice [D4057](#), as a guideline. The fuel supplier shall have the capability to analyze the fuel samples using the test methods specified in [Table 3](#) and this section. The fuel supplier shall provide an adequate supply of fuel sample containers with packaging and pre-addressed return labels to each Sequence VG laboratory. Upon receipt of all fuel samples required in [8.2.6](#) from the laboratories, the fuel supplier shall perform the following analyses, report the results to the submitting laboratory, and tabulate the results in a database.

Reid vapor pressure (Test Method D323)	Washed gums (Test Method D381)
API gravity (Test Method D287 or D1298)	Unwashed gums (Test Method D381)
Distillation (Test Method D86)	
Lead (Test Method D3237 or D5059)	

8.2.6.1 When results from the physical and chemical tests listed above appear to differ significantly from the expected results, analyze a second sample, or conduct the following tests, or do both:

Hydrocarbon speciation (Test Method D2789)
Oxidation stability (Test Method D525)
Potential gums (Test Method D873)

8.2.6.2 The fuel supplier shall also issue a bimonthly analysis of the fuel from the main storage tank, which should represent normal aging. The analysis shall include the parameters in [Table 3](#).

8.2.6.3 Forward the results of the analyses performed in [8.2.6](#) and [8.2.6.1](#) to the TMC for inclusion in the appropriate data base.

8.2.7 Fuel Batch Shipment and Storage—Ship the fuel in containers with the minimum allowable venting as dictated by all safety and environmental regulations, especially when shipment times are anticipated to be longer than one week. Store the fuel following all applicable safety and environmental regulations.

8.3 Engine Oil and Engine Oil System:

8.3.1 Test Oil Description:

8.3.1.1 The test oil sample shall be uncontaminated and representative of the lubricant formulation being evaluated.

8.3.1.2 A minimum of 7.5 L of new oil is required to complete the test. A 20 L sample of new oil is normally provided to allow for inadvertent losses.

8.3.2 System Description:

8.3.2.1 Configure the oil system as shown in [Fig. A3.8](#) to minimize stand-to-stand variations that could influence test severity. Measure engine oil pressure at the points shown in [Fig. 5](#). The oil flow rate and external pressure drop are controlled by specifying the volume, plumbing configuration, and orientation of the heat exchanger. The oil flow out of the vertically mounted heat exchanger shall be level with the oil-in thermocouple. The lengths of the lines are not specified although the line diameters are indicated in [Fig. A3.8](#). The line length and diameter have a large influence on the volume of the

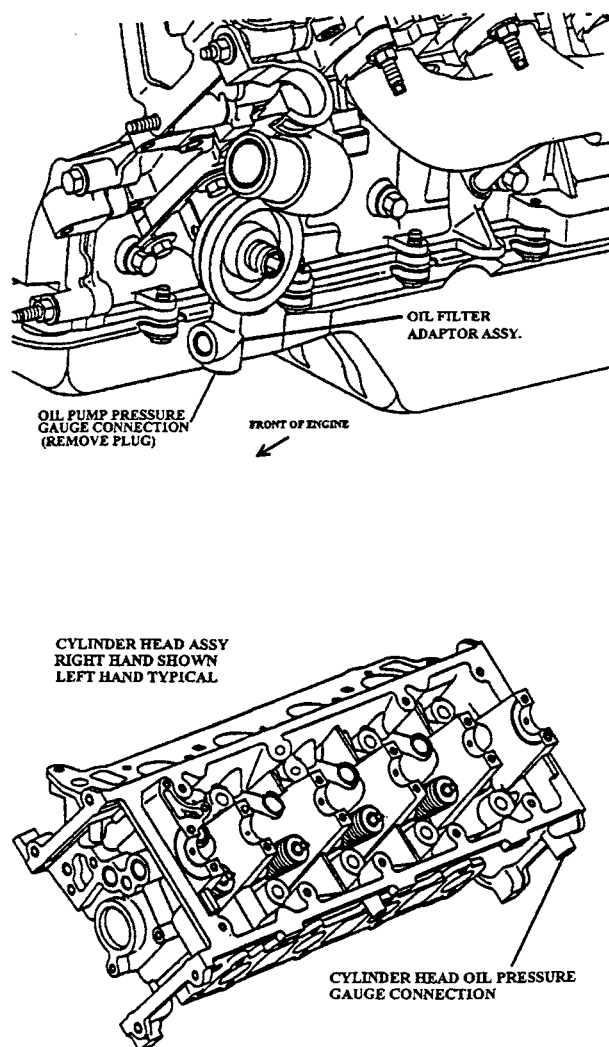


FIG. 5 Oil Pressure Gage Connections

external system. The internal volume of the entire external system shall be (540 ± 30) mL.

8.3.2.2 Use oil filter adapter OHT6A-0007-1 ([X2.1.11](#)), oil filter OHT6A-012-2 ([X2.1.11](#)) or OHT6A-012-2LS ([X2.1.11](#)). Be sure all hoses and fittings on the oil heat exchanger are properly connected and secure. *The external oil system components shall not be brass, copper or galvanized, as these metals may influence used oil analysis.*

8.3.3 Heat Exchanger—The heat exchanger has been chosen to minimize the volume of the external system. The heat exchanger has adequate but not excessive capacity to control the oil temperature. The system requires a high level of maintenance to provide adequate cooling, especially when process water temperature is high. An effective, well-maintained process water control system is necessary to achieve the specified oil temperatures. Use vertically mounted ITT heat exchanger P/N 5-160-02-008-002 ([X2.1.9](#)). Configure the system to allow the process water to flow through the vertical tubes and the oil through the shell. This orientation facilitates cleaning of the tubes.

8.3.4 System Cleaning:

TABLE 4 Test Ramping Requirements^A

Stage III to I	
Engine speed	1195 r/min within (5 to 20) s
Manifold absolute pressure	68.8 kPa within (20 to 80) s
Oil inlet temperature	67.5 °C within (8 ± 2) min
Coolant outlet temperature	56.5 °C within (6 ± 2) min
Rocker arm cover inlet temperature	29 °C within 17 min
Stage I to II	
Engine speed	2895 r/min within (30 to 90) s
Manifold absolute pressure	66 ± 0.2 kPa within (60 to 150) s
Oil inlet temperature	99.5 °C within (7 ± 2) min
Coolant outlet temperature	84.5 °C within (7 ± 2) min
Rocker arm cover inlet temperature	84.5 °C within (17 ± 2) min
Stage II to III	
Engine speed	715 r/min within (5 to 20) s
Engine power	< 3 kW at (5 to 20) s
Oil inlet temperature	46 °C within (15 ± 2) min
Coolant outlet temperature	46 °C within (9 ± 2) min
Rocker arm cover inlet temperature	30 °C within (10 ± 2) min
Lambda	0.705 to 0.765 at 15 s

^A Test Ramping Requirements Information—At the start of the III to I ramp, return the mass air flow to engine control module relay to its normal position, allowing the mass air flow sensor to provide the normal signal to the engine.

8.3.4.1 Clean the external oil cooling system thoroughly before each test. An acceptable technique for cleaning the oil heat exchanger is detailed in Annex A6. Flush and rinse the external lines before each test. The specific technique used (removed from or flushed on the stand, and so forth) is left to the discretion of the laboratory.

8.3.4.2 Regardless of the flushing technique employed, use an organic solvent (see 7.7.2) for the final flushing followed by separate rinses with hot water (> 60 °C) and degreasing solvent (7.7.1) before air-drying the components. (**Warning**—Incomplete cleaning of the external oil system may allow debris to dislodge and circulate throughout the engine during subsequent tests. Incomplete cleaning may also cause oil temperature control problems and contaminate subsequent test oils.)

8.3.5 Control Specifications—The operating conditions are specified in Table 2. Additional information concerning the oil pressure, is found in 12.5.7. Cyclic ramping specifications are detailed in Table 4.

8.4 Coolants:

8.4.1 Description—The engine coolant is equal parts of demineralized (less than 0.34 g/kg) or distilled water and a fully formulated ethylene glycol based automotive antifreeze to protect against corrosion of all system components. The RAC coolant is a solution of demineralized (less than 0.34 g/kg) or distilled water and an additive treatment of 475 mL of Pencoool 2000^{21,11} per 15 L of water.

8.4.2 General System Description —The following guidelines are common to both the engine and RAC coolant systems:

8.4.2.1 A transparent section is required to permit visual inspection of the coolant. Provide air bleeds to allow removal of entrained air. Provide a drain at the low point of the system to allow complete draining of the system.

8.4.2.2 An effective, well-maintained process water control system is necessary to achieve the specified coolant temperatures.

8.4.2.3 The system shall allow precise calibration of the flowmeters, after installation in the test stand. Avoid turbulence near the measurement meters, and the flowmeters used for calibration.

8.4.3 Engine Coolant System Description:

8.4.3.1 Configure the engine cooling system according to the schematic diagram shown in Fig. A3.18. The engine coolant system volume shall be (24 ± 2) L. This volume includes all equipment, plumbing, and the engine excluding the coolant reservoir and plumbing connecting the coolant reservoir with the main system (see Fig. A3.18). The coolant reservoir volume shall be (9.0 ± 2) L. The thermostat housing is modified to accept the coolant outlet temperature thermocouple (9.1.3). Do not install the thermostat. Block coolant bypass port in intake manifold (7.6.2.1). Inspect the water pump drive belt for defects before installation.

8.4.3.2 A radiator cap is used to limit system pressure to 105 kPa. Pressurize the coolant system to (70 ± 10) kPa at the top of the coolant reservoir (Fig. A3.18).

8.4.3.3 The engine coolant flow rate and outlet temperature are controlled in accordance with the specifications listed in Table 2. Information concerning the cooling flow rate measurement device is detailed in 9.3.2. Cyclic ramping specifications are detailed in Table 4. The coolant flow rate is measured with a venturi flowmeter (X2.1.6) and controlled with an in-line flow control valve.

8.4.3.4 As a minimum, inspect and clean the engine coolant system components, external to the engine, prior to running each reference calibration test. A specific flushing technique is not specified. However, the technique should employ a commercial descaling cleaner (7.7.3).

8.4.4 RAC Coolant System Description:

8.4.4.1 Inspect and clean the complete RAC control system prior to running each reference oil calibration test. A specific flushing technique is not specified. However, the technique should employ a commercial descaling cleaner (7.7.3).

8.4.4.2 Schematic diagrams of the RAC coolant control systems are shown in Fig. 6. Derive heat for the control system from an external source, such as hot water, steam, or an electric immersion heater.

8.4.4.3 Control the RAC coolant flow rate and inlet temperature in accordance with the specifications listed in Table 2. The coolant pressure is not specified, but design the system to minimize the pressure on the RAC and prevent distortion of the jacket. (**Warning**—Maintain the system pressure below 70 kPa to prevent distortion of the RAC jacket.)

8.5 Cyclic ramping specifications are detailed in Table 4.

8.6 Stage III Closed Loop AFR Control:

8.6.1 Modify the mass airflow sensor to engine control module wiring in accordance with Fig. A3.14 to supply a simulated mass air flow sensor signal to provide closed loop AFR control during Stage III.

8.6.1.1 Vary the simulated mass airflow sensor signal to obtain a constant fuel flow. Periodically adjust the fuel flow set point to obtain the lambda values in Table 2.

²¹ The sole source of supply of Pencoool 2000 coolant known to the committee at this time is Penray Cos., Inc., 1801 Estes Ave., Elk Grove, IL 60007.

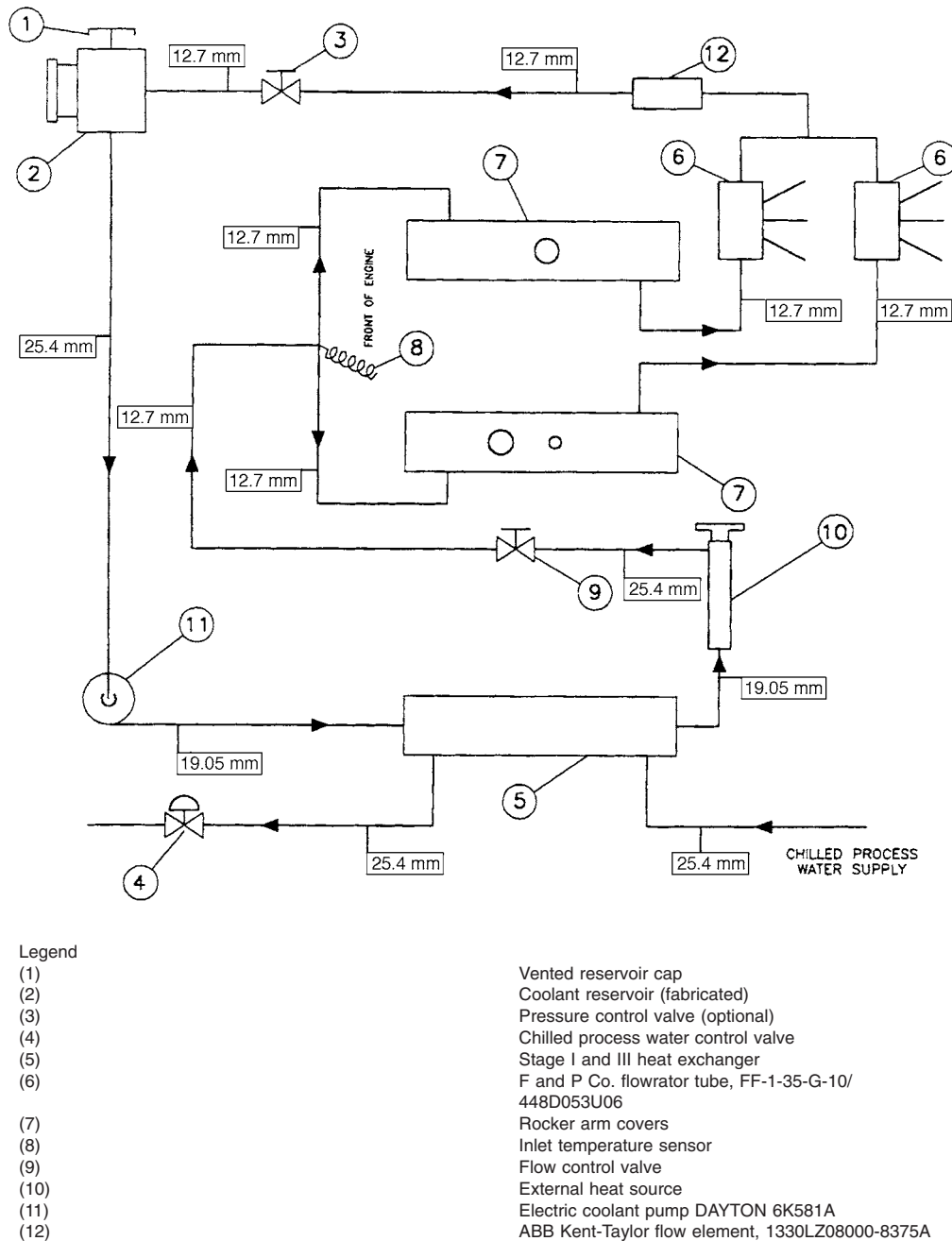


FIG. 6 Typical Rocker Arm Cover Heating and Cooling System

8.6.1.2 Alternatively, use the average of lambda from both the left and right cylinder bank AFR sensors to provide the feedback for the mass air flow sensor to directly control the lambda values during Stage III.

9. Measurement Instrumentation

9.1 Temperatures:

9.1.1 Equipment:

9.1.1.1 Temperature measurement locations for the six required temperatures are specified. Use thermocouples that are calibratable to 0.5 °C. Use only OEM temperature sensors for EEC inputs.

9.1.1.2 All thermocouples, except the intake-air thermocouple, shall be premium and sheathed. The intake-air thermocouple may be an open-tip type. The diameter and length of the thermocouples shall be 3 mm by 100 mm. Thermocouples, wires, and extension wires should be matched to perform in accordance with the special limits of error as defined in ANSI MC96.1.

9.1.2 *Engine Coolant Inlet*—Install the sensor in the outlet perpendicular to the run of the tee fitting upstream from the water pump inlet (300 to 400) mm. Install sensor with the tip in the center of the stream of flow, directly opposite of the perpendicular outlet. (See Fig. A3.18).

9.1.3 Engine Coolant Outlet—Install the temperature sensor in the modified thermostat housing. Locate the tip of the temperature sensor in the center of the stream of flow and is located in the thermostat housing *neck* within 80 mm of the housing outlet.

9.1.4 Engine Oil Inlet—Install the tip of the sensor at the center of the flow stream through the external oil filter adapter (see Fig. A3.8). Tip of sensor shall be even with the machined surface of the oil filter adapter.

9.1.5 Engine Oil Outlet—Install the tip of the sensor at the center of the cross fitting attached to the bottom of the heat exchanger (see Fig. A3.8). Locate the sensor along the same axis, but opposite, the outlet port connected to the heat exchanger. The tip shall be within 2 mm of the center distance between the external most surfaces of the outlets along the axes.

9.1.6 Intake Air—Install the tip of the thermocouple mid-stream in the air cleaner (see Fig. A3.1). Insertion depth shall be (55 ± 2) mm.

9.1.7 RAC Coolant Inlet—Install the tip of the thermocouple at the center of the cross fitting before the inlets of the RAC's (see Fig. 6, item 8). Locate the sensor along the same axis, but opposite the inlet port of the incoming fluid. The tip shall be within 2 mm of the center distance between the external most surfaces of the outlets along the axes.

9.1.8 Calibration—Calibrate all thermocouples prior to a reference oil test. The temperature measurement system shall indicate within ± 0.5 °C of the laboratory calibration standard. The calibration standard shall be traceable to NIST.

9.2 Pressures:

9.2.1 Equipment—Pressure measurement for each of the eight required parameters is detailed in the following sections. This allows reasonable opportunity for adaptation of existing test stand instrumentation. However, the accuracy and resolution of the pressure measurement sensors and the complete pressure measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.²² Replace pressure sensors that are part of the EEC system with only Ford specified equipment.

NOTE 5—Tubing between the pressure tap locations and the final pressure sensors should incorporate condensate traps, as indicated by good engineering practice. This is particularly important in applications where low air pressures are transmitted by means of lines which pass through low-lying trenches between the test stand and the instrument console.

9.2.2 Intake Manifold Absolute—Measure the manifold absolute pressure at the port on the top side of the throttle body spacer (see Figs. A3.2 and A3.27).

9.2.3 Engine Oil—Measure oil pump pressure at the bottom port of the oil filter adapter housing on the engine block (see Fig. 5 and Figs. A3.24 and A3.25). Take cylinder head oil pressure measurements on the sides of the cylinder heads on the rear of the left cylinder head and front of the right cylinder head (see Fig. 5 and Figs. A3.23 and A3.26). Use individually dedicated pressure sensors.

9.2.4 Engine Coolant Pressure—Measure engine coolant pressure at the top of the coolant reservoir as shown in Fig. A3.18.

9.2.5 RAC Coolant—RAC coolant pressure can be measured at the coolant inlet cross fitting as is done with temperature although monitoring of RAC pressure is not required. Pressure should remain adequate as long as temperature and flow are within the limits of Table 2.

9.2.6 Fuel—Measure the fuel pressure near the injector rail inlet as shown in Fig. 1. When utilizing a pressure gage mounted directly to the injector rail, the gage should be a damped, liquid-filled type. (**Warning**—Too much mass attached to the fuel rail may cause it to leak. Any instrumentation attached to the fuel rail should be supported by something other than the fuel rail.)

9.2.7 Intake Air—Measure the intake-air pressure in the air cleaner housing in the location shown in Fig. A3.1. Insertion depth of the probe shall be (50 ± 2) mm. If a manometer is used, install a liquid trap to prevent manometer fluid from entering the intake-air cleaner.

9.2.8 Crankcase—Measure the crankcase pressure at the dipstick tube. The sensor shall be capable of measuring positive and negative pressure. If a manometer is utilized, install a liquid trap to prevent manometer fluid from entering the crankcase.

9.2.9 Exhaust Back Pressure—Measure the exhaust back pressure with the exhaust gas sampling probe located downstream in the Y (see Fig. A3.16). A sensor capable of absolute or gage measurement corrected with barometric pressure reading is recommended. Install a condensate trap between the probe and sensor to accumulate water present in the exhaust gas.

9.2.10 Calibration—Calibrate all pressure measurement sensors prior to a reference oil test. The MAP pressure measurement system shall indicate within 0.1 kPa of the laboratory calibration standard. All other pressure measurement systems shall conform to the guidelines in ASTM Research Report RR:D02-1218.²² The calibration standard shall be traceable to NIST.

9.3 Flow Rates:

9.3.1 Equipment—Flow rate measurement for each of the four required parameters is detailed in the following subsections. With the exception of the engine coolant and blowby flow rates, measurement equipment is not specified for a given parameter. This allows reasonable opportunity for adaptation of existing test stand instrumentation.

9.3.2 Engine Coolant—Determine the engine coolant flow rate by measuring the differential pressure drop across the specified venturi flowmeter (see Fig. A3.18). Flowmeter is available from the supplier in X2.1.6. Take precautions to prevent air pockets from forming in the lines to the pressure sensor. Transparent lines or bleed lines, or both, are beneficial in this application. Ensure that the manufacturer's required straight sections of pipe are installed immediately up and down stream of the flowmeter.

9.3.3 RAC Coolant—Measure the total volumetric coolant flow rate through the RAC system and the individual RAC flowrates as shown in Fig. 6.

²² Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1218.

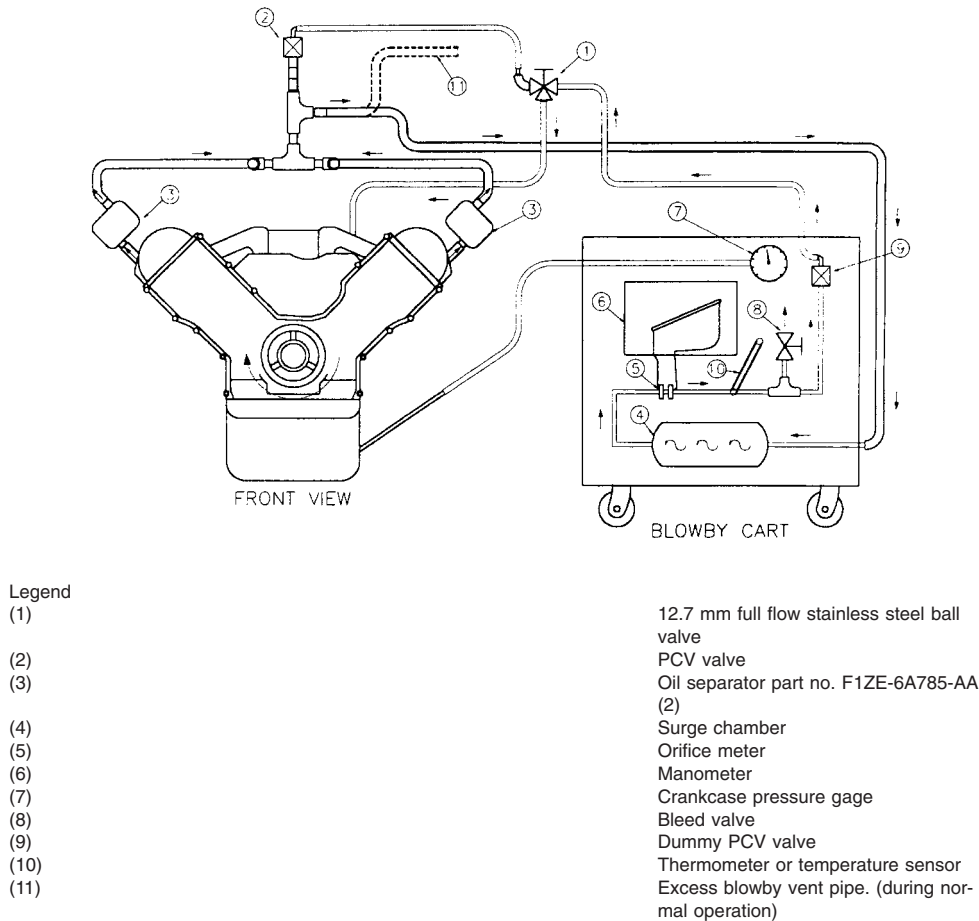


FIG. 7 Blowby Measurement Apparatus

9.3.3.1 *Calibration*—Calibrate the flowmeters used in the measurement of both the engine coolant flow rate and RAC coolant flow prior to a reference oil test. Calibrate the flowmeters as installed in the system at the test stand with test fluid. Calibrate the flowmeters with a turbine flowmeter or by a volume/time method at Stage I operating conditions.

