Designation: D4998 – 13

Standard Test Method for Evaluating Wear Characteristics of Tractor Hydraulic Fluids[1]

This standard is issued under the fixed designation D4998; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method is used to screen lubricants for gear wear. It is primarily applicable to tractor hydraulic fluids but may be suitable for other applications.

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

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific warning information is given in Sections 7 and 9.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)

D323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)

D329 Specification for Acetone

D4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants

2.2 *Deutsches Institut fur Normung (DIN):*[3]

DIN 17210 Part 1: Tolerances for Spur Gears; Tolerances for the Deviation of Singly Determined Values

DIN 3962 Casehardened Steel; Material Specifications

DIN 50150 Testing of Steel and Cast Steel Conversion Table for Vickers Hardness, Brinell Hardness, Rockwell Hardness and Tensile Strength

DIN 51354 Mechanical Testing of Gear Oils in the FZG Gear Test Machine

3. Terminology

3.1 *Definitions:*

3.1.1 *abrasive wear, n*—wear due to hard particles or hard protuberances forced against and moving along a solid surface. **D4175**

3.1.2 *scoring, n—in tribology*, a severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding. **D4175**

3.1.3 *scratches, n*—the result of mechanical removal or displacement, or both, of material from a surface by the action of abrasive particles or protuberances sliding across the surfaces. **D4175**

3.1.4 *scuffing, n—in lubrication*, damage caused by instantaneous localized welding between surfaces in relative motion that does not result in immobilization of the parts. **D4175**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *wear, n*—the loss of material from contacting surfaces of the gear teeth.

4. Summary of Test Method

4.1 A modified FZG gear oil test machine is operated for 20 h under controlled conditions of speed (100 r/min), torque (tenth stage), and temperature (121 °C). Test gears are lubricated with the test oil.

4.2 The test gears are weighed and visually examined before and after the test. The gear mass loss and the visually observed damage to the gear teeth are used to evaluate the wear obtained with the test fluid.

5. Significance and Use

5.1 Many modern tractor designs use the hydraulic fluid to lubricate the transmission and final drive gears. This test method is used to assess the suitability of the tractor hydraulic fluids as lubricants for transmission and final drive gears of tractors.

6. Apparatus

6.1 *FZG Gear Oil Test Machine*—The test machine is described in Annex A1 and illustrated in Fig. A2.1 and Fig. A3.1.

6.2 *Precision Test Gears*—The test gears are standard FZG tooth profile A gears as described in Annex A1 and Table A1.1.

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.B0.03 on Automotive Gear Lubricants & Fluids.

Current edition approved June 15, 2013. Published July 2013. Originally approved in 1989. Last previous edition approved in 2011 as D4998 – 11. DOI: 10.1520/D4998-13.

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

[3] DIN standards are available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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

6.3 *Gear Case Heater*—A 750 W gear case heater capable of bringing the oil to test temperature in (20 to 25) min.

6.4 *Temperature Controller*—A proportional band-type 1000 W temperature controller for maintaining the oil temperature within 1 °C of the desired test temperature. The thermocouple is securely attached to the inside right wall of the gear case, 28 mm from the rear wall and 60 mm from the bottom, projecting 15 mm into the gear case.

6.5 *Analytical Balance*—An analytical balance with 2 kg capacity and accurate within 1 mg for weighing test gears.

6.6 *Magnifying Lens,* of 3 to 6 power.

6.7 *Compressed Air*—551 kPa minimum.

6.8 *Steam Hot Plate,* or bearing heater, with surface temperatures below 75 °C.

7. Reagents and Materials

7.1 *Mineral Spirits Solvent*—Commercial grade, conforming to the requirements of Specification D235. (**Warning—** Flammable. Vapor harmful. Keep away from heat, sparks, and open flame. Keep container closed. Use with adequate ventilation. Avoid prolonged breathing of vapor or spray mist. Avoid prolonged or repeated skin contact.)

7.2 *Acetone*—Commercial grade, conforming to the requirements of Specification D329. (**Warning—**Flammable. Vapor harmful. Keep away from heat, sparks, and open flame. Keep container closed. Use with adequate ventilation. Avoid prolonged breathing of vapor or spray mist. Avoid prolonged or repeated skin contact.)

7.3 *Pentane*—Commercial grade *n*-pentane, conforming to the requirements of Table A5.1. (**Warning—**Flammable. Vapor harmful. Keep away from heat, sparks, and open flame. Keep container closed. Use with adequate ventilation. Avoid prolonged breathing of vapor or spray mist. Avoid prolonged or repeated skin contact.)

