



# Standard Test Method for Evaluation of Engine Oils for Roller Follower Wear in Light-Duty Diesel Engine<sup>1</sup>

This standard is issued under the fixed designation D 5966; 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 ( $\epsilon$ ) 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.<sup>2</sup>

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.<sup>3</sup> 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 of units used in this test method are stated in either inch-pound units or SI units and are to be regarded separately as the standard.

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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<sup>2</sup> ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489. This edition incorporated revisions contained in all Information Letters through No. 04-1-06-1.

<sup>3</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D02-1218.

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## 2. Referenced Documents

### 2.1 ASTM Standards:

- D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure<sup>4</sup>
- D92 Test Method for Flash and Fire Points by Cleveland Open Cup<sup>4</sup>
- D97 Test Method for Pour Point of Petroleum Products<sup>4</sup>
- D130 Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test<sup>4</sup>
- 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)<sup>4</sup>

<sup>4</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- D 86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure
- D 93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
- D 97 Test Method for Pour Point of Petroleum Products
- D 130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
- D 235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
- D 287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
- D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the and Calculation of Dynamic Viscosity)
- D 446 Specifications and Operating Instructions for Glass Capillary Kinematic Viscometer<sup>4</sup>
- D 482 Test Method for Ash from Petroleum Products<sup>4</sup>
- D 524 Test Method for Ramsbottom Carbon Residue of Petroleum Products<sup>4</sup>
- D 613 Test Method for Cetane Number of Diesel Fuel Oil
- D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption<sup>4</sup>
- D 2500 Test Method for Cloud Point of Petroleum Products<sup>4</sup>
- D 2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-Ray Fluorescence Spectrometry<sup>4</sup>
- D 2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge<sup>4</sup>
- D 4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants— Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers
- D 482 Test Method for Ash from Petroleum Products
- D 524 Test Method for Ramsbottom Carbon Residue of Petroleum Products
- D 613 Test Method for Cetane Number of Diesel Fuel Oil
- D 664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
- D 976 Test Method for Calculated Cetane Index of Distillate Fuels
- D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
- D 2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)
- D 2500 Test Method for Cloud Point of Petroleum Products
- D 2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
- D 2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge
- D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter
- D 4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants
- D 4485 Specification for Performance of Engine Oils
- D 4737 Test Method for Calculated Cetane Index by Four Variable Equation
- D 5185 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<sup>7</sup>
- D 5186 Test Method for Determination of Aromatic Content of Diesel Fuels and Aviation Turbine Fuels by Supercritical Fluid Chromatography<sup>7</sup>
- D 5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions<sup>7</sup>
- D 5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence HD)— 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)
- E 29 Practice for Using Significant Digits in Test Data to Determine Conformance With Specifications
- E 344 Terminology Relating to Thermometry and Hydrometry
- 2.2 Society of Automotive Engineers (SAE):
- SAE J183 Engine Oil Performance and Engine Service Classification
- SAE J726 Air Cleaner Test Code (Includes Piezometer Ring Specifications)
- 2.3 American Petroleum Institute (API):
- API 1509 Oil Licensing and Certification System
- 2.4 American National Standards Institute (ANSI):<sup>5</sup>
- 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. **D 5302** **D 4175**

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.

<sup>4</sup> Annual Book of ASTM Standards, Vol 06.04.

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

3.1.3 *calibrate*, *v*—to determine the indication or output of a measuring device with respect to that of a standard. E 344

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. ~~D5844~~ D 4175

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. ~~Subcommittee B Glossary~~ D 4175

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. D 4485

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. D 4485

3.1.8 *lubricant*, *n*—any material interposed between two surfaces that reduces friction or wear, or both, between them. ~~Subcommittee B Glossary~~<sup>14</sup> D 4175

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. ~~Subcommittee B Glossary~~<sup>14</sup> D 4175

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. ~~D5844~~ D 4175

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. D 4175

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. ~~D5302~~ D 4175

#### 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.<sup>3</sup>

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.<sup>3</sup> 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 D 4485.

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 *Aliphatic Naphtha*, acceptable from any supplier. ~~(Cleaning Solvent, For cleaning parts, use only mineral spirits meeting the requirements of Specification D 235, Type II, Class C for Aromatic Content (0–2% vol), Flash Point (142°F/61°C, min) and Color (not darker than +25 on the Saybolt Scale or 25 on Pt-Co Scale. (Warning—Flammable. Health hazard. Use adequate safety provisions with all solvents and cleansers.)—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 Howell LSRD-4 reference diesel fuel are required for each test. —Approximately 600 L

of PC-9 Reference Diesel Fuel are required for each test.<sup>6</sup> (**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 Fig. A5.20, Form 20. If any results fall outside the tolerances shown on Fig. A5.20, Form 20, the laboratory should contact the Test Monitoring Center (TMC)<sup>2</sup> 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. A 25-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 8.1.8 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.

