Designation: D5966 – 13

Standard Test Method for
Evaluation of Engine Oils for Roller Follower Wear in Light-Duty Diesel Engine[1]

This standard is issued under the fixed designation D5966; 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.

INTRODUCTION

This test method is continually undergoing changes to reflect refinements in procedure, obsolescence of parts or reagents. These changes or updates, as well as general information regarding the test method, are issued as information letters by the ASTM Test Monitoring Center (TMC). Copies of information letters pertaining to the test method may be obtained by contacting the ASTM Test Monitoring Center.[2]

The test method can be used by any properly equipped laboratory, without assistance of anyone not associated with that laboratory. However, TMC provides reference oils and an assessment of the test results obtained on those oils by the laboratory. By this means, the laboratory will know whether their use of the test method gives results statistically similar to those obtained by other laboratories. Furthermore, various agencies require that a laboratory utilize the TMC services in seeking qualification of oils against specifications. For example, the U.S. Army imposes such a requirement, in connection with several military lubricant specifications.

Accordingly, this test method is written for use by laboratories which utilize the TMC services. Laboratories that choose not to use these services may simply ignore those portions of the test procedure which refer to the TMC.

1. Scope*

1.1 This engine lubricant test method is commonly referred to as the Roller Follower Wear Test. Its primary result, roller follower shaft wear in the hydraulic valve lifter assembly, has been correlated with vehicles used in stop-and-go delivery service prior to 1993. It is one of the test methods required to evaluate lubricants intended to satisfy the API CG-4 performance category. This test has also been referred to as the 6.2 L Test.

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

1.2.1 *Exceptions*—Where there is no direct SI equivalent, such as pipe fittings, thermocouple diameters, and NPT screw threads. Also, roller follower wear is measured in mils.

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.*

1.4 *Table of Contents:*

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0.02 on Heavy Duty Engine Oils.

Current edition approved May 1, 2013. Published May 2013. Originally approved in 1996. Last previous edition approved in 2012 as D5966 – 12. DOI: 10.1520/D5966-123.

[2] ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489. This edition incorporated revisions contained in all Information Letters through No. 12-1.

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

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure
D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
D97 Test Method for Pour Point of Petroleum Products
D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D446 Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers
D482 Test Method for Ash from Petroleum Products
D524 Test Method for Ramsbottom Carbon Residue of Petroleum Products
D613 Test Method for Cetane Number of Diesel Fuel Oil
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D976 Test Method for Calculated Cetane Index of Distillate Fuels
D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)
D2500 Test Method for Cloud Point of Petroleum Products
D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants
D4485 Specification for Performance of Active API Service Category Engine Oils
D4737 Test Method for Calculated Cetane Index by Four Variable Equation
D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D7422 Test Method for Evaluation of Diesel Engine Oils in T-12 Exhaust Gas Recirculation Diesel Engine
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2 *American National Standards Institute (ANSI):*[4]

MC96.1 Temperature Measurement Thermocouples

3. Terminology

3.1 *Definitions:*

3.1.1 *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.

3.1.2 *BTDC (before top dead center), n*—used with the degree symbol to indicate the angular position of the crankshaft relative to its position at the point of uppermost travel of the piston in the cylinder.

3.1.3 *calibrate, v*—to determine the indication or output of a device (e.g., thermometer, manometer, engine) with respect to that of a standard.

3.1.4 *candidate oil, n*—an oil which is intended to have the performance characteristics necessary to satisfy a specification and is tested against that specification. **D4175**

3.1.5 *engine oil, n*—a liquid that reduces friction or wear, or both, between the moving parts within an engine; removes heat, particularly from the underside of pistons; and serves as a combustion gas sealant for piston rings.

3.1.5.1 *Discussion*—It may contain additives to enhance certain properties. Inhibition of engine rusting, deposit formation, valve train wear, oil oxidation and foaming are examples. **D4175**

3.1.6 *light-duty, adj— in internal combustion engine operation*, characterized by average speeds, power output, and internal temperatures that are generally much lower than the potential maximums. **D4485**

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

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

3.1.7 *light-duty engine, n— in internal combustion engine types*, one that is designed to be normally operated at substantially less than its peak output. **D4485**

3.1.8 *lubricant, n*—any material interposed between two surfaces that reduces friction or wear, or both, between them. **D4175**

3.1.9 *lubricating oil, n*—a liquid lubricant, usually comprising several ingredients, including a major portion of base oil and minor portions of various additives. **D4175**

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

3.1.10.1 *Discussion*—Reference oils are used to calibrate testing facilities, to compare the performance of other oils, or to evaluate other materials (such as seals) that interact with oils. **D4175**

3.1.11 *used oil, n*—any oil that has been in a piece of equipment (for example, an engine, gearbox, transformer, or turbine), whether operated or not. **D4175**

3.1.12 *wear, n*—the loss of material from a surface, generally occurring between two surfaces in relative motion, and resulting from mechanical or chemical action, or a combination of both. **D7422**

4. Summary of Test Method

4.1 A pre-assembled GM V8 diesel test engine is installed on a test stand and operated for 50 h.

4.2 The test engine operating conditions are generally more extreme than typical service operating conditions. These conditions provide high soot loading and accelerated roller follower shaft wear while maintaining correlation with wear levels found in the field.

4.3 At the end of the test, the performance of the engine oil is determined by measuring the level of wear on the roller follower shafts.

5. Significance and Use

5.1 This test method is used to determine the ability of an engine crankcase oil to control wear that can develop in the field under low to moderate engine speeds and heavy engine torques. Side-by-side comparisons of two or more oils in delivery van fleets were used to demonstrate the field performance of various oils. The specific operating conditions of this test method were developed to provide correlation with the field performance of these oils.

5.2 This test method, along with other test methods, defines the minimum performance level of the Category API CG-4 for heavy duty diesel engine lubricants. Passing limits for this category are included in Specification D4485.

5.3 The design of the engine used in this test method is not representative of all modern diesel engines. Consider this factor, along with the specific operating conditions used to accelerate wear, when extrapolating test results.

6. Apparatus

6.1 A listing and complete description of all apparatus used in the test is found in Annex A3. Information concerning procurement of apparatus can be found in Appendix X1.

7. Reagents

7.1 *Guidelines on Substitution*—No substitutions for the reagents listed in 7.1.1 – 7.1.3 are allowed.

7.1.1 *Cleaning Solvent,* For cleaning parts, use only mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content (volume fraction (0 to 2) %), Flash Point (61°C, min) and Color (not darker than +25 on the 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.

7.1.2 *Engine Coolant*—The engine coolant is a solution of demineralized water that has less than 0.03 g/kg dissolved solids and an ethylene glycol based anti-freeze mixed at the following concentration—70 % antifreeze and 30 % water by volume.

7.1.2.1 *Demineralized Water,* is used as a generic term to describe *pure* water. Deionized or distilled water may also be used as long as the total dissolved solids content is less than 0.03 g/kg.

7.1.3 *Fuel*—Approximately 600 L of either PC-9 or PC-9-HS Reference Diesel Fuel are required for each test.[5] (**Warning—**Combustible. Health hazard. Use adequate safety provisions.)

7.1.3.1 *Fuel Batch Analysis*—Each fuel shipment does not need to be analyzed upon receipt from the supplier. However, laboratories are responsible for periodic checks for contamination. Any analysis results for parameters tested should be within the tolerances shown on Form 20. If any results fall outside the tolerances shown on Form 20, the laboratory should contact the Test Monitoring Center (TMC)[2] for help in resolving the problem.

7.1.3.2 *Fuel Batch Storage*—The fuel should be stored in accordance with all applicable safety and environmental regulations.

7.1.4 *Break-In Oil*—Approximately 8 kg of break-in oil are necessary for new engine break-in. Break-in oil is defined as any SAE 15W-40, API CG-4 quality oil.

7.1.5 *Non-Reference Test Oil*—A minimum of 20 kg of new oil are required to complete the test. A25 kg sample of new oil is normally provided to allow for inadvertent losses.

7.1.6 *Calibration Test Oil*—A 22 kg sample of reference oil is provided by the TMC for each calibration test.

8. Preparation of Apparatus

8.1 *New Engine Preparation*—Paragraphs 8.1.1 through 8.1.7 describe preparations that are only performed on a new engine before conducting the new engine break-in.

8.1.1 *Engine Front Cover Installation*—Install the front cover to the front of the engine block with the gasket supplied and torque all bolts to 40 N·m.

8.1.2 *Oil Sump Drain Location*—Install a drain in the sump as described in A3.9.3.7.

8.1.3 *Glow Plug Replacement*—Remove the glow plugs and install 27-in. dry seal NPT socket pressure plugs. Torque the plugs to 20 N·m.

[5] Available from Chevron Phillips, Phillips 66 Co., Marketing Services Center, P.O. Box 968, Borger, TX 79008–0968.

8.1.4 *Cold Start Solenoid Disablement*—Disconnect the cold start solenoid.

8.1.5 *Exhaust Manifolds*—Check the flanges to ensure the gasket surfaces are not distorted. Install the required water-cooled exhaust manifolds with the discharge toward the rear of the engine. Use the special studs supplied with the manifolds, and torque the studs to 30 N·m.

8.1.6 *Rocker Arm Cover Preparation*—Install a new seal to each rocker arm cover lid. Install a new gasket on each rocker arm cover mounting flange. Install the rocker arm covers, but not the lids, at this time.

NOTE 1—The rocker arm cover lid is removed after each test. An adhesive material may be used to adhere the gasket to the rocker arm cover lid. Installation of a small amount of petroleum jelly to the sealing surface facilitates removal and extends the life of the seal.

8.1.7 *Injection Pump Position Verification*—Verify the dynamic timing marks on the engine and injection pump flanges are properly aligned. The mark is a line scribed across the top of the pump mounting flange and the injection pump gear drive cover flange.

8.2 *Installation of Auxiliary Systems and Miscellaneous Components:*

8.2.1 *Exhaust Back Pressure Transducer Lines*—Check the lines leading to the pressure transducer. Remove any obstructions in the lines.