9.3.4 Blowby:

9.3.4.1 Measure the blowby flow rate using the apparatus shown in Fig. 7. The measurement system routes the blowby through an external, sharp-edged orifice and into the engine intake manifold by means of an auxiliary (*dummy*) PCV valve. Maintain crankcase pressure during operation of the system at (0.0 ± 25) Pa to minimize the potential for crankcase leakage. Mount the dummy PCV valve and orifice plate in a vertical position.

9.3.4.2 Determine the blowby flow rate by measuring the differential pressure drop across the sharp-edged orifice; an inclined manometer or differential pressure sensor is required for measurement of the differential pressure drop. The differential pressure drop sensor shall have a range from (0 to 1) kPa.

9.3.4.3 Fabricate the sharp-edged orifice assembly that is specifically designed for blowby flow rate measurement in strict compliance with the specifications that are available from the TMC. Additional information on the orifice system can be obtained from the source listed in X2.1.8 The assembly

contains five orifices. The 9.525 mm orifice is generally satisfactory for the range of blowby flow rate encountered. The complete orifice assembly can also be purchased from the supplier listed in X2.1.11.

9.3.4.4 *Maintenance*—As a minimum, clean the blowby measurement apparatus weekly. Replace the o-rings with each cleaning. Exercise particular care when cleaning the orifice meter assembly. Clean the three-way valve by soaking the valve in agitated organic solvent (see 7.7.2) until clean, followed by hot ($> 60^\circ\text{C}$) water rinse and spray rinse with degreasing solvent (7.7.1). Use compressed air to force-dry. Inspect the port passages and remove any carbonaceous deposits by scraping. If the valve is disassembled for cleaning, make sure the core is properly seated upon reassembly.

9.3.4.5 *Calibration*—Calibrate the blowby orifice meters used for laboratory measurements standards every six months. Calibrate laboratory blowby measurements standards, not used for production, yearly. The calibration standard shall be traceable to the NIST. Calibrate the temperature measuring devices in the blowby system every six months. (**Warning** —Internal leakage within the three-way valve may cause some of the blowby gas to pass directly to the intake manifold from the test PCV valve and result in erroneous blowby flow rate measurements (see Fig. 7).)

9.4 Fuel Consumption—Determine the fuel consumption rate by measuring the amount of make-up fuel flowing from the external fuel tank. The measurement point is upstream of the return flow from the fuel rail (see Fig. 1).

9.4.1 Calibration—Calibrate mass flowmeter or gravimetric systems prior to each reference oil test. Volumetric systems shall be temperature and specific gravity compensated and calibrated against a mass flow device. The flowmeter located on the test stand shall be within 1 % of the calibration standard.

9.5 Speed and Torque:

9.5.1 Required Capabilities—The dynamometer speed and torque control systems shall be capable of maintaining the limits specified in Table 2 and meet the ramping requirements specified in Table 4. These limits require control within $\pm 0.9\%$ for operation during Stages I and II. Because the dynamometer and driveline frictional losses might approach the power produced by the engine during Stage III, manage the control input and system response during Stage III carefully to maintain engine operation within the specified tolerances. These tolerances are necessary to maintain a stable air-fuel ratio during Stage III. Hydraulic dynamometers have slow control response at low speeds and are not suitable for operation during Stage III.

9.5.2 Suitable Systems—Utilize a full closed-loop system using a dry gap dynamometer. A typical closed-loop system maintains engine speed by varying the electrical current to the dynamometer and maintains engine power by varying the engine throttle position. The total driveline inertia through to the dynamometer, excluding the engine flywheel, shall be $(0.8 \pm 0.1) \text{ kg}\cdot\text{m}^2$.

9.5.3 Calibration—Calibrate the load cell transducer and readout system with deadweights at least once per test. Calibration of the zero scale readout is recommended once per day during the oil level soak period. Calibrate the speed measurement system prior to a reference oil test.

9.6 Exhaust Gas:

9.6.1 Equipment:

9.6.1.1 Determine the air-fuel ratio using a wide band sensor to measure Lambda. The device shall have a minimum accuracy of $\pm 2\%$. Suitable devices are available from the suppliers listed in X2.1.2.2.

9.6.1.2 Calibrate, zero, and span the AFR sensor in accordance with the user's manual prior to conducting a stand reference oil test sequence or whenever a sensor is replaced.

9.6.2 Calibration (General)—Calibrate the exhaust gas analysis equipment before each set of measurements taken during the test. The calibration technique should compensate for the flow rate sensitivity of the exhaust gas analysis meters.

9.7 Humidity:

9.7.1 The intake air humidity is recorded using the laboratory's primary humidity measurement system. Make corrections to each reading, for non-standard barometric conditions, using an additive correction derived from the perfect gas law.

9.7.2 Primary Measurement System Calibration—The primary laboratory measurement system is calibrated at each stand on a semi-annual basis using a hygrometer with a minimum dew point accuracy of $\pm 0.55^\circ\text{C}$ at 16°C . The

TABLE 5 Humidity Calibration Example

NOTE 1—Test Type-VG; Test Stand – 29; Date – 11/12/96; Barometric pressure – 29.1 in. Hg; Humidity correction – to 0.28 g/kg.

NOTE 2—Humidity readings are corrected for non-standard barometric pressure.

NOTE 3—X = Mean difference, g/kg – 0.2.
S = Standard deviation, g/kg – 0.11.

NOTE 4—If mean difference > 1.4 g/kg, calibration is invalid.

NOTE 5—If standard deviation > 0.71 g/kg, calibration is invalid.

Reading	Zi	Yi	Yi-Zi
	System Humidity	Calibration Humidity	Difference
1	11.3	11.4	0.1
2	11.2	11.5	0.3
3	11.2	11.5	0.3
4	11.2	11.6	0.4
5	11.3	11.6	0.3
6	11.3	11.6	0.3
7	11.3	11.6	0.3
8	11.3	11.6	0.3
9	11.4	11.6	0.2
10	11.4	11.7	0.3
11	11.5	11.7	0.2
12	11.5	11.7	0.2
13	11.4	11.6	0.2
14	11.4	11.6	0.2
15	11.5	11.6	0.1
16	11.6	11.6	0.0
17	11.6	11.7	0.1
18	11.6	11.7	0.1
19	11.6	11.7	0.1
20	11.5	11.7	0.2

calibration consists of a series of 20 paired measurements between the primary laboratory system and the calibration hygrometer (see Table 5 for an example). The measurement interval shall be appropriate for the time constant of the humidity measuring instruments and the control system. Comparison periods of 20 min to 2 h, with measurements recorded at intervals of (1 to 6) min intervals, are typically acceptable. The measurements taken with the calibration hygrometer are corrected to standard barometric pressure (101.1 kPa) using the perfect gas law. The sample line shall be non-hygroscopic. Exercise precaution to prevent condensation of the sample.

9.7.3 The difference between each pair is computed and used to form a mean and standard deviation. The absolute value of the mean difference cannot exceed 1.4 g/kg, and the standard deviation cannot exceed 0.71 g/kg. Both of these requirements shall be met to consider the primary humidity measurement system to be calibrated. If either of these requirements cannot be met, the laboratory shall investigate the cause, make repairs, and recalibrate. The calibration data is maintained for two years.

9.7.4 Sample Location—The calibration sample tap is located on the air line to the engine, between the main duct and entrance to the air filter housing.

10. Miscellaneous Laboratory Equipment

10.1 STAR Tester—A STAR (self test automatic readout) tester will be necessary to diagnose the EEC system in case of a malfunction or operational abnormality. Instructions on the use of the STAR tester can be found in the service manual.

10.2 *Beaker*—A beaker with a capacity of 5000 mL is suitable for the initial oil fill. A beaker with a capacity of 500 mL is suitable for oil additions.

11. Test Stand Calibration

11.1 Verification:

11.1.1 Verify the calibration of test stands with reference oils supplied by the TMC. Stand calibration tests are normally conducted upon expiration of the 180 day calibration time period or after completing 15 non-reference oil tests, or both. However, calibration time periods may be adjusted by the TMC. Any non-reference oil test started within 180 days of the previous calibration test is considered within the calibration period, providing not more than 14 non-reference oil tests have been completed since the previous calibration test in the stand.

11.1.2 A reference oil sample of 22.4 L is provided by the TMC for each stand calibration test.

11.2 Unacceptable Calibration Results:

11.2.1 It is recognized that a certain percentage of calibration tests fall outside the acceptance limits because of the application of statistics in the development of the acceptance limits. Failure of a reference oil test to meet Shewhart or EWMA precision control chart limits can be indicative of a false alarm or a stand, laboratory, or industry problem. When this occurs, the laboratory, in conjunction with the TMC shall attempt to determine the problem source. The TMC may solicit input from industry expertise (other testing laboratories, the test sponsor, ASTM Technical Guidance Committee, Sequence VG Surveillance Panel, Sequence VG Operation and Hardware Subpanel, and so on) to help determine the cause and extent of a problem. The Sequence VG Surveillance Panel adjudicates industry problems.

11.2.2 If the TMC determines the problem is a false alarm and is stand-related, there is no impact on other non-reference tests running in other stands within the laboratory. If the TMC determines the problem is laboratory-related, non-reference tests run during the problem period shall be considered invalid, unless there is specific evidence to the contrary for each individual test.

11.2.3 The TMC reschedules a calibration test once it is satisfied that no particular problem exists or the problem has been resolved. The laboratory shall provide adequate documentation to support conclusions reached during this process. Attach this documentation to the acceptable calibration test report. It shall provide sufficient information to show how the problem related to other tests operated during the same period.

11.3 *Test Stand Modifications*—Report modification of test stand control systems or completion of any nonstandard test on a calibrated stand to the TMC immediately. A nonstandard test includes any test completed under a modified procedure requiring hardware or controller modifications to the test stand. The TMC determines whether another calibration test is necessary after the modifications have been completed.

11.4 Reference Oil Accountability :

11.4.1 Laboratories conducting calibration tests are required to provide a full accounting of the identification and quantities of all reference oils used.

TABLE 6 Sequence VG Break-in Schedule

NOTE 1—*Coolant Flow Control Valve*—Run the coolant flow control valve wide open during the entire break-in schedule. During test operation, set flow per requirements delineated in Stage I of [Table 2](#).

Condition	Oil		Step		
	Leveling	1	2	3	
Duration, min	2, min	5	40	45	
Total time, h:min		0:05	0:45	1:30	
Engine speed, r/min	1500 ± 25	700 ± 15	2900 ± 5	700 ± 15	
Engine power, kW		1.30 ± 0.2	record	1.30 ± 0.2	
Manifold abs press, kPaA	37.6		66 ± 0.2	record	
Engine oil in, °C	80 ± 2		100 ± 0.2	45 ± 1	
Engine coolant out, °C	90 ± 2		85 ± 0.2	45 ± 1	
RAC coolant in, °C			85 ± 0.2	29 ± 1	
Lambda			1.0	0.75	
Exhaust back pressure, kPaA					
Speed, power and MAP ramps					
Oil leveling – 20 s ramp fr/idle					
Step 1 to 2 – 60 s ramp					
Step 2 to 3 – 15 s ramp					

11.4.2 With the exception of new oil analysis required in [13.6](#), perform no physical or chemical analysis of new reference oils without the permission of the TMC. Retain engine parts from reference oil tests for six months.

11.5 Test Numbering System:

11.5.1 *Acceptable Tests*—The test number shall follow the format *AAA-BB-CCC*. *AAA* represents the test stand number. *BB* represents the number of tests since last reference. *CCC* represents the total number of tests on the stand. As an example, 6-10-175 represents the 175 test on Stand 6 and the tenth test since the last reference. Consecutively number all tests on a given stand.

11.5.2 *Unacceptable or Aborted Tests*—If a calibration test is aborted or the results are outside the acceptance limits, the *CCC* portion of the test number for subsequent calibration test(s) shall include a letter suffix. Begin the suffix with the letter *A* and continue alphabetically until a calibration test is completed within the acceptance limits. For example, if three consecutive unacceptable calibration test are completed on the same test stand, and the test stand number of the first test is 6-0-175, the next two test numbers would be 6-0-175A and 6-0-175B. If the results of the next calibration test are acceptable, the test number 6-0-175C would permanently identify the test and appear on future correspondence. The completion of any amount of operational time on tests other than calibration tests will cause the test number to increase by one. Add no letter suffix to the test number of tests other than calibration tests.

12. Test Procedure

12.1 Pre-test Procedure:

12.1.1 *Engine Break-In Procedure*—Run break-in schedule listed in [Table 6](#). Conduct the break-in before each test using the test oil.

12.1.1.1 Charge the engine with 3000 g of test oil before the break-in run. Run the engine at (1500 ± 25) r/min and 37.6 kPa MAP until the oil temperature reaches (80 ± 2) °C or for at least 2 min. Record the dipstick level (20 ± 2) min after shutdown. This shall be the Test Full mark for this test. Use the table in [Annex A8](#) to determine the oil level.

12.1.1.2 The laboratory ambient atmosphere shall be reasonably free of contaminants. The temperature and humidity levels of the operating area are not specified. Divert air from fans or ventilation systems away from the test engine.

12.1.1.3 The break-in allows an opportunity to check EEC system operation, blowby levels, Lambda for Stage II and III, check for leaks in the various systems and purge air from the cooling systems. Specifications concerning the break-in procedure are shown in **Table 6**. The engine start-up and shutdown procedures are detailed in **12.2.1** and **12.2.2** respectively.

12.1.1.4 During Step 1, bleed the air from the engine and RAC coolant systems and check all fluid systems for leaks.

12.1.1.5 During Step 2, check blowby level for the Stage II conditions. A high or low blowby flow rate at this time could be indicative of the blowby flow rate during the test. A ring gap adjustment can be performed at this time or after the break-in, but within the first 48 h of the test, to achieve an adequate blowby flow rate. Testing has shown that a blowby range of (65 to 75) L/min during the break-in typically produces acceptable blowby during the test. However, the need for a ring gap adjustment is at the laboratory's discretion, noting that a ring gap adjustment cannot be made at any other time during the test.

12.1.1.6 During Step 3 (see **Table 6**) check the operation of the idle load control system and EEC system operation. Allow the oil and coolant temperatures to reach $(45 \pm 0.5) ^\circ\text{C}$. Lambda values should approximate the values listed in **Table 6**. If not, check the idle load circuit and the EEC system operation with a STAR tester.

12.1.1.7 Record all normal parameters in Steps 2 and 3 after operation at each step for 35 min. (**Warning**—Prolonged operation at a rich air-fuel ratio can cause excessive fuel dilution and alter test severity.)

NOTE 6—The engine normally requires approximately 20 min to reach steady-state conditions after a step change.

12.1.1.8 Check and record oil level after break-in. If piston rings are regapped or replaced during or after the break-in, ensure that the oil level is brought back to the last known oil level by adding new oil or removing oil.

12.2 Engine Operating Procedure:

12.2.1 *Engine Start-up*—Use the following detailed procedure each time the engine is started.

12.2.1.1 Turn on the ignition, safety circuits, fuel management system, fuel pump, and the rocker arm cover coolant pump.

12.2.1.2 Connect the intake-air supply duct.

12.2.1.3 *Crank The Engine*—The engine should start within 4 s. Since the engine has a crankshaft driven oil pump, cranking oil pressure might be low. If used, disable a low oil pressure ignition shutoff during engine starting to allow the engine to start even though the oil pressure is low. The inclusion of this type switch could lead to excessive cranking time to start the engine.

12.2.1.4 If starting difficulties are encountered, the laboratory should not continue to crank the engine excessively. Perform diagnostics to determine the reason the engine will not start (ignition problems, insufficient or excess fuel, and so

forth). (**Warning**—Excessive cranking times can promote additional fuel dilution of the test oil and can adversely affect the test. In addition to other precautions, do not attempt to pour gasoline into the intake-air horn.)

12.2.2 Engine Shutdown:

12.2.2.1 *Scheduled Shutdown Procedure*—Follow the procedure detailed as follows, each time a scheduled shutdown is performed. Scheduled shutdowns include shutdowns that occur during engine break-in and oil leveling:

(1) Bring the engine speed to (700 ± 50) r/min for 10 min.

(2) Switch the ignition off. (Turn off power to the EEC and ignition, maintain power to the keep alive memory (KAM).)

(3) Turn off fuel pump

(4) Reduce the intake-air pressure to atmospheric.

12.2.2.2 *Unscheduled Engine Shutdown*—Follow the procedure detailed as follows, each time an unscheduled engine shutdown is performed:

(1) Stop test timer when ramp down starts.

(2) *Ramp to Stage 3:*

From Stage 1—15 s speed and load setpoint ramp; 6 min setpoint ramp of other controlled parameters.

From Stage 2—Perform Stage 2 to 3 ramp (**Table 4**).

NOTE 7—Total cooldown time is 6 min after the initiation of the ramp to Stage 3 conditions.

(3) Switch the ignition and RAC coolant pump off (turn off power to the EEC and ignition, maintain power to the KAM).

(4) Turn off fuel pump.

(5) Reduce the intake-air pressure to atmospheric.

12.2.2.3 *Start-Up After Unscheduled Shutdown*—Follow the procedure detailed as follows, each time an engine start-up is performed after an unscheduled shutdown.

(1) *Start*—5 min in Stage 3, then to:

Return to Stage 1—Stage 3 to 1 ramp (**Table 4**).

Return to Stage 2—60 s speed and load setpoint ramp; 10 min setpoint ramp of other controlled parameters.

NOTE 8—Test time resumes after all controlled parameters are within specification

12.2.2.4 *Start-Up After Oil Leveling Period*—Follow the procedure detailed as follows, each time an engine start-up is performed after an oil leveling period.

(1) *Start*—5 min in Stage 3; then Stage 3 to 1 ramp (**Table 4**).

12.2.3 Cyclic Schedule, General Description:

12.2.3.1 The test is composed of three stages as shown in **Table 2**. Together, the three stages comprise one cycle. Each cycle lasts 4 h and is repeated 54 times for a total of 216 h. Six consecutive cycles are completed each 24 h period. Every sixth cycle is modified to provide time for oil sampling and leveling. This modification is described in **12.3.1**.

12.2.3.2 Ramping requirements specifying parameter change rates are shown in **Table 4**. The rate of speed, temperature, and load changes, as well as the amount of enrichment between stages, can influence sludge severity and engine component wear. Therefore, ramping rates are very important.

12.2.4 *Unscheduled Downtime*—The oil leveling periods of 30 min are the only scheduled shutdowns allowed during the

test and are counted as test time. However, the test can be interrupted to perform necessary maintenance (see 12.3.5). Note all unscheduled downtime on the Supplemental Operational Data Form of the final test report.

12.2.5 Resumption of Test Time After Unscheduled Shutdown—After an unscheduled shutdown, test time does not begin until the engine has reached operating conditions for the stage at which the shutdown occurred.

12.3 Periodic Measurements and Functions:

12.3.1 Blowby Flow Rate Measurement—Every sixth cycle, measure and record the blowby flow rate at (30 ± 5) min into Stage II. The engine shall be stable and operating at normal Stage II operating conditions. Measure blowby when the gas temperature is at least 32 °C. Blowby gas temperature shall not differ from the laboratory average by more than ± 5 °C. The installation of the blowby flow rate measurement apparatus is shown in Fig. 7. The procedure for measuring blowby flow rate is detailed in 12.3.1.1. Complete only one set (Stage II) of blowby flow rate measurement during each six cycles. Under special circumstances additional blowby flow rate measurements can be performed to determine or verify a problem with the flow rate measurement apparatus or the engine. Record additional blowby flow rate measurements and an explanation of the reason for the additional measurements. Include these data in the supplemental operational data in the final test report.

12.3.1.1 Measurement Procedure: (1) Connect the apparatus pressure sensor to the dipstick tube.

(2) Open the bleeder valve completely.

(3) Connect the bleeder line to the three-way valve.

(4) Position the three-way valve to divert intake manifold vacuum from the engine PCV valve to the *dummy* PCV valve in the blowby measurement apparatus.

(5) Connect the hose from the blowby meter surge chamber to the 15.9 mm inside-diameter air vent hose on the air cleaner.

(6) Adjust the bleeder valve to maintain crankcase pressure at (0 ± 25) Pa.

(7) Record the differential pressure, blowby gas temperature, and the barometric pressure.

(8) Disconnect the apparatus pressure sensor and reconnect the engine crankcase pressure sensor to the dipstick tube.

(9) Disconnect the surge chamber hose from the air vent hose.

(10) Position the three-way valve to divert intake manifold vacuum to the engine PCV valve and disconnect the bleeder line from the three-way valve.

(11) Connect the air vent hose to the intake-air cleaner.

(12) Calculate the blowby flow rate and correct the value to 38 °C and 100 kPa using the calibration data for the orifice.

$$\text{corrected blowby flowrate} = \text{blowby flowrate} \times (3.100(P/273.15+T))^{0.5}$$

where:

P = baro-pressure, kPa, and

T = gas temperature, °C.

12.3.2 Ignition Timing Measurement—Ignition timing is set by the EEC and can only be checked with a STAR tester. Ignition timing need only be checked if improper EEC and ignition operation is suspected.

12.3.3 Exhaust Gas Analysis:

12.3.3.1 The recorded readings for exhaust gas Lambda are taken during each stage and each cycle and shall be measured immediately after the engine oil and coolant temperatures have reached steady-state conditions (approximately 20 min $\pm$ 5 min into each stage). The data are used to confirm that the EEC system is operating the engine at the correct air/fuel ratio.

12.3.4 Oil Additions and Used Oil Sampling:

12.3.4.1 Oil Leveling and Sampling Procedure—Make-up oil additions for leveling and oil sampling occur at intervals of 24 h. Annex A10 shows the cycle when this is to occur. Used oil additions are permitted only during engine reassembly for maintenance (see 12.4.2.2). Add new oil to the engine only when the level is below the original test full level by more than 400 g. Add only enough new oil to reach the low mark of 400 g. No other new oil additions are permitted during the test, except after piston ring gap adjustment (see 12.1.1.8). In the event that the oil level is above the test full mark, do not remove oil until the level is above the test full mark by more than 200 g. Drain off a sufficient amount of oil so that the level is at the 200 g above test full mark. Record the amount drained on the oil leveling sheet. The procedure is shown on the *Oil Sampling, Addition and Leveling Worksheet* in Annex A10. This form serves as the oil sampling and oil addition data sheet.

(1) Remove a 150 mL purge sample within first 10 min of Stage III.

(2) Remove a 60 mL analysis sample within first 10 min of Stage III.

(3) Return the purge sample to the engine.

(4) Shut-down the engine 10 min after the start of Stage III. Do not shut off the RAC coolant pump.

(5) Record the dipstick level in millimetres (20 ± 2) min after the engine is shutdown.

(6) Compute the oil level in grams. The difference between the oil level and the Test Full mark is oil consumed or gained. Use the chart in Annex A8 to determine the level. Do not add oil at 216 h. This allows the final drain to be used as a backup to the sample taken at 216 h.

(7) If the level is more than 400 g below the Test Full mark, record the amount of new oil added to bring the level to the mark, -400 g. However, never add more than 400 g during an oil addition.

(8) If the level is more than 200 g above the Test Full mark, record the amount of oil drained to bring the level to the mark, +200 g.

(9) Restart the engine (30 ± 1) min after shutdown (Step 4). Allow the engine to run at Stage III conditions for (5 ± 1) min, then resume normal operation.

12.3.5 General Maintenance—The scheduled shutdown periods of 30 min during oil leveling allow limited opportunity for engine and stand maintenance. In addition, the test can be shut down at any convenient time to perform unscheduled maintenance. However, minimize the duration of a shutdown. Report any unscheduled shutdown on the Supplemental Operational Data Sheet.

12.4 Special Maintenance Procedures—Functions that require special maintenance procedures are listed in this section.

These maintenance procedures are specifically detailed because of the effect on test validity or because they require special care while being completed.

12.4.1 Blowby Flow Rate Adjustment—A blowby adjustment can only be made during the break-in or within the first 48 h of the test. Blowby might drop from the break-in level but the corrected average Stage II blowby for the test during the first 120 h of the test shall fall within the range from (60 to 70) L/min. Adjust the blowby by changing the ring gaps or replacing piston rings as necessary. Ensure that the ring and piston combination in each cylinder meet the criteria in [Table 1](#). Use the ring cutting procedure outlined in [7.8.5.2](#).

