



Standard Test Method for Evaluating Wear Characteristics of Tractor Hydraulic Fluids¹

This standard is issued under the fixed designation D 4998; 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.

^{ε1} NOTE—Warning notes were editorially moved into the standard text in July 2003.

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 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.* Specific warning information is given in Sections 7 and 9.

2. Referenced Documents

2.1 ASTM Standards:

D 216 Method of Test for Distillation of Natural Gasoline²

D 235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)³

D 323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)⁴

D 329 Specification for Acetone³

2.2 Deutsches Institut für Normung (DIN):⁵

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 Standard 51354, Mechanical Testing of Gear Oils in the FZG Gear Test Machine

3. Terminology

3.1 Definitions:

3.1.1 *abrasion*—wear by displacement of material caused by hard particles or hard protuberances.

3.1.2 *scoring*—the formation of severe scratches in the direction of sliding.

3.1.2.1 *Discussion*—Scoring may be due to local solid phase welding or to abrasion. The term *scuffing* is sometimes used as a synonym for scoring.

3.1.3 *scratching*—the formation of fine lines in the direction of sliding that may be due to asperities on the harder slider or to hard particles between the surface or embedded in one of them.

3.1.3.1 *Discussion*—Scratching is considered less damaging than scoring or scuffing.

3.1.4 *scuffing*—localized damage caused by the occurrence of solid phase welding between sliding surfaces, without local surface melting.

3.1.4.1 *Discussion*—The term *scoring* is sometimes used as a synonym for scuffing.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *wear*—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), load (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 weight loss and the visually observed damage to the gear teeth are used to evaluate the wear obtained with the test fluid.

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

Current edition approved May 10, 2003. Published July 2003. Originally approved in 1989. Last previous edition approved in 1995 as D 4998–95.

² Discontinued. See 1988 *Annual Book of ASTM Standards*, Vol 05.01. Replaced by D 86.

³ *Annual Book of ASTM Standards*, Vol 06.04.

⁴ *Annual Book of ASTM Standards*, Vol 05.01.

⁵ DIN Standards are available from the American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036.

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

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 D 235. (**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.)

7.2 *Acetone*—Commercial grade, conforming to the requirements of Specification D 329. (**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.)

7.3 *Pentane*—Commercial grade *n*-pentane, conforming to the requirements of Table A5.1. (**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.)

8. Preparation of Apparatus

8.1 Assemble the FZG machine according to the “Operating Instructions for the FZG Gear Oil Test Rig”⁶ 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 6.3.⁵

9. Procedure

9.1 *FZG Test Machine Assembly*⁷—Assemble the test machine according to the instructions given in Section 3,⁶ 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.⁸

9.2 *Machine Cleaning*—Flush the test gear case and associated parts with mineral spirits solvent. (**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, and finally in pentane. (**Warning**—(acetone, pentane) Flammable. Health hazard. In addition to other precautions, acetone, and pentane. Vapors may cause flash fire. Keep away from heat, sparks, and open flame. Keep container closed. Use with adequate ventilation. Avoid buildup of vapors. Eliminate all sources of ignition, especially, non-explosion-proof electrical devices and heaters. Avoid prolonged breathing of vapor or spray mist. Avoid prolonged or repeated skin contact.) 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 must be clean, dry, and at ambient temperature. Record the weight of each gear, rounding to the nearest milligram. Add the weight of each gear and record the sum as initial total gear weight (*TW*).

9.6 *Gear Installation*—Install the test gears according to 4.1.⁷

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

⁷ The FZG testing machine gears, or suitable balance may be ordered from the following sources: Max Weiland, 8201 Sochtenau-Krottenmuhl, Germany, Strama Maschinebau GmbH, Postfach 0353, Straubing, Germany, Falax, 2055 Comprehensive Drive, Aurora, IL 60505, U.S.A., and Petrolab, 874 Albany-Shaker Rd., Latham, NY 12110, USA.

⁸ Available from the National Fire Protection Assoc., 1 Batterymarch Park, Quincy, MA 02269.

