



# Standard Test Method for Evaluation of Load-Carrying Capacity of Lubricants Under Conditions of Low Speed and High Torque Used for Final Hypoid Drive Axles<sup>1</sup>

This standard is issued under the fixed designation D 6121; 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.

## 1. Scope

1.1 This test method is commonly referred to as the L-37 test.<sup>2</sup> This test method covers a test procedure for evaluating the load-carrying, wear, and extreme pressure properties of a gear lubricant in a hypoid axle under conditions of low-speed, high-torque operation.

1.2 This test method also provides for the running of the low axle temperature (Canadian) L-37 test. The procedure for the low axle temperature (Canadian) L-37 test is identical to the standard L-37 test with the exceptions of the items specifically listed in **Annex A6**. The procedure modifications listed in **Annex A6** refer to the corresponding section of the standard L-37 test method.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific warning information is given in Sections 4 and 7.

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>3</sup>

**D 235** Specification for Mineral Spirits (Petroleum Spirits)

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0.03 on Automotive Gear Lubricants & Fluids.

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<sup>2</sup> Until the next revision of this test method, the ASTM Test Monitoring Center (TMC) will update changes in this test method by means of Information Letters. This edition includes all Information Letters through No. 07-2. Information Letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave, Pittsburgh, PA 15206, Attn: Administrator. The TMC is also the source of reference oils.

<sup>3</sup> 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.

(Hydrocarbon Dry Cleaning Solvent)

**E 29** Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2 *Military Specification:*<sup>4</sup>

**MIL-PRF-2105E** Lubricating Oil, Gear, Multipurpose

2.3 *AGMA National Standard:*<sup>5</sup>

Nomenclature of Gear Tooth Failure Modes

2.4 *SAE Standard:*<sup>6</sup>

**SAE J308** Information Report on Axle and Manual Transmission Lubricants

**SAE J2360** Lubricating Oil, Gear Multipurpose (Metric) Military Use

## 3. Terminology

### 3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *abrasive wear, n—on ring and pinion gears*, removal of material from the operating surface of the gear caused by lapping of mating surfaces by fine particles suspended in lubricant, fuel, or air or imbedded in a surface.

**CRC Rating Manual No. 21<sup>7</sup>**

3.1.2 *adhesive wear, n—on ring and pinion gears*, removal of material from the operating surface of the gear caused by shearing of junctions formed between operating surfaces in direct metal-to-metal contact; sheared-off particles either remain affixed to the harder of the mating surfaces or act as wear particles between the surfaces. **CRC Rating Manual No. 21**

3.1.3 *burnish, n—on ring and pinion gears*, an alteration of the original manufactured surface to a dull or brightly polished condition. **CRC Rating Manual No. 21**

3.1.4 *corrosion, n—in final drive axles*, a general alteration of the finished surfaces of bearings or gears by discoloration, accompanied by roughening not attributable to mechanical action. **CRC Rating Manual No. 21**

<sup>4</sup> Available from Standardization Documents Order Desk, Bldg 4, Section D, 700 Robbins Avenue, Philadelphia, PA 19111-5098.

<sup>5</sup> American Gear Manufacturers Assn. (AGMA), 1500 King St., Suite 201, Alexandria, VA 22314.

<sup>6</sup> Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

<sup>7</sup> Available from Coordinating Research Council (CRC), 219 Perimeter Ctr. Pkwy., Atlanta, GA 30346.

3.1.5 *deposits, n*—in final drive axles, material of pasty, gummy, or brittle nature adhering to or collecting around any of the working parts. **CRC Rating Manual No. 21**

3.1.6 *discoloration, n*—on ring and pinion gears, any alteration in the normal color of finished steel surfaces. **CRC Rating Manual No. 21**

3.1.7 *pitting, n*—on ring and pinion gears, small irregular cavities in the tooth surface, resulting from the breaking out of small areas of surface metal. **CRC Rating Manual No. 21**

3.1.8 *ridging, n*—on ring and pinion gears, an alteration of the tooth surface to give a series of parallel raised and polished ridges running diagonally in the direction of sliding motion, either partially or completely across the tooth surfaces of gears. **CRC Rating Manual No. 21**