12.4.1.1 High Blowby Flow Rate Adjustment—Reduce high blowby flow rate by replacing the compression rings with new rings that have smaller ring gaps.

12.4.1.2 Low Blowby Flow Rate Adjustment—Increase low blowby flow rate by increasing the ring gaps of the compression rings.

12.4.2 Engine Disassembly and Reassembly for Maintenance (Before End of Test):

12.4.2.1 Engine assembly and disassembly shall adhere to the procedures in [7.8](#) and [12.6.2](#), respectively

12.4.2.2 When the engine is disassembled for maintenance, drain as much test oil as possible from the oil pan, and retain the oil for installation in the engine after reassembly. Take precautions to ensure the oil is not contaminated and to ensure the deposits are not disturbed on any parts that are used to determine the final test results. The Ford 4.6 L engine contains numerous areas that hold oil after the engine is drained. All parts should be placed in or over clean drain pans to collect oil that drains off while maintenance is being performed.

12.4.2.3 During reassembly, used, drained test oil may be used to lubricate the engine parts. Do not use EF-411 oil or new test oil during engine reassembly. After the engine has been reassembled, charge the oil pan with the oil removed from the oil pan and collected from the engine parts during disassembly and maintenance. Record all new oil additions and report them in the Supplemental Operational Data.

12.5 Diagnostic Data Review—This section outlines significant characteristics of specific engine operating parameters. The parameters can directly influence the test or can be used to indicate normalcy of other parameters.

12.5.1 Manifold Absolute Pressure—Manifold absolute pressure is used in Stages I and II to control engine throttle position.

12.5.2 Engine Torque—Engine torque is not controlled in Stages I and II. It should remain relatively constant throughout a test and from test to test. Large differences in torque reading could be indicative of control or engine problems.

12.5.3 Fuel Consumption Rate—The fuel consumption rate should remain relatively constant throughout the test. Fuel consumption rate is not a specifically controlled parameter but is used as a diagnostics tool.

12.5.4 Spark Knock—Spark knock does not normally occur in the VG test. The octane rating of the fuel, ignition timing, engine speed and torque, and operating temperatures do not promote spark knock. Spark knock indicates abnormal combustion is occurring and can cause extensive engine damage.

Take corrective action immediately if spark knock is noted. Errors in the measurement and control of engine torque, ignition timing, operating temperatures, and air/fuel ratio may result in spark knock.

12.5.5 Exhaust Gas Component Levels:

12.5.5.1 Use the Lambda levels in the exhaust gas to determine the characteristics of combustion that occur during the test. Use this parameter to determine the normalcy of combustion and any significant changes in combustion that occur throughout a particular test. Lambda in all three stages is controlled by the program in the EPROM chip. No adjustments can be made to change the exhaust gas Lambda. If Lambda differs from what appears in [Table 2](#), check the EEC system. Correcting a fault in the EEC system is the only way to achieve the correct Lambda value.

12.5.6 Crankcase Pressure—Crankcase pressure is a function of blowby flow rate and PCV valve flow. High crankcase pressure is usually caused by high blowby flow rate or a significant loss of PCV valve flow. Incorrect three-way valve plumbing or port plugging also promotes high crankcase pressure. Low or negative crankcase pressure might be caused by low blowby flow rate or a restriction of vent air to the PCV valve.

12.5.7 Oil Pressure—The oil pressure is a function of oil viscosity and operating temperature. The oil pressure should remain consistent throughout the test, unless the oil exhibits a significant change in viscosity.

12.5.8 Oil Temperature Differential—The oil temperature differential is primarily a function of oil flow rate and oil viscosity and is normally stable throughout the test. The differential can change if the oil viscosity changes significantly during the test.

12.5.9 Coolant Temperature Differential—The coolant temperature differential is primarily a function of the coolant flow rate and is normally stable throughout the test. Large variations in the differential can be caused by coolant flow rate or temperature measurement errors. Coolant flow rate measurement errors can be caused by foreign objects in or near the venturi flowmeter.

12.6 End of Test Procedure:

12.6.1 Final Drain—Drain the engine coolant and RAC coolant immediately after the completion of the last test cycle. Engine oil can be drained with the engine in or out of the engine stand. Allow the engine to stand for (6 to 12) h in the same attitude in which it was positioned on the test stand prior to drain. This allows the oil to drain completely into the oil pan. Drain the oil from the engine.

12.6.2 Engine Disassembly—During disassembly, use extreme care not to disturb engine deposits and to ensure the original location of the parts can be identified with respect to either the cylinder number, valve location, or both.

12.6.3 Parts Layout for Rating:

12.6.3.1 Arrange the following parts in the parts rating area in accordance with the layouts detailed in this section. After the parts have been arranged, allow the parts to drain for (4 to 8) h before rating. Do not attempt to accelerate or force the oil draining. Any fixtures can be used to support the parts as long as they orient the parts in the specified configurations.

12.6.3.2 *Rocker Arm Covers*—Position the RAC’s vertically (upper jacket surface perpendicular to the ground) with the front of the RAC at the bottom.

12.6.3.3 *Camshaft Baffles*—Position the camshaft baffles vertically (top baffle surface perpendicular to the ground) with the rear of the camshaft baffle pointing down.

12.6.3.4 *Cylinder Heads*—Position the cylinder heads with RAC gasket surface pointing down.

12.6.3.5 *Front Cover*—Position the front cover in the same orientation as it is installed in the engine.

12.6.3.6 *Oil Pan*—Position the oil pan upside down, with the pan rail at a 45° angle, with sump end pointing down.

12.6.3.7 *Oil Pan Baffles*—Position the oil pan baffles vertically on the front edges.

12.6.3.8 *Oil Screen and Pickup Tube*—Position the oil screen and pickup tube in the same orientation as they are installed in the engine. The screen should be raised off of the supporting surface to allow drainage. A fixture is necessary to support the oil screen and pickup tube.

13. Interpretation of Results

13.1 Parts Rating Area-Environment :

13.1.1 Ensure that the ambient atmosphere of the parts rating area is reasonably free of contaminants, and the temperature maintained at $(24 \pm 3) ^\circ\text{C}$.

13.1.2 Rate all engine parts except the pistons, RAC, and cylinder block under cool white fluorescent lighting exhibiting approximately 4100 K color temperature, a CRI of 62 and an illumination level of (3800 to 5400) lx. All background and adjacent surfaces shall be flat white.

13.1.3 Rate pistons and RAC’s against a white background using white fluorescent bulbs and a 100 % white deflector. Maintain the illumination level between (3800 to 6500) lx, and measure the illumination level 355 mm from the desk top.

13.1.4 If multiple ratings are deemed necessary of a given part or parts, consensus rating may be used according to the following: The raters shall be from the same laboratory or from an outside rater if required (no Red, White, or Blue rater available at the lab). Report only one rating value, and this value shall be agreed to by the original rater involved. Document any consensus rating in the comment section of the test report.

13.1.5 All raters of Sequence VG engine parts shall attend an ASTM Light Duty Deposit Rating Workshop every 12 months $\pm$ 30 days and produce data that meet the ASTM definitions of Blue, Red, or White for varnish. If a rater is unable to meet this requirement, the rater can continue to rate Sequence VG parts during a grace period of 45 days after the completion of the workshop and can follow the procedure described in 13.1.6 to generate data that meet the ASTM definitions of Blue, Red, or White.

13.1.6 A rater who is unable to meet the requirement in 13.1.5 can schedule a visit to the TMC to generate data on ASTM Light Duty Deposit Rating Workshop parts and receive an assessment of rating performance compared to data collected at recent workshops. Visits to the TMC will be scheduled based on availability of parts.

TABLE 7 Interpolated Average Sludge Site Ratings

Total	Site Ratings	Total	Site Ratings
<0.125	clean	≥ 3.500 <6.000	C
≥ 0.125 < 0.375	¼ A	≥ 6.000 < 12.00	D
≥ 0.375 < 0.625	½ A	≥ 12.00 < 24.00	E
≥ 0.625 < 0.875	¾ A	≥ 24.00 < 48.00	F
≥ 0.875 < 1.250	A	≥ 48.00 < 96.00	G
≥ 1.250 < 1.750	AB	≥ 96.00 < 192.0	H
≥ 1.750 < 2.500	B	≥ 192.0 < 384.0	I
≥ 2.500 < 3.500	BC	≥ 384.0	J

13.1.7 The TMC selects a minimum of 24 parts from a collection of workshop parts for the rater to rate varnish. The TMC provides rating booths and lights, but the rater is responsible for providing any necessary rating aids. The TMC analyzes the data and determine if the requirement in 13.1.5 has been met. If the requirement in 13.1.5 has not been met, any time remaining in the grace period of 45 days is forfeited.

13.1.8 A second attempt to generate rating data at the TMC is permitted only after the rater receives training from an experienced industry rater. The experienced industry rater shall verify to the TMC, in writing, that the rater training has taken place. No more than two attempts are permitted between ASTM Light Duty Deposit Rating Workshops.

13.2 Sludge Ratings:

13.2.1 Rate the following parts for sludge deposits: RAC (2), valve deck (2), camshaft baffle (2), timing chain cover, oil pan, and oil pan baffle. Use the rating locations identified on the rating worksheets (see Annex A11). Determine the ratings using the techniques detailed in ASTM Deposit Rating Manual 20. Perform the sludge ratings before performing any other required ratings or measurements.

13.2.1.1 If the test was run using Haltermann fuel, Batch TF2221LS20, average the two RAC sludge ratings to obtain the original RAC result. Correct the original result by adding 0.23, the industry correction factor. Add the corrected result and the lab severity adjustment to obtain the final RAC sludge result.

(1) If the test was run using Haltermann fuel batch XC2721NX10, average the two RAC sludge ratings to obtain the original RACE result. Add the original result and the laboratory severity adjustment to obtain the final RAC sludge result.

13.2.2 Average Sludge (Unweighted Average of 9 Parts):

13.2.2.1 To determine the sludge rating merit for each part, use the self-weighting procedure as follows:

(1) Determine the sludge depth at each of the sites shown on rating worksheets. A site is defined as a diameter circular area of 20 mm.

(2) Determine an interpolated sludge value for a designated site that exhibits more than one level of sludge depth within this area. This value is generated by multiplying each rated value’s volume factor by the percentage of area covered, totaling these volume factor percentages, and comparing the total to the values given in Table 7 to determine the rating for the site. As an example, if a site was determined to be 50 % A and 50 % E, the calculation would be: 50 % of the average sludge depth factor for A (or 1.0), plus 50 % of the average sludge depth factor for E (or 16.0); that is: $[(0.5 \times 1.0 = 0.5)] +$

$[0.5 \times 16.0 = 8] = 8.5$), and the calculated site sludge depth would be a D. In the event that there are areas where it is apparent that deposits had been formed, but are no longer adhering to the part, the rating site is the closest point to the designated point that eliminates the voided area from the 20 mm rating area.

(3) Add the total rating checks made for each line on the appropriate worksheets. These shall equal 10 or 20, depending on the part that is rated.

(4) Multiply the total rating checks made on each line by ten or five, respectively (refer to (3)), to obtain the percent covered by the rated sludge depth. The grand total shall equal 100 %.

(5) Convert the percent covered by the rated sludge depth at each location to a volume factor using the procedure shown in ASTM Deposit Rating Manual 20.

(6) Add the volume factors on each line to determine the total volume factor. Use ASTM Deposit Rating Manual 20 to convert the total volume factor to the sludge merit rating.

13.2.2.2 If the test was run using Haltermann fuel, Batch TF2221LS20, correct the original AES merit rating by adding 0.42, the industry correction factor. Add the corrected result and the lab severity adjustment to obtain the final AES result.

(1) If the test was run using Haltermann fuel batch SC2721NX10, add the original AES result and the laboratory severity adjustment to obtain the final AES result.

13.2.2.3 *Flaky, Bubbly Sludge Deposits*—Since the occurrence of flaky, bubbly sludge deposits is thought to have a possible detrimental effect on long-term engine lubrication system performance, document the occurrence of this type of deposit in the Supplemental Operational Data section of the Final Test Report. Record the engine part(s) where this type of deposit was observed and the total percent of the surface area covered. The following is suggested wording—approximately 6 % of the (left or right) rocker arm cover was found to exhibit flaky, bubbly sludge deposits.

13.3 Varnish Ratings:

13.3.1 *Preparation of Parts*—Rate the following parts for varnish deposits—piston skirts (8, thrust side only) and left and right camshaft baffles. Perform the varnish ratings after the sludge ratings are completed. The rating locations and dimensions shall conform with the locations and dimensions detailed on the rating worksheets (see [Annex A11](#)). Avoid disturbing adjacent sludge deposits when the parts are being prepared for varnish ratings. Heavy sludge can be removed from a varnish rating area prior to wiping with a 25 mm rubber spatula. Wipe all parts firmly with wiping materials specified in CRC Manual No. 20. Firmly rub all wiping areas in the same direction until the surface is dry and free of sludge (until no more deposit is present on the wiping material after wiping).

13.3.2 *Average Varnish (Unweighted Average of three Parts)*—Use the procedure detailed as follows, to determine the varnish rating of each part:

13.3.2.1 Rate any areas where varnish deposits have been altered during disassembly or sludge removal according to deposits on the surrounding non-altered areas. Do not rate altered areas as *clean*.

13.3.2.2 Determine original varnish ratings of all parts by comparison of the deposit on the rating location using the

ASTM Rust/Varnish/Lacquer Rating Scale for non-rubbing parts from ASTM Deposit Rating Manual 20. If the test was run using Haltermann fuel, Batch TF2221LS20, use fixed industry correction factors of 0.39 for APV and 0.12 for AEV. For both APV and AEV, add the original results, the industry correction factors, and lab severity adjustments to obtain the final results.

(1) If the test was run using Haltermann fuel batch XC2721NX10 and completed before Oct. 1, 2009, correct APV by adding 1.325 and dividing by 1.207. Correct AEV by adding 3.011 and dividing by 1.356. If the test was run using Haltermann fuel batch XC2721NX10 and completed on or after Oct. 1, 2009, correct APV by subtracting 0.24. Correct AEV by subtracting 0.12. For both APV and AEV, add the corrected results and the lab severity adjustments to obtain the final results.

13.4 Clogging:

13.4.1 Oil Screen Clogging:

13.4.1.1 Use the following procedure to determine the percentage of the oil screen clogged by sludge:

(1) Use a device to blow air across the screen to remove any retained oil on the screen. A suitable device can be obtained from the supplier listed in [X2.1.21](#).

(2) Regulate the air pressure to (130 ± 10) kPa.

(3) Connect the device to the screen.

(4) Allow air to flow for (5 to 10) s.

(5) Remove the device and rate.

13.4.1.2 Flexible, transparent rating aids can be made for different surface areas so that when compared to the test screen's surface, a more accurate determination of surface clogging is possible.

13.4.1.3 Determine the percentage of the total screen opening that is obstructed with debris. Determine the percentage of the total screen opening that is obstructed with sludge. Transform the oil screen sludge results by taking the natural log (ln) of the oil screen sludge rating plus one; that is, $\ln(\text{oil screen clogging} + \text{one})$. Round the transformed value to four decimal places. Report both transformed and original result on the appropriate form(s). Where laboratory bias is determined to be significant, adjust the results for severity in accordance with the Lubricant Test Monitoring System.²³ Round this adjusted result to four decimal places and convert to original units by subtracting one from the antilog (e^x) of the adjusted result in transformed units. Record this value as the final result in original units on the appropriate form(s). Label as sludge all matter present on the oil screen that is not immediately recognizable as debris. Label all matter of indeterminate composition as sludge.

13.5 Sticking:

13.5.1 *Compression Rings*—Record the number of stuck compression rings. Definitions to classify the degree and type of sticking are detailed in Section 3. List both hot and cold stuck compression rings on the Test Results Summary page.

²³ Available from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206.

Denote hot or cold stuck rings on the Supplemental Operational Data page and include the ring location (top or second) and the piston number.

13.6 *Used Oil Analyses:*

13.6.1 Perform the following analyses on the used oil samples taken every 24 h and on the final drain: Viscosity at 40 °C (Test Method **D445**), wear metals (Test Method **D5185**), and fuel dilution (Test Method **D3525**). Take samples at (0, 24, 48, 72, 96, 120, 144, 168, 192, and 216) h.

13.6.2 *Fuel Dilution*—Determine the fuel dilution, mass percent, by gas chromatography (see Test Method **D3525**, with the following modifications) on the used oil samples.

13.6.2.1 Use C16 in place of C14 for the internal standard (1μL injector volume).

13.6.2.2 Presume that all components lighter than C16 are fuel.

13.6.2.3 The integrator should establish a horizontal baseline under the output curve until the leading edge of C16 is reached. Establish a second baseline extending horizontally from the output curve, at the intersection of the output curve, and the leading edge of the C16 peak.

13.6.2.4 Column details are 3050 mm by 3.2 mm SS; and the packing material is 5 % OV-1 on Chromosorb W HP.

13.6.2.5 Increase the oven temperature from (60 to 320) °C, with the rate of change of temperature controlled at 8 °C/min. Hold the temperature at 320 °C for 16 min to elute oil.

13.7 *Additional Measurements:*

13.7.1 *Follower Pin Wear*—Measure the wear on the pins from the followers from cylinder No. 8, intake and exhaust, using the following procedure:

13.7.1.1 Label one end of each follower with the position in the engine; i.e., 8I, 8E.

13.7.1.2 Label the opposite end of the roller pin with an arrow indicating the top of the rocker and the position of the measurement.

13.7.1.3 Using a vice to hold the rockers, punch out the pins from the rockers with a 5 mm diameter punch.

13.7.1.4 Measure the wear steps on both follower pins using a surface finish analyzer.

13.7.1.5 Set the machine up following the manufacturer's instructions for measuring the depth of the wear.

13.7.1.6 Place the follower pin in a V-block with the arrow up (**13.7.1.2**).

13.7.1.7 Lower the stylus onto the follower pin, and center the pin horizontally.

13.7.1.8 Set the travel points on the machine so the stylus transverses the length of the worn surface, starting on an unworn surface at one end and completing its trace on the unworn surface at the opposite end. Position stylus to start and finish on an area between the worn surface and the area that was pressed into the rocker body.

13.7.1.9 Take a trace.

13.7.1.10 Position the evaluation length lines to bracket the displayed wear step so the measurement only evaluates the wear step maximum depth.

13.7.2 *Ring Gap Increase*—Using the top rings from pistons in cylinders 1 and 8, clean the rings thoroughly, and measure the ring gap after the rings have been installed in the master

bore (**7.5.5**). Calculate the ring gap increase. Compensate for any ring gap adjustments made during the test. Average the results and record. Determine the maximum ring gap increase and record.

14. *Assessment of Test Validity*

14.1 *General*—The testing laboratory shall assess the validity of tests that have deviations from the procedure. The TMC and Test Sponsor shall assist the laboratory in the determination of calibration test validity, if requested by the laboratory. Use the following guidelines as a basis for determining test validity:

14.2 *Used Oil Analyses-Interpretation :*

14.2.1 *Iron and Aluminum Content*—The aluminum and iron content of the used oil samples can indicate the level of wear that occurs during a test. Increased camshaft bearing wear causes the aluminum content to increase. Increased camshaft, rocker arm, and cylinder bore wear causes the iron content to increase. The rate of change in iron levels indicates the rate of change of wear levels, although wear tends to be linear throughout the test.

14.2.2 *Silicon Content*—Silicon content indicates the level of contamination of the oil from external sources and silicone-based gaskets. Silicone-based gaskets are used to seal the oil pan and rocker covers. Investigate the presence of silicone-based sealers, the cleanliness of engine parts during build-up, the cleanliness of the intake air, and the cleanliness of containers used for dispensing and sampling the oil if high levels of silicon are experienced.

14.2.3 *Fuel Dilution*—Fuel dilution indicates the degree to which the crankcase oil has been diluted with fuel. Fuel dilution of the crankcase oil is necessary to achieve adequate test severity. However, excessive fuel dilution can promote increased sludge severity and component wear. Investigate a higher level of fuel dilution than is normally noted.

14.3 *Blowby Flow Rate*—The corrected average blowby flow rate during Stage II during the first 120 h of the test shall fall within the range from (60 to 70) L/min. Blowby should remain relatively constant throughout the entire test. Blowby typically drops slightly in the first 23 h of the test. Excursions below 60 L/min are acceptable as long as the average is between (60 and 70) L/min. If two consecutive Stage II readings within the first 120 h, are less than 56 L/min or the average is not within the prescribed limits, consider the test operationally invalid.

14.4 *Manifold Absolute Pressure (MAP)*—Throttle position is set by manifold absolute pressure during Stage I and II to account for the altitude of the laboratory, ambient barometric pressure, and the mechanical efficiency of the engine.

14.5 *Fuel Consumption Rate*—The fuel consumption rate should not exceed (9.0, 19.0, 5.0) kg/h for Stages I, II and III, respectively.

14.6 *Oil Consumption:*

14.6.1 Oil consumption should not occur early in the test. During this time period of the test, fuel dilution levels may increase oil levels above the test full mark. If the oil level is above the test full mark by 200 g or more, then the engine, EEC

system, fuel injectors, and so forth should be checked for a malfunction that could be causing excessive fuel dilution.

14.6.2 The total amount of new oil added during the test shall not exceed 2000 g and no more than 400 g can be added at any 24 h oil leveling period.

14.7 *Engine Parts Replacement*—Parts that are rated to determine the final test results cannot be replaced during the test. The following parts can be replaced, if necessary (record the circumstances involved in the replacement): ignition system components, EEC system and EPROM chip, PCV valve, seals and gaskets, valves or valve springs, fuel injectors, oil separator (PCV system), and spark plugs.

14.8 *Quality Index*—Requirements for quality index are listed in **Annex A2**. If the end of test quality index value is below 0.000 for reference oil tests, review the test operations with the TMC. The TMC issues a letter to the laboratory and the test purchaser on its opinion. The laboratory documents its comments regarding end of test quality index values less than 0.000 for non-reference oil tests. The laboratory or test purchaser might request TMC review of test operations for non-reference oil tests. The TMC issues a letter to document its opinion. If a test has greater than 2 h without recorded operational data on any controlled parameter, the test is operationally invalid.

14.9 Report results on all reference oil tests run to completion, regardless of validity.

15. Final Test Report

15.1 *Report Forms*—For reference oil tests, the standardized report form set and data dictionary for reporting test results and for summarizing the operational data are required.

16. Precision and Bias

16.1 *Test Precision—Reference Oils:*

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

TABLE 8 Reference Oil Statistics^A

Variable, Merits	Intermediate Precision		Reproducibility	
	S _{i.p.}	i.p. ^B	S _R	R ^B
Average engine sludge	0.45	1.26	0.46	1.29
Rocker cover sludge	0.25	0.70	0.27	0.76
Average engine varnish	0.10	0.28	0.10	0.28
Oil screen clogging, sludge ^C	0.793	2.220	0.819	2.293
Average piston varnish	0.20	0.56	0.20	0.56

^A These statistics are based on results obtained on Test Monitoring Center Reference Oils 1006, 1006-2, 1007, 1008, and 1009 over the period from Sept. 16, 1998 through Nov. 5, 2004.

^B This value is obtained by multiplying the standard deviation by 2.8.

^C This parameter is transformed using $\ln(\text{result}+1)$. 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 precision or reproducibility) precision limit.

NOTE 9—"Intermediate precision" is the appropriate term for this test method rather than "repeatability," which defines more rigorous within-laboratory conditions.

16.1.1.1 *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 8** in only one case in twenty.

16.1.2 *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.

16.1.2.1 *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 in **Table 8** in only one case in twenty.

16.2 *Bias*—Bias will be determined by applying an accepted statistical technique to reference oil test results, and when a significant bias is determined, a severity adjustment will be permitted for non-reference oil test results.

17. Keywords

17.1 lubricating oils; Sequence VG; sludge and varnish; spark-ignition automotive engine; stop-and-go service

ANNEXES

(Mandatory Information)

A1. SAFETY PRECAUTIONS

A1.1 *General Information:*

A1.1.1 The operation of this procedure *can* expose personnel to hazardous materials, operations, and equipment. Personnel who are involved in the design, installation, and operation should be thoroughly trained and experienced. Personnel should be provided with safety glasses, hearing protection, and proper tools. All loose clothing should be removed or secured.