8. Preparation of Apparatus

8.1 Assemble the FZG machine according to the "Operating Instructions for the FZG Gear Oil Test Rig"[4] except that the drive motor and gearing must be modified to provide an input shaft speed of (100 ± 3) r/min. Use the S23 torsional shaft in assembling. Care must be taken to ensure the accuracy of shaft alignment as described in 6.3.[3]

9. Procedure

9.1 *FZG Test Machine Assembly*[5]—Assemble the test machine according to the instructions given in Section 3,[4] except employ a modified, low speed drive motor as described in Annex A1.

NOTE 1—In addition to other precautions, machinery guards are supplied with the FZG test machine to protect personnel from hazards associated with rotating machinery. These should be properly installed before operating the equipment.

NOTE 2—In addition to other precautions, the electrical connections for the drive motor and heater should be installed in accordance with the current edition of the National Electrical Code.[6]

9.2 *Machine Cleaning*—Flush the test gear case and associated parts with mineral spirits solvent (see 7.1). (**Warning—** Combustible. Vapor harmful. Keep away from heat, sparks, and open flame. Keep container closed. Use with adequate ventilation. Avoid prolonged breathing of vapor or spray mist. Avoid prolonged or repeated skin contact.) Fill the gear case with mineral spirits solvent to a level that is above the shaft center line. Manually rotate the shafts so that the bearings are rinsed. Drain mineral spirits solvent from the gear case. Refill gear case with fresh mineral spirits solvent, manually rotate shafts, and drain. Dry gear case with compressed air.

9.3 *Gear Condition*—Examine the gear tooth faces with a magnifying lens of 3 to 6 power. Do not use gears with imperfections on the tooth faces.

9.4 *Gear Cleaning*—Wash the test gears in mineral spirits solvent, then acetone (see 7.2), and finally in pentane (see 7.3). After cleaning, handle the gears only with clean tongs or with clean gloves. Allow the gears to dry. To prevent water condensation following gear cleaning, carefully warm the gears to room temperature with a clean, steam hot plate or bearing heater with surface temperature below 75 °C.

9.5 *Gear Weighing*—Weigh the individual gears using an analytical balance. The gears shall be clean, dry, and at ambient temperature. Record the mass of each gear, rounding to the nearest milligram. Add the mass of each gear and record the sum as initial total gear mass (TM_i).

9.6 *Gear Installation*—Install the test gears.[5]

9.7 *Test Procedure*—Fill the gear case with test fluid until level with the shaft centerline. Install all machine guards in their proper operating positions. Set the temperature controller to 121 °C. With the heater on and no torque applied, start motor to run at 100 r/min test speed. When temperature stabilizes at (121±3)°C for (20 to 25) min, stop the motor and apply a tenth stage load. The tenth stage load consists of applying a torque of 373 N·m by means of the torque arm, weights, and the bolted load clutch. Turn on the motor and operate at (100 ± 3) r/min for 20 h ± 10 min. Deviations from these limits are to be listed in the report's comments section.

9.8 *Gear Removal, Cleaning, and Weighing*—Remove the test gears,[4] using extreme care to avoid gear damage. Clean and weigh the gears as described in 9.4 and 9.5.[4] Record the total mass of both gears after testing as total final mass, (TM_f).

9.9 *Gear Tooth Inspection*—Record the number of teeth on each gear that show only the original grinding pattern, scratches, scoring, or scuffing. In this test, scratches are the least severe type of defacement, scoring is intermediate, and

[4] "Operating Instructions for the FZG Gear Oil Test Rig," Max Weiland, (after Professor, Dr. D. G. Nieman) April 1969, 8201 Sochtenau-Krotenmuhl, Germany.

[5] The FZG testing machine gears, or suitable balance may be ordered from the following sources: Max Weiland, 8201 Sochtenau-Krotenmuhl, Germany, Strama Maschinebau GmbH, Postfach 0353, Straubing, Germany, Falex, 2055 Comprehensive Drive, Aurora, IL 60505, USA, and Petrolab, 874 Albany-Shaker Rd., Latham, NY 12110, USA.

[6] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.

scuffing is the most severe. If a tooth exhibits more than one type of defacement, record only the more severe one.