3.1.9 *rippling, n*—on ring and pinion gears, an alteration of the tooth surface to give an appearance of a more or less regular pattern resembling ripples on water or fish scales. **CRC Rating Manual No. 21**

3.1.10 *scoring, n*—on ring and pinion gears, the rapid removal of metal from the tooth surfaces caused by the tearing out of small contacting particles that have welded together as a result of metal-to-metal contact. The scored surface is characterized by a matte or dull finish. **CRC Rating Manual No. 21**

3.1.11 *scratching, n*—on ring and pinion gears, an alteration of the tooth surface in the form of irregular scratches, of random length, across the tooth surface in the direction of sliding of the surfaces. **CRC Rating Manual No. 21**

3.1.12 *spalling, n*—on ring and pinion gears, the breaking out of flakes of irregular area of the tooth surface, a condition more extensive than pitting. **CRC Rating Manual No. 21**

3.1.13 *surface fatigue, n*—on ring and pinion gears, the failure of the ring gear and pinion material as a result of repeated surface or subsurface stresses that are beyond the endurance limit of the material. It is characterized by the removal of metal and the formation of cavities. **AGMA National Standard**

3.1.14 *wear, n*—on ring and pinion gears, the removal of metal, without evidence of surface fatigue or adhesive wear, resulting in partial or complete elimination of tool or grinding marks or development of a discernible shoulder ridge at the bottom of the contact area near the root or at the toe or heel end of pinion tooth contact area (abrasive wear). **CRC Rating Manual No. 21**

#### 4. Summary of Test Method

4.1 Prior to each test run, inspect the test unit (final axle assembly) and measure and record confirming manufacturing specifications.

4.2 Begin the test when the axle assembly is installed on the test stand and charged with test lubricant.

4.3 *Gear Conditioning Phase*—Run the charged test unit for 100 min at 440 wheel r/min and 395 lbf-ft (535 N-m) torque per wheel, maintaining an axle sump temperature of 297°F (147°C). (**Warning**—High-speed rotating equipment, electrical shock, high-temperature surfaces.)

4.4 *Gear Test Phase*—Next, run the test unit for 24 h at 80 wheel r/min, 1740 lbf-ft. (2359 N-m) torque per wheel and an axle sump temperature of 275°F (135°C). (**Warning**—See 4.3.)

4.5 The test is completed at the end of the gear test phase. Visually inspect the test parts.

4.5.1 Remove the ring gear, pinion, and pinion bearing, and rate for various forms of distress. Use the condition of the ring gear and pinion to evaluate the performance of the test oil.

#### 5. Significance and Use

5.1 This test method measures a lubricant's ability to protect final drive axles from abrasive wear, adhesive wear, plastic deformation, and surface fatigue when subjected to low-speed, high-torque conditions. Lack of protection can lead to premature gear or bearing failure, or both.

5.2 This test method is used, or referred to, in the following documents:

5.2.1 American Petroleum Institute (API) Publication 1560.<sup>8</sup>

5.2.2 STP-512A.<sup>9</sup>

5.2.3 SAE J308.

5.2.4 Military Specification MIL-PRF-2105E.

5.2.5 SAE J2360.

#### 6. Apparatus

6.1 *Test Unit*—The test unit is a new complete hypoid truck axle assembly less axle shafts, Dana Model 60, 5.86 to 1 ratio.<sup>10</sup> See Annex A6 for part numbers.

6.2 *Test Stand and Laboratory Equipment:*

6.2.1 *Axle Vent*—Vent the axle to the atmosphere throughout the entire test and arrange the vent so that no water enters the housing.

6.2.2 *Axle Cover*—The axle cover has a 3.5-in. (8.9-cm) inspection port installed, as shown in Fig. A2.1. This allows filling the axle and provides a means for inspecting the axle after the gear condition phase (see 10.1). Install a thermocouple, as described in 6.2.4.1.

6.2.3 *Test Stand Configuration*—Mount the complete assembly in a rigid fixture as shown in Fig. A3.1. Mount the test unit in the test stand with pinion and axle shaft centerlines horizontal.