A1.1.2 The laboratory facilities should be inspected and approved by the laboratory's safety department. All laboratory areas should be kept clean and free of oil and fuel spills. The laboratory should also be kept free of tripping hazards. Containers of fuel and oil should not be allowed to accumulate excessively. A fixed fire protection system and adequate fire

extinguishers should be available in all parts of the laboratory. Emergency showers should be provided throughout the laboratory.

A1.1.3 The test stands should be equipped with a fuel shut-off valve that is designed to automatically interrupt the fuel supply when the engine is not running. The engine should also be automatically shutdown if any of the following events occur: dynamometer loses field current, engine overspeeds, exhaust system fails, room ventilation fails, or the fire protection system activates. Guards should be installed around all external rotating parts and hot surfaces. All fuel lines, oil lines, steam lines, process water lines, and electrical wiring should be properly routed, protected, and kept in good working order.

A1.1.4 This test method can expose personnel to physical hazards and various hazardous chemicals to prepare parts for the test. These chemicals and a summary of specific precautions concerning each chemical are listed below. Emergency showers and eye-rinse facilities should be provided in parts preparation areas.

A1.2 *Physical Hazards:*

- A1.2.1 Electrical shock.
- A1.2.2 High-speed rotating equipment.
- A1.2.3 High-temperature surfaces.
- A1.2.4 Noise.

A1.3 *Hazardous Chemicals and Materials:*

A1.3.1 *Solvent (meeting Specification D235, Type II, Class C requirements) (See 7.7.1):*

A1.3.1.1 Before opening the container, relieve pressure. Keep the container tightly closed when not in use.

A1.3.1.2 Store at moderate temperatures and keep away from heat, sparks, open flame, oxidizing agents, acids, and bases.

A1.3.1.3 Use dry chemical, foam, or CO₂ as extinguishing media.

A1.3.1.4 Use safety glasses and impervious gloves when handling.

A1.3.1.5 Use cartridge or air-line respirators in enclosed areas.

A1.3.1.6 Use only if adequate ventilation is available.

A1.3.1.7 Avoid contact with eyes, skin, and clothing.

A1.3.2 *Cooling System Cleanser; (DuPont formulation or equivalent):*

A1.3.2.1 Store at moderate temperatures. Keep container closed until use.

A1.3.2.2 Use safety glasses and impervious gloves when handling.

A1.3.2.3 Use respiratory protection in absence of proper environmental control.

A1.3.2.4 Use only if adequate ventilation is available.

A1.3.2.5 Avoid contact with eyes, skin, and clothing.

A1.3.3 *Acidic Cleaner with Inhibitor (Dearsol 134):*

A1.3.3.1 Store at moderate temperatures. Keep container closed until use.

A1.3.3.2 Use safety glasses and impervious gloves when handling.

A1.3.3.3 Use respiratory protection in absence of proper environmental control. Use only if adequate ventilation is available.

A1.3.3.4 Avoid contact with eyes, skin, and clothing.

A1.3.4 *Unleaded Gasoline (Haltermann VG Fuel)—(Warning—Flammable. Health hazard.)*

A1.3.4.1 Before opening the container, relieve pressure. Keep the container tightly closed when not in use.

A1.3.4.2 Store at moderate temperatures and keep away from heat, sparks, open flame, and oxidizing agents.

A1.3.4.3 Use dry chemical, foam, or CO₂ as extinguishing media.

A1.3.4.4 Use safety glasses and impervious gloves when handling.

A1.3.4.5 Use respiratory hydrocarbon vapor canisters in enclosed areas.

A1.3.4.6 Use only if adequate ventilation is available.

A1.3.4.7 Avoid contact with eyes, skin, and clothing.

A1.3.5 *New and Used Oil Samples:*

A1.3.5.1 Store at moderate temperatures and keep away from extreme heat, sparks, open flame, and oxidizing agents.

A1.3.5.2 Use dry chemical, foam, or CO₂ as extinguishing media.

A1.3.5.3 Use safety glasses and impervious gloves when handling.

A1.3.5.4 Avoid contact with eyes, skin, and clothing.

A1.3.5.5 *Used Oil Samples Only—(Warning—Health hazard.)* Since used oils contain compounds that were not originally present in the new oil, follow the most stringent Material Safety Data Sheets guidelines for all components present. *In addition to other precautions, note that continuous contact with used motor oils has caused skin cancer in laboratory mice.*

A1.3.6 *Organic Solvent (Penmul):*

A1.3.6.1 Before opening the container, relieve pressure. Keep the container tightly closed when not in use.

A1.3.6.2 Store at moderate temperatures and keep away from heat, sparks, open flame, and strong oxidizing agents.

A1.3.6.3 Use dry chemical, foam, or CO₂ as extinguishing media.

A1.3.6.4 Use safety glasses and impervious gloves when handling.

A1.3.6.5 Use respiratory hydrocarbon vapor canister in enclosed area.

A1.3.6.6 Use only if adequate ventilation is available.

A1.3.6.7 Avoid contact with eyes, skin, and clothing.

A2. CONTROL AND DATA ACQUISITION REQUIREMENTS

TABLE A2.1 Accuracy Levels of Data Points to be Used in QI Calculations

Parameter	Field Length
Speed	5.0
Humidity	5.1
Temperature	5.1
Manifold Absolute Pressure	5.1
Intake Air Pressure	6.3
Exhaust Backpressure	6.1
Coolant Outlet Pressure	6.1
Coolant Flow	6.1

A2.1 General Description:

A2.1.1 The data acquisition system shall be capable of logging the operational data in digital format. It is to the advantage of the laboratory that the system be capable of real time plotting of controlled parameters to help assess test validity. The systems shall be capable of calculating real time quality index as this will be monitored throughout the test as designated in **A2.5**.

A2.1.2 Control capability is not dictated by this procedure. The control system shall be capable of keeping the controlled parameters within the limits specified in **Table 2** (see **8.3.5**) and maintain the quality index shown in **A2.5**.

A2.1.3 Design the control and data acquisition system to meet the requirements listed below. Use the recommendations laid out in the Instrumentation Task Force Report and Data Acquisition Task Force Report for any items not addressed in **Annex A2**.

A2.2 *Digital Recording Frequency*—The maximum allowable time period over which data can be accumulated is one second. This data can be filtered, as described in **A2.6**, and will be considered a reading.

A2.3 Steady State Operation:

A2.3.1 This portion of the test will start, at most, 20 min after the beginning of a transition and continue until the beginning of the next stage. By 20 min into a stage all parameters shall be in the steady state condition listed in **Table 2**. The start of the transition is considered the start of the stage. Calculate the quality index using values reported to the accuracy levels in **Table A2.1**.

A2.3.2 The time intervals between recorded readings shall not exceed 1 min. Data shall be recorded throughout the length of the steady state portion of each stage.

A2.4 Transitions :

A2.4.1 This portion of the test shall be, at most, the first 20 min of each stage. Ramping requirements are listed in **Table 4**.

A2.4.2 During the transition, the time intervals between recorded readings shall not exceed 1 min.

A2.5 Quality Index:

TABLE A2.2 L and U Constants and Over and Under-Range Values

Parameter	Stages	L	U	Over-Range	Under-Range
Coolflow	1	47.47	48.53	87.0	0
Cooloutt	1	56.71	57.29	113.0	0
	2	84.71	85.29	113.0	0
	3	44.71	45.29	113.0	0
Exhbprs	1	103.83	104.17	115.0	0
	2	106.83	107.17	115.0	0
Humidity	1, 2, 3	10.85	11.95	64.0	0
Intairpr	1, 2, 3	0.04	0.06	1.05	0
Intairt	1, 2, 3	29.80	30.20	49.0	0
Oilint	1	67.79	68.21	120.0	0
	2	99.79	100.21	120.0	0
	3	44.79	45.21	120.0	0
Speed	1	1198.1	1201.9	3156.0	0
	2	2898.1	2901.9	3156.0	0
	3	698.1	701.9	3156.0	0
Map	1	68.60	69.40	76.0	0
	2	65.60	66.40	76.0	0
Cooloutp	1, 2, 3	69.35	70.65	159.0	0
Raccint	1, 3	28.63	29.37	120.0	0
	2	84.63	85.37	120.0	0
Raccfl	1, 2, 3	14.85	15.15	29.0	0

TABLE A2.3 Maximum Allowable Time Constants

Control Parameter	Time Constant, s
Engine speed, r/min	1.9
Manifold abs press, kPa	1.8
Engine oil in, °C	2.4
Engine coolant out, °C	2.4
Engine coolant flow, L/min	17.0
RAC coolant in, °C	2.4
Rocker cover flow, L/min	2.0
Intake, air, °C	2.4
Intake air press, kPa	2.6
Exhaust back pressure, kPa	1.7
Engine coolant pressure	2.0

A2.5.1 Calculate and record the quality index for each controlled parameter for the steady state portion of each test stage throughout the entire test.

A2.5.2 Update the quality index periodically throughout the test to determine the operational validity while the test is in progress. This could indicate if the test operational validity is in question before the test has completed.

A2.5.3 Use the following equation and the values listed in **Table A2.2** to calculate the Q_i .

$$1 - \frac{1}{n} \sum_{i=1}^n \left(\frac{U+L - 2X_i}{U-L} \right)^2 = \text{Quality index} \quad (\text{A2.1})$$

where:

X_i = values of the parameter measured,
 U = allowable upper limit of X ,
 L = allowable lower limit of X , and
 n = number of measurements taken.

A2.5.4 Reset data that is greater than the over-range values listed in **Table A2.2** with the over-range value listed in **Table A2.2**.

A2.5.5 Reset data that is lower than the under-range values listed in **Table A2.2** with the under-range value listed in **Table A2.2**.

A2.5.6 Round the Q_i values to the nearest 0.001.

A2.5.7 Report the Q_i values on Form 6 of the test report.

A2.5.8 If the end-of-test Quality index value is below 0.000 for reference oil tests, review the test operations with the TMC. The TMC issues a letter to the laboratory and the test sponsor on its opinion.

A2.5.8.1 The laboratory documents its comments regarding the end-of-test Quality index values less than 0.000 for

non-reference oil tests. The laboratory or test sponsor might request TMC review of test operations for non-reference oil tests. The TMC issues a letter to document its opinion.

A2.6 *Time Constants:*

A2.6.1 Filtering can be applied to all control parameters. The amount of filtering applied shall not allow time constants to exceed the values listed in **Table A2.3**. This time constant shall pertain to the entire system, running from the sensor to the display and data acquisition.

A2.6.2 Maximum allowable system time constants for the controlled parameters are shown in **Table A2.3**.

A3. DETAILED SPECIFICATIONS AND PHOTOGRAPHS OF APPARATUS

A3.1 **Figs. A3.1-A3.28** show the detailed specifications and photographs of apparatus.

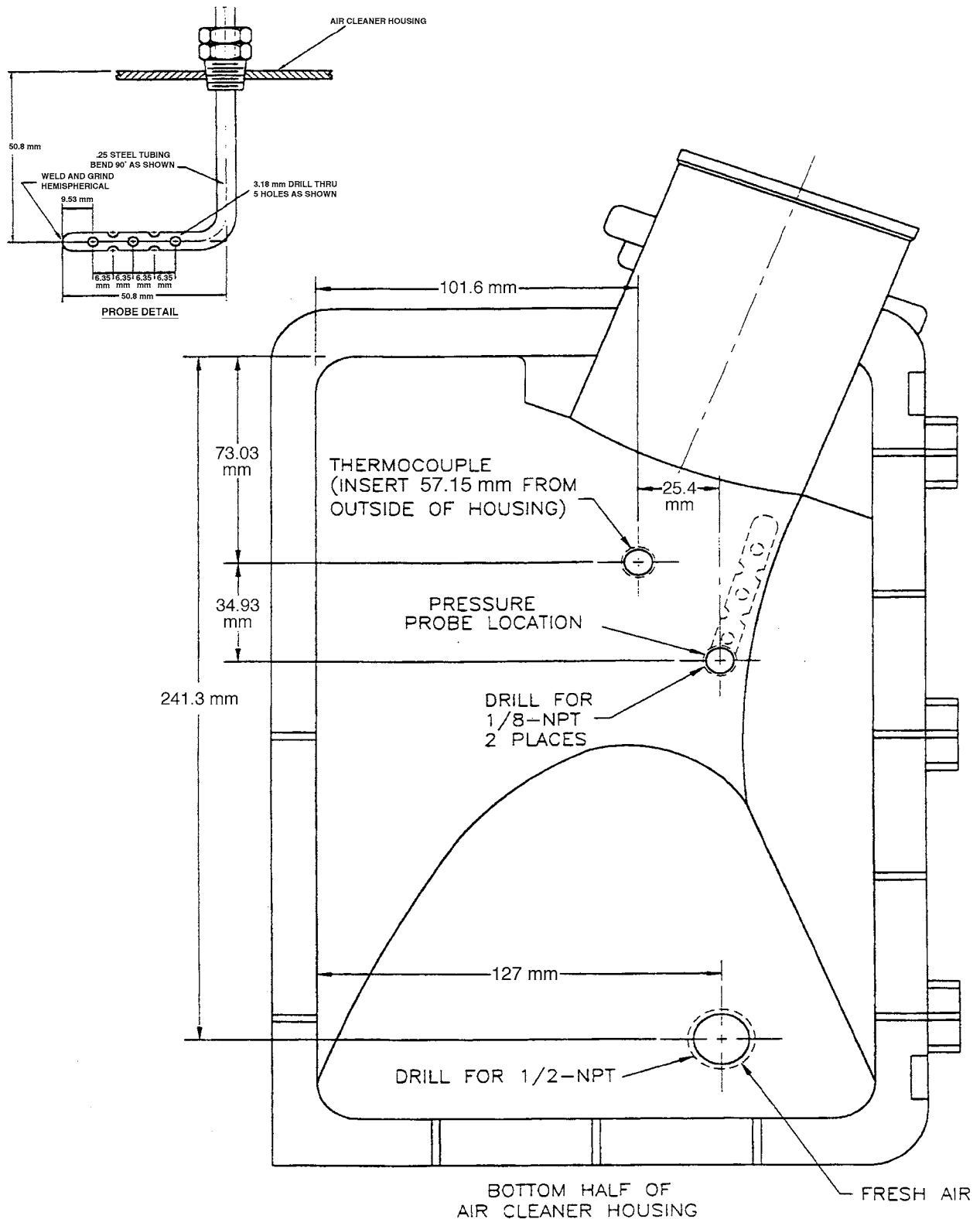


FIG. A3.1 Air Cleaner Housing Modifications

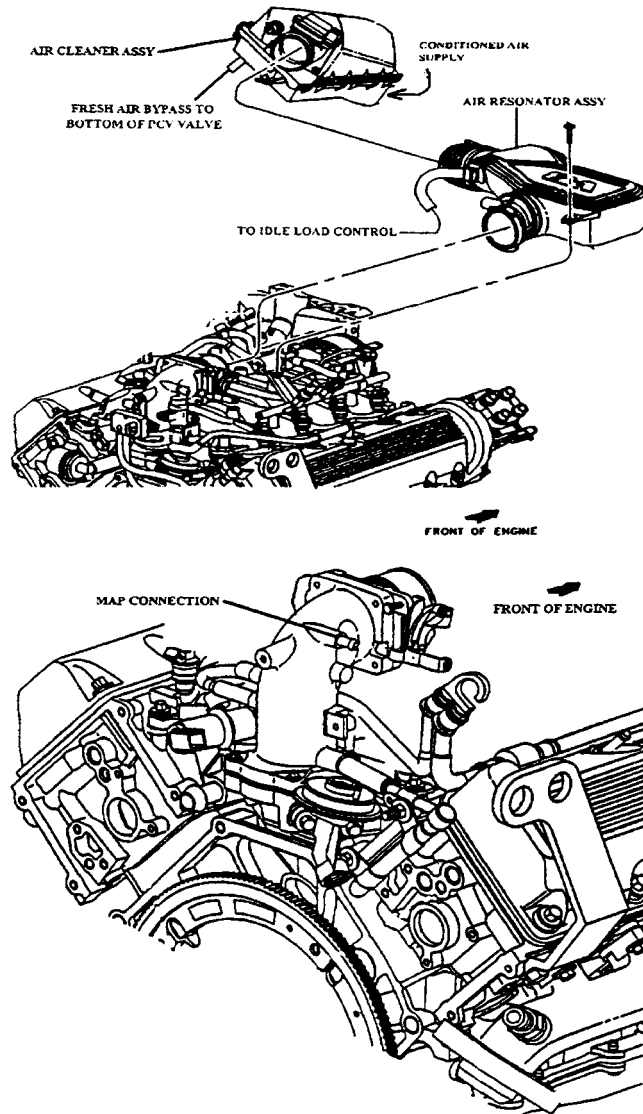


FIG. A3.2 Engine Air Intake System Assembly and Connections

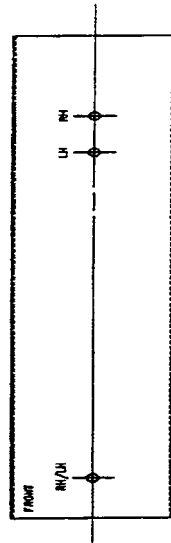
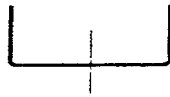


FIG. A3.3 Camshaft Baffle

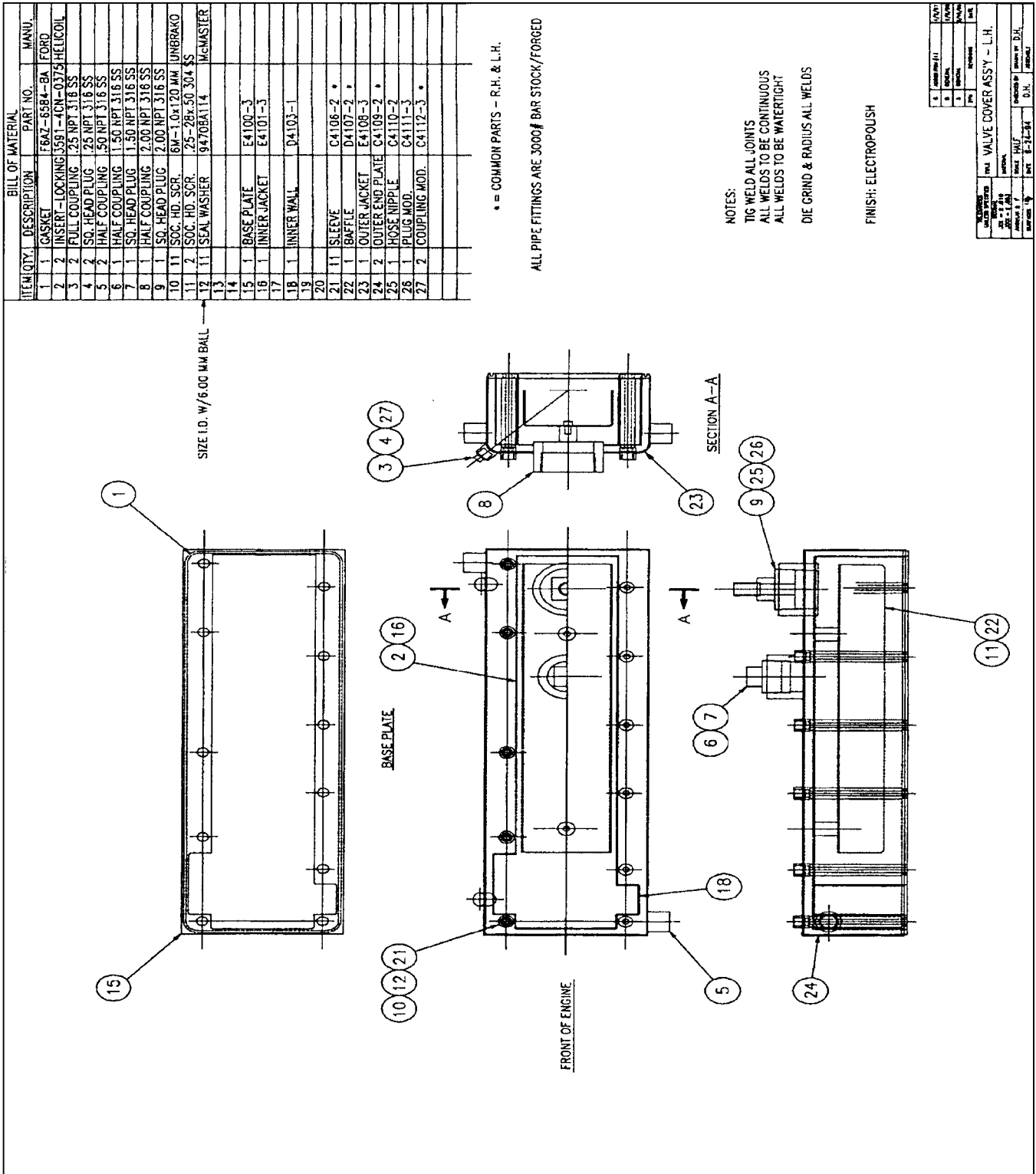


FIG. A3.4 Rocker Arm Cover with Water Jacket, Left

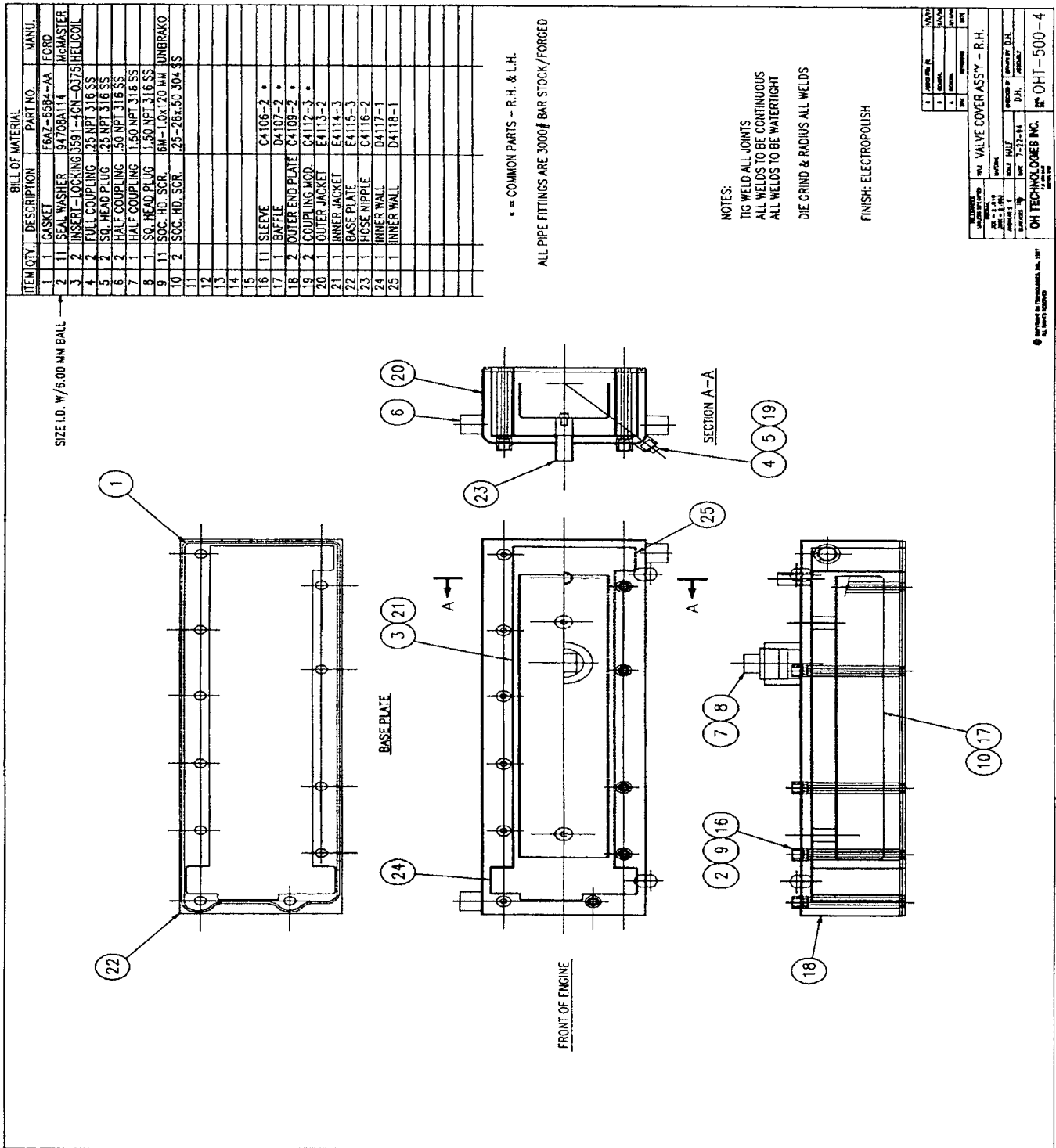
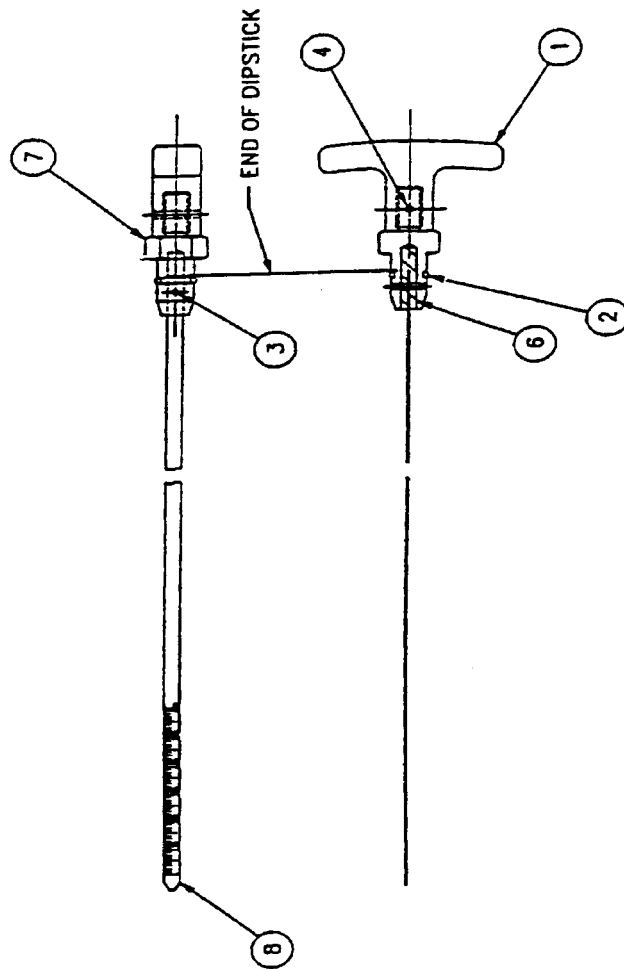


