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Standard Test Method for Evaluation of Engine Oils for Roller Follower Wear in Light-Duty Diesel Engine¹

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 1993.³ 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 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.

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² ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489. This edition incorporated revisions contained in all Information Letters through No. 06-1.

³ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report D02-1218.

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.*

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2. Referenced Documents
2.1 ASTM Standards:⁴

- 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

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.

- 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 and Relative Density of Liquids by Digital Density Meter
- D4175** Terminology Relating to Petroleum, Petroleum Products, and Lubricants
- D4485** Specification for Performance of Engine Oils
- D4737** Test Method for Calculated Cetane Index by Four Variable Equation
- D5185** Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
- E29** Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E344** Terminology Relating to Thermometry and Hydrometry
- 2.2 *American National Standards Institute (ANSI):⁵*
- MC96.1** Temperature Measurement Thermocouples

3. Terminology
3.1 Definitions:

- 3.1.1 *blowby, n*—in internal combustion engines, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **D4175**
- 3.1.2 *BTDC, adj*—abbreviation for Before Top Dead Center, 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 measuring device with respect to that of a standard. **E344**
- 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**
- 3.1.7 *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**

⁵ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

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, or reduction of material on, a surface.

3.1.12.1 *Discussion*—Wear generally occurs between two surfaces moving relative to each other, and is the result of mechanical or chemical action or a combination of both.

D4175

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.³

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 loads. Side-by-side comparisons of two or more oils in delivery van fleets were used to demonstrate the field performance of various oils.³ 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. This factor, along with the specific operating conditions used to accelerate wear, shall be considered 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 which 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 PC-9 Reference Diesel Fuel are required for each test.⁶ (**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*—A22 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 **8.1.8** 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.

⁶ 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 can 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 Brass and copper fittings may influence used oil wear metals analyses and shall not be used in the external oil system.

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*—The following procedure shall be used 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.

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

- 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 which came 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

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.

specifications shown in Table 4 for all parameters except engine speed and torque.

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 weight 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 1 for 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