8.2.2 *Crankcase Ventilation System*—Clean the oil separator. Install the crankcase vent tube to the atmosphere by way of the oil separator on the rear of the right rocker arm cover as shown in Fig. A3.3.

8.2.3 *External Oil System Installation*—Configure the external oil system according to the schematic diagram shown in Fig. A3.2. Ensure all hoses and fittings on the oil heat exchanger are properly connected and secure.

8.2.3.1 Do not use brass and copper fittings in the external oil system, as they can influence used oil wear metals analyses.

8.2.4 *Engine Cooling System Installation*—A suggested engine cooling system is shown in Fig. A3.4.

8.2.4.1 Remove the thermostat.

8.2.5 *Engine Coolant System Charge*—Charge the engine with coolant solution mixed to the concentration shown in 7.1.2.

8.2.6 *Intake Air System Installation*—Install the intake air horn and Piezometer ring.

8.2.7 *Exhaust System Installation*—Install the exhaust manifolds and the exhaust manifold discharge flanges.

9. Test Procedure

9.1 *Description of Test Segments and Organization of Test Procedure Sections:*

9.1.1 *New Engine Break-in*—A break-in is only performed on a new engine. A break-in is not performed before each steady state test. New engine break-in is detailed in 9.7.

9.1.2 *Pretest Procedure*—The pretest segment is used to flush previous oil from the test engine and is performed before each 50 h wear test. Pretest segment is detailed in 9.8.

9.1.3 *Fifty-Hour Steady State Test*—The actual test used to measure roller follower shaft wear is a 50 h test run at steady state conditions shown in Table 1. Paragraph 9.9 describes the operation of the 50 h test.

9.1.4 *Engine Starting and Shutdown Procedures*—Paragraphs 9.3 – 9.5 describe the engine starting and shutdown procedures.

9.2 *Engine Parts Replacement*—The roller followers cannot be replaced during the test. Record the circumstances involved in any other engine parts replacement on the Supplemental Operational Data pages.

9.3 *Engine Starting Procedure*—Use the following procedure each time the engine is started:

9.3.1 Turn on the safety circuits and the engine coolant pump.

9.3.2 Crank the engine.

9.3.3 The control systems shall allow the engine to start within 10 s. (**Warning—**Verify that the oil sump and cooling system have been charged before starting the engine.) (**Warning—**Verify there is an adequate supply of cooling water to the exhaust manifolds and external heat exchangers. Without sufficient coolant flow, the engine and exhaust manifolds will overheat and sustain serious damage.) (**Warning—**Do not spray starting fluids into the intake-air horn to assist engine starting.) (**Warning—**Do not crank the engine excessively. If starting difficulties are encountered, perform diagnostics to determine why engine will not start. Excessive cranking times may promote increased engine wear.)

9.3.4 Operate the engine speed at 1000 r/min and no power 5 min.

9.3.5 After 5 min, increase the power to 7.5 kW and maintain the engine speed at 1000 r/min. Maintain this condition for 15 min. The test time begins 10 min after the completion of the 15 min warm-up period.

9.3.6 During the 10 min after the warm-up, maintain the engine speed at 1000 r/min and increase the power until the fuel consumption rate meets the specification shown in Table 1. Maintain these conditions for the duration of the test.

9.4 *Normal Engine Shutdown Procedure*—Unless an emergency condition exists, each time the engine is shutdown, use the following procedure.

TABLE 1 Steady State Operating Conditions

Parameter	Specification
Speed, r/min	1000 ± 5
Torque, N·m	Record
Power, kW	Record (target range, 30–34 kW)
Fuel rate, kg/h (6.2 L engine)	9.00 ± 0.10
Fuel rate, kg/h (6.5 L engine)	9.40 ± 0.10
Fuel temperature, °C	35.0 ± 2.0
Coolant inlet temperature, °C	Record
Coolant outlet temperature, °C	120.0 ± 2.0
Coolant flow rate, L/min	Record (target range, 53–61 L/min)
Coolant pressure, kPa	Record (target range, 93–107 kPa)
Main oil gallery temperature, °C	120.0 ± 2.0
Intake air temperature, °C	32.0 ± 2.0
Exhaust temperature, °C	Record
Oil sump temperature, °C	Record
Intake air pressure, kPa	97.0 ± 1.0
Crankcase pressure, kPa	Record
Exhaust back pressure, kPa	103.0 ± 1.0

9.4.1 Reduce the engine power to 0 kW.
9.4.2 Operate the engine for 5 min.
9.4.3 Stop the engine.

9.5 *Emergency Shutdown Procedure*—If an emergency condition exists, shut off the fuel supply and stop the engine.

9.6 *Unscheduled Shutdowns and Downtime*—The test can be shut down at any convenient time to perform unscheduled maintenance. Report all unscheduled shutdowns on Form 19 of the final test report.

9.6.1 *Resumption of Test Time After a Shutdown*—After a shutdown, test time begins 10 min after the completion of the 15 min period at 7.5 kW in 9.3.5.

9.7 *New Engine Break-in*—The break-in provides an opportunity to stabilize a new engine and is only performed after a new engine has been installed on the test stand and prior to a reference test. The break-in is not performed before each 50 h non-reference test.

9.7.1 The break-in is comprised of two stages—a stepped, steady state stage and a cyclic stage. Table 2 describes the steady state stage. The cyclic portion is described in Table 3 (see 9.7.3.3 and 9.7.3.4).

9.7.1.1 Use the lifters that are included in the assembled engine for the engine break-in.

9.7.2 *New Engine Break-in Oil Charge:*

9.7.2.1 Install a new AC PF-35 oil filter.

9.7.2.2 Connect the flush system outlet to the oil cooler.

9.7.2.3 Use the flush system to charge 6.5 kg of break-in oil into the engine.

NOTE 2—Break-in oil is defined in 7.1.5.

9.7.2.4 Remove the flush system outlet hose from the oil cooler and cap the oil cooler fitting.

9.7.3 *New Engine Break-in Operating Procedure:*

9.7.3.1 Start the engine according to 9.3.

9.7.3.2 Operate the engine according to the steady state sequence shown in Table 2.

9.7.3.3 Operate the engine according to the cyclic sequence shown in Table 3. Except for speed and torque, use the targets shown in Table 4 for all other controller set points. Total cycle length is 30 min (a cycle includes Steps 2 through 17). Each transition is 30 s in length. Steps 2 through 11 are 60 s each; Steps 12 through 17 are 120 s each. Repeat the cycle 100 times to complete the cyclic portion of the break-in in 50 h.

9.7.3.4 The engine will not maintain specifications for some of the parameters shown in Table 4 especially during the cyclic stage. Controller set points should be maintained at the specifications shown in Table 4 for all parameters except engine speed and torque.

TABLE 2 Break-in Sequence, Steady State Stage[A]

Step	Engine Speed, r/min	Engine Torque, N·m	Time, min
1	1000	120	30
2	2000	140	30
3	3000	180	30
4	3600	200	30
5	3800	0	30
6	3000	max	30

[A] See Table 4 for remaining steady state break-in specifications.

TABLE 3 Break-in Sequence, Cyclic Stage

Step	Engine Speed, r/min	Engine Torque, N·m	Stage Length, min
1	650 (Idle)	(0)	
2	max. governed (3800)	(0)	1
3	3600	max (310)	1
4	2800	max (350)	1
5	2000	max (370)	1
6	1450	220	1
7	max. governed (3800)	(0)	1
8	3600	max (310)	1
9	2800	max (350)	1
10	2000	max (370)	1
11	1450	(220)	1
12	max governed (3800)	(0)	2
13	3600	max (310)	2
14	2800	max (350)	2
15	2000	full (370)	2
16	1450	(220)	2
17	650 (Idle)	(0)	2

TABLE 4 Break-in Operating Targets, Steady State and Cyclic Stages[A]

Controlled Parameter	Specification
Engine speed, r/min	see Tables 1 and 2
Torque, N·m	see Tables 1 and 2
Power, kW	Record
Fuel temperature, °C	35 ± 2
Coolant inlet temperature, °C	Record
Coolant outlet temperature, °C	120 ± 2
Coolant flow rate, L/min	190 ± 8
Coolant pressure, kPa	100 ± 7
Main oil gallery pressure, kPa	Record
Main oil gallery temperature, °C	120 ± 2
Intake air temperature, °C	32 ± 2
Exhaust temperature, °C	Record
Oil sump temperature, °C	Record

[A] The retention of break-in data is at the discretion of the laboratory.

9.7.3.5 The engine will consume oil during the cyclic portion of the break-in. An engine will normally consume 1 L of oil/16 h of break-in operation. Approximately 1 L of oil should be added during Step 17 at 17 h and 34 h.

9.8 *Pretest Procedure*—The engine pretest procedure allows an opportunity to charge the crankcase with test oil, verify injection timing, check the crankcase dipstick level and install test lifters (roller followers). Complete the pretest procedure before running each steady state reference or non-reference test for 50 h.

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

9.8.2 *Initial Test Oil Flush and Lifter Installation:*

9.8.2.1 Weigh and install a new AC PF-35 oil filter.

9.8.2.2 Connect the flush system inlet to the fitting on the bottom of the oil pan.

9.8.2.3 Connect the flush system outlet to the external oil cooler inlet.

9.8.2.4 Charge 6.0 kg of test oil into the engine. Record the actual weight of the oil charge.

9.8.2.5 Circulate the oil with the flush system for 15 min.

9.8.2.6 Drain and weigh the oil from the engine. Remove, weigh, and discard the oil filter.

9.8.2.7 Install a new set of hydraulic lifters in the engine position noted on the roller follower shaft. Orient the hydraulic lifters so that the oil hole faces the front of the engine.

NOTE 3—A description of the markings on the end of the roller follower shafts is shown in Fig. A6.1.

NOTE 4—A map of hydraulic lifter positions in the engine is shown in Fig. A3.4.