FIG. A3.5 Rocker Arm Cover with Water Jacket, Right

BILL OF MATERIAL			
ITEM	QTY	DESCRIPTION	PART NO.
1	1	T-HANDLE	33712
2	1	O-RING	2-011 VITON
3	1	SPRING PIN	91610A205
4	1	M2x10 ST. STL.	
5	1	SPRING PIN	92383A204
6	1	INSERT	510001
7	1	ADAPTER	510002
8	1	DIPSTICK	510003



ENLARGED VIEW
2X SIZE

FIG. A3.6 Oil Level Indicator (Dipstick)

BILL OF MATERIAL				
ITEM	QTY	DESCRIPTION	PART NO.	UNIT
1	1	OIL PAN	7146-14174-1A	FORM
2	1	FLAT Baffle	7146-14174-1A	FORM
3	1	FRONT Baffle	7146-14174-1B	FORM
4	11	STOCK LOCK WHEEL	11131-14174-1A	WHL-520L
5	2			
6	1	OIL PAN MOD.	581001	
7	1	FLAT Baffle MOD.	581001	
8	1	FRONT Baffle MOD.	581001	
9	2	STAND-OFF	581001-1	
10	2	STAND-OFF	581001-2	
11	2	STAND-OFF	581001-3	
12	2	STAND-OFF	581001	
13	2	BRACKET	581001	
14	2	BRACKET	581001	
15				
16				
17	11	LOC. WHEEL	58-10112.0 ST. STL	

SEE END 501001

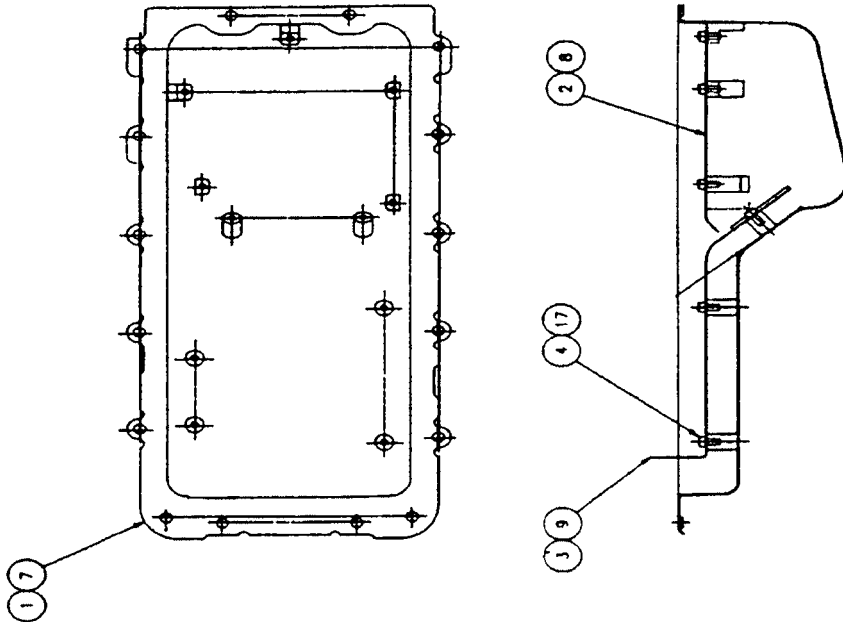
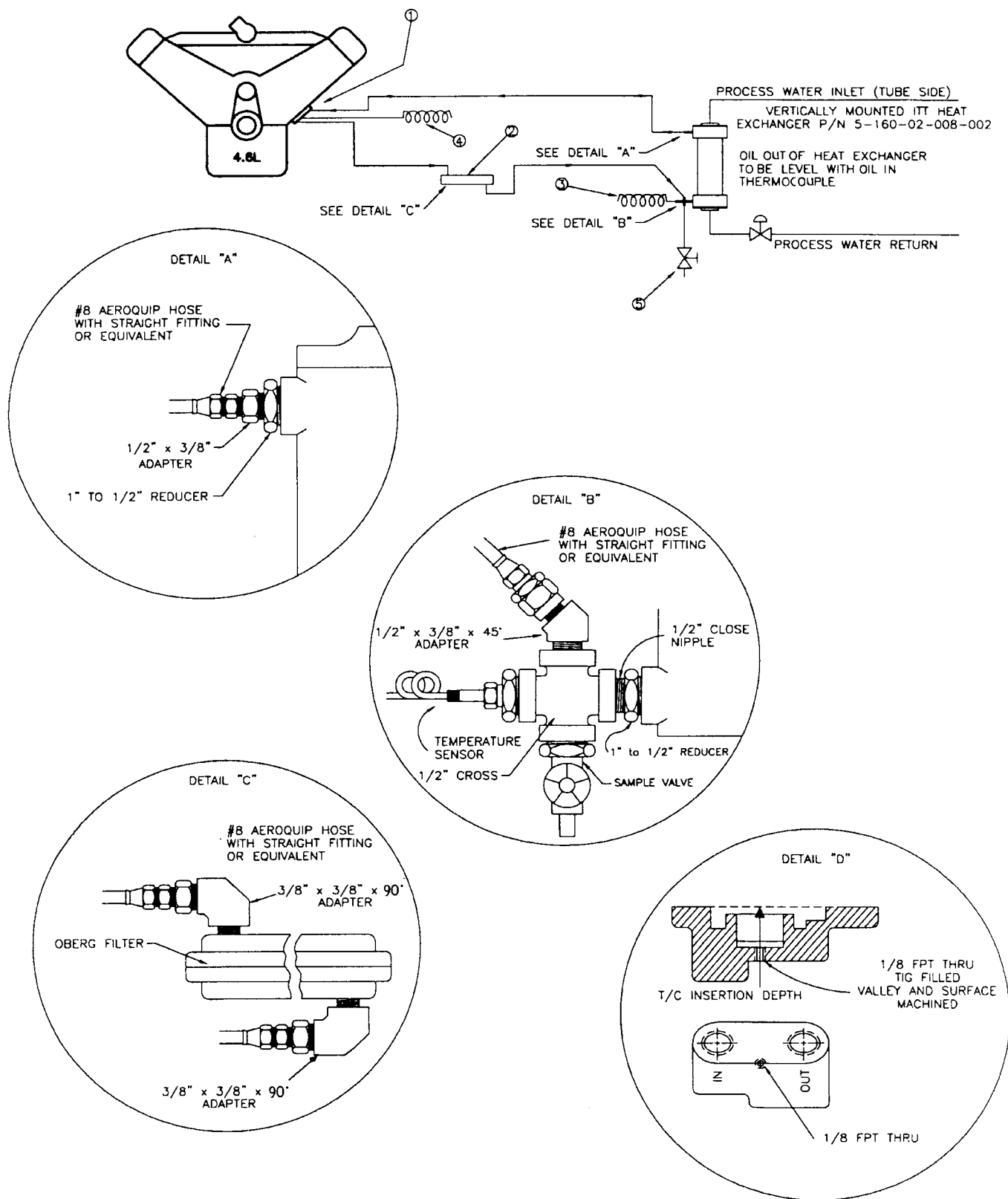
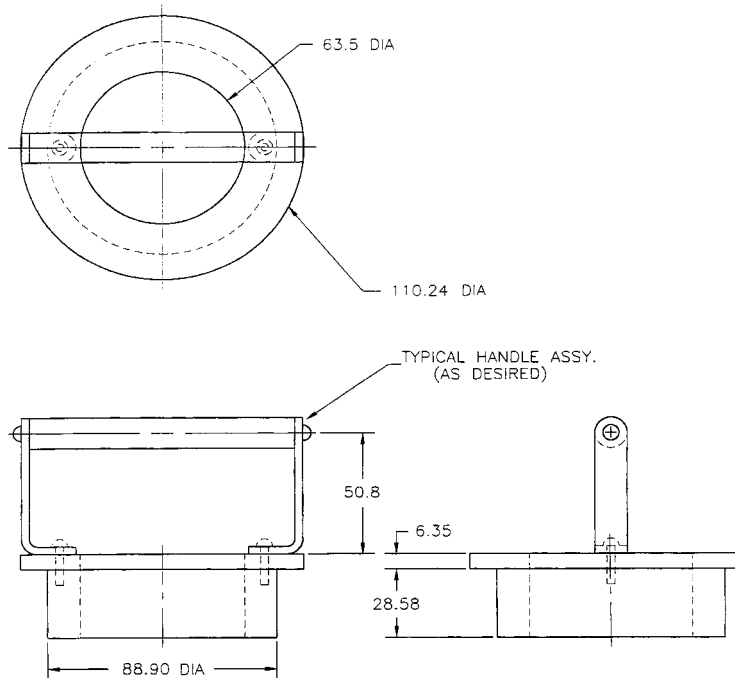


FIG. A3.7 Oil Pan Assembly with Removable Baffles



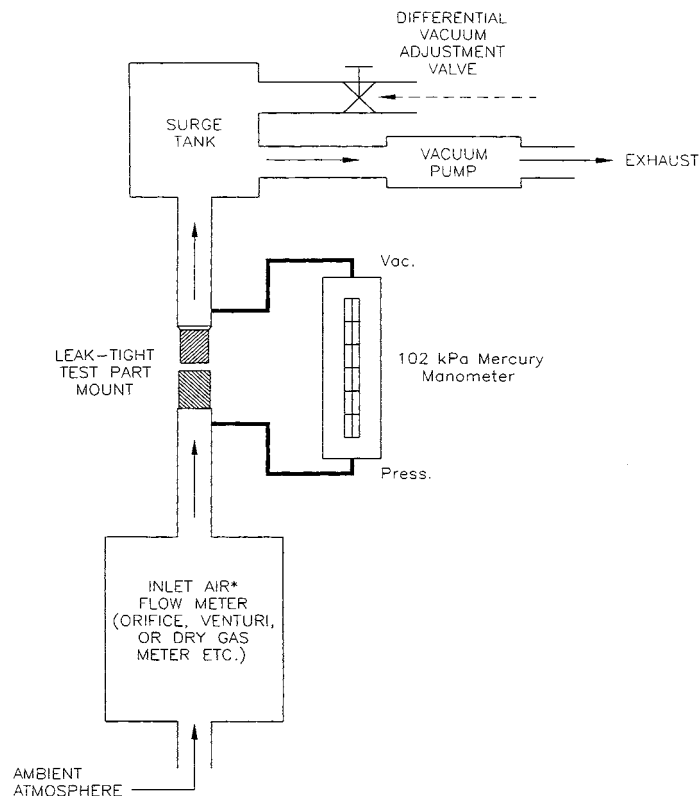
- NOTE 1—(1) External oil filter adapter with temperature in sensor and oil pressure gage taps, OHT6A-007-1
 (2) Oil filter, OHT6A-012-2, with steel relief valve and 60 μ m screen
 (3) Temperature sensor oil out
 (4) Temperature control sensor oil in
 (5) Oil sample valve
- NOTE 2—External system oil volume 570 $\pm$ 30 mL.

FIG. A3.8 Oil Cooling System Specification



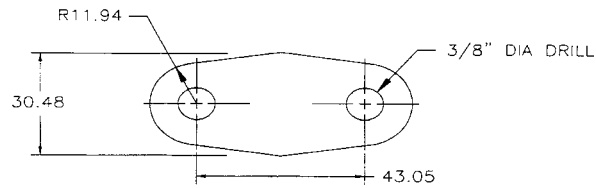
NOTE 1—Dimensions are in millimetres; Tolerances: ± 0.13 ; Material: aluminum.

FIG. A3.9 Piston Ring Positioner



NOTE 1—The inlet flow meter must calibrate to within 5 % of the standard (pre-calibrated) orifices at the pressure differentials stamped on the orifices.

FIG. A3.10 PCV Valve Flow Test Apparatus



NOTE 1—Dimensions are in millimetres.

FIG. A3.11 EGR Block Off Plate

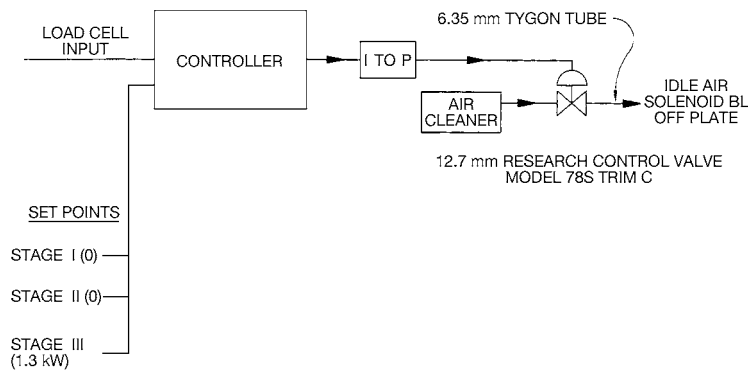
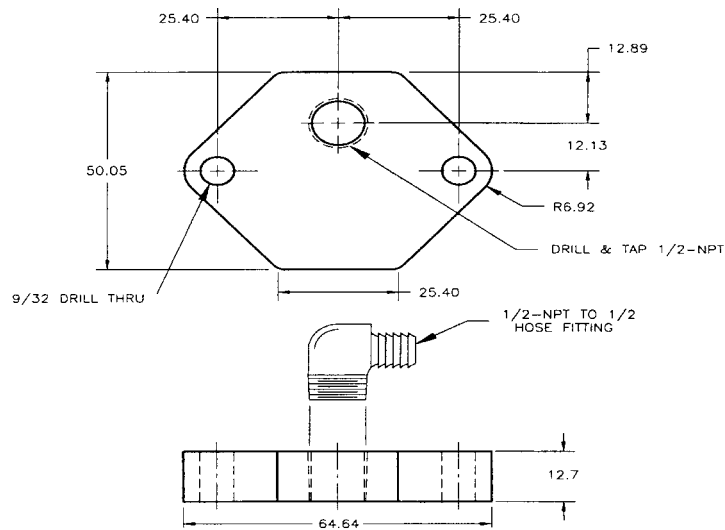


FIG. A3.12 Idle Air Control



NOTE 1—Dimensions are in millimetres.

FIG. A3.13 Idle Air Block Off Plate

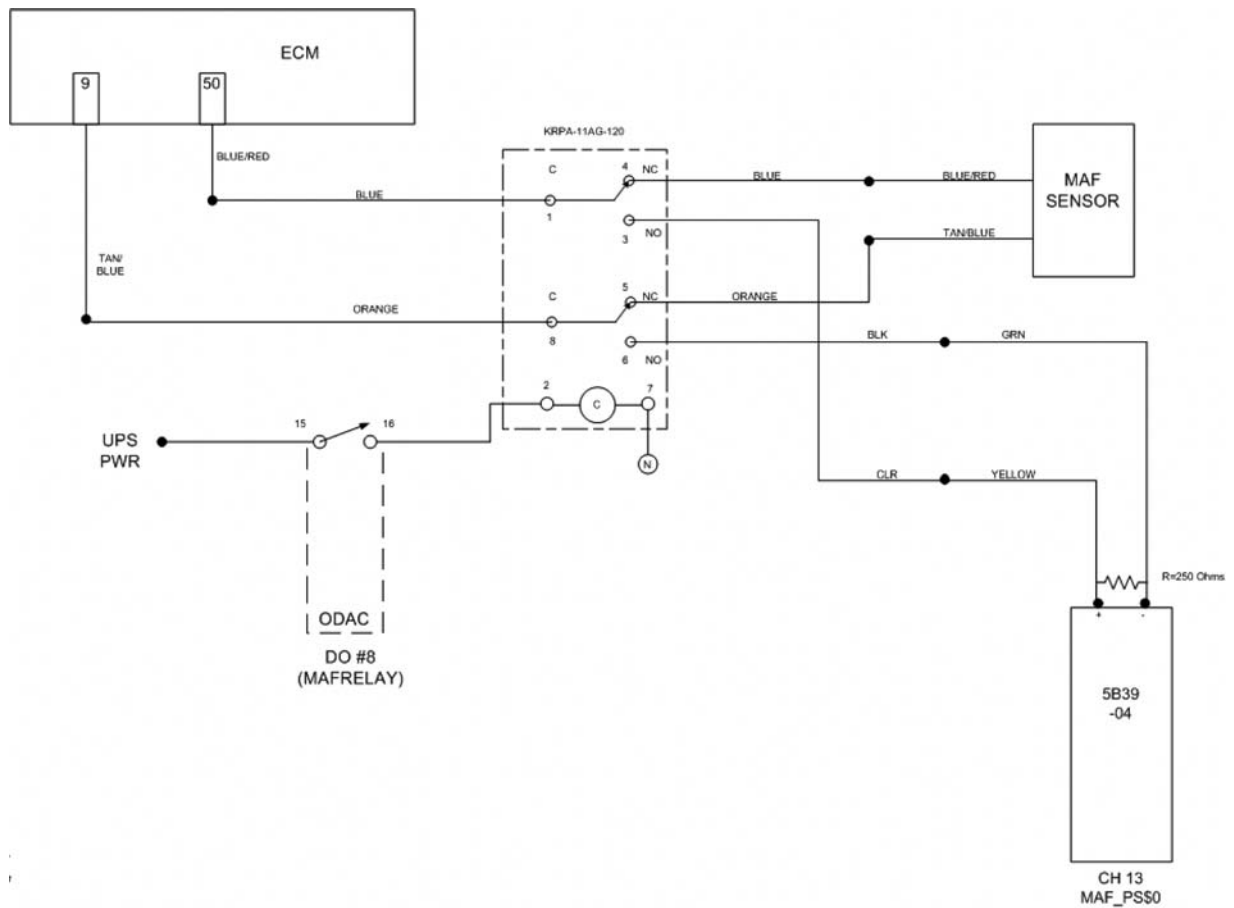


FIG. A3.14 Mass Air Flow Sensor Modifications

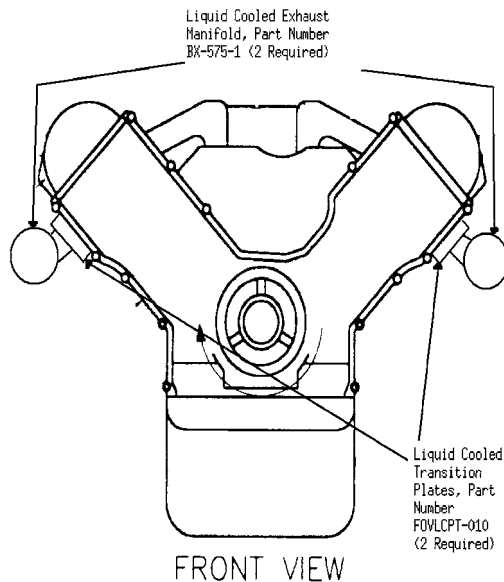
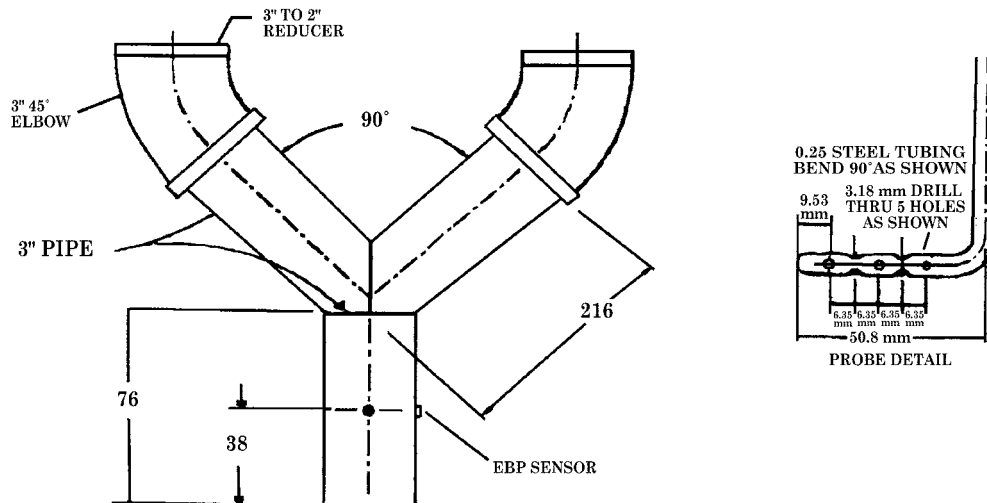
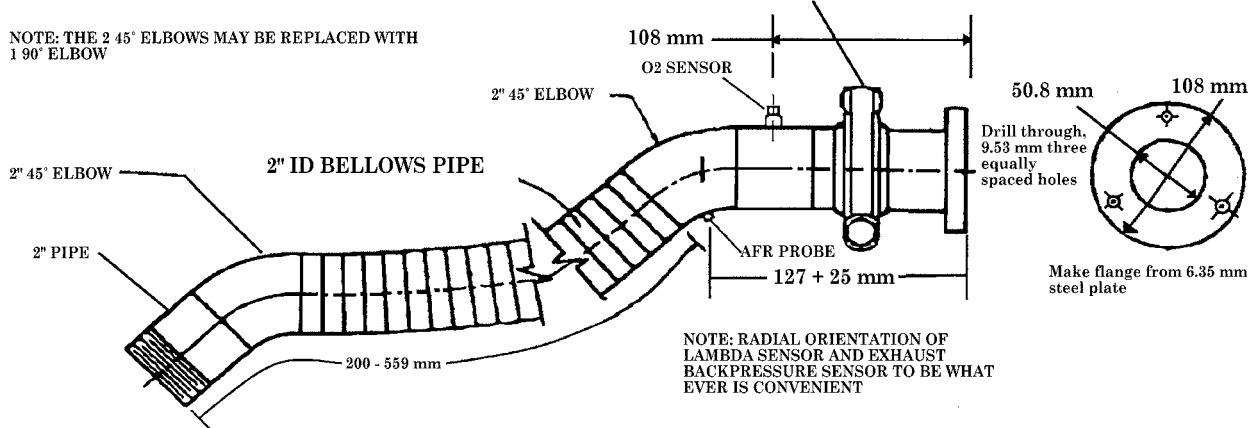


FIG. A3.15 Typical Exhaust System, Engine to Laboratory Exhaust



Cherry-Burrell 1 Clamp Fitting
Male 14W1 - 5 2" 29-790
Female 15W1 - 5 2" 29-797

NOTE: THE 2 45° ELBOWS MAY BE REPLACED WITH
1 90° ELBOW



NOTE 1—Dimensions are in millimetres.