6.2.4 *Temperature Control*—The test axle housing shall include a means of maintaining the lubricant at a specified temperature. This shall include a thermocouple, a temperature recording system, and a cooling method.

6.2.4.1 *Thermocouple*—Determine the thermocouple location on the rear cover using the cover plate temperature sensor locating device as shown in Fig. A4.1.

<sup>8</sup> "Lubricant Service Designations for Automotive Manual Transmissions, Manual Transaxles, and Axles," available from American Petroleum Institute, 1220 L St. NW, Washington, DC 20005.

<sup>9</sup> "Laboratory Performance Tests for Automotive Gear Lubricants Intended for API GL-5 Service."

<sup>10</sup> The sole source of supply of the apparatus known to the committee at this time is Dana Corp., P.O. Box 2424, Fort Wayne, IN 46801. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,<sup>1</sup> which you may attend.

(1) Install the thermocouple such that the thermocouple tip is flush with the cover plate lip by placing the cover plate face on a flat surface and inserting the thermocouple into the cover plate until the thermocouple tip is flush with the flat surface.

(2) Lock the thermocouple into place.

6.2.4.2 *Temperature Recording System*—The temperature recording system shall record the temperature of the test oil throughout the test.

6.2.4.3 *Axle Cooling*—Use three spray nozzles to distribute water over the cover plate and axle housing as shown in Fig. A5.1. Actuate the water control valve by the temperature PID control system. See A6.3.2.1 for L-37 Canadian Version test.

(1) Spray nozzles<sup>11</sup> shall be any combination of the following part numbers depending on how the system is plumbed: Straight Male NPT (Part No. 3/8GG-SS22), 90° Male NPT (Part No. 3/8GGA-SS22), Straight Female NPT (Part No. 3/8G-SS22), and 90° Female NPT (Part No. 3/8GA-SS22).

(2) Use a single control valve to control the cooling water supply. The control shall be a ½ in. two-way, C linear trim, air to close, Research Control valve. Use a single PID loop to maintain the axle lubricant temperature control for both the Standard and Canadian version test. A separate PID loop control for each version is not permitted. See A6.3.2.2 for L-37 Canadian Version test.

(3) Use only ¾ or ½ in. line material to the spray nozzles.

(4) Use a minimum supply water pressure of 25 psi to the control valve.

(5) Use an axle box cover as shown in Fig. A5.2. The purpose is to contain water and eliminate drafts.

(6) Use a locating pin or stop block as an indexing device to ensure that all subsequent axle installations are consistently installed perpendicular with the axle housing cover to engine and transmission driveshaft centerline.

6.2.5 *Power Source*—The power source consists of a gasoline-powered V-8 engine capable of maintaining test conditions.

6.2.6 *Dynamometers and Torque Control System*—Use two axle dynamometers with sufficient torque absorbing capacity to maintain axle torque and speed conditions. Suitable control equipment with sensitivity of adjustment to permit maintenance of test conditions is required.

6.2.7 *Dynamometer Connecting Shafts*—Fabricate shafts connecting the dynamometer to the axle shafts. Shafts shall be strong enough to handle the torques encountered and shall be dynamically (spin) balanced.

6.2.8 *Drive Shaft and Universal Joints*—Fabricate a shaft with universal joints connecting the manual transmission and test axle. The shaft shall have a  $4 \pm 0.2$ -in. ( $10.1 \pm 0.51$ -cm) outside diameter with a  $0.095 \pm 0.005$  in. ( $0.24 \pm 0.013$  cm)

wall thickness. Shaft and universal joints should be strong enough to handle the torques encountered and shall be dynamically (spin) balanced.

6.2.9 *Transmission and Coupling*—Couple the engine to the test unit through a clutch and manual transmission of sufficient torque carrying capacity to operate normally under test conditions.

6.3 *Speed Measuring and Control System*, capable of measuring speed of both axles and also of maintaining test conditions.

## 7. Reagents and Materials

7.1 *Sealing Compound*, where necessary, Permatex No. 2, or equivalent.