9.8.2.8 Install the hydraulic lifter guide and hold down plates. Torque the hold down plates to 35 N·m.

9.8.2.9 Install the push rods and rocker arm assemblies in the engine locations marked on the parts. Torque the rocker arm shafts to 50 N·m. Refer to the GM Diesel Engine service manual (GM 16015.05-2) for proper installation.

9.8.3 *Second Test Oil Flush:*

9.8.3.1 Weigh and install a new test oil filter.

9.8.3.2 Charge 6.0 kg of test oil into the engine by way of the flush system. Record the actual mass of the oil charge.

9.8.3.3 Install the rocker arm cover lids.

9.8.3.4 Circulate the oil with the flush cart for 15 min.

9.8.3.5 After the oil has circulated for 5 min, crank the engine for a minimum of 2 min. Leave the flush system on while the engine is cranked.

9.8.3.6 Drain and weigh the oil from the engine. Remove, weigh, and discard the oil filter.

9.8.4 *Test Oil Charge:*

9.8.4.1 Weigh and install new oil filter.

9.8.4.2 Disconnect the flush system inlet hose from the oil pan. Install the cap on the oil pan fitting.

9.8.4.3 Use the flush system to charge 6.0 kg of test oil into the engine. Turn off the flush system before the inlet hose picks up air.

9.8.4.4 Remove the flush system outlet hose from the oil cooler. Install the cap on the oil cooler fitting. Be careful not to lose any portion of the test oil charge.

9.8.4.5 Purge the flush system into a container and pour all purged oil into the engine.

9.8.4.6 After a minimum of 2 min, check the oil level with the dipstick. The oil level should be at or near the full mark.

9.8.5 *Installation of the Crankcase Pressure Transducer*—Remove the dipstick and install the line leading to the crankcase pressure transducer to the dipstick tube.

9.8.6 *Calibration of the TDC Indicator*—Verifying the calibration of the TDC indicator located on the harmonic balancer is recommended.

9.8.7 *Verification of Injection Timing*—Start the engine according to 9.3. After the engine speed and fuel rate have stabilized at the specifications shown in Table 1, verify the injection timing is 11.5 ± 0.5 using the default settings on the timing meter. If the injection timing is outside this specification, rotate the injection pump and remeasure the timing.

9.9 *Fifty-Hour Steady State Test*—Start the engine according to 9.3. Operate the engine at the steady state conditions noted in Table 1for 50 h.

9.10 *Periodic Measurements:*

9.10.1 *Operational Data Acquisition*—Record the operational parameters shown in Table 1 (with the exception of coolant flow rate and coolant pressure) with automated data acquisition at a minimum frequency of once every 6 min.

9.10.2 *Injection Timing Measurement*—Measure and record the injection timing at least once every test.

9.11 *Oil Sampling and Oil Addition Procedures*—Take used oil samples at 25 h and 50 h and add oil at 25 h. Make no other new oil additions or samples during the test. The sampling and new oil addition procedures are detailed below.

9.11.1 *Twenty-Five-Hour Oil Sampling and Oil Addition Procedure:*

NOTE 5—The engine is not shut down for oil addition or oil sampling at 25 h.

9.11.1.1 Weigh 1.0 kg of new oil into a beaker.

9.11.1.2 Remove a 100 mL purge from the engine. Then remove a 100 mL analysis sample from the engine. Label the sample bottle for identification with the test number, date, test hour, and oil code.

9.11.1.3 Pour the 1.0 kg of new test oil and the 100 mL purge into the engine.

9.11.2 *Fifty-Hour Oil Sampling Procedure:*

NOTE 6—The engine is not shut down for oil sampling at 50 h.

9.11.2.1 Remove a 100 mL purge from the engine. Remove a 100 mL analysis sample from the engine. Label the sample bottle for identification with the test number, date, test hour, and oil code.

9.12 *End of Test (EOT) Procedure:*

9.12.1 *Engine Oil Removal*—Drain the oil from the sump within 60 min of EOT.

9.12.2 *Solvent Flush:*

9.12.2.1 Charge approximately 7 L of solvent into the engine by way of the flush system.

9.12.2.2 Circulate the solvent with the flush system for 20 min. While the solvent is circulating through the engine, rotate the engine two complete revolutions by hand to flush the valve train assembly.

9.12.2.3 Disconnect the flush system, and drain the solvent from the engine. If the engine is going to be laid up, flush and drain the engine with a 15W40 API CG-4 quality oil to prevent rusting.

9.12.3 *Lifter Removal*—Remove the lids from the rocker arm covers and remove the lifters from the engine.

9.12.4 *Roller Follower Shaft Removal*—Remove the axle from the lifter body by pressing the shaft from the body.

10. Calculation and Interpretation of Test Results

10.1 *Environment of Parts Measurement Area*—The ambient atmosphere of the parts measurement area shall be reasonably free of contaminants. Maintain the temperature within ±3.0 °C of the temperature of the area when the machines were calibrated.

10.2 *Roller Follower Shaft Wear Measurements*—Measure and record the shape of the wear scar using a skidless stylus type measuring device. Make the measurement with the reference line etched on the end of the roller follower shaft in a vertical position in the measuring device. Calculate the wear from the wear trace chart. In this test, wear for a given shaft is defined as the maximum vertical depth shown on the wear trace chart. An example of a typical wear trace and wear determination is shown in Fig. A6.2. Record the calculated wear and corresponding lifter position number.

10.3 *Oil Analysis:*

10.3.1 *Wear Metals*—Measure Al, Cr, Cu, Fe, Pb, Si, and Sn content on oil samples at 0 h (new oil from container), 25 h and 50 h. Test Method D5185 is recommended.

10.3.2 *Viscosity*—Measure kinematic viscosity at 100 °C on oil samples from 0 h (new oil), 25 h and 50 h in accordance with Annex A7.

10.3.3 *Soot Quantity*—Determine the soot quantity, mass %, on oil samples from 0 h (new oil), 25 h and 50 h in accordance with Annex A8.

10.4 *Assessment of Test Validity*—Specific requirements to determine test validity status are shown in Table 5. The testing laboratory shall use engineering judgment to assess the validity of tests which have deviations from the items listed in Table 5. The TMC will assist the laboratory in the determination of test validity, if requested by the laboratory. The mean of each parameter listed below, except injection timing, shall fall within the ranges listed below.

10.5 Measure injection timing only once per test. All other parameters are measured at least once per 6 min.

10.6 All instrumentation shall be calibrated in accordance with Table A4.1.

11. Final Test Report

11.1 *Reporting Calibration Test Results*—Report all calibration (reference oil) tests to the TMC within five days of test completion using the standardized report forms and data dictionary that are available on the ASTM Test Monitoring Center web page at http://www.astmtmc.cmu.edu. Electronic transfer of the test report can be done using the ASTM Data Communications Committee Test Report Transmission Model (see Section 2—Flat File Transmission Format) available from the ASTM TMC. A copy of the final test report (all forms) should be submitted by mail to the test developer and the TMC within 30 days of test completion (see A9.1).

11.2 *Report Forms*—For reference oil test, the standardized report form set and data dictionary for reporting test results and for summarizing the operational data are required. The list of final report forms is shown in Annex A5.

TABLE 5 Operational Validity Requirements

Parameter	Specification
Speed, r/min	1000 ± 5
Fuel rate, kg/h (6.2 L engine)	9.0 ± 0.10
Fuel rate, kg/h (6.5 L engine)	9.40 ± 0.10
Fuel temperature, °C	35.0 ± 2.0
Coolant outlet temperature, °C	120.0 ± 2.0
Main oil gallery temperature, °C	120.0 ± 2.0
Intake air temperature, °C	32.0 ± 2.0
Intake air pressure, kPa	97.0 ± 1.0
Exhaust back pressure, kPa	103.0 ± 1.0
Injection timing, °BTDC	11.5 ± 0.5

11.2.1 *Electronic Data Transmission of Test Results*—Annex A5 contains the RFWT and Header Data dictionaries. Additional information is also provided for its use. This information is provided to anyone wishing to transmit test information electronically. For more information on electronic transmissions, contact the TMC.

11.3 *Interim Non-Valid Calibration Test Summary*—This information includes test run number, test start and completion dates, the blind oil code, the industry oil code, the reason the test was not acceptable, the corrective action, and any other pertinent information. Include this information in the comments section of Form 19. Include a comment for each non-valid or aborted calibration test in a series.

11.4 *Severity Adjustments*—This test incorporates the use of a Severity Adjustment (SA) for non-reference test results. A control chart technique, described in 11.4.1 and 11.4.2, has been selected for the purpose of identifying when a bias becomes significant for Roller Follower Shaft Wear. When a significant bias is identified, a SA is applied to non-reference test results. The SA remains in effect until subsequent calibration test results indicate that the bias is no longer significant. SAs are calculated and applied on a laboratory basis.

11.4.1 *Control Chart Technique For Severity Adjustments (SA)*—Standardized calibration test results are applied using an exponentially weighted moving average (EWMA) technique. Values are standardized to delta/s (result—target)/standard deviation). The targets and standard deviations for current calibration oils are published by the ASTM TMC. Include all operationally valid calibration tests in a laboratory control chart. Chart tests in order of completion. Record completion of tests by EOT date and time. EOT time is reported as hour and minute (Central Time) according to the 24 h clock (1 am = 1:00, 1 pm = 13:00). Reporting test completion time enables the TMC to properly order tests that are completed on the same day for industry plotting purposes. Report calibration tests to the TMC in order of test completion. A minimum of two tests is required to initialize a control chart.

11.4.2 Calculate EWMA values using the following equation:

$$Z_i = 0.2(Y_i) + 0.8(Z_{i-1}) \quad (1)$$

where:

Z_0 = 0,
Y_i = standardized test result, and
Z = EWMA of the standardized test result at test order *i*.

If the absolute value of EWMA, rounded to three places after the decimal, exceeds 0.600 then apply an SA to subsequent non-reference results.

11.4.3 *Calculation of Severity Adjustment*—The following example illustrates how to compute and apply EWMA and SA values. Please note, that test targets are presented for examples only.