FIG. A3.16 Typical Laboratory Exhaust System

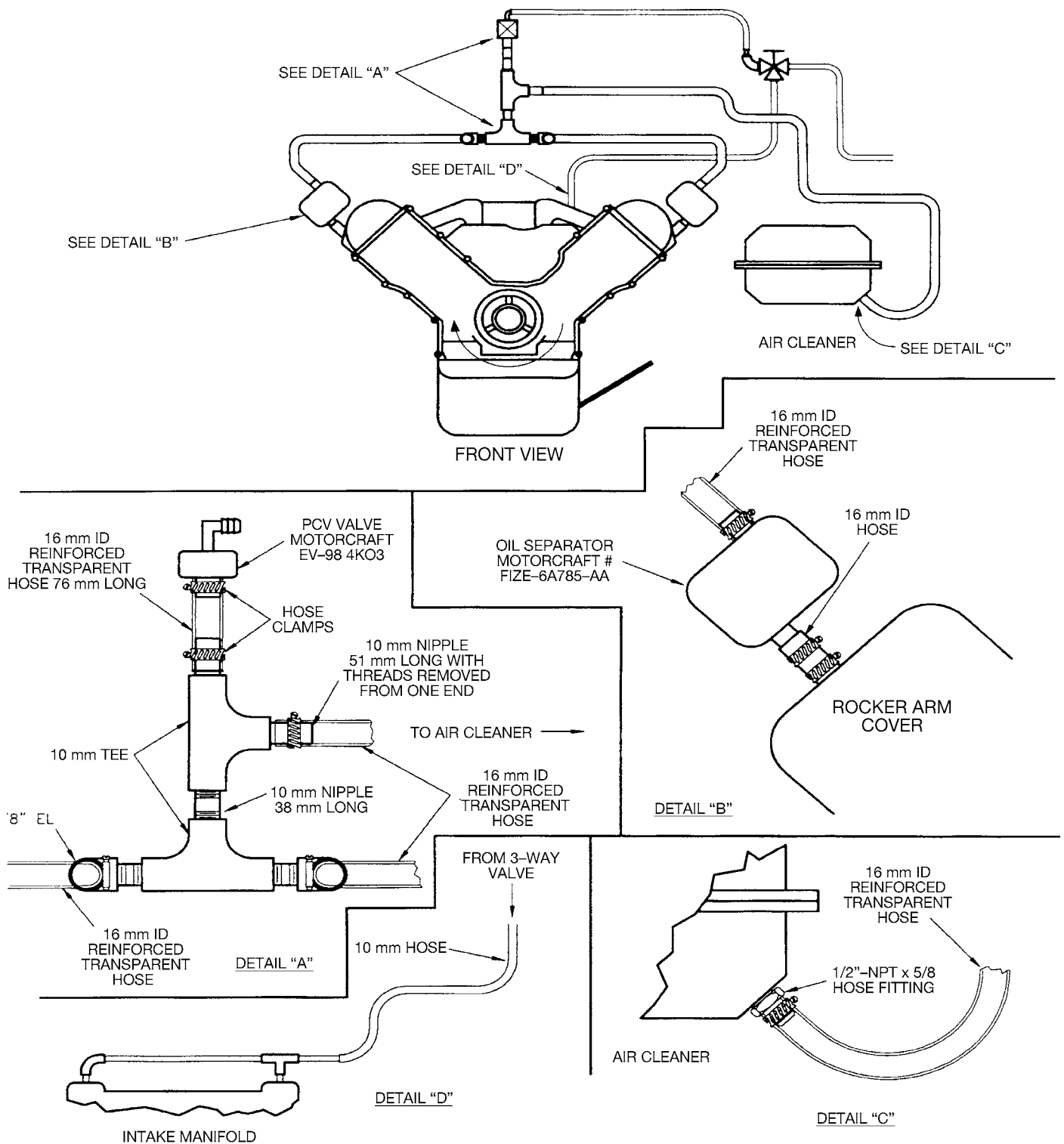
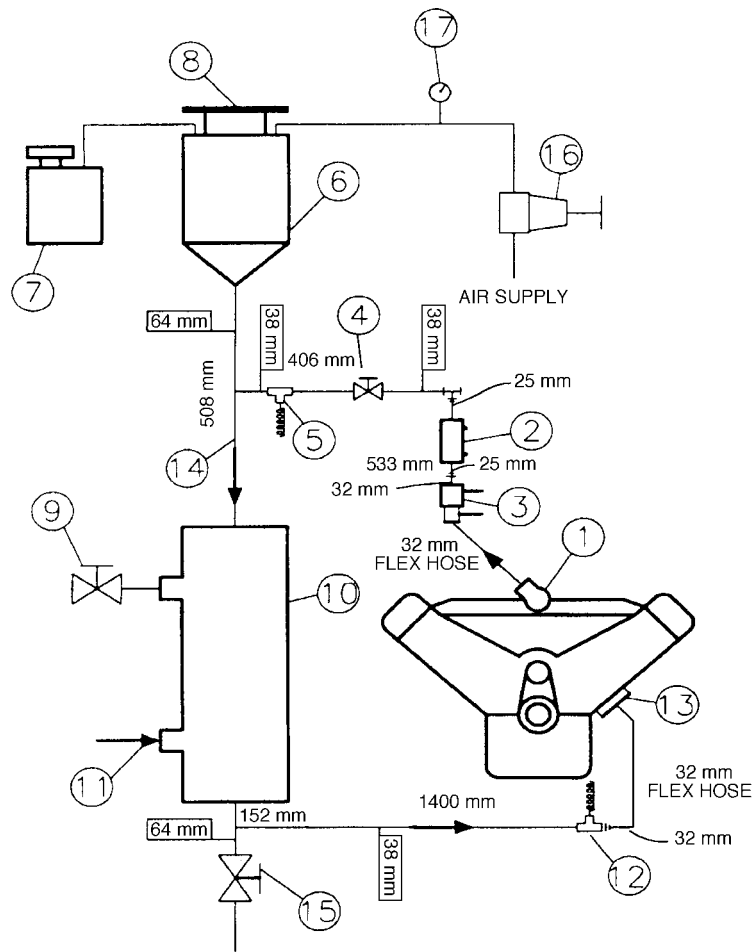


FIG. A3.17 Closed Crankcase Ventilation System, Typical Fittings and Parts Configuration



FRONT VIEW OF ENGINE

NOTE 1—Observe temperature sensor locations in thermostat housing and at water pump inlet.

NOTE 2—Components of Engine Cooling System—

- (1) Thermostat housing with temperature sensor
- (2) Sight glass
- (3) Venturi flowmeter Barco Model 725 1¼ in. with pressure taps BR-12725-20-31
- (4) Flow control valve
- (5) Optional temperature control sensor
- (6) Fabricated coolant reservoir
- (7) Constant full expansion tank
- (8) Pressure radiator cap (MOTORCRAFT RS40 P/N D2YY-8100-A)
- (9) Process water control valve (regulated by temperature controller with three remote set points)
- (10) Heat exchanger (ITT Standard P/N 5-030-06-048-001 TYP.)
- (11) Process water supply (shell side)
- (12) Tee with temperature sensor for coolant inlet; located (305 to 406) mm upstream of pump inlet
- (13) Water pump inlet
- (14) Engine coolant (tube side)
- (15) Coolant system drain valve
- (16) Coolant pressure regulator
- (17) Coolant pressure gage

FIG. A3.18 Typical Engine Cooling System Schematic

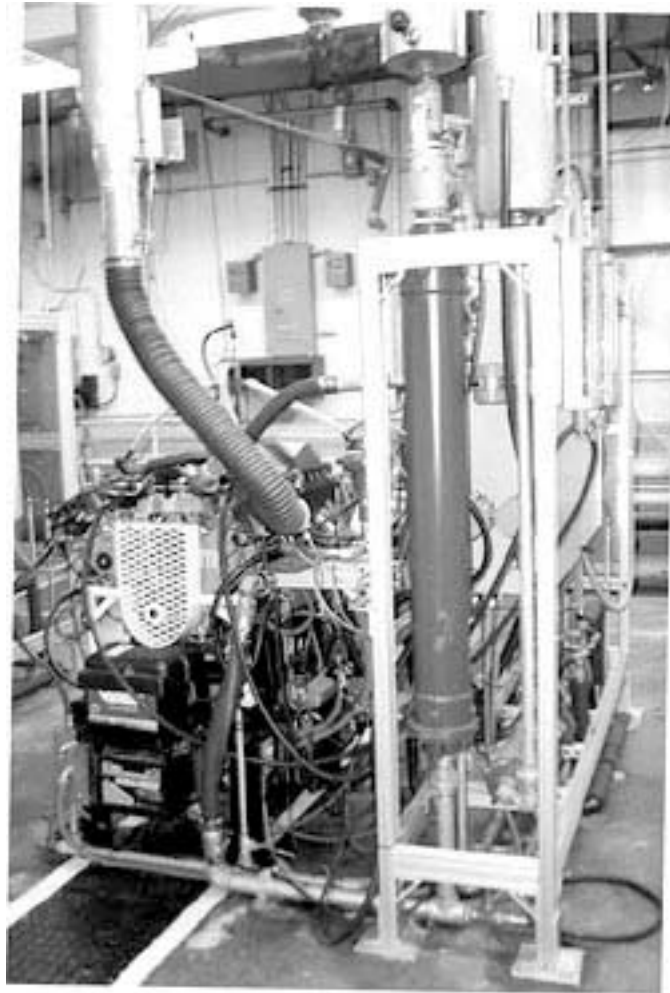


FIG. A3.19 Typical Test Stand, Left Forward View

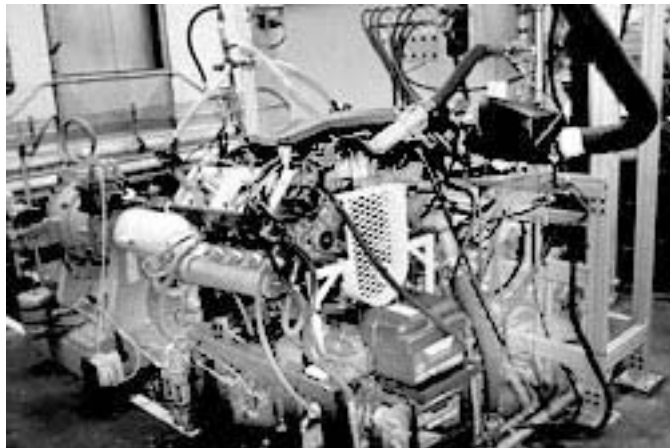


FIG. A3.20 Typical Test Stand, Right Forward View



FIG. A3.21 Intake Air Supply System, Air Cleaner, Resonator and Idle Load Control



FIG. A3.22 Typical Engine Cooling System, Venturi Flowmeter



FIG. A3.23 Typical Cooling System, Flow Control Valve, Venturi Flowmeter, Reservoir and Sight Glass

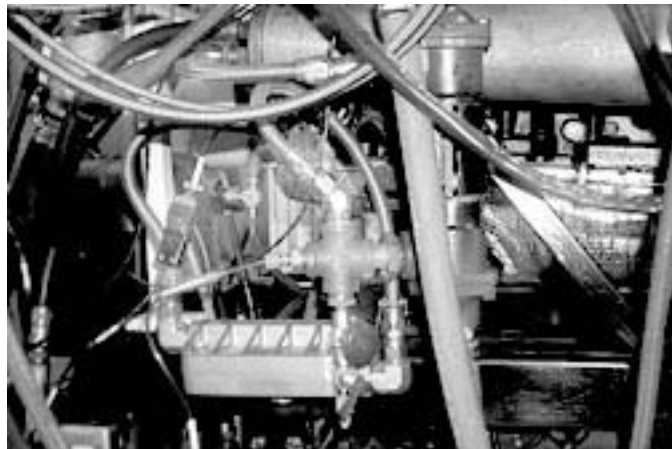


FIG. A3.24 Oil Cooling System Required Heat Exchanger Mounting and Typical Hoses and Fittings



FIG. A3.25 Oil Cooling System, Adapter Housing at the Engine with Typical Fittings for Temperature Sensors, Pressure Tap and Oil Filter



FIG. A3.26 Engine Ventilation System

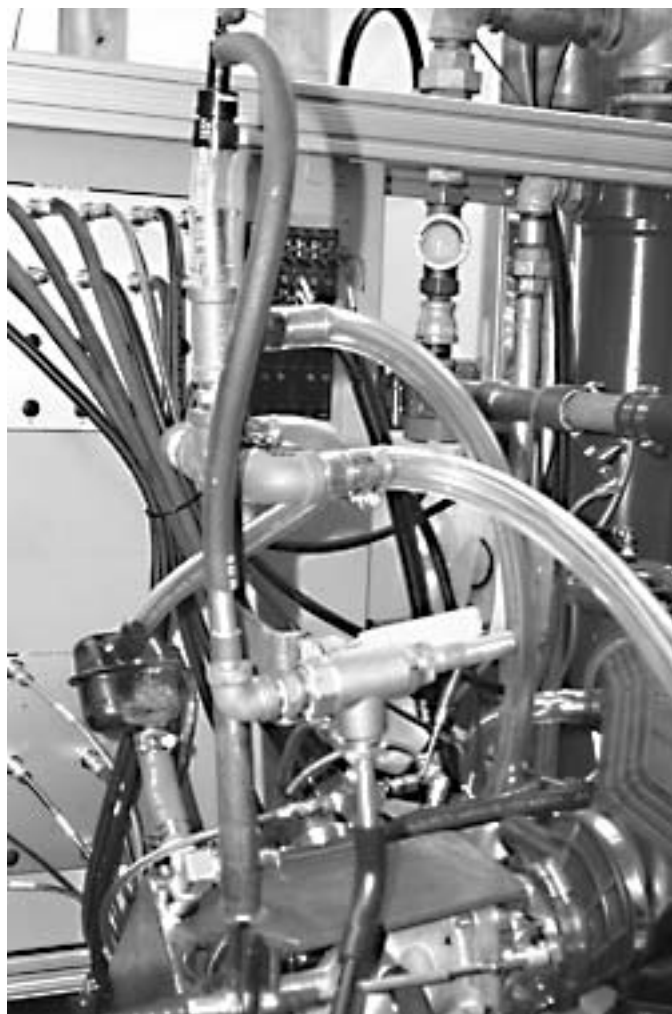


FIG. A3.27 Engine Ventilation System, 3-Way Valve

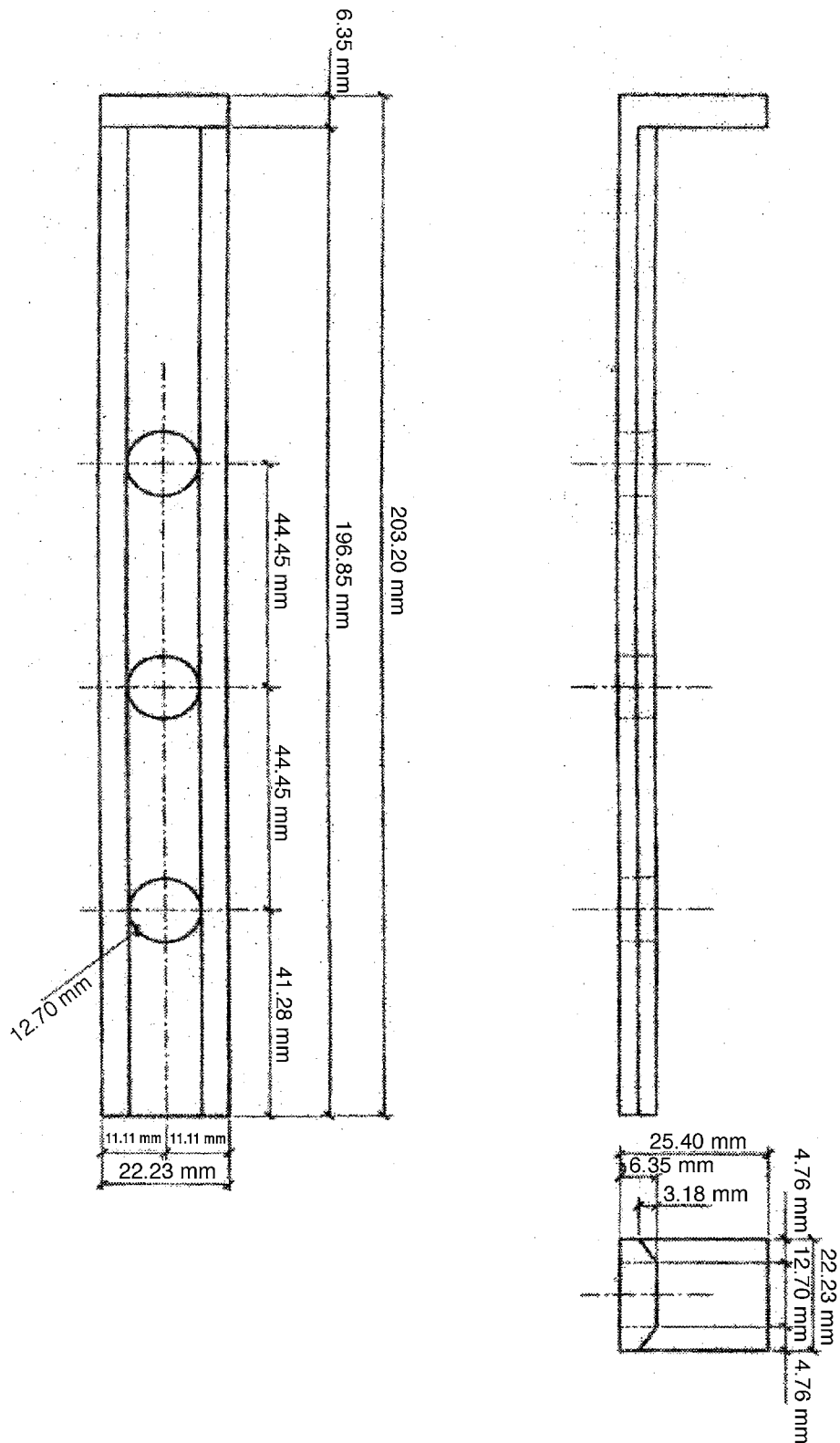


FIG. A3.28 Bore Measurement Ladder

**TABLE A4.1 Special Tools**

Tool No.	Description
D81L-6135-A	Piston pin remover and replacer
T80T-4000-W	Driver handle
T91P-6571-A	Valve stem seal replacer
T91P-6565-A	Valve spring compressor
T91P-6565-AH	Valve spring spacer

A4. SPECIAL SERVICE TOOLS FOR THE TEST ENGINE

A4.1 **Table A4.1** lists tools needed for the test engine.

A5. TEST ENGINE PART NUMBER LISTING

A5.1 **Tables A5.1-A5.7** list the test engine part numbers.



TABLE A5.1 Engine Parts Kit

	Prefix	Part Number		Description	Quantity
		Base	Suffix		
1	OG	804	AA	Engine Assembly	2
2	D8ZE	6A666	A2B	PCV Valve (EV-98)	4
3	E5TE	9601	AB	Air Filter Element	4
4	AGSF	32P	PF4	Spark Plug Assembly	32
5	F1AE	6065	BB	Bolt M11X1.5 21035 Hex	80
6	F1AE	6345	AD	Main Bolt	36
7	F1AE	6K258	AD	Main Bolt w/Stud Pickup	4
8	Q3U1L	6K109	AA	Oversize Piston, 0.125 mm	8
9	Q3U1L	6K109	AA	Oversize Piston Ring Set, 0.125 mm	8
10	Q3U1L	6K109	AA	Oversize Piston, 0.25 mm	8
11	Q3U1L	6K109	AA	Oversize Piston Ring Set, 0.25 mm	8
12	Q3U1L	6K109	AA	Oversize Piston, 0.375 mm	8
13	Q3U1L	6K109	AA	Oversize Piston Ring Set, 0.375 mm	8
14	Q3U1L	6K109	AA	Oversize Piston, 0.5 mm	8
15	Q3U1L	6K109	AA	Oversize Piston Ring Set, 0.5 mm	8
16	1W7E	6C315	AA	Crank Sensor Assembly	4
17	1W7E	6B288	AA	Cam Position Sensor	4
18	F65E	6251	B8A	Truck Camshaft-LH ^A	4
19	F65E	6C255	A8A	Truck Camshaft-RH ^A	4
20	YU1L	6622	AA	Screen and Cover Assembly	4
21	F6TE	6529	AB	Roller Follower	64
22	F65E	6C501	AA	Valve Tappet	64
23	F5AE	6507	AA	Intake Valve ^B	24
24	F1AE	6505	CC	Exhaust Valve ^B	24
25	F1AZ	6571	A	Valve Seal ^B	48
26	F5AE	6268	AA	Timing Chain	8
27	F81E	6M269	AA	Timing Chain Tensioner – LH	4
28	F81E	6L266	AA	Timing Chain Tensioner – RH	4
29	F3AE	6K297	AA	Timing Chain Guide – LH	4
30	F3AE	6K297	BA	Timing Chain Guide – RH	4
31	1L2E	6L253	AA	Tensioner Arm – LH	4
32	1L2E	6L253	BA	Tensioner Arm – RH	4
33	XL3E	6306	BA	Crankshaft Sprocket	4
34	F9ZE	6333	AA	Main Crankshaft Bearing	20
35	F9ZE	6A338	AA	Main Crankshaft Bearing	16
36	F9ZE	6A339	AA	Thrust Bearing	4
37	F9ZE	6A341	AA	Thrust Washer	20
38	F9ZE	6211	AA	Connecting Rod Bearing Set	64
39	F8AE	6621	AA	Oil Pump Assembly	4
40		N806435	S	Oil Gallery Plug	8
41	VG	LT	01	Cylinder Head Assembly ^B	2
42	VG	FA3		Cam Bearing Set	8

^A Camshafts to be polished by supplier in X2.1.11.^B Cylinder heads are obtained from supplier in X2.1.21 and are received assembled. Quantities listed are for an additional 3 builds.TABLE A5.2 Engine Dress Kit^A

	Prefix	Part Number		Description	Quantity
		Base	Suffix		
1	F6AE	6D080	BC	Front Cover	1
2	FOTE	9F593	D5A	Fuel Injectors	16
3	F47E	6A785	AA	Oil Separator	4
4	XL3F	9F472	AA	Sensor, Exhaust Gas Oxygen	20
5	F5AE	6C324	AB	Vacuum Line Tube	2

^A The components within the engine dress kit can be used for two tests.TABLE A5.3 Stand Setup Kit^A

	Prefix	Part Number		Description	Quantity
		Base	Suffix		
1	F5AE	9R504	BD	Air Resonator Assembly	1
2	F3AE	12A166	BD	Ignition Bracket	1
3	F6AE	12257	EB	Ignition Mtg Bracket Assembly	1
4	F2AE	9600	BA	Air Cleaner Assembly	1
5	F6ZR	6375	AC	Flywheel	1
6	F4AE	9424	CA	Intake Manifold	1
7	F8KE	19A216	AD	Grooved Idler Pulley	1
8	F2AE	9A589	AA	Throttle Spacer	1
9	F7AE	6B209	AB	Belt Tensioner	1
10	F8AE	8501	AB	Water Pump Assembly	1
11	F6PE	6C275	AA	Adapter Plate Tensioner	2

^A Long term stand service items.