10. Calculation

10.1 *Gear Mass Change*—Determine the total mass change (*TMC*) of the precision test gears as follows:

$$TMC = (TM_i) - (TM_f) \quad (1)$$

where:

TM_i = total initial mass, and
TM_f = total final mass.

11. Report

11.1 *TMC and Gear Tooth Condition*—Report the total mass change of the gears in milligrams, and the numbers of teeth as determined in 9.9. Note the occurrence of any other surface defects (see Appendix X1).

12. Precision and Bias[7]

12.1 The precision of this test method was not determined in accordance with currently accepted guidelines (for example, Committee D02's research report RR:D02-1007 "Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants"). Only one oil was tested in six laboratories. The precision of only the wear portion of the test method was determined by statistical examination of interlaboratory results as follows and is most useful for nominal wear results in the neighborhood of 25 mg:

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

NOTE 3—Intermediate Precision is the appropriate term for this test method, rather than repeatability, which defines more rigorous within-laboratory conditions.

12.1.2 *Intermediate Precision Limit (i.p.)*—The difference between two test results for wear obtained under intermediate precision conditions that would, in the long run, in the normal and correct conduct of the test method, exceed 27.4 mg in only one case in twenty.

12.1.3 *Reproducibility*—The difference between two single and independent test results for wear obtained by different operators working in different laboratories on identical test material would, in the long run, in normal and correct operation of the test method, exceed 43.2 mg in only one case in twenty.

12.2 *Bias*—The procedure in Test Method D4998 has no bias because the value of wear results can be determined only in terms of the test method.

12.3 *Results*—The test oil used was a heavy-duty transmission oil formulation, SAE 30 viscosity, without added viscosity index improver. All tests were done with 19 L samples of test oil drawn from a single drum and sent to the laboratories. No test gears were distributed. Each laboratory used test gears from its own stock.

Laboratory	Wear Results, mg Run 1	Wear Results, mg Run 2
A	26.9	34.1
B	24.0	39.0
C	36.0	36.0
D	34.0	12.0
E	11.8	30.8
F	13.8	12.4

13. Keywords

13.1 anti-wear characteristics; fluid; FZG; gear systems; hydraulic fluid; lubricants; petroleum and petroleum products; transmission fluid and gear oil; wear and wear life of lubricants

[7] Supporting data (copies of the test results, calculations, and FZG Machine Operating Procedure) have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1367.

ANNEXES

(Mandatory Information)

A1. FZG GEAR OIL TEST MACHINE INFORMATION

A1.1 *Ordering Information*—The FZG test machine can be ordered.[5]

A1.1.1 *Description* (from DIN 51354):

A1.1.1.1 FZG test machine, and

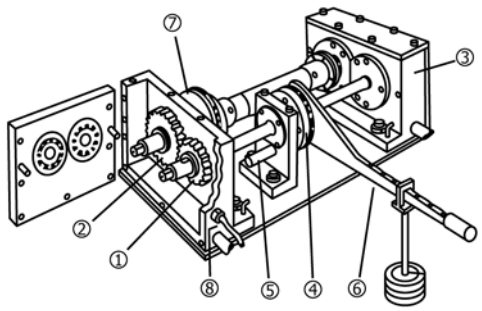
A1.1.1.2 FZG gears (tooth Profile A, with faint Maag finish).

A1.2 *Modification to the FZG Test Machine*—A low-speed drive shall be added to provide an input shaft speed of (100 ± 3) r/min. The low-speed drive can be obtained by adding a variable-frequency speed controller to the standard FZG 5.4 kW motor or a suitable speed reducer. The drive shall provide a smooth and constant rotation. Install a suitable flexible coupling between the drive and the FZG test machine. See Table A1.1.

TABLE A1.1 Design Data of the Test Gears Tooth Profile "A"

Nomenclature	Dimensional Value	Unit
Center distance	91.5	mm
Effective face width	20	mm
Diameter of pitch circle		
pinion	73.2	mm
wheel	109.8	mm
Diameter of tip circle		
pinion	88.7	mm
wheel	112.5	mm
Pitch	4.575	mm
Number of teeth		
pinion	16	...
wheel	24	...
Profile displacement		
pinion	0.8635	...
wheel	–0.5	...
Pressure angle	20	degrees
Working pressure angle	22.5	degrees
Circumferential speed at pitch circle (at 100 r/min)	0.383	m/s
Length of tip contact		
pinion	14.7	mm
wheel	3.3	mm
Maximum sliding speed		
pinion	0.257	m/s
wheel	0.061	m/s
Hertzian stress at tooth tip (under test conditions of tenth stage load and 100 r/min)		
pinion	199.9	kgf/mm^2
wheel	166.3	kgf/mm^2

A2. DIAGRAM OF FZG GEAR OIL TEST MACHINE[4]



① Pinion
② Gear Wheel
③ Drive Gears
④ Load Clutch
⑤ Locking Pin
⑥ Lever Arm with Weight Pieces
⑦ Torque Measuring Clutch
⑧ Temperature Sensor

FIG. A2.1 FZG Gear Oil Test Machine

A3. DIAGRAM OF FZG GEAR OIL TEST MACHINE[4]

.