Roller Follower Shaft Wear SA
TMC Oil 1004
Applicable Test Targets:
Mean = 0.41
Standard Deviation = 0.07

$$Z_1 = -0.400$$

Test Result:

$T_2 = 0.30$

Standard Test Result:

$Y_2 = (Ti - \text{Mean})/\text{Standard Deviation} = -1.571$

EWMA: $Z_2 = 0.2(Y2) + 0.8(Z1) = -0.634$

11.4.3.1 Since ‖−0.634‖ > 0.600, apply an SA: SA = (−1) (EWMA) (standard deviation). Round this result to two decimal places. Enter this number on Form 1 under the non-reference oil test block in the space for severity adjustment. Add this value to non-reference average wear results. Enter the adjusted wear value in the appropriate space. An SA will remain in effect until the next calibration test. At that time, calculate a new EWMA.

12. Precision and Bias

12.1 *Precision*—Test precision is established on the basis of operationally valid reference oil test results monitored by the TMC.

12.1.1 *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.

NOTE 7—Intermediate precision is the appropriate term for the method, rather than repeatability which defines more rigorous within-laboratory conditions.

12.1.1.1 *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 6 in only one case in twenty. When only a single test result is available, the Intermediate Precision Limit can be used to calculate a range (test result ± Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time in twenty.

12.1.1.2 *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.

12.1.1.3 *Reproducibility Limit (R)*—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 6 in only one case in twenty. When only a single test result is available, the Reproducibility Limit can be used to calculate a range (test result ± Reproducibility Limit) outside of which a second test result would be expected to fall about one time in twenty.

TABLE 6 Test Precision

Parameter	Intermediate Precision (i.p.)	Reproducibility (*R*)
Roller follower wear	0.13	0.14

12.2 *Precision Estimate*—Test precision, as of June 23, 2006, is shown in Table 6.

12.3 *Bias*—Bias is determined by applying a defined statistical technique to calibration test results. When a significant bias is determined, a severity adjustment is applied to the non-reference oil test result.

13. Keywords

13.1 calibrate; diesel engine; engine oil; light-duty; light-duty engine; lubricant; reference oil; roller follower shaft wear; used oil wear

ANNEXES

(Mandatory Information)

A1. GUIDELINES FOR TEST PART SUBSTITUTION OR MODIFICATION

A1.1 *Engine Component Modifications*—No modifications are allowed to bring any engine component within a specification or cause a part to operate within a specification.

A1.2 *Test Part Substitution*—Obtain all lifters and engines used from the supplier listed in Appendix X1. Obtain oil filters used in the 50 h, steady state portion of the test from the supplier listed in Appendix X1.

A1.3 *Substitution or Modification of Auxiliary Test Stand Equipment*—Substitutions or modifications of auxiliary test stand equipment are only allowed where explicitly stated or if the word *suggested* is used to describe a modification or component.

A2. GUIDELINES FOR UNITS AND SPECIFICATION FORMATS

A2.1 *Significant Digits*—The appropriate number of significant digits for each operational parameter is shown in Table A2.1. Report operational data and wear measurement using the number of significant digits specified in Table A2.1.

A2.1.1 The following information applies to all specified limits in this standard. For purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off *to the nearest unit* in the last right hand figure used in expressing the limiting value in Table A2.1. This is in accordance with the rounding-off method of Practice E29.

TABLE A2.1 Significant Digits for Operating Conditions

Parameter	Round off to Nearest
Speed	1 r/min
Torque	1 N·m
Power	0.1 kW
Fuel rate	0.01 kg/h
Fuel temperature	0.1 °C
Coolant inlet temperature	0.1 °C
Coolant outlet temperature	0.1 °C
Coolant flow rate	1 L/min
Coolant pressure	1 kPa
Main oil gallery temperature	0.1 °C
Intake air temperature	0.1 °C
Exhaust temperature	0.1 °C
Oil sump temperature	0.1 °C
Intake air pressure	0.1 kPa
Crankcase pressure	0.01 kPa
Exhaust back pressure	0.1 kPa
Injection timing	0.1°BTDC
Significant Digits for Wear Results	
Parameter	Round off to nearest
Roller follower shaft wear	0.00001 in.

A2.2 *Units for Measurements and Unit Conversions*—All dimensions have been specified with rounded, convenient SI values where possible. The intent of this procedure is to cause all measurements to be completed directly in appropriate SI units.

A2.3 *Units for Reporting Results*—All data except roller follower shaft wear should be reported in appropriate SI units.

A2.4 *Specification Formats*—Specifications are listed in three different formats throughout the standard. Specifications which have a target and no tolerance are listed as x.xxx. For example, torque specifications are listed as 40 N·m. Specifications which have a target and a tolerance are listed as xx.xx ± x.xx. For example, engine speed is 1000 ± 5 r/min. Specifications which have ranges but no target are used when (*1*) the value of the parameter is not critical as long as the parameter is within the range specified or (*2*) the measurement technique is not precise.

A2.4.1 Specifications with a target imply the correct value is the target and the mean of a random sample representing the parameter should be equivalent to the target. The range is intended as a guide for maximum acceptable variation around the mean. Operation within the range specified does not imply that the parameter will not bias the final test results.

A2.4.1.1 Do not intentionally calibrate or control a parameter with a target at a level other than the target.

A3. DETAILED SPECIFICATIONS OF THE APPARATUS

A3.1 The test engine is based on the General Motor Corporation's V8 indirect injection diesel engine. Assemble the test engine using modified cylinder heads and an individually timed injection pump.

A3.2 Use an engine test stand equipped to control engine speed and torque, and various temperatures, pressures, and flow rates.

A3.3 Use an automated data acquisition system to measure various operating parameters.

A3.4 Use external systems to control engine intake air, fuel, coolant, and oil temperatures and pressures.

A3.5 Various external apparatus are required to measure and calibrate engine components, control systems, and operating parameters.

A3.6 *Organization of Apparatus Description Sections*—Detailed description of the apparatus is grouped into the following sections:

A3.6.1 *The Test Engine*—Paragraph A3.7.

A3.6.2 *Control Systems*—Paragraph A3.8.

A3.6.3 *Measurement Transducers and Systems*—Paragraph A3.9.

A3.7 Test Engine

A3.7.1 *Test Engine Kit*—Obtain the engine kit from the supplier listed in A9.1.3 which contains all the necessary *consumable* hardware for fifteen tests. A complete list of parts included in the kit is shown in Tables A3.1 and A3.2.

A3.7.1.1 *Critical Parts*—A critical part is any part that will impact combustion (fuel rate, injection timing, compression ratio, air flow, and oil consumption) or roller follower lubrication and loading (see Table A3.1).

TABLE A3.1 Critical Parts

Part No.	Description
	Engine assembly (6.2 or 6.5 L HD NA C/K)
	Short block assembly
10149616	Block assembly (6.2 or 6.5 L one pc seal)
14077141	Piston (NA)
14032399	Top rings
14025533	Second ring
23500288	Oil ring
14025524	Piston rod assembly (upper)
	Cylinder head assembly (HD NA 10)
10149663	Exhaust valves
14033927	Inlet valves
10230426	Prechambers (+ 10 % revolution throttle)
14025512	Valve springs
23502552	Exhaust valve stem seal
	Inlet valve stem seal
10163736	Head gasket (blue stripe)
14066308	Camshaft
23502598	Oil pan
BX-6202-1	Oil filter (Bowden)
DX-109561	Valve cover gasket (Western auto gasket)
10163737	Nozzle
10154615	Injection pump—(Arctic pump)
17109650	Lifter assembly

TABLE A3.2 Engine Test Kit

Part No.	Test Kit Item
BX-6200-1	Test kit—includes 1 each BX-6201-1, 30 each BX-6202-1 and 240 each BX-6204-1
BX-6201-1	Engine—complete with exception of front cover
BX-6202-1	Test oil filter
BX-6203-1	Front cover
BX-6204-1	Hydraulic lifter
BX-6205-1	Water cooled manifolds, left and right side
BX-6206-1	Exhaust manifold discharge flanges
BX-6207-1	Gaskets for exhaust manifold discharge flange
BX-6208-1	Studs for exhaust manifold
BX-6209-1	Time trac injection timing indicator w/¼ in. transducer
BX-6210-1	Intake air horn
BX-6212-1L	Rocker arm cover assembly, left
BX-6212-1R	Rocker arm cover assembly, right
BX-350-3	Oil separator

A3.7.2 *Specially Fabricated Engine Parts*—The following subsections detail the specially fabricated engine parts used in this test method:

A3.7.2.1 *Exhaust Manifold Discharge Flanges*—The flanges are required and are available from the supplier listed in Appendix X1.

A3.7.2.2 *Intake Air Horn*—The design, including all modifications is required. Obtain modified intake air horns from the supplier listed in Appendix X1.

A3.7.2.3 *Rocker Arm Cover*—The specially fabricated rocker arm cover is required. Obtain rocker arm covers from the supplier listed in Appendix X1.

A3.7.2.4 *Engine Front Cover*—The engine front cover is required. Obtain front covers from the supplier listed in Appendix X1.

A3.7.3 *Engine Measurement and Assembly Equipment*—Required special engine measurement and assembly equipment is described in A3.7.3.1 – A3.7.3.4. Items routinely used in the laboratory and workshop are not included.

A3.7.3.1 *Injection Timing Measurement* —Measure injection timing using the indicator located on the harmonic balancer. Use a Stanadyne Time Trac injection timing measurement device. Obtain it from the supplier listed in Appendix X1.

A3.7.3.2 *Oil Flush System*—A flush system is required to flush the engine oil system between tests. The design of the system is not specified, but the reservoir should be capable of holding a minimum of 8 L of fluid.

A3.7.3.3 *Hydraulic Lifter Removal Tool*—The tool, Part No. J-29834, is not required, but it facilitates the removal of the hydraulic lifters from the engine. Information concerning tool acquisition is shown in Appendix X1.

A3.7.3.4 *Wear Measurement Device*—Use a skidless stylus type measuring device to measure the wear on the roller follower shafts.