TABLE A5.4 Gasket Kit^A

	Prefix	Part Number		Description	Quantity
		Base	Suffix		
1	XL3E	6051	BB	Cylinder Head Gasket RH	1
2	XL3E	6083	BB	Cylinder Head Gasket LH	1
3	F1AE	6625	AA	Oil Pump Inlet Tube Gasket	1
4	F3AE	6700	AA	Front Crankshaft Seal	1
5	F3AE	6701	AA	Rear Crankshaft Seal	1
6	F4AE	6710	AB	Oil Pan Gasket	1
7	F4AE	9461	AA	Intake Manifold Gasket	2
8	F6AE	6584	EA	Rocker Cover Gasket RH	1
9	F6AE	6A559	EA	Rocker Cover Gasket LH	1
10	F23E	6734	AA	Oil Drain Plug Gasket	1
11	F65E	6A636	BA	Oil Filter Adapter Gasket	1
12	F1AE	6D081	AD	Front Cover Gasket RH	1
13	F1AE	6D081	BB	Front Cover Gasket Center	1
14	F1AE	6D081	CD	Front Cover Gasket LH	1
15	F65E	9E936	BC	A/Change Cntrl/Mani Gasket	1
16	E83E	9F670	AA	Idle Air Bypass Gasket	1
17	F4AE	9H486	AA	Spacer to Intake Manifold Gasket	1
18		N806807	S	Water Outlet O-ring	1
19		87006	S96	Dipstick Tube O-ring	1
20		391108	S	Water Pump O-ring	1
21	F37E	9448	AB	Exhaust Manifold Gasket	2
22	XW7E	9448	AA	Exhaust Manifold Gasket	23

^A Engine build will use a new gasket kit. The components can be reused during a test, if the parts are still serviceable.

TABLE A5.5 Fastener Kit^A

	Prefix	Part Number		Description	Quantity
		Base	Suffix		
1		N606502	S36	Bolt M5X0.8X37 Hex Flng Pilot	8
2		N804394	S8M	Scr & Wash-M6X1.0X24 Hex Hd	7
3		N806156	S309	Bolt M8X1.25X43 Hex Flng Pilot	13
4		N808139	S100	Bolt M10X1X26.5 Hex Hd Lk Pilot	6
5		N806300	S309	Bolt M8X1.25X1.25X103.1 Hex Shld	5
6		N804178	S309	Nut M8X1.25 Hex Flng	5
7		N806154	S309	Screw & Washer M6X1.0X32.5 Hex Hd	10
8		N806178	S309	Bolt M8X1.25X93 Hex Flng Hd	2
9		N808102	S309	Bolt & Washer M8X1.25X28 Hex Hd	9
10		N806139	S2	Bolt M12X1.5X52.5 Hex Flng Pilot	1
11		N806165	S2	Washer 13.5X39.5X7.35 Flat Hardened	1
12		N605907	S2	Bolt M8X1.25X33 Hex Flng Hd Pilot	12
13		N806282	S309	Screw & Washer M8X1.25X19.0 Hex Hd	4
14		N806179	S	Screw & Washer	2
15		N806180	S2	Stud Spacer M8X1.25X37.9 Hex	1
16		N806183	S309	Oil Pump Bolt	4
17		N806177	S309	Bolt M8X1.25X53.0 Hex Flng Hd Pilot	12
18		N606543	S100	Bolt M8X1.25X53 Hex Flng	4
19		N605904	S426	Bolt	1
20		N804958	S8	Screw & Washer	4
21		N806155	S2	Screw & Washer	2

^A Long term stand service items.

TABLE A5.6 Engine Finish Kit^A

	Prefix	Part Number		Description	Quantity
		Base	Suffix		
1	F5LU	12029	AA	Ignition Coil	2
2	F5AE	9F792	AC	Fuel Rail	1
3	F2AF	12A648	AA	ECT Sensor	1
4	F3PE	9E926	NB	Throttle Assembly	1
5	F8PE	12259	LA	Wire and Bracket Assembly	1
6	F8ZU	9E926	AD	Throttle Assembly	1
6	F2AB	12A522	AC	Engine Wire Harness	1
7	E7EF	9F479	A2A	Map Sensor	1
8	F2VF	12B579	A2A	MAF Sensor	1
9	F5SF	12K072	AA	Ignition Module	1
10	F2RE	12297	BA	Wire Separator	12

^A Long term engine service items; they can be used as long as they remain serviceable.

TABLE A5.7 Supplemental Stand Set-up Kit^A

	Prefix	Part Number		Description	Quantity
		Base	Suffix		
1	F3AE	12A166	BD	Ignition Bracket	1
2	F6AE	12257	EB	Ignition Mounting Bracket	1
3	F4AE	9424	CA	Intake Manifold	1
4	F8KE	19A216	AD	Grooved Idler Pulley	1
5	F2AE	9A589	AA	Throttle Spacer	1
6	F7AE	6B209	AB	Belt Tensioner	1

^A Long term service items; can be used as long as they remain serviceable.

A6. EXTERNAL OIL HEAT EXCHANGER CLEANING TECHNIQUE

A6.1 Remove and completely disassemble the heat exchanger including the end caps.

A6.2 Flush the shell side of the heat exchanger with an organic solvent for a minimum of 12 h to ensure the removal of all deposits. This can be accomplished by using a positive displacement pump to flow the solvent through the heat exchanger at a flow rate of (0.63 ± 0.126) L/s. Several heat exchangers can be flushed at the same time by connecting them in series. Flushing can be required for longer than 12 h if the deposits are particularly heavy or the solvent is aged. Filtration of the solvent can extend the useful life of the solvent.

A6.3 Rinse the heat exchanger with hot water.

A6.4 Rinse the heat exchanger with degreasing solvent (see 7.7.1).

A6.5 Air-Dry Heat Exchanger:

NOTE A6.1—The tube side of the heat exchanger should be periodically cleaned to ensure adequate heat transfer. A rifle bore cleaner attached to an electric drill has been found to be an effective way to remove process water deposits. Ultrasonic cleaning is also effective in this application.

A7. SEQUENCE VG REPORT FORMS AND DATA DICTIONARY

A7.1 Download the actual report forms and data dictionary separately from the ASTM Test Monitoring Center Web Page at <http://www.astmtmc.cmu.edu/>, or they can be obtained in hardcopy format from the TMC.

Table of Contents

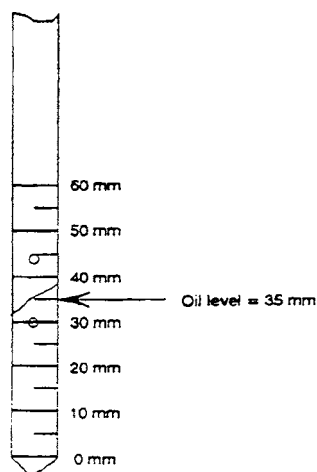
1. Title / Validity Declaration Page	Form 1
2. Table of Contents	Form 2
3. Summary of Test Method	Form 3
4. Test Result Summary	Form 4
5. Test Results Summary	Form 5
6. Operational Summary	Form 6

7. Oil Addition Record and Blowby Rates	Form 7
8. Analysis of Oil	Form 8
9. Downtime Occurrences and Other Comments	Form 9

NOTE 1—If the non reference oil test results are also to be submitted as candidate oil test results to the registration organization, use the report forms and data dictionary (that are maintained for reporting reference oil results) for reporting the candidate oil test results. Include the ACC Code of Practice Test Laboratory Conformance statement.

10. ACC Conformance Statement

A8. DIPSTICK CALIBRATION



Sequence VG Dipstick Correlation:
Slope = 21 g/mm
Offset = 1953 mm

FIG. A8.1 Typical Dipstick Calibration

TABLE A8.1 Typical Dipstick Calibration

NOTE 1—The dipstick level is measured from the bottom of the dipstick up, zero being at the bottom and 60 mm at the top. The minor increments are 1 mm each. Always insert the dipstick with the words “Engine Oil” facing up. Read the oil level at the centerline of the dipstick.

Dipstick, mm	Total Oil, g
0	1953
1	1974
2	1995
3	2016
4	2037
5	2058
6	2079
7	2100
8	2121
9	2142
10	2163
11	2184
12	2205
13	2226
14	2247
15	2268
16	2289
17	2310
18	2331
19	2352
20	2373
21	2394
22	2415
23	2436
24	2457
25	2478
26	2499
27	2520
28	2541
29	2562
30	2583
31	2604
32	2625
33	2646
34	2667
35	2688
36	2709
37	2730
38	2751
39	2772
40	2793
41	2814
42	2835
43	2856
44	2877
45	2898
46	2919
47	2940
48	2961
49	2982
50	3003
51	3024
52	3045
53	3066
54	3087
55	3108
56	3129
57	3150
58	3171
59	3192
60	3213

A8.1 A typical dipstick calibration is presented in Fig. A8.1 and Table A8.1.

A9. CRITICAL PART SUPPLIER LIST

A9.1 Test Engine—The required engine for use in the VG test procedure is a 4.6 L 2V engine which is supplied by the test sponsor (Ford Motor Company):

Ford Motor Co.
21500 Oakwood Blvd.
POEE Bldg., MD 44 (D-145)
P.O. Box 2053
Dearborn, MI 48121

A9.2 Various Materials—RAC kits, camshaft baffles, oil filter adapters, dipstick assembly with tube, and other critical parts delineated in procedure are available from the following supplier:

OH Technologies
9300 Progress Pkwy.
Mentor, OH 44060

A9.3 Various Materials—Exhaust manifold transition plates and valve deck rating templates are available from the following supplier:

Test Engineering, Inc.
12758 Cimarron Path, Ste. 102
San Antonio, TX 78249-3417

A9.4 Water Cooled Exhaust Manifolds—The required exhaust manifolds are available from the following supplier:

Bowden Manufacturing Corp.
4590 Beidler Rd.
Willoughby, OH 44074-4682

A9.5 Cylinder Heads—Additional cylinder heads are available from the following supplier:

Bishop International, Inc.
224 North Corinth St.
Dallas, TX 75203
Toll-free: 800-843-5068

A9.6 Cylinder Head Modifications—When using cylinder heads from **A9.5**, cam bore machining and valve guide installation are available from the following supplier:

E&E Engine Machine and Parts
1602 South Flores
San Antonio, TX 78204
(210) 225-1141

A10. OPERATIONAL DATA LOG—ENGINE OIL

A10.1 See **Fig. A10.1** for oil sampling, addition, and leveling record.



Sequence VG Oil Sampling, Addition and Leveling Record

Test No.: _____ Client Oil Code: _____ Lab Oil Code: _____ Date : _____

Test Full mark

Cycle	6	12	18	24	30	36	42	48	54
Test Hour	24	48	72	96	120	144	168	192	216
Specific Action Time, hr:min	23:25	47:25	71:25	95:25	119:25	143:25	167:25	191:25	215:25
1. Remove a 150 mL purge sample.	5	5	5	5	5	5	5	5	5
2. Remove a 60 mL analysis sample.	2	2	2	2	2	2	2	2	2
3. Return the purge sample to Engine.	X	X	X	X	X	X	X	X	X
4. Shut down the Engine.	X	X	X	X	X	X	X	X	X
5. Record the dipstick level in mm, 20 min after the engine is shutdown.									
6. Computed oil level in g. (difference from the Test Full mark, low (-) or high (+), use the conversion chart.									
7. If level is more than 400 g below Test Full Mark in Step 6, record amount of new oil added (in g) to bring the level to -400 g. (do not add oil at 216 h)									
8. If level is more than 200 g above Test Full, record the amount of oil drained (in g) to bring level to +200 g mark.									
9. Restart engine 5 min before official beginning of Stage I.	X	X	X	X	X	X	X	X	X
10. Operator's Initials.									

Oil Consumption - Calculate the oil consumption per 24 h period according to the equations shown below.

Oil Consumption - (grams per each 24 h) = $x - z - 52$

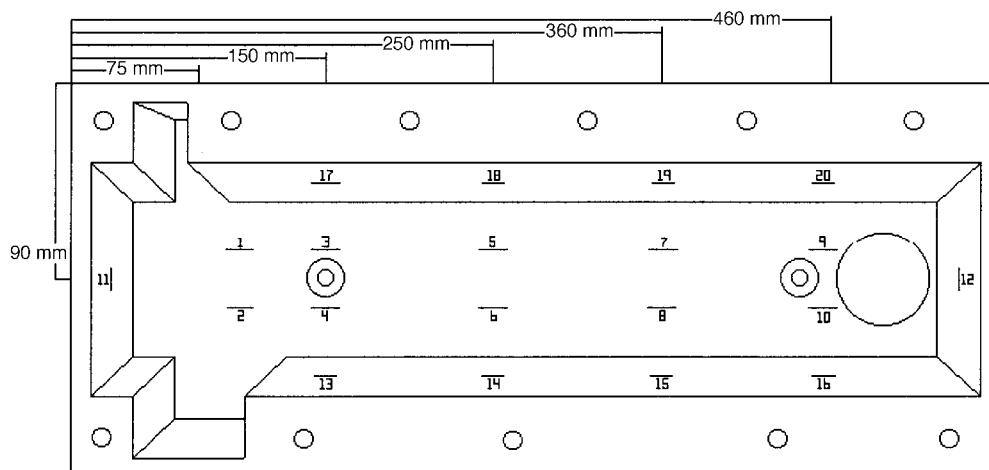
where x = the Final Oil Level of the previous period (use -400 if oil was added at the previous period)

z = the Final Oil Level of the current period

FIG. A10.1 Oil Sampling, Addition and Leveling Record

A11. RATING WORKSHEETS

A11.1 Rating worksheets are provided in Figs. A11.1-A11.12.



Rating sites on the top surface of the RAC are located 30 mm from the side. (No.1 thru 10)

With the exception of (No. 2) which is 65 mm from the side.

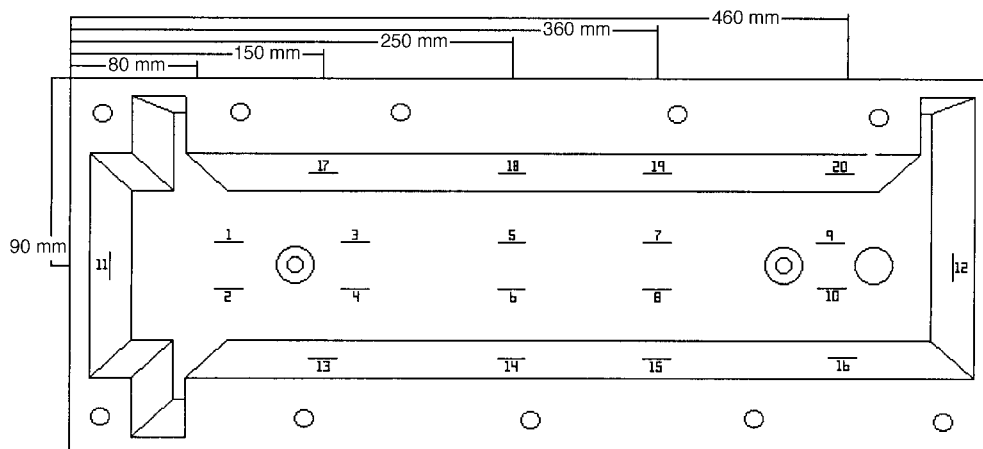
Rating sites on vertical surfaces are located 50 mm from the bottom of the cover.

Depth gauge should be oriented as indicated by (—) and dimensions shown.

DEPTH																					TOTAL	%	VOLUME
SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CHECKS	COVERED	FACTOR
CLEAN																							
1/4 A																							
1/2 A																							
3/4 A																							
A																							
AB																							
B																							
BC																							
C																							
D																							
E																							
F																							
G																							
H																							
I																							
GRAND TOTAL																					20	100	

SLUDGE MERIT RATING _____

FIG. A11.1 Sludge Rating of Left Rocker Cover

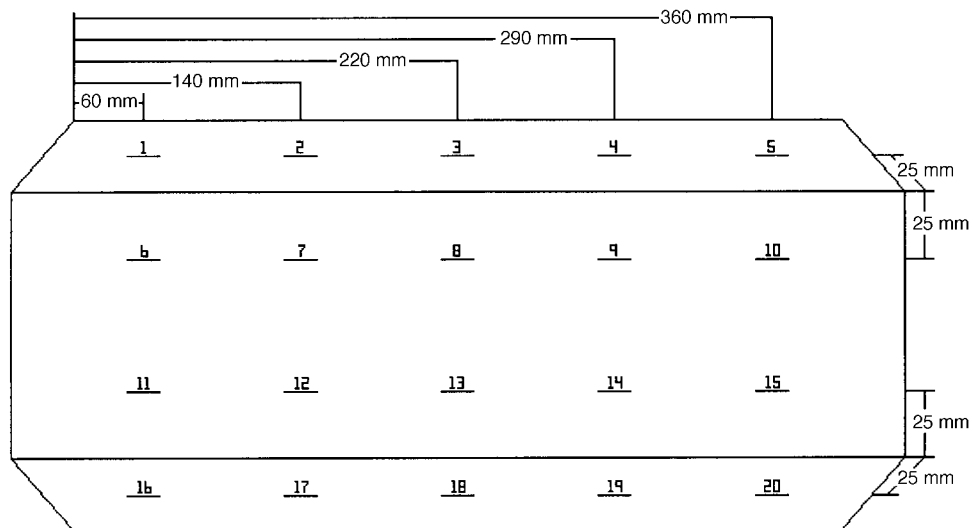


Rating sites on the top surface of the RAC are located 30 mm from the side. (No.1 thru 10)
 Rating sites on vertical surfaces are located 50 mm from the bottom of the cover.
 Depth gauge should be oriented as indicated by (—) and dimensions shown.

DEPTH																					TOTAL	%	VOLUME
SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CHECKS	COVERED	FACTOR
CLEAN																							
1/4 A																							
1/2 A																							
3/4 A																							
A																							
AB																							
B																							
BC																							
C																							
D																							
E																							
F																							
G																							
H																							
I																							
GRAND TOTAL																					20	100	

SLUDGE MERIT RATING _____

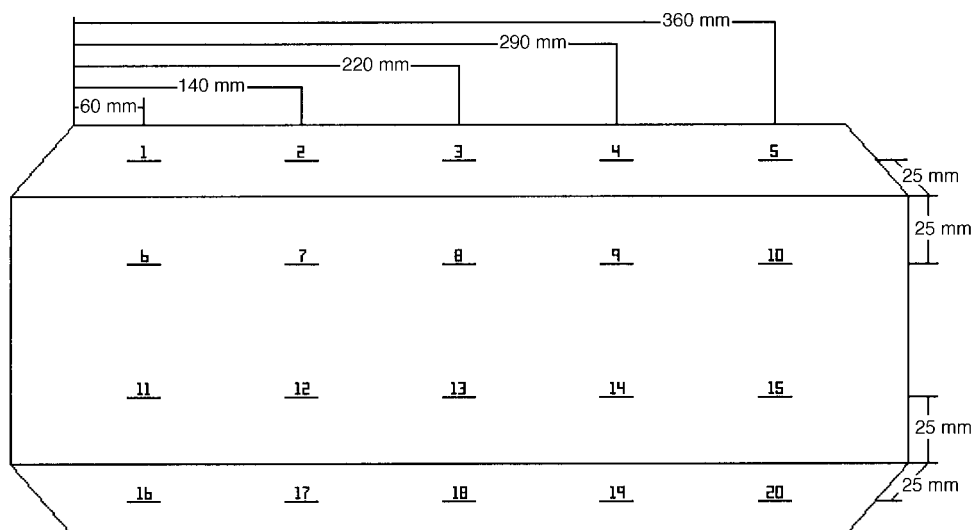
FIG. A11.2 Sludge Rating of Right Rocker Cover



DEPTH																					TOTAL	%	VOLUME
SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CHECKS	COVERED	FACTOR
CLEAN																							
1/4 A																							
1/2 A																							
3/4 A																							
A																							
AB																							
B																							
BC																							
C																							
D																							
E																							
F																							
G																							
H																							
I																							
GRAND TOTAL																					20	100	

SLUDGE MERIT RATING _____

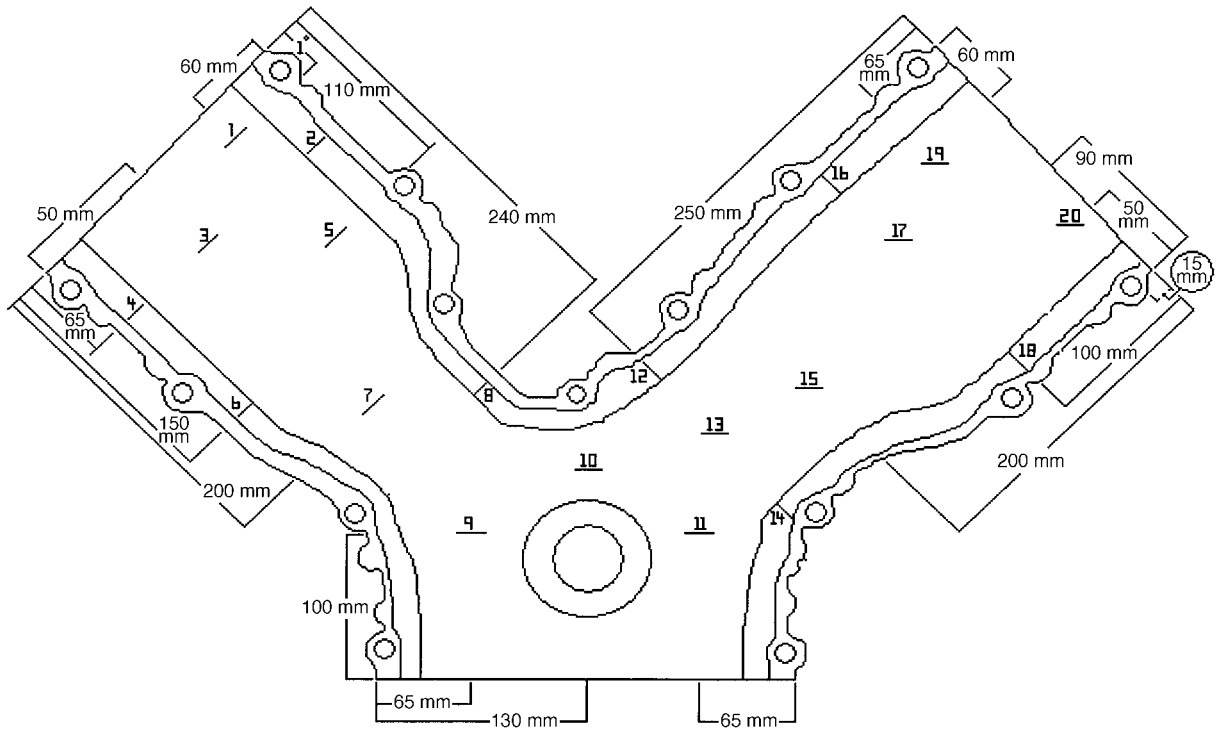
FIG. A11.3 Sludge Rating of Left Cam Baffle



DEPTH																					TOTAL	%	VOLUME
SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CHECKS	COVERED	FACTOR
CLEAN																							
1/4 A																							
1/2 A																							
3/4 A																							
A																							
AB																							
B																							
BC																							
C																							
D																							
E																							
F																							
G																							
H																							
I																							
GRAND TOTAL																					20	100	

SLUDGE MERIT RATING _____

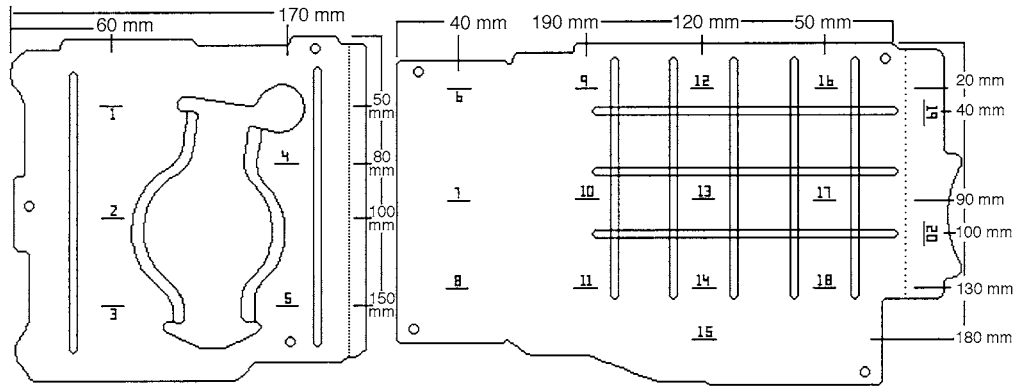
FIG. A11.4 Sludge Rating of Right Cam Baffle



DEPTH																					TOTAL	%	VOLUME
SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CHECKS	COVERED	FACTOR
CLEAN																							
1/4 A																							
1/2 A																							
3/4 A																							
A																							
AB																							
B																							
BC																							
C																							
D																							
E																							
F																							
G																							
H																							
I																							
GRAND TOTAL																					20	100	