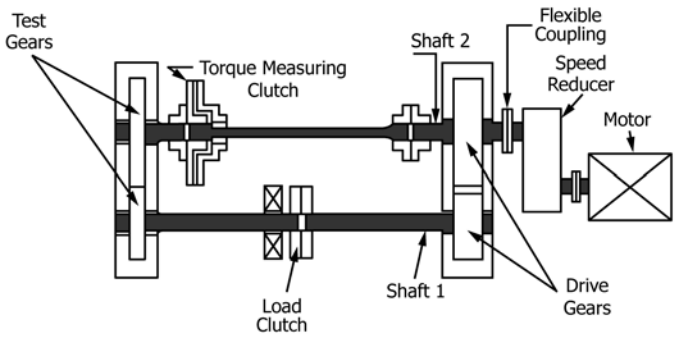


FIG. A3.1 Diagram of FZG Gear Oil Test Machine

A4. MANUFACTURING DATA FOR THE TEST GEARS, TOOTH PROFILE "A"

A4.1 *Material* :

A4.1.1 20 MnCr 5 according to DIN 17210, however, with a Brinell hardness HB 30 from (3.295 to 3.726) kPa after blank hardening of a 10 mm disk (that corresponds, according to DIN 50150, to a tensile strength of (1.127 to 1.274) kPa).

A4.1.2 For reasons of strength, the negatively corrected wheels ($z = 24$) are to be die-forged, whereas the pinions can be manufactured from rolled bar stock.

A4.2 *Heat Treatment:*

A4.2.1 The test gears are to be case-hardened to a case depth of (0.6 to 0.8) mm, the Vickers hardness HV 10 to be 4.903 kPa. Even at the tooth tips, the case shall not show any evidence of supercarbonization in form of free cementite. A boundary formation free of austenite is to be obtained by double hardening.

A4.2.2 Surface hardness after annealing is as follows: 60 to 62 HRC.

A4.2.3 Tensile strength of the core, determined from Brinell hardness according to DIN 50150 is as follows: (0.980 to 1.225) kPa.

A4.3 *Gearing Quality:*

A4.3.1 Grade 5 according to DIN 3962, sheet 4.

A4.3.2 Mean roughness index, R_a is as follows: (0.4 to 0.6) µm.

A4.4 *Grinding*—Maag cross-grinding, 154 rolling motions per minute.

A4.5 *Tooth Correction*—Without tip and root recess, with lateral crown.

A5. PENTANE REQUIREMENTS

A5.1 The requirements for pentane are listed in Table A5.1.

TABLE A5.1 Requirements of Pentane

Distillation	
Initial boiling point, °C, min	33.3
Dry point, °C, max	40.5
Olefins	none
Isopentane, %, max	20
n-Pentane, %, min	80
Reid Vapor Pressure, kPa, max, (Test Method D323)	17

APPENDIX

(Nonmandatory Information)

X1. SAMPLE DATA SHEET

PRETEST GEAR CONDITION

Pinion _____

Gear _____

PRETEST GEAR MASS, mg

Pinion _____

Gear _____

Total (TM_i) _____

POST-TEST GEAR MASS, mg

Pinion _____

Gear _____

Total (TM_f) _____

CALCULATION OF TOTAL MASS CHANGE (TMC)

$(TM_i) - (TM_f) = TMC$

___ – ___ = mg

POST-TEST GEAR APPEARANCE	Pinion	Gear
For each gear, record the number of teeth that exhibit the following:		
Original Grinding Marks	____	____
Scratches	____	____
Scoring	____	____
Scuffing	____	____
Total	16	24
Note other surface defects, if any:		

SUMMARY OF CHANGES

Subcommittee D02.B0.03 has identified the location of selected changes to this standard since the last issue (D4998 – 11) that may impact the use of this standard.

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