A3.7.4 *Miscellaneous Equipment:*

A3.7.4.1 *Used Oil Sample Containers*

Containers are necessary to obtain and store used oil samples. High density polyethylene containers (120 mL) are recommended for oil samples. (**Warning—**In addition to other precautions, glass containers are fragile and may cause injury or exposure to hazardous materials, if broken.)

A3.8 Test Stand Configuration and Control Systems

A3.8.1 *Engine Speed, Torque, and Fuel Consumption Rate Control Systems*—Engine speed, torque, and fuel consumption rate control systems shall be capable of maintaining the limits specified in Table 1. Speed, torque, and fuel consumption rate and parameters affecting air flow through the engine are interactive. Engine speed is typically controlled by varying dynamometer excitation, while engine fuel consumption rate and torque are altered by varying the throttle position. Typical laboratory practices to control torque and fuel consumption rate include fixed throttle position or closed-loop, feedback control systems.

A3.8.2 *Fuel Supply System*—The design is not specified, but the system shall be capable of controlling fuel temperature according to the specification shown in Table 1. Maintain fuel transfer pressure above 45 kPa.

A3.8.3 *Intake Air System*—Configure the air supply system according to the schematic diagram shown in Fig. A3.1. Fabricate a Piezometer ring according to Fig. A3.1. The control

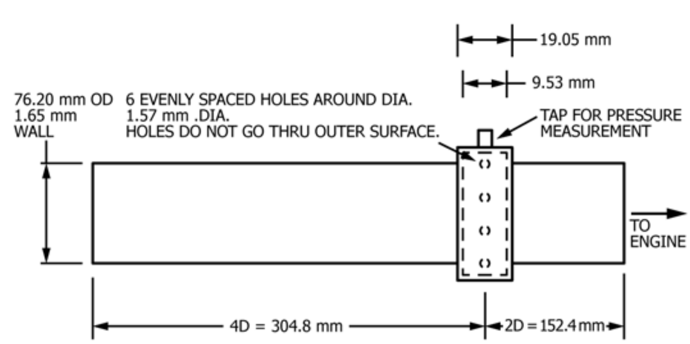

FIG. A3.1 Air Intake Piezometer Ring

system shall be capable of maintaining the intake-air temperature and pressure specifications shown in Table 1.

A3.8.4 *Engine Coolant System*—A suggested cooling system is shown in the schematic diagram A3.5. The Barco flow meter is the only required component.

A3.8.5 *Exhaust Manifold Coolant System*—Maintain the outlet water temperature of the water cooled manifolds below 60 °C. Water-cooled exhaust plumbing downstream of the exhaust probes is a typical laboratory practice. Exhaust system design downstream of the water cooled manifold discharge flanges is not specified. (**Warning—**Good engineering practices should be utilized to ensure safe operation of this system. High temperature, low water flow, or low water pressure alarms, or both, are recommended to prevent damage due to lack of cooling during engine operation.)

A3.8.6 *External Oil System*—Configure the external oil system according to the schematic diagram shown in Fig. A3.2. Install −8 lines to and from the oil cooler. Install a sample valve and a connection for the flush system to the line returning oil from the cooler. Performance specifications are shown in Table 1.

A3.8.7 *Crankcase Ventilation System*—Configure the crankcase ventilation system as shown in Fig. A3.3.

A3.8.8 *Drive Line Configuration*—Configure the engine mounting so that the crankshaft is horizontal. The engine cannot be used to drive any external engine accessory.

A3.8.9 *Engine Starting Motor*—Air driven starter motors are strongly recommended because of the 2 min engine cranking time during the oil flush procedure.

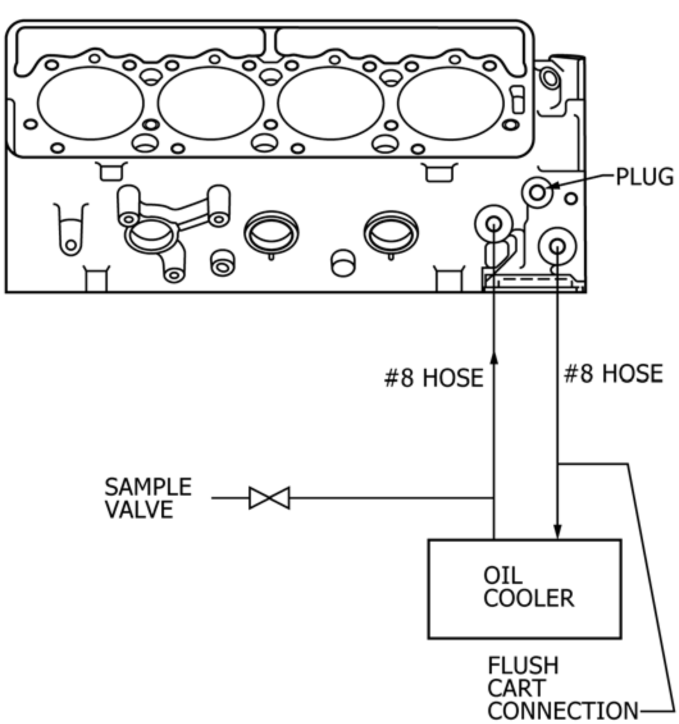

FIG. A3.2 External Oil Cooling System

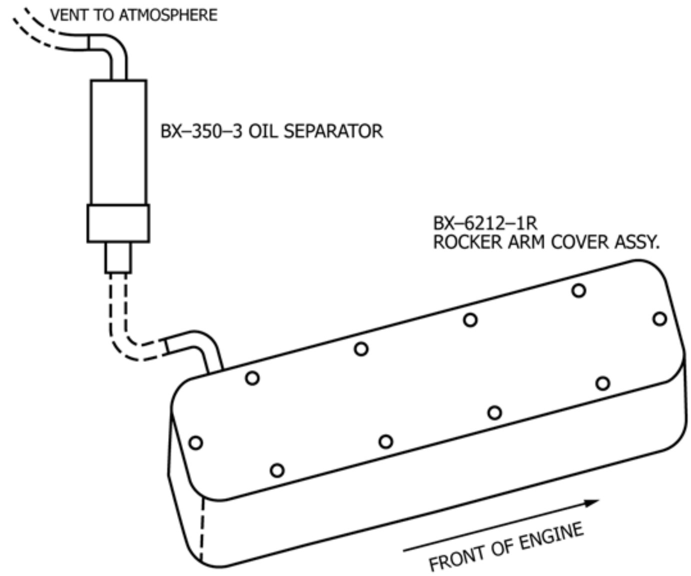

FIG. A3.3 Crankcase Ventilation System

A3.9 Measurement Transducers and Systems

A3.9.1 *Engine Speed Measurement*—Engine speed is typically measured using a pulsed (magnetic pick-up based) system.

A3.9.1.1 *Engine Speed Measurement Calibration*—Calibrate the engine speed measurement and readout system before each calibration test.

A3.9.2 *Engine Torque Measurement*—Measure engine torque with a torque cell attached to the dynamometer torque arm.

A3.9.2.1 *Engine Torque Measurement Calibration*—Span the torque measurement and readout system with deadweights before each engine calibration test. This may be done more frequently as needed.

A3.9.3 *Temperature Measurement Equipment:*

A3.9.3.1 Temperature measurement equipment and locations for the five required temperatures are specified. Alternative temperature measurement equipment shall be approved by the TMC. The accuracy and resolution of the temperature measurement sensors and the complete temperature measurement system shall follow the guidelines detailed in the research report.[6]

A3.9.3.2 All thermocouples shall be premium, sheathed, grounded types with premium wire. All thermocouples, with the exception of the engine exhaust temperature thermocouples, shall be 3.2 mm diameter. The engine exhaust temperature thermocouples shall be 3.2 mm or 6.4 mm diameter. Match thermocouples, wires, and extension wires to perform in accordance with the *special* limits of error as defined in ANSI MC96.1.

A3.9.3.3 *Coolant Inlet*—Install the tip at the center of the flow stream just before the flow is split into the right and left bank of the engine.

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

A3.9.3.4 *Coolant Outlet*—Install the tip to a depth of approximately 100 mm at the center of the flow stream in a thermostat housing tapped to accept a 3.2 mm diameter thermocouple.

A3.9.3.5 *Fuel Inlet*—Install the tip in a 6.4 mm diameter tee at the center of the flow stream approximately 50 mm upstream of the fuel filter, located behind the intake manifold.

A3.9.3.6 *Oil Gallery*—Remove the oil pressure sending unit which is located on the left rear on the top of the block. Install a 6.4 mm diameter NPT pipe closed nipple in the engine block. Install a ¼-in. diameter NPT pipe closed nipple in the engine block. Install a 6.4 mm diameter thermocouple into the nipple. Install the thermocouple tip until it bottoms out in the oil gallery and back the thermocouple out approximately 6 mm. The installation depth will be about 150 mm.

A3.9.3.7 *Oil Sump*—Locate the thermocouple on the right side of the sump, approximately 50 mm from the bottom, and 150 mm from the rear. Install the tip into the sump approximately 75 mm.

A3.9.3.8 *Intake Air*—Install the tip midstream in the intake-air horn downstream of the inlet of the intake-air horn approximately 25 mm. This is downstream from the Piezometer ring, as shown in Fig. A3.1, approximately 200 mm.

A3.9.3.9 *Exhaust Gas*—Install the thermocouple into the bottom port on each water cooled manifold discharge flange.

A3.9.3.10 *Temperature Measurement Calibration*—Calibrate all thermocouples and temperature measurement systems before each calibration test. Each temperature measurement system shall indicate within ± 0.5 °C of the laboratory calibration standard. The calibration standard shall be traceable to national standards.

A3.9.4 *Pressure Measurement Equipment*—Requirements for pressure measurement are detailed in the following sections. Specific measurement equipment is not specified. 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.[6]

A3.9.4.1 Operate pressure measurement transducers in a temperature controlled environment with a maximum temperature variation of ± 3 °C to prevent calibration drift. (**Warning—**Tubing between the pressure tap locations and the final pressure sensors should incorporate condensate traps as necessary by good engineering practice. This is particularly important in applications where low air pressures are transmitted by way of lines which pass through low-lying trenches between the test stand and the instrument console.)