⁶ “Operating Instructions for the FZG Gear Oil Test Rig,” Max Weiland, (after Professor, Dr. D. G. Nieman) April 1969, 8201 Sochtenau-Krottenmuhl, Germany.

to 121°C. With the heater on and no load applied, start motor to run at 100 r/min test speed. When temperature stabilizes at 121°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.

9.8 *Gear Removal, Cleaning, and Weighing*—Remove the test gears in accordance with 4.2,⁶ using extreme care to avoid gear damage. Clean and weigh the gears as described in 9.4 and 9.5.⁶ Record the total weight of both gears after testing at total final weight, (TW_f).

9.9 *Gear Tooth Inspection*—Record the number of teeth on each gear which show only the original grinding pattern or the more severe wear characteristic of scratches, scoring, or scuffing. Note the occurrence of any other surface defects, (see Appendix X1).

10. Calculation

10.1 *Gear Weight Change*—Determine the total weight change (TWC) of the precision test gears as follows:

$$TWC = (TW_i) - (TW_f) \quad (1)$$

where:

TW_i = total initial weight and

TW_f = total final weight

11. Report

11.1 *TWC and Gear Tooth Condition*—Report the following: The total weight change in milligrams, and the total number of teeth on each gear that exhibit the most severe of the original grinding pattern, scratches, scoring, or scuffing.

12. Precision and Bias⁹

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 *Repeatability*—The difference between two test results for wear obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in normal and correct operation of this test method, exceed 27.4 mg in only one case in twenty.

12.1.2 *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 D 4998 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 from 5-gal 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	Results, Run 1	Wear, 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

⁹ 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 may be ordered.⁷

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

A1.1.1.1 FZG test machine, and

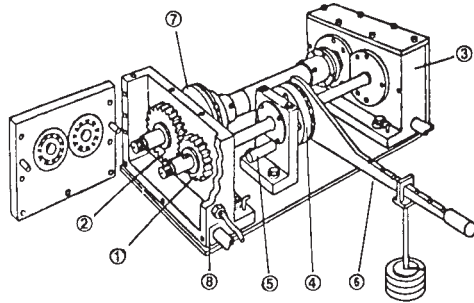
A1.1.1.2 FZG gears (tooth Profile A, with faint Maag finish).

A1.2 *Modification to the FZG Test Machine*—A lowspeed drive must 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 must provide a smooth and constant rotation. A suitable flexible coupling must be installed between the drive and the FZG test machine.

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
	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 MACHINE⁶



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

FIG. A2.1 FZG Gear Oil Test Machine

A3. DIAGRAM OF FZG GEAR OIL TEST MACHINE⁶

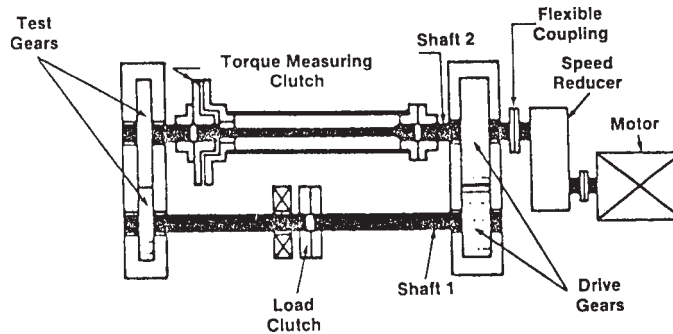


FIG. A3.1 Diagram of FZG Gear Oil Test Machine

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

A4.1 Material:

A4.1.1 20 MnCr 5 according to DIN 17 210, 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 50 150, 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 50 150 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 (Method D 216)	
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 D 323)	17

APPENDIX

(Nonmandatory Information)

X1. SAMPLE DATA SHEET

PRETEST GEAR CONDITION
 Pinion _____
 Gear _____

PRETEST GEAR WEIGHT, mg
 Pinion _____
 Gear _____
 Total (TW_i) _____

POST-TEST GEAR WEIGHT, mg
 Pinion _____
 Gear _____
 Total (TW_f) _____

CALCULATION OF TOTAL WEIGHT CHANGE (TWC)

$$(TW_i) - (TW_f) = TWC$$

$$\underline{\quad} - \underline{\quad} = \text{mg}$$

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: _____

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