7.2 *Solvent*—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 Saybolt Scale or 25 on Pt-Co Scale). (**Warning**—Combustible. Health hazard.) Obtain a Certificate of Analysis for each batch of solvent from the supplier.

## 8. Preparation of Apparatus

8.1 *Cleaning of Reusable Hardware*—Clean as necessary all reusable parts including axle shafts, thermocouples axle housing cover, and all associated drain pans and funnels used for the addition of and collection of test oil.

### 8.2 Preparation of Axle:

8.2.1 Record the “as received” drive side contact pattern length and flank values as noted on the axle housing from Dana Corp.<sup>10</sup> Length values of  $L^2$  and  $L^3$  and flank values of  $F^{-1}$ ,  $F^0$ , and  $F^{+1}$  are considered acceptable. Any adjustments that are made to the axle prior to testing shall be noted in the comments section of the test report. Axle housings from prior gear batches that do not have contact pattern markings shall be patterned and reported by the test labs in the test report.

8.2.2 *Break and Turn Torque Measurements*—Determine and record the torques required to break and to turn the pinion shaft of the completely assembled test unit.

8.2.3 *Backlash Measurements*—Record the backlash on the test axle reported from the manufacturer. To be acceptable, the backlash reported by the manufacturer shall be between 0.004 to 0.012 in. (0.102 to 0.305 mm).

8.2.3.1 If the test axle does not have a reported backlash from the manufacturer, the average backlash, as measured in 8.2.3.2, shall be between 0.004 and 0.009 in. (0.102 to 0.229 mm).

8.2.3.2 Remove the cover plate. Measure and record backlash at four equally spaced locations. Report the average and the four readings.

8.2.4 *Cleaning*—Wash the test unit using a cleaning solvent (see 7.2), paying particular attention to the pinion bearings to remove all preservative oil. Dry by blowing with clean, dry compressed air.

8.2.5 Lubricate the carrier bearings, pinion bearings, differential gears, and the ring gear and pinion, using the test lubricant or a non-additized neutral base oil.

<sup>11</sup> The sole source of supply of the apparatus known to the committee at this time is Spray Systems Company, and the spray nozzles can be purchased through E.I. Pfaff Company, 3443 Edwards Road, Suite D, Cincinnati, OH 45208. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,<sup>1</sup> which you may attend.

8.2.6 Lubricant added in 8.2.5 shall be drained thoroughly before installing the axle and charging the test unit with the test oil. Place the pinion in a vertical position with the yoke up and the cover off for a minimum of 5 min.

8.2.7 Install axle shafts in test unit.

8.3 Install the test unit on the stand with pinion and axle shaft centerlines horizontal. Connect dynamometers and drive shaft to the test unit.

8.4 Bolt the axle cover with gasket (apply sealant, if needed) onto the axle housing and fill the axle assembly with  $6.0 \pm 0.1$  pt ( $2.8 \pm 0.05$  L) of test lubricant. This step may occur before or after the test unit is installed on the stand as described in 8.3.

## 9. Calibration and Standardization

### 9.1 Reference Oils and Hardware:

9.1.1 Reference oils for stand calibration are available from the ASTM Test Monitoring Center (TMC)<sup>2</sup> and approved hardware through ASTM Subcommittee D02.B0.03.<sup>12</sup>

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

### 9.2 Stand Calibration:

9.2.1 Laboratories wishing to calibrate test stands using reference oils and approved hardware shall participate in the Lubricant Test Monitoring System (LTMS) calibration program administered for this test method by the TMC (see Annex A1). The TMC distributes reference oils as blind coded samples for test stand calibration. Report all test starts and test data using reference oils to the TMC. Calibration frequency is subject to change as required. Current calibration information is available from the TMC. Send all reference oil test results to the TMC within five (5) days of test completion. Extensions to this response time may be granted only with prior approval of the TMC.

9.2.2 The TMC shall inspect new test stands for compliance with this test method. A test stand is considered new when a test stand is moved. Additionally, circumstances involving significant changes to stand apparatus, instrumentation, and operation may require an existing test stand to meet new test stand calibration requirements. Consult with the TMC regarding these matters.