A3.9.4.2 *Oil Pressure*—Measure oil pressure at the tee installed in place of the oil pressure sending unit, located at the left, rear of the engine (see A3.9.3.6).

A3.9.4.3 *Intake-Air Pressure*—Measure the intake-air pressure by way of a 6.4 mm diameter pressure tap mounted in a Piezometer ring on the intake air system (see Fig. A3.1).

A3.9.4.4 *Crankcase Pressure*—Measure the crankcase pressure at the dipstick tube.

A3.9.4.5 *Exhaust Back Pressure*—Locate the exhaust back pressure taps on the top of each water cooled manifold discharge flange. Tie both taps together. A sensor capable of absolute measurement is required. A condensate trap should be installed between the probe and sensor to accumulate water present in the exhaust gas.

A3.9.4.6 *Coolant System Pressure*—Measure the coolant system pressure at the top of the expansion tank as detailed in Fig. A3.4.

A3.9.4.7 *Fuel Pressure*—Measure fuel pressure upstream of the location of the fuel inlet thermocouple.

A3.9.4.8 *Pressure Measurement Calibration*—Calibrate all pressure transducer and measurement systems before each calibration test. Calibrate pressure measurement transducers in a temperature controlled environment. The calibration temperature shall be the same nominal value as the temperature in which the transducers are operated during testing.

A3.9.5 *Flow Rate Measurement Equipment*—Flow rate measurement for the required parameters is detailed in the following subsections. Measurement equipment is only specified for engine coolant flow rate. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the flow rate measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.[6]

A3.9.5.1 *Coolant Flow Rate*—Determine the engine coolant flow rate by measuring the differential pressure across the specified venturi flow meter. The pressure drop is approximately 5.0 kPa in the controlled flow range. Take precautions to prevent air pockets from forming in the lines to the pressure sensor. Transparent lines and bleed lines are beneficial in this application.

A3.9.5.2 *Coolant Flow Rate Calibration*—Calibrate the engine coolant flow meter before each calibration test as installed in the system at the test stand. Alternatively, the flow meter may be detached from the test stand and calibrated, providing the adjacent upstream and downstream plumbing is left intact during the calibration process. Calibrate the flow against a turbine flow meter or by a volume/time method.

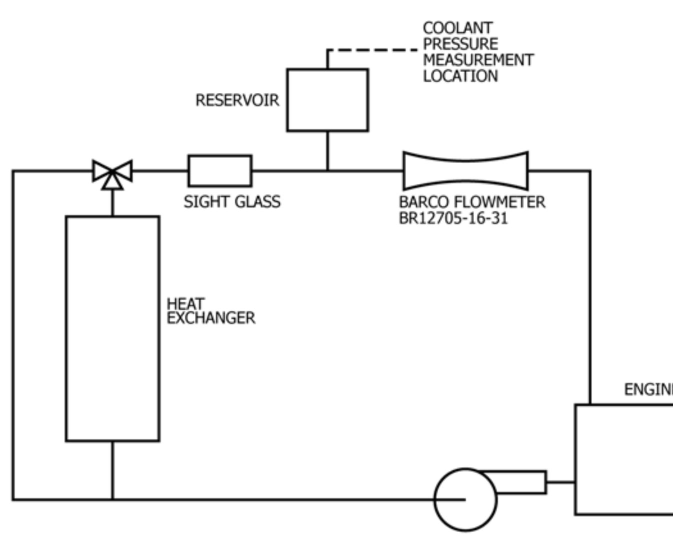

FIG. A3.4 Engine Coolant System

A3.9.5.3 *Fuel Consumption Rate*—Determine the fuel consumption rate by measuring the rate of fuel flowing to the day tank.

A3.9.5.4 *Fuel Consumption Rate Measurement Calibration*—Calibrate fuel consumption rate measurement before every calibration test. Volumetric systems shall be temperature-compensated and calibrated against a mass flow device. The flow meter located on the test stand shall indicate within 0.2 % of the calibration standard.

A4. CALIBRATION

A4.1 *Organization of Calibration Description Sections*—Calibration is divided into two categories—measurement system calibration and test/engine calibration. Details on measurement system calibration are shown with each system or device in Annex A3. A summary of calibration frequency for measurement systems and a cross reference to the corresponding apparatus section is shown in Table A4.1.

A4.2 Details on test engine/stand calibration are shown in A4.3.

A4.3 *Test Engine/Stand Calibration*—Calibrate the test stand and engine as a unit by running a 50 h steady state test after an engine has completed the break-in with a reference oil supplied by the TMC. The TMC uses the Lubricant Test Monitoring System (LTMS) to judge operationally valid calibration test results. (A document describing the LTMS is available from the TMC.) If the calibration test results are within the LTMS limits, then the test stand is considered to be calibrated. A calibrated engine cannot be removed from the test stand on which it was calibrated without invalidating the remainder of the calibration period.

A4.3.1 *Test Engine/Stand Calibration Period*—Each test engine kit has a total life of fifteen tests (both non-reference and calibration tests are included in the test count). An engine/stand is considered calibrated for 9 months or until the completion of the fifteenth test on the engine kit. Calibration time periods may be adjusted by the TMC. Any deviation from the standard calibration time frequency shall be approved by the TMC and reported in the comment section of the Unscheduled Downtime and Maintenance Summary (see Annex A5) of the final test report. Any non-reference test started within 9 months of the completion date of the previous calibration test is considered within the calibration time period.

A4.3.1.1 *Modification of test stand control systems or completion of any non-standard test on a calibrated stand shall be reported to the TMC immediately*. A *non-standard* test includes any test completed under a modified procedure requiring hardware or controller set-point modifications to the test stand. The TMC determines whether another calibration test is necessary after the modifications have been completed.

TABLE A4.1 Measurement System Calibration Frequency

Measurement System	Calibration Frequency	Section Reference
Temperature	before each calibration test	A3.9.3.10
Pressure	before each calibration test	A3.9.4.7
Engine coolant flow	before each calibration test	A3.9.5.2
Fuel flow	before each calibration test	A3.9.5.4
Engine speed	before each calibration test	A3.9.1.1
Dynamometer torque	before each calibration test	A3.9.2.1

A4.3.2 *Unacceptable Calibration Results*—Failure of a calibration test to meet LTMS control chart limits can be indicative of a false alarm, testing stand, testing laboratory, or industry related problem. When this occurs, the laboratory, in conjunction with the TMC, shall attempt to determine the problem source. If it is determined to be a false alarm or testing stand problem, there is no impact on non-reference tests running in other testing stands within that laboratory. If it is determined that the problem is laboratory related, non-reference tests running during the problem period shall be considered invalid unless there is specific evidence to the contrary for each individual test. The Surveillance Panel adjudicates industry problems.

A4.3.3 *Reference Oil Accountability*—Laboratories conducting calibration tests are required to provide a full accounting of the identification and quantities of all reference oils used. With the exception of the new oil analysis required in 10.3, no physical or chemical analysis of new reference oils may be performed without permission from the TMC.

A4.3.4 *Used Reference Oil and Used Calibration Test Parts Storage*—Retain all samples of used reference oil for 90 days. Retain each roller follower shaft from a calibration test for six months.

A4.3.5 *Test Numbering System:*

A4.3.5.1 *Acceptable Tests*—The test number shall follow the format AAA-BBB-CCC-DD. AAA represents the stand number. BBB represents the number of tests run on a particular stand. CCC represents the engine kit number. DD represents the number of tests run on a particular engine. As an example, 6-40-21-8 represents the fortieth test on Stand 6 and the eighth test on Engine Kit 21. Please note, all tests on a given stand shall be consecutively numbered.

A4.3.5.2 *Unacceptable or Aborted Tests*—If a calibration test is aborted or the results are outside the acceptance limits, the BBB portion of the test number for subsequent calibration test(s) includes a letter suffix. The suffix begins with the letter *A* and continues alphabetically until a calibration test is completed within the acceptance limits. For example, if three consecutive unacceptable calibration tests are completed on the same test stand and the test number of the first test is 6-40-21-8, the next two test numbers would be 6-40A-21-9 and 6-40B-21-10. If the results of the next calibration test are acceptable, the test number 6-40C-21-11 would permanently identify the test and appear on future correspondence. The completion of any amount of operational time on tests other than calibration tests causes the test number to be increased by one. No letter suffix is added to the test number of tests other than calibration tests.

A5. FINAL REPORT FORMS

A5.1 The required report forms are available on the ASTM Test Monitoring Center web page at http://www.astmtmc.cmu.edu/ or can be obtained in hard copy format from the TMC.

Form 0	Cover Sheet
Form 1	Test Lab Affidavit
Form 2	Summary of Roller Follower Wear
Forms 3–16	Operational Data Summary
Form 17	Oil Analysis Summary
Forms 18–20	Unscheduled Downtime and Maintenance Summary
Form 21	Test Fuel Analysis (Last Batch)
Form 22	Characteristics of the Data Acquisition System

NOTE A5.1—If the non-reference oil test results are also to be submitted as candidate oil test results to the registration organization, report the candidate oil test results using the report forms and data dictionary that are maintained for reporting reference oil results. Include the ACC Code of Practice Test Laboratory Conformance statement.

Form 23	ACC Test Laboratory Conformance Statement

A6. ILLUSTRATIONS

A6.1 Fig. A6.1 is an illustration of roller follower shaft markings and Fig. A6.2 is a shaft wear depth example.