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.

<sup>6</sup>Annual Book of ASTM Standards, Vol 05.04.

<sup>2</sup>Available from Chevron Phillips, Phillips 66 Co., Marketing Services Center, P.O. Box 968, Borger, TX 79008-0968.



**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                        |

9.1.4 *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 load 5 min.

9.3.5 After 5 min, increase the load 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 load 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, the following procedure shall be followed each time the engine is shutdown.

9.4.1 Reduce the engine load 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 Fig. A5.19 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.

**TABLE 2 Break-in Sequence, Steady State Stage<sup>A</sup>**

| Step | Engine Speed, r/min | Engine Load, 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                | full power       | 30        |

<sup>A</sup> See Table 4 for remaining steady state break-in specifications.

**TABLE 3 Break-in Sequence, Cyclic Stage**

| Step | Engine Speed, r/min  | Engine Load, N·m | Stage Length, min |
|------|----------------------|------------------|-------------------|
| 1    | 650                  | idle             |                   |
| 2    | max. governed (3800) | no load          | 1                 |
| 3    | 3600                 | full (310)       | 1                 |
| 4    | 2800                 | full (350)       | 1                 |
| 5    | 2000                 | full (370)       | 1                 |
| 6    | 1450                 | 220              | 1                 |
| 7    | max. governed (3800) | no load          | 1                 |
| 8    | 3600                 | full (310)       | 1                 |
| 9    | 2800                 | full (350)       | 1                 |
| 10   | 2000                 | full (370)       | 1                 |
| 11   | 1450                 | 220              | 1                 |
| 12   | max. governed (3800) | no load          | 2                 |
| 13   | 3600                 | full (310)       | 2                 |
| 14   | 2800                 | full (350)       | 2                 |
| 15   | 2000                 | full (370)       | 2                 |
| 16   | 1450                 | 220              | 2                 |
| 17   | 650                  | idle             | 2                 |

### 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 load, 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 50-h cyclic portion of the break-in.

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 load.

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 50-h steady state reference or non-reference test.

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.

**TABLE 4 Break-in Operating Targets, Steady State and Cyclic Stages<sup>A</sup>**

| 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             |

<sup>A</sup> The retention of break-in data is at the discretion of the laboratory.

### 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  $11.5 \pm 0.5$  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 for 50 h at the steady state conditions noted in Table 1.

### 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 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 ~~aliphatic naphtha~~ aliphatic naphtha 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  $\pm 3.0^{\circ}\text{C}$  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 D 5185 is recommended.

10.3.2 *Viscosity*—Measure kinematic viscosity at  $100^{\circ}\text{C}$  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 Injection timing is only measured 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. Facsimile transmit Fig. A5.1, Fig. A5.2, Fig. A5.3, Fig. A5.17, and Fig. A5.19 (reference Annex A5) to the ASTM TMC.<sup>2</sup> 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 (reference~~ 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*—~~The final report forms are shown in~~ 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. These forms are to be used for both calibration and non-reference tests. Use the Data Dictionary formats as shown in Annex A5 to report test values.

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.

**TABLE 5 Operational Validity Requirements**

| Parameter  | Specification   |
|--|-----------------|
| Speed, r/min                                     | 1000 $\pm$ 5    |
| Fuel rate, kg/h (6.2 L engine)                   | 9.0 $\pm$ 0.10  |
| Fuel rate, kg/h (6.5 L engine)                   | 9.40 $\pm$ 0.10 |
| Fuel temperature, $^{\circ}\text{C}$             | 35.0 $\pm$ 2.0  |
| Coolant outlet temperature, $^{\circ}\text{C}$   | 120.0 $\pm$ 2.0 |
| Main oil gallery temperature, $^{\circ}\text{C}$ | 120.0 $\pm$ 2.0 |
| Intake air temperature, $^{\circ}\text{C}$       | 32.0 $\pm$ 2.0  |
| Intake air pressure, kPa                         | 97.0 $\pm$ 1.0  |
| Exhaust back pressure, kPa                       | 103.0 $\pm$ 1.0 |
| Injection timing, $^{\circ}\text{BTDC}$          | 11.5 $\pm$ 0.5  |

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 Fig. A5.19 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

ASTM D5966-08

$Z_1 = -0.400$

Test Result:

$T_2 = 0.30$

Standard Test Result:

$Y_2 = (T_2 - \text{Mean}) / \text{Standard Deviation} = -1.571$

EWMA:  $Z_2 = 0.2(Y_2) + 0.8(Z_1) = -0.634$

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 Fig. A5.2 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 *Reference Oil Precision and Reproducibility*—The TMC determines estimates of precision from calibration test results. These precision data are periodically updated and are available from the TMC.

12.2 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 below shows the precision data (repeatability and reproducibility) for the Roller Follower Wear Test. Data was obtained from April 1993 through April 1995, 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  $\pm$  Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time in twenty.