9.2.3 *Reference Test Frequency*—One reference test is required every two months or after 650 test hours on non-reference fluids, whichever occurs first.

9.2.3.1 Reference oil test frequency may be adjusted due to the following reasons:

(1) *Procedural Deviations*—On occasions when a laboratory becomes aware of a significant deviation from the test

method, such as might arise during an in-house review or a TMC inspection, the laboratory and the TMC shall agree on an appropriate course of action to remedy the deviation. This action may include the shortening of existing reference oil calibration periods.

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

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

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

9.2.4 When a test stand is out of calibration for a period of six months or longer, renumber the stand, and follow LTMS guidelines for new stand introduction.

9.2.5 Report modification of test stand apparatus or completion of any nonstandard test on a calibrated test stand to the TMC immediately. The TMC will determine whether another calibration test is necessary.

9.2.6 Alternate testing of L-37 and L-42<sup>13</sup> tests does not necessitate recalibration as long as the above requirements are met.

9.3 Every test start on any test stand shall receive a sequential test run number designated before testing begins. All tests, including aborted starts and operationally invalid tests, must retain their test number.

9.4 *Instrumentation Calibration*—Calibrate the axle speed measuring system, temperature control system, and torque measuring system to occur at a maximum of four months or 50

<sup>12</sup> The responsible ASTM surveillance panel.

<sup>13</sup> The L-42 procedure is currently being developed into a standard test method by Subcommittee D02.B0.

tests against a known standard traceable to the National Institute of Standards and Technology (NIST)<sup>14</sup> or a physical constant.

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

## 10. Test Procedure

### 10.1 Gear Conditioning Phase:

10.1.1 Set the temperature control to maintain a lubricant temperature of  $297 \pm 3^\circ\text{F}$  ( $147.2 \pm 1.7^\circ\text{C}$ ). See **A6.3.3.2** for L-37 Canadian Version test.

10.1.2 With the engine warmed up and with no load on the dynamometers, shift smoothly to a gear appropriate for the test conditions.

10.1.3 After reaching the appropriate gear, accelerate smoothly to  $440 \pm 5$  wheel r/min and apply dynamometer load to achieve a torque load of  $395 \pm 15$  lbf-ft ( $535 \pm 20$  N-m) on each wheel (see **Note 1**).

**NOTE 1**—The time required to accelerate to the test conditions of 440 wheel r/min and 395 lbf-ft is about 5 min.

10.1.4 The test starts when required speed and torque conditions are reached. Record the time as start of the test.

10.1.5 After reaching speed and load conditions, run the test for  $100 \pm 1$  min.

10.1.6 To ensure accuracy of the test, record speed, load, and temperature at a minimum of once every minute.

10.1.7 At the end of the 100 min, and as the load and linear speed ramp-down is started, set the axle lubricant temperature controller to a set point of  $275 \pm 3^\circ\text{F}$  ( $135.0 \pm 1.7^\circ\text{C}$ ). Shift transmission to neutral and ensure that the axles stop turning. Record ending time and temperature of the lubricant. See **A6.3.3.3** for L-37 Canadian Version test.

**NOTE 2**—The intent is to allow water to be added to the axle unit while it is still turning to cool the axle lubricant temperature and ensure that the water is shut off when the axle lubricant temperature drops below the set point.

10.1.8 Restart the test, as detailed in **10.3.1**, if the test is stopped for any reason (power outage, maintenance, and so forth). This stoppage shall count as one of the allowed

shutdowns during the test. Do not calculate deviation percent values or report out of limit operational values until test conditions are again achieved. If the test is stopped at the start of the conditioning phase, before speed and torque conditions are reached, the stoppage will not count as one of the allowed shutdowns.

### 10.2 Gear Test Phase:

10.2.1 Ensure that the temperature control is still set to maintain a lubricant temperature of  $275 \pm 3^\circ\text{F}$  ( $135.0 \pm 1.7^\circ\text{C}$ ). See **A6.3.3.4** for L-37 Canadian Version test.