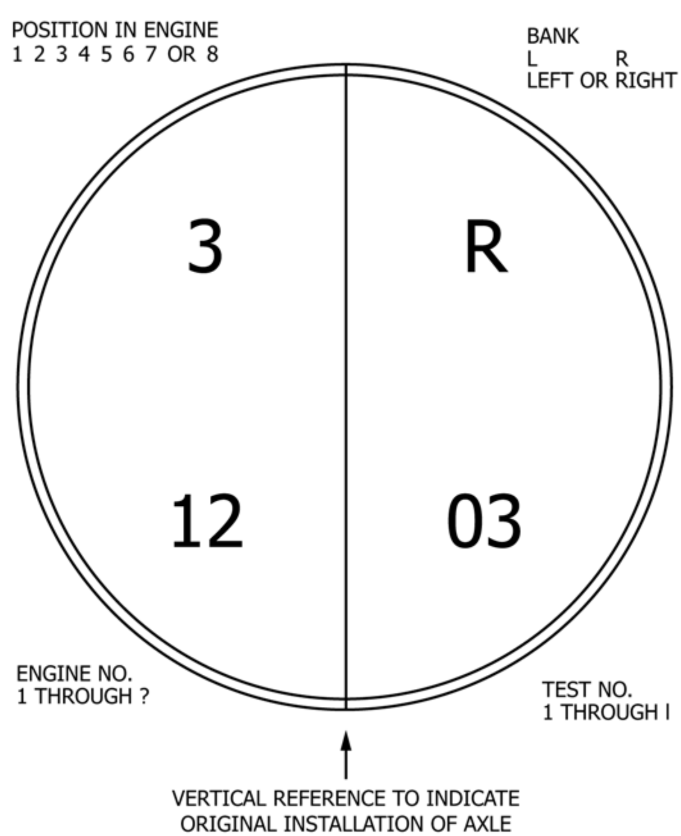

FIG. A6.1 Roller Follower Shaft Markings

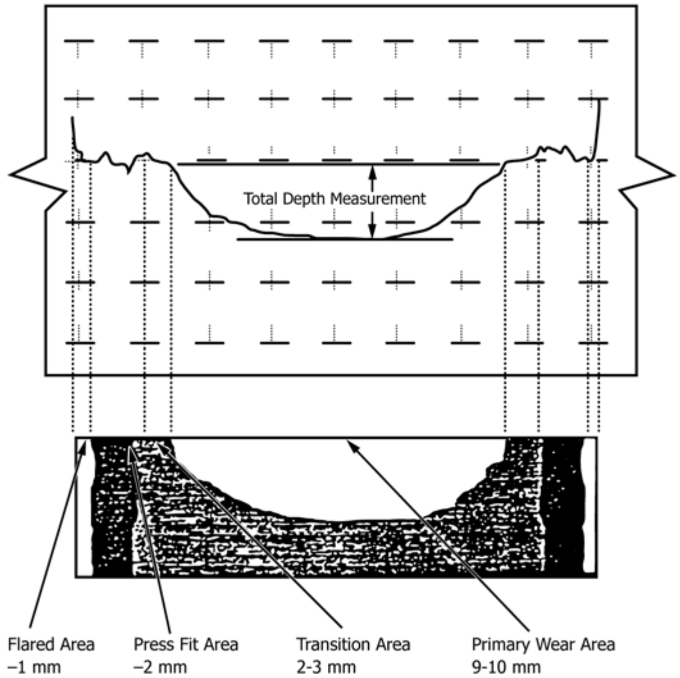

FIG. A6.2 Shaft Wear Depth Example

A7. KINEMATIC VISCOSITY AT 100 °C PROCEDURE FOR THE ROLLER FOLLOWER WEAR TEST

A7.1 This procedure follows Test Method D445 as stated in the 1994 *Annual Book of ASTM Standards*. There are some modifications and additions.

A7.2 *New Oil Samples:*

A7.2.1 Use 200 Reverse Flow tube for analyzing all samples.

A7.2.2 Portions of Article 11 of Test Method D445, follow procedure for Opaque Liquids as outlined here; two tubes, first bulb measurement only.

A7.2.3 Shake all new oil samples using the following procedure. This procedure requires a Red Devil Model 5600 Commercial Paint Shaker or equivalent. Model 5600 subjects the sample to a 497 r/min in a circular motion with a 22.23 mm radius. The springs that hold the machine also provide some up and down motion to the sample. Do not prep more than two samples (four tubes) at the same time.

A7.2.3.1 Be sure cap is tight on sample container.

A7.2.3.2 Place the sample on the paint shaker.

A7.2.3.3 Shake for 5 min.

A7.2.3.4 Remove sample container from paint shaker.

A7.2.3.5 Portions of the sample can now be taken for analysis. No more than 2 min should pass between step A7.2.3.4 and charging of the viscosity tubes.

A7.2.4 Follow step 11.4 of Test Method D445. As specified, two viscometers should be charged. It is not necessary to heat the sample. Allow the sample to be drawn up to ~6.4 mm past the fill line. See Fig. A7.1.

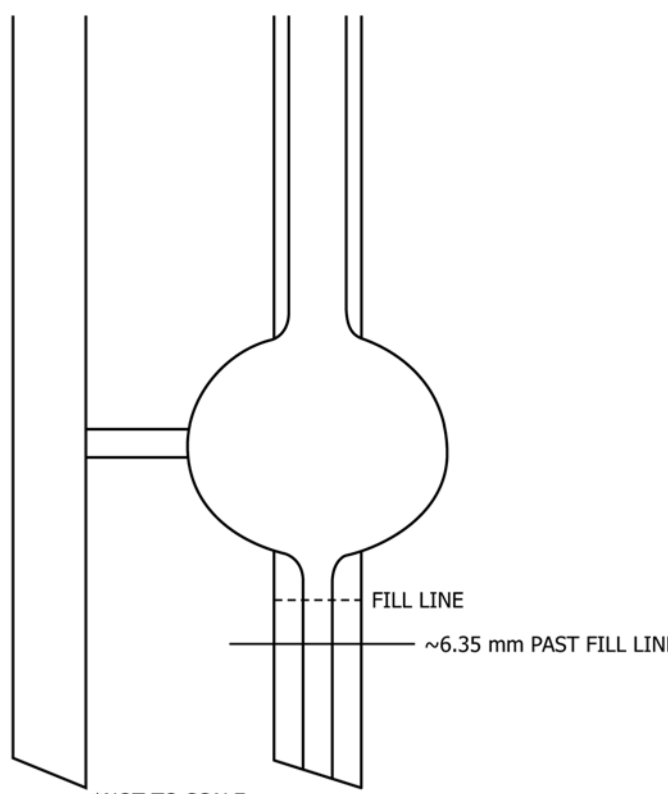

FIG. A7.1 Viscometer Fill Line

A7.2.5 Invert the tube to an upright position and wipe excess sample off of Tube N with a Kimwipe or clean soft cloth.

A7.2.6 Referring to Fig. A7.2, pull a vacuum on Tube L drawing sample to ~¾ the length of the capillary, Tube R.

A7.2.7 Place stopper on the end of Tube N to prevent the sample from flowing in the tube.

A7.2.7.1 The sample shall not reach the first timing mark E as this will void the test!!

A7.2.8 Follow step 11.4.1 of Test Method D445. Please note that the viscometer should be mounted upright in the desired bath keeping Tube L vertical. Ensure the bath liquid level is above Bulb D. Use a bath soak time of 15 min ± 30 s.

A7.2.9 With the sample flowing freely, once the oil comes in contact with the first timing mark E, immediately start the timer. See Fig. A7.3.

A7.2.10 Measure the time required for the oil ring of contact to pass from the first timing mark E to the second timing mark F. As soon as the oil ring of contact reaches F, stop the timer. See Fig. A7.4.

A7.2.11 Finally, follow step 11.6 of Test Method D445. Report the viscometer results individually and report the average.

A7.3 *Used Oil Samples:*

A7.3.1 Use a 200 Reverse Flow tube for analyzing all samples. However, if the flow time is greater than 1000 s, use a 300 Reverse Flow tube. For flows exceeding the 1000 s and the millimetres squared per second range given for a 300 Reverse Flow Tube, follow what is stated in Fig. A3.2 given in Test Method D446.