SLUDGE MERIT RATING _____

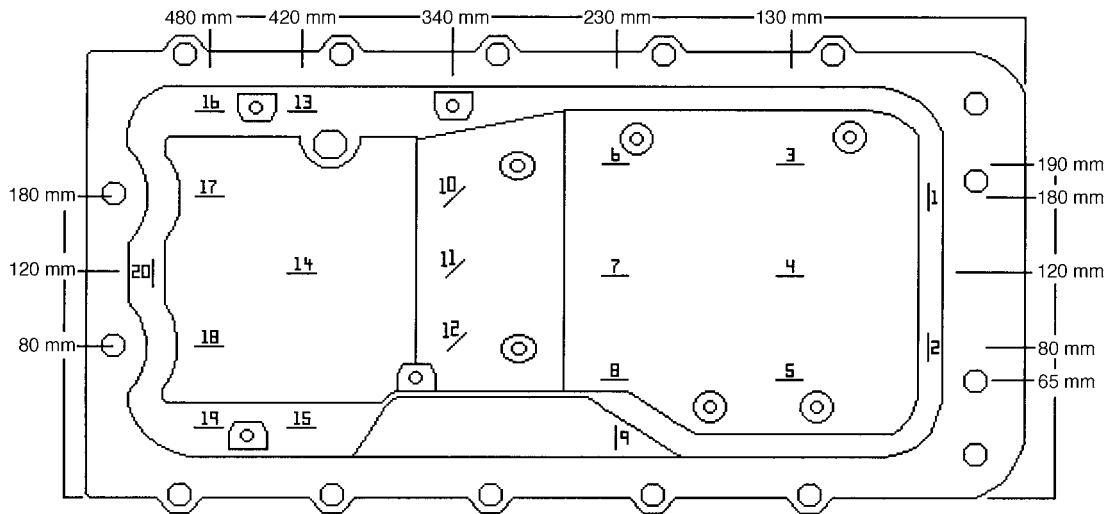
FIG. A11.5 Sludge Rating of Timing Gear Cover



DEPTH																					TOTAL	%	VOLUME
SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CHECKS	COVERED	FACTOR
CLEAN																							
1/4 A																							
1/2 A																							
3/4 A																							
A																							
AB																							
B																							
BC																							
C																							
D																							
E																							
F																							
G																							
H																							
I																							
GRAND TOTAL																					20	100	

SLUDGE MERIT RATING _____

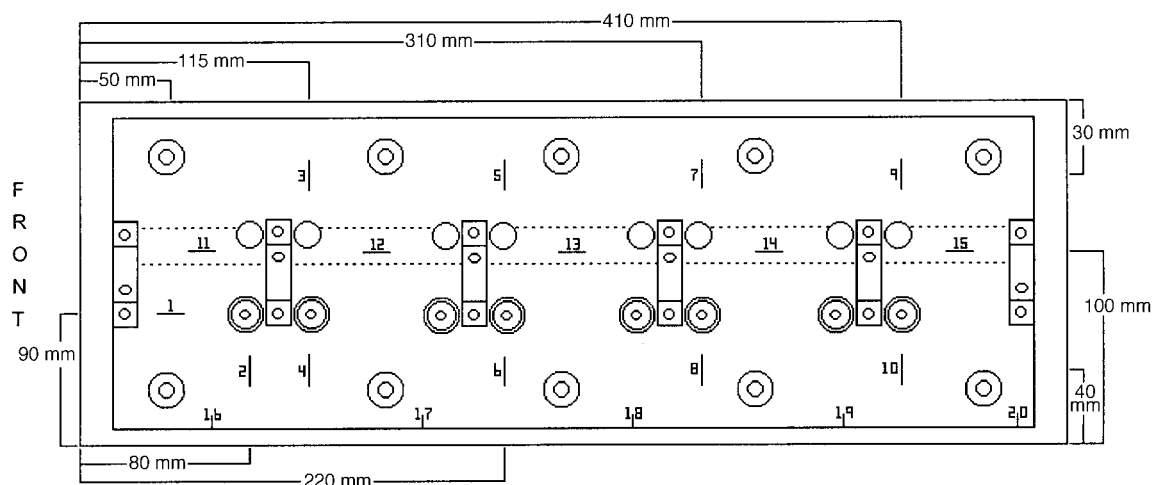
FIG. A11.6 Sludge Rating of Oil Pan Baffles



DEPTH																					TOTAL	%	VOLUME
SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CHECKS	COVERED	FACTOR
CLEAN																							
1/4 A																							
1/2 A																							
3/4 A																							
A																							
AB																							
B																							
BC																							
C																							
D																							
E																							
F																							
G																							
H																							
I																							
GRAND TOTAL																					20	100	

SLUDGE MERIT RATING _____

FIG. A11.7 Sludge Rating of Oil Pan

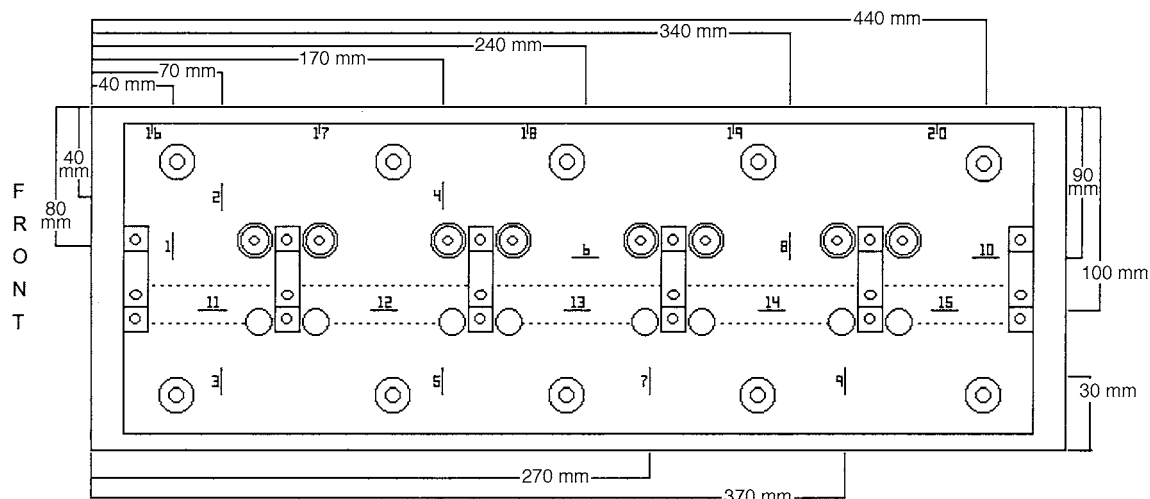


Rating sites 16, 17, 18, 19, and 20 are located 25 mm below gasket mounting surface.
From front straight edge, rating site 16 is 60 mm, rating site 17 is 170 mm, rating site 18 is 270 mm,
rating site 19 is 370 mm, and rating site 20 is 460 mm.

DEPTH																					TOTAL	%	VOLUME
SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CHECKS	COVERED	FACTOR
CLEAN																							
1/4 A																							
1/2 A																							
3/4 A																							
A																							
AB																							
B																							
BC																							
C																							
D																							
E																							
F																							
G																							
H																							
I																							
GRAND TOTAL																					20	100	

SLUDGE MERIT RATING _____

FIG. A11.8 Sludge Rating of Left Valve Deck

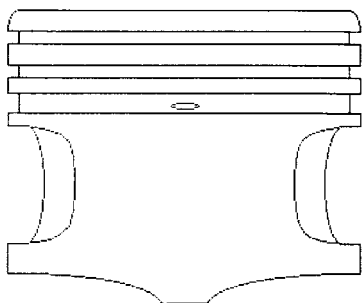


Rating sites 16, 17, 18, 19, and 20 are located 25 mm below gasket mounting surface.
From front straight edge, rating site 16 is 30 mm, rating site 17 is 130 mm, rating site 18 is 230 mm,
rating site 19 is 330 mm, and rating site 20 is 430 mm.

DEPTH																					TOTAL	%	VOLUME
SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CHECKS	COVERED	FACTOR
CLEAN																							
1/4 A																							
1/2 A																							
3/4 A																							
A																							
AB																							
B																							
BC																							
C																							
D																							
E																							
F																							
G																							
H																							
I																							
GRAND TOTAL																					20	100	

SLUDGE MERIT RATING _____

FIG. A11.9 Sludge Rating of Right Valve Deck



OIL Ring Clogging

Piston Number			Piston Number	
1	%		5	%
2	%		6	%
3	%		7	%
4	%		8	%
Average	%			

Piston Number	Thrust
1	
2	
3	
4	
5	
6	
7	
8	
Total	
Average	

Varnish Rating = Avg. Thrust = _____

Piston Ring Sticking

Piston Number	Top Ring	Second Ring	Oil Ring
1			
2			
3			
4			
5			
6			
7			
8			
Total			
Hot Stuck			
Cold Stuck			

0 = Free Ring H = Hot Stuck Ring
 T = Tight Ring C = Cold Stuck Ring
 Oil Rings Will Either Be Cold Stuck or Free

Piston 1

%Area	Rate	Merit

Piston 2

%Area	Rate	Merit

Piston 3

%Area	Rate	Merit

Piston 4

%Area	Rate	Merit

Piston 5

%Area	Rate	Merit

Piston 6

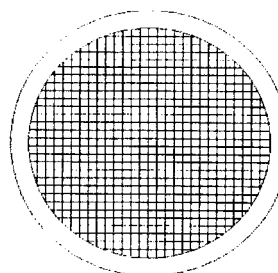
%Area	Rate	Merit

Piston 7

%Area	Rate	Merit

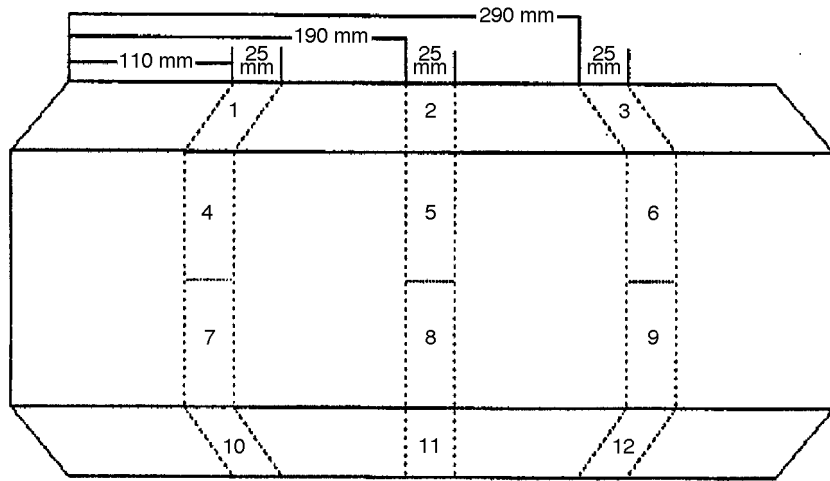
Piston 8

%Area	Rate	Merit



Oil Screen
% Plugging _____
Sludge % _____
Debris % _____

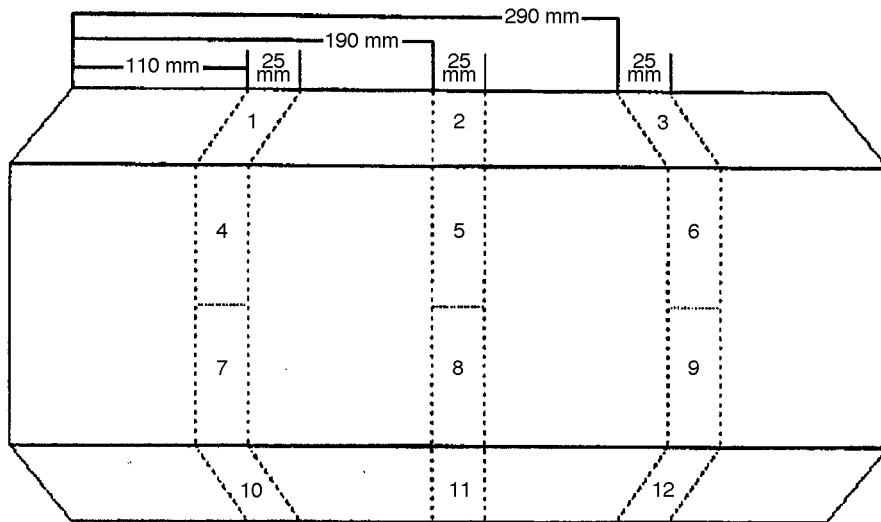
FIG. A11.10 Varnish Rating of Piston Skirts Piston Ring Sticking and Oil Ring Clogging. Oil Screen Percent Plugging



AREA	RATING
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

$$\text{VARNISH RATING} = \frac{\text{TOTAL}}{12} = \underline{\hspace{2cm}}$$

FIG. A11.11 Varnish Rating of Left Camshaft Baffle



AREA	RATING
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

VARNISH RATING = $\frac{\text{TOTAL}}{12}$ = _____

FIG. A11.12 Varnish Rating of Right Camshaft Baffle

A12. FUEL INJECTOR FLOW MEASUREMENTS

A12.1 Fuel Injector Test Rig—A suitable device capable of accurate, repeatable flow measurement of port fuel injectors is required. This device shall be capable of performing necessary port fuel injector evaluations as outlined below. Since no suitable commercially available apparatus has been identified, design of the test rig is up to the laboratory. Use Stoddard solvent as the fluid for flow testing injectors.

A12.2 Fuel Injectors—Prior to installations, evaluate all injectors (new and used) for spray patterns and flow rate using a suitable apparatus as identified above. The evaluation procedure is outlined in this section. Injectors may be cleaned and reused if the criteria outlined in this section are satisfied.

A12.3 Perform a visual inspection of each injector. Ensure that they have been cleaned of all oily deposits. Check O-ring for cracking or tearing and replace as required.

A12.4 To remove any assembly residue before flow-testing, flush new injectors for 30 s.

A12.5 Using a rig as described, place the injector(s) in the rig and turn on the pressure source to the injector(s). After the pressure source is turned on, the test fluid starts to flow through

the injector(s). Maintain the test fluid pressure supplied to the injector(s) during the entire test at (290 ± 3.4) kPa. Maintaining this pressure is critical because a small change in pressure has a dramatic effect on the flow rate and spray pattern. Once pressure is set, zero the volume-measuring device.

A12.6 Flow-test each injector for a 60 s period. While the injector is flowing, make a visual observation of the spray pattern quality. The spray pattern should be typical for the make and model of the injector. At the completion of the 60 s period leave pressure on closed injector(s) for at least 30 s. The injector(s) shall not leak or drip. Discard any injector that leaks or drips.

A12.7 The acceptable total flow for each injector after the 60 s test shall be (188 to 203) mL at (290 ± 3.4) kPa of test fluid pressure. Discard any injector that flows above or below this range.

APPENDIXES

(Nonmandatory Information)

X1. PISTON AND RING MEASUREMENTS RECORD FORMS

X1.1 The necessary engine measurement record forms are shown in **Figs. X1.1-X1.3**.

Engine Measurement Record

Oil Code: _____

Test Number: _____

TOP RING WIDTH (mm)

Number	1	2	3	4	5	6	7	8

SECOND RING WIDTH (mm)

Number	1	2	3	4	5	6	7	8

TOP RING GROOVE WIDTH (mm)

Number	1	2	3	4	5	6	7	8

SECOND RING GROOVE WIDTH (mm)

Number	1	2	3	4	5	6	7	8

TOP RING SIDE CLEARANCE (mm)

Number	1	2	3	4	5	6	7	8

SECOND RING SIDE CLEARANCE (mm)

Number	1	2	3	4	5	6	7	8

FIG. X1.1 Piston Ring Side Clearance



Engine Measurement Record

Oil Code: _____

Test Number: _____

TOP RING GROOVE CHAMFER (mm)

Number	1	2	3	4	5	6	7	8
Top								
Bottom								

SECOND RING GROOVE CHAMFER (mm)

Number	1	2	3	4	5	6	7	8
Top								
Bottom								

TOP RING GAP MEASURED IN ENGINE BLOCK (mm)

Number	1	2	3	4	5	6	7	8

SECOND RING GAP MEASURED IN ENGINE BLOCK (mm)

Number	1	2	3	4	5	6	7	8

FIG. X1.2 Piston Ring Groove Chamfer and Ring Gap



Engine Measurement Record

Oil Code: _____

Test Number: _____

TOP RING GAP INCREASE^A, (μm)

Number	1	2	3	4	5	6	7	8
Initial								
Before Rework								
After Rework								
Final								
Total Mass Loss ^B								

^A Ring Gaps measured in standard bore.^B Total mass loss = (Initial – Rework) + (After Rework – Final)SECOND RING GAP INCREASE^A, (μm)

Number	1	2	3	4	5	6	7	8
Initial								
Before Rework								
After Rework								
Final								
Total Mass Loss ^C								

^C Total mass loss = (Initial – Rework) + (After Rework – Final)

FIG. X1.3 Piston Ring Masses

X2. SOURCES OF MATERIALS AND INFORMATION

X2.1 The following sources are provided for convenience only. This does not represent an exclusive or complete listing of required materials or information sources.

X2.1.1 *ASTM Sequence VG Test Parts*—ASTM Sequence VG Test Parts Kits can be purchased through Ford Power Products distributors and Ford or Lincoln-Mercury dealers.

X2.1.2 *ASTM Test Monitoring Center*—All communications with the TMC should be directed as follows:

ASTM Test Monitoring Center
6555 Penn Ave.
Pittsburgh, PA 15206-4489

X2.1.3 *Test Sponsor*—All communications with the test sponsor (Ford Motor Co.) should be directed as follows:

Ford Motor Co.
21500 Oakwood Blvd.
POEE Bldg., MD 44 (D-145)
P.O. Box 2053
Dearborn, MI 48121

X2.1.4 *Aeroquip Hose and Fittings*—Aeroquip hose and fittings can be obtained from the following supplier:

Aeroquip Corp.
1225 W. Main
Van Wert, OH 45891

X2.1.5 *Fuel Information and Availability*—General information concerning VG fuel, including availability, can be obtained from the following:

Haltermann Products
1201 S. Sheldon Rd.
P.O. Box 249
Channelview, TX 79530-0429

X2.1.6 Engine Coolant Flowmeter—Barco flowmeters for the engine coolant system (PN BR 12705-16-310) can be obtained from the following supplier:

Aeroquip Corp.
1225 W. Main
Van Wert, OH 45891

X2.1.7 Intake-Air Humidity Instruments—The Alnor Dewpointer, EG & G, Foxboro, Hy-Cal, General Eastern and Protimeter dewpoint meters are suitable for measurement of the intake-air specific humidity.

X2.1.8 Blowby Flow Rate Orifice—Information concerning the blowby flow rate orifice meter is available from the following:

General Motors Research Laboratories Fuels and Lubricants Dept.
30500 Mound Rd.
Warren, MI 48090-9055

X2.1.9 Heat Exchangers—ITT Standard Heat Exchangers can be obtained from the following supplier:

Kinetics Engineering Corp.
2055 Silber Road, Suite 101
Houston, TX 77055

X2.1.10 Fuel Flow Measurement—Mass fuel flowmeters are available from the following supplier:

Micro Motion Corp.
7070 Winchester Circle
Boulder, CO 80301

X2.1.11 Various Materials—RAC kits, camshaft baffles, oil filter adapters and various other test stand parts and component calibration devices utilized in this test method are available from the following supplier:

OH Technologies
9300 Progress Pkwy.
Mentor, OH 44060

X2.1.12 Parts Washer and Chemicals—A dishwasher type parts cleaner and associated chemicals can be obtained from the following supplier:

Better Engineering Manufacturing
8361 Town Court Center
Baltimore, MD 21236-4964

X2.1.13 Crankcase and Intake—Air Pressure Gages—Gages are available from the following supplier:

Dwyer Instrument Co.
Junction of Indiana State Highway 212 and U.S. Highway 12
P.O. Box 373
Michigan City, IN 46360

X2.1.14 RAC Coolant—Nacool 2000 Engine Cooling System Treatment is available from the following supplier:

Nalco Chemical Co. Functional Chemicals Group
One Nalco Ctr.

Naperville, IL 60566-1024

X2.1.15 Lubricants—EF-411 and Vacmul 3-D are available from local distributors of Mobil products.

X2.1.16 Connecting Rod Heater—The Sunnen Model CRH-50 connecting rod heater is available from the following supplier:

Sunnen Inc.
7910 Manchester
St. Louis, MO 63143

X2.1.17 Tygon Hose—Tygon hose is available through local Cadillac Plastic Co. distributors or the following supplier:

The Norton Co.
12 East Avenue
Tallmadge, OH 44278

X2.1.18 Rating Lamps—Suitable rating lamps are available from the following supplier:

Dazor Manufacturing Corp.
4455 Duncan Ave.
St. Louis, MO 63110

X2.1.19 Special Tools for the Test Engine—Special tools to facilitate assembly and disassembly of the engine are available from the following supplier:

Owatonna Tool Co.
2013 4th St.
NW Owatonna, MN 55060

X2.1.20 Oil Filter—Ober oil filter, LFS-55, and oil screen, LFS-5528WCF, are available from the following suppliers:

Oberg Enterprises, Inc.
12429 Highway 99 South, Unit 80
Everett, WA 98204

or

OH Technologies, Inc.
9300 Progress Parkway
Mentor, OH 44061

X2.1.21 Inspected Engine Parts—Pre-measured and calibrated Sequence VG engine parts and various components and calibration devices are available from the supplier listed below:

Test Engineering, Inc.
12758 Cimarron Path, Ste 102
San Antonio, TX 78249-3417
Attn: John Knight
210-690-1958
210-690-1959 (FAX)

X2.1.22 Lambda Measurement Devices—Recommended devices for measuring exhaust gas Lambda are available from the following suppliers:

Innovative LM-1
Innovative Technology, Inc.
5 Jenner, Suite 100
Irvine, CA 92618
AFM1000 single channel AFR module
Engine Control and Engineering
Sunnyvale, CA 94089
<http://www.ecm-co.com>

X3. DESCRIPTION OF SCOTT QUARTERLY GAS AUDIT SERVICE

X3.1 The Scott Quarterly Gas Audit Service is a subscription service to audit the performance of CO and O₂ analysis instruments and is offered by Scott Environmental Technology (see X2.1.14). The service is completed once every three months and utilizes span gases of CO and O₂ in a balance of N₂. The exact concentration of the span gases is unknown to the customer, but falls within a specified range.

X3.2 The subscriber analyzes the span gas with the instrumentation used for VE testing. The gas is introduced through the calibration port and the sample inlet of the system. The laboratory submits the results to Scott, and Scott publishes a

report detailing individual results and a statistical analysis using data from all participating laboratories.

X3.3 Differences in results obtained at the sample port and the calibration inlet normally result from operating procedures, leaks in the sampling system, or improper design of the sampling system. Differences in results between a specific laboratory and the industry average usually indicate deficiencies in the analyzer or the quality of the calibration gases.

X3.4 Calibration gases traceable to national standards can also be utilized to verify the performance of exhaust gas analysis equipment.

SUMMARY OF CHANGES

Subcommittee D02.B0 has identified the location of selected changes to this standard since the last issue (D6593 – 13a) that may impact the use of this standard. (Approved Oct. 1, 2013.)

(1) Subsection 7.2 was revised to specify how test parts can be modified.

(2) Several subsections (7.6.3.2, 7.6.4, 13.1.4, 13.1.5, 13.1.6, 13.1.8, 13.2.2.1(5) and (6), and 13.3.2.2) have been updated to reflect the proper rating manuals and/or workshop designation.

(3) Subsections 7.3 and 7.4.8 have been modified to allow repairs to be made to damaged threads in the cylinder block and rocker arm cover.

Subcommittee D02.B0 has identified the location of selected changes to this standard since the last issue (D6593 – 13) that may impact the use of this standard. (Approved June 15, 2013.)

(1) Only editorial changes were made, applying Form and Style (including SI 10) guidelines.

Subcommittee D02.B0.01 has identified the location of selected changes to this standard since the last issue (D6593 – 10) that may impact the use of this standard. (Approved May 1, 2013.)

(1) Subsection 7.9.4.1 notes an alternative supplier of cylinder heads.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the ASTM website (www.astm.org/COPYRIGHT/).