10.2.2 With the engine warmed up and with no load on the dynamometers, shift smoothly to a gear appropriate for the test conditions.

**NOTE 3**—The transition from the end of the conditioning phase (see **10.1.7**) to the appropriate test gear of the gear test phase is approximately 5 min.

10.2.3 After reaching the appropriate gear, accelerate smoothly to  $80 \pm 1$  wheel r/min and apply dynamometer load to achieve a torque load of  $1044 \pm 35$  lbf-ft ( $1415 \pm 47$  N-m) on each wheel. Hold at this condition until the axle lubricant temperature reaches  $175 \pm 3^\circ\text{F}$  ( $1.0 \pm 1.7^\circ\text{C}$ ).

**NOTE 4**—The time required to accelerate to the test conditions of 80 wheel r/min and 1044 lbf-ft is about 10 min.

10.2.3.1 Once the axle lubricant temperature reaches  $175 \pm 3^\circ\text{F}$  ( $1.0 \pm 1.7^\circ\text{C}$ ), immediately apply dynamometer load to achieve a torque load of  $1740 \pm 35$  lbf-ft ( $2359 \pm 47$  N-m) on each wheel.

10.2.4 The test phase starts when required speed, torque, and temperature conditions are reached. Record the time as start of the test phase.

10.2.5 After reaching speed, load, and temperature conditions, run the test for  $24 \pm 0.2$  h.

10.2.6 To ensure test accuracy, record speed, load, and temperature at a minimum of once every minute.

10.2.7 At the end of 24 h, close the throttle smoothly, shift the transmission to neutral, and record time and temperature of the lubricant.

10.2.8 Disconnect the drive shaft and axle shafts from the dynamometers, and remove the test unit from the test stand while the test unit is hot.

10.2.9 Restart the test, as detailed in **10.3.1**, if the test is stopped for any reason (power outage, maintenance, and so forth). This stoppage shall count as one of the allowed shutdowns during the test. Do not calculate deviation percent values or report out of limit operational values until test conditions are again achieved. If the test is stopped at the start of the test phase, before test conditions are reached (speed, load, and axle temperature), the stoppage will not count as one of the allowed shutdowns.

**10.3 Unscheduled Downtime**—An unscheduled downtime event is defined as any time the engine, or gears, or both, stop turning during the steady state gear conditioning or steady state gear test phases after test conditions are achieved.

**10.3.1 Restart After Unscheduled Downtime**—Restart the test as outlined in **10.3.1.1** through **10.3.1.5** any time there is an unscheduled downtime event.

<sup>14</sup> National Institute of Standards and Technology (formerly National Bureau of Standards), Gaithersburg, MD 20899.

10.3.1.1 Set the temperature control to maintain the lubricant temperature at the set point condition when the shutdown occurred.

10.3.1.2 With the engine warmed up and with no load on the dynamometers, shift smoothly to a gear appropriate for the test condition.

10.3.1.3 After reaching the appropriate gear, accelerate smoothly to the wheel r/min set point condition at the time of the shutdown.

10.3.1.4 Apply a dynamometer load on each wheel to achieve a torque value that is 60 % of the set point value when the shutdown occurred. Hold at this condition until the lubricant temperature reaches  $175 \pm 3^\circ\text{F}$  ( $1.0 \pm 1.7^\circ\text{C}$ ).

10.3.1.5 Once lubricant temperature reaches  $175 \pm 3^\circ\text{F}$  ( $1.0 \pm 1.7^\circ\text{C}$ ), immediately apply dynamometer load on each wheel to achieve the torque load set point condition at the time of the shutdown.

## 11. Axle Post Test Measurements

### 11.1 Break and Turn Torques:

11.1.1 While the unit is hot, determine and record the torque required to break and to turn the pinion shaft of the completely assembled test unit.

11.1.2 Allow the unit to cool, and record the torques required to break and to turn the pinion shaft of the completely assembled test unit.

11.2 Drain the axle of test lubricant. This may occur anytime after 10.2.7 has been completed.

11.3 *Backlash Measurements*—Remove the cover plate. Record backlash at four equally spaced locations on the ring gear and calculate the average of the four readings.