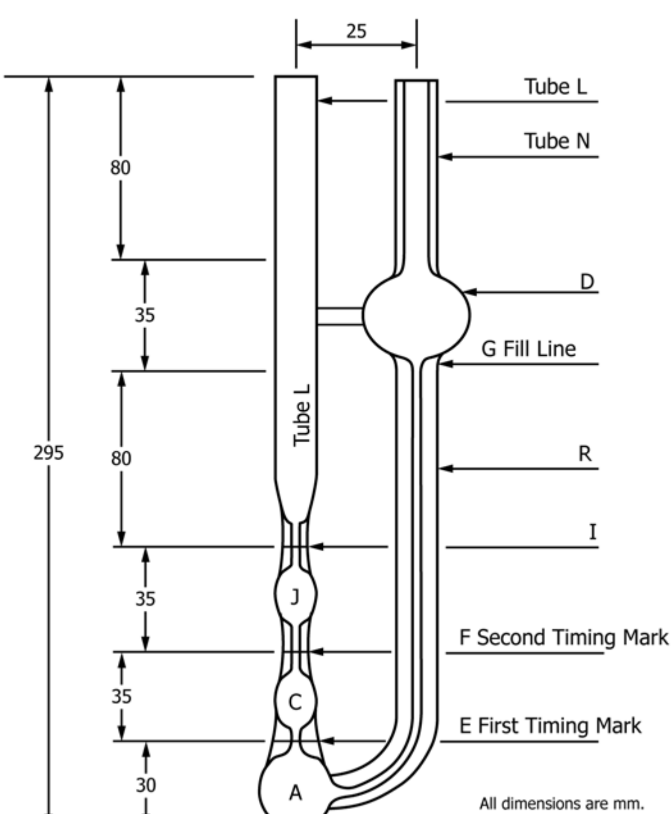

FIG. A7.2 200 Reverse Flow Viscometer

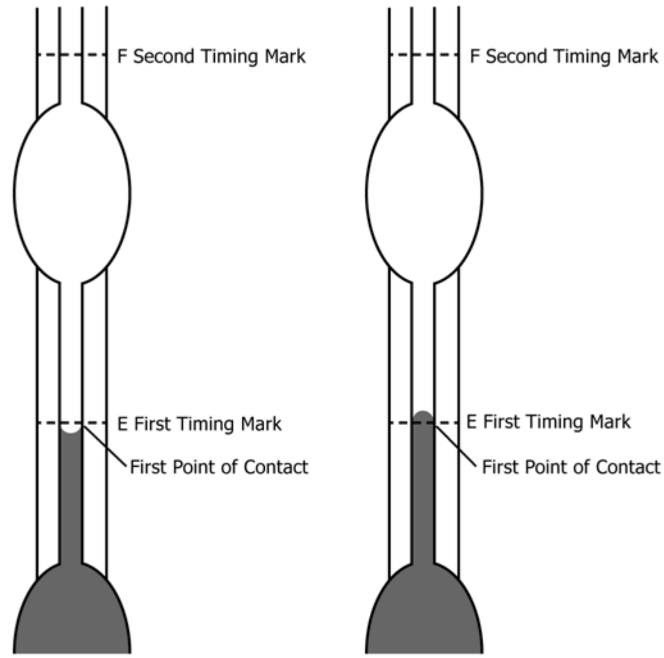

FIG. A7.3 First Timing Mark

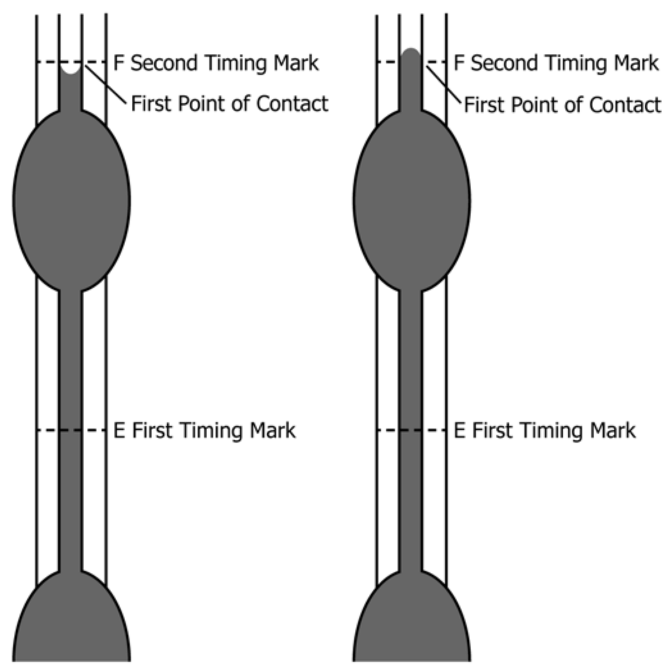

FIG. A7.4 Second Timing Mark

A7.3.2 Portions of Article 11 of Test Method D445, follow procedure for Opaque Liquids; two tubes, first bulb measurement only. It is not necessary to heat or filter the sample.

A7.3.3 Shake all used oil samples using the following procedure. This procedure requires a Red Devil Model 5600 Commercial Paint Shaker or equivalent. Model 5600 subjects the sample to 497 r/min in a circular motion with a 22.23 mm radius. The springs that hold the machine also provide up and down motion to the sample. Do not prep more than two samples (four tubes) at the same time.

A7.3.3.1 Be sure cap is tight on sample container.

A7.3.3.2 Place the sample on the paint shaker.

A7.3.3.3 Shake for 5 min.

A7.3.3.4 Remove sample container from paint shaker.

A7.3.3.5 Portions of the sample may now be taken for analysis. No more than 2 min should pass between step A7.3.3.4 and the charging of the viscosity tubes.

A7.3.4 Follow step 11.4 of Test Method D445. As specified, two viscometers should be charged. It is not necessary to heat the sample. Allow the sample to be drawn up to ~6.4 mm past the fill line. See Fig. A7.1.

A7.3.5 Invert the tube to an upright position and wipe excess sample off of Tube N with a Kimwipe or clean soft cloth.

A7.3.6 Referring to Fig. A7.2, pull a vacuum on Tube L drawing sample to ~¾ the length of the capillary, Tube R.

A7.3.7 Place stopper on the end of Tube N to prevent the sample from flowing in the tube.

A7.3.7.1 The sample shall not reach the first timing mark E as this will void the test!!

A7.3.8 Follow step 11.4.1 of Test Method D445. Please note that the viscometer should be mounted upright in the desired bath keeping Tube L vertical. Ensure the bath liquid level is above Bulb D. Use a bath soak time of 15 min ± 30 s.

A7.3.9 With the sample flowing freely, once the oil comes in, contact with the first timing mark E, immediately start the timer. See Fig. A7.3.

A7.3.10 Measure the time required for the oil ring of contact to pass from the first timing mark E to the second timing mark F. As soon as the oil ring of contact reaches F, stop the timer. See Fig. A7.4.

A7.3.11 Finally, follow step 11.6 of Test Method D445. Report the viscometer results individually and report the average.

A8. ENHANCED THERMAL GRAVIMETRIC ANALYSIS (TGA) PROCEDURE FOR SOOT MEASUREMENT

A8.1 TGA Procedure

A8.1.1 Be sure cap is tight on sample container.

A8.1.2 Place sample on a commercial paint shaker.

A8.1.3 Shake for 5 min.

A8.1.4 Remove sample container from paint shaker.

A8.1.5 Portions of the sample may now be taken for analysis. No more than 2 min should pass between step A8.1.4 and filling the TGA sample pan.

A8.2 TGA Procedure

A8.2.1 *Purge Flow Rate*— Use the setting recommended by the TGA instrument manufacturer.

A8.2.1.1 *Nitrogen*—minimum purity, 99.99 %.

A8.2.1.2 *Oxygen*—minimum purity, 99.99 % .

A8.2.2 *Sample Size*— 20 mg.

A8.2.3 *Program Steps:*

A8.2.3.1 *Initial Purge Gas*—Nitrogen.

A8.2.3.2 Isothermal at 50 °C for 1 min.

A8.2.3.3 Heat to 550 °C at 100 °C/min.

A8.2.3.4 Isothermal at 550 °C for 1 min.

A8.2.3.5 Heat to 650 °C at 20 °C/min.

A8.2.3.6 Switch gas purge gas to oxygen.

A8.2.3.7 Heat to 750 °C at 20 °C/min. The program is considered finished once a stable mass residue remains unchanged for 5 min or longer.

A8.2.4 Soot is the difference in mass plateaus at purge gas change, approximately 650 °C, and after a stable mass residue is obtained around 750 °C. If the actual sample mass is reported, convert the difference to percent of the total. The soot value should be reported to the nearest mass fraction of 0.1 %.

A9. SOURCES OF MATERIAL AND INFORMATION

A9.1 Send test engine/stand calibration final reports to the ASTM TMC[2] and GM Powertrain, Powertrain Headquarters, 895 Joslyn Rd. 1J34, Pontiac, MI 48340-2920.

A9.1.1 Obtain reference oil from the supplier listed below: ASTM TMC.[6]

A9.1.2 Obtain test fuel from Howell Hydrocarbons Inc., 1201 S. Sheldon Rd., P.O. Box 429, Channelview, TX 77530-0429.

A9.1.3 Obtain test engines, test roller followers, and related components from Bowden Manufacturing Corp., 4590 Beidler Rd., Willoughby, OH 44094.

APPENDIXES

(Nonmandatory Information)

X1. PC-9 AND PC-9-HS REFERENCE DIESEL FUEL PROPERTIES

X1.1 The properties for PC-9 and PC-9-HS Reference Diesel Fuel are the same as shown in Table X1.1.

TABLE X1.1 PC-9 and PC-9-HS Reference Test Fuel

Property	Test Method	Minimum[A]	Maximum[A]
Sulfur, mass %	D2622	0.04	0.05
Gravity, °API	D287 or D4052	34.5	36.5 (37)
Hydrocarbon Composition, Vol %			
Aromatics	D1319 (FIA)	27 (28)	33
Olefin	D1319 (FIA)	Report	
Cetane Number	D613	40 (42)	48
Cetane Index	D4737 and D976	Report	
Copper Strip Corrosion	D130	...	1
Flash Point, °C	D93	54	...
Pour Point, °C	D97	...	-18
Cloud Point, °C	D2500	Report	
Carbon Residue on 10 % Residuum, mass %	D524 (10 % Bottoms)	...	0.35
Water and Sediment, Vol %	D2709	...	0.05
Viscosity, mm^2/s @ 40 °C	D445	2.4	3.0
Ash, mass %	D482	...	0.005
Total Acid Number	D664	...	0.05
Strong Acid Number	D664	...	0.00
Accelerated Stability	D2274	Report	
Distillation, °C	D86	...	...
10 % Vol		Report	
50 % Vol		Report	
90 % Vol		282	338
EP		Report	

[A] Minimum/maximum numbers in parentheses are EPA Certification Fuel Specifications.

X2. DIAGNOSTIC DATA REVIEW

X2.1 This section outlines significant characteristics of specific engine operating parameters. The parameters may directly influence the test or may be used to indicate normalcy of other parameters.

X2.1.1 *Fuel Consumption Rate/Engine Speed/Engine Load/Injection Timing*—All four parameters can affect soot generation.

X2.1.2 *Crankcase Pressure*—Crankcase pressure is a function of blowby flow rate and is normally slightly above atmospheric pressure.

X2.1.3 *Oil Pressure*— Oil pressure increases throughout the test because of increased soot loading.

X2.1.4 *Oil Temperature Differential*—The oil temperature differential is primarily a function of heat rejection to the oil, oil flow rate, and oil viscosity and is normally stable throughout the test.

X2.1.5 *Coolant Temperature Differential*—The coolant temperature differential is primarily a function of coolant flow rate and heat rejection to the coolant and is normally stable throughout the test. Large variations in the differential may 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 flow meter.

SUMMARY OF CHANGES

Subcommittee D02.B0.02 has identified the location of selected changes to this standard since the last issue (D5966 – 12) that may impact the use of this standard. (Approved May 1, 2013.)

(1) Subsection 7.1.3 revised the designation for fuel.

Subcommittee D02.B0.02 has identified the location of selected changes to this standard since the last issue (D5966 – 10) that may impact the use of this standard. (Approved Dec. 1, 2012.)

(1) Editorially improved the standard by applying Form and Style (including SI 10) guidelines.