11.4 Completely disassemble the differential and the pinion shaft assemblies for inspection.

## 12. Determination of Test Results<sup>15</sup>

12.1 *Pinion Bearing Rating*—Examine the bearings for wear, surface fatigue corrosion, and deposits in accordance with CRC Rating Manual 21.

### 12.2 Gear Rating:

12.2.1 Examine the tooth surfaces on the drive side of the pinion and ring gear for the following distresses in accordance with CRC Rating Manual 21 and **Annex A9**: burnishing, wear, pitting/spalling, ridging, rippling, scoring, discoloration, corrosion, and deposits. Rate the distress types of wear, rippling, and ridging using the CRC Reference Photography of Gear Distress photographs. The photographs shall have a serial number of SN001 or greater and have an issuance date of July 8, 2000 or later.

12.2.2 Rate each distress by identifying its level of distress in accordance with **Table A9.1**. Four distress types (ridging, rippling, scoring, and wear) are assigned a numerical value between 0 and 10 corresponding to the rated level of distress, as shown in **Table A9.1**. The pitting/spalling distress type is assigned numerical values also shown in **Table A9.1**.

12.2.3 When using the nonlubricated hardware, gear set C1L426/P4L415A, determine a numerical pitting/spalling value, excluding any pitting/spalling value between 9.3 and 9.9, inclusively, in the wear step area of the drive side pinion tooth, as per **Annex A10**.

12.2.3.1 When using the nonlubricated hardware, gear set V1L303/P4L514A, determine a numerical pitting/spalling value, excluding any pitting/spalling value between 3.0 and 9.9, inclusive, in the wear step area of the drive side pinion tooth, as per **Annex A10**.

12.2.3.2 Report this rating value on Form 1 and Form 2 (**Annex A7**) of the test report package.

NOTE 5—If non-reference oil test results are to be used as candidate oil test results against a specification, report the non-reference oil test results on the same standardized report form set and data dictionary as used for reference oil test results.

12.2.3.3 When using the lubricated hardware, gear set V1L686/P4L626A, for non-reference oil tests, add a correction factor of 0.5186 to the pinion transformed ridging test result, and add a correction factor of 0.9922 to the ring transformed ridging test result. Record these results on Form 1 of the test report (**Annex A7**). See **A6.3.4** for L-37 Canadian Version test.

12.3 When using gear set V1L686/P4L626A, a thin polished line visible in the root heel of the pinion and on the crown of the ring gear may be evident. The polish line may vary in length and prominence due to the build position of the ring and pinion gears and manufacturing accuracy of the carrier. This condition is normal and not oil related. Note this condition in the final test report comment section as *Root and Tip line polishing and a function of the gear set manufacturing process — V1L686/P4L626A*.

12.4 For a test rating to be valid, the gears shall be rated by an individual who has participated in an ASTM gear-rater calibration workshop within the previous twelve months<sup>16</sup> and has been calibrated as outlined in the L-37 Rater Calibration Monitoring System (RCMS). The RCMS calibration period is every six months or as otherwise required by the RCMS. A copy of the RCMS document is available on the ASTM Test Monitoring Center web page at <http://www.astmtmc.cmu.edu/>, or they can be obtained in hardcopy format from the TMC.

12.5 *Test Validity*—The test is determined to be operationally valid if the percent deviation of the critical operating parameters and number of shutdowns are within the limits specified and defined in **Annex A8**.

12.6 Consider as non-interpretable any non-reference oil test that has not been run in a calibrated test stand or not conducted on approved hardware, or both. Indicate on the cover page of the test report that the test is non-interpretable and that it has not been conducted in a valid manner in accordance with the test method.

12.7 Consider as non-interpretable any reference or non-reference oil test that has one or more broken pinions or ring gear teeth. Note any tooth breakage in the comment section of the test report.

<sup>15</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D02-1415.

<sup>16</sup> Training for those rating gear sets for gear distress levels may be obtained from Coordinating Research Council, 219 Perimeter Ctr. Pkwy., Atlanta, GA 30346.