INTERNATIONAL STANDARD

ISO 14635-3

Second edition
2023-07

Gears — FZG test procedures —

Part 3:
FZG test method A/2,8/50 for relative scuffing load-carrying capacity and wear characteristics of semifluid gear greases

Engrenages — Méthodes d'essai FZG —

Partie 3: Méthode FZG A/2,8/50 pour évaluer la capacité de charge au grippage et les caractéristiques d'usure des graisses d'engrenages semi-fluides

Reference number
ISO 14635-3:2023(E)

Published in Switzerland

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 60, *Gears*, Subcommittee SC 2, *Gear capacity calculation*.

This second edition cancels and replaces the first edition (ISO 14635-3:2005), of which it constitutes a minor revision. The changes are as follows:

— ISO 1328-1:1995[1)] has been dated as this document uses accuracy grade which is numerically different than tolerance class in ISO 1328-1:2013;

— replacement of ISO 4287 which has been withdrawn and replaced by ISO 21920-2;

— replacement of ISO 4964 which has been withdrawn and similar information can be found in ISO 18265;

— replacement of some bibliography entries which were withdrawn, and changes from dated to undated references;

— Table 1, description "pitch line velocity (v_w)" has been replaced by "circumferential velocity at the pitch line" to harmonize the wording with the ISO 6336-series;

— Table 1, symbol for "specific sliding" has been corrected according to ISO 21771;

— Table 2, grinding: unit for "generating stroke drive" has been corrected;

— Table 3, information on the load coupling has been harmonized with ISO 14635-1;

— Clause 9, the reporting value of the specific weight loss has been corrected.

A list of all parts in the ISO 14635 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

1) Cancelled and replaced by ISO 1328-1:2013.

Introduction

The types of gear failure which can be influenced by the lubricant are scuffing, low-speed wear and the gear fatigue phenomena known as micro- and macropitting. In the gear design process, these types of gear damage are taken into consideration by the use of specific lubricant and service-related characteristic values. In order to provide a reasonable estimate of performance in service, adequate lubricant test procedures are required. The FZG[2)] test procedures described in ISO 14635-1, ISO 14635-2 and ISO 14635-3 can be regarded as tools for the determination of relative scuffing performance of lubricants. Characteristic values can be introduced into the load-carrying capacity calculation of gears. ISO 14635-1 FZG test method, A/8,3/90 for relative scuffing load-carrying capacity of oils, is useful for the majority of applications in industrial and marine gears. ISO 14635-2, FZG step load test A10/16, 6R/120, is related to the relative scuffing load-carrying capacity of high extreme pressure (EP) oils as used, e.g. for the lubrication of automotive driveline components such as manual transmissions. ISO 14635-3 FZG test method A/2,8/50 describes a test procedure for the determination of the relative scuffing load-carrying capacity and wear characteristics of semi-fluid greases used for enclosed gear drives. Other FZG test procedures for the determination of low-speed wear, micro- and macropitting load capacity of gears are currently being considered for standardization. They can be added later to ISO 14635 as further parts.

It has been assumed by the compilers of this test method that anyone using the method will either be fully trained and familiar with all normal engineering and laboratory practice, or will be under the direct supervision of such a person. It is the responsibility of the operator to ensure that all local legislative and statutory requirements are met.

When the rig is running, there are long-loaded shafts and highly stressed test gears turning at high speed and precaution needs to be taken to protect personnel. It is also necessary to provide protection from noise.

2) FZG = Forschungsstelle für Zahnräder und Getriebebau, Technische Universität München (Gear Research Centre, Technical University, Munich).

Gears — FZG test procedures —

Part 3:
FZG test method A/2,8/50 for relative scuffing load-carrying capacity and wear characteristics of semifluid gear greases

1 Scope

This document specifies a test method based on a FZG four-square test machine for determining the relative load-carrying capacity of semi-fluid gear greases defined by the gear surface damage known as scuffing.

This method is useful for evaluating the scuffing load capacity potential of semi-fluid gear greases of NLGI classes 0 to 000, typically used with highly stressed gearing for enclosed gear drives. It can only be applied to greases giving a sufficient lubricant flow in the test gear box of the FZG test machine.

NOTE The test method is technically equivalent to DIN Fachbericht 74.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1328-1:1995[3)], *Cylindrical gears — ISO system of accuracy — Part 1: Definitions and allowable values of deviations relevant to flanks of gear teeth*

ISO 6743-6, *Lubricants, industrial oils and related products (class L) — Classification — Part 6: Family C (Gears)*

ISO 12925-1, *Lubricants, industrial oils and related products (class L) — Family C (Gears) — Part 1: Specifications for lubricants for enclosed gear systems*

ISO 18265, *Metallic materials — Conversion of hardness values*

ISO 21920-2, *Geometrical product specifications (GPS) — Surface texture: Profile — Part 2: Terms, definitions and surface texture parameters*

ASTM D 235, *Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3) Cancelled and replaced by ISO 1328-1:2013.

3.1
scuffing
particularly severe form of gear tooth surface damage in which seizure or welding together of areas of tooth surface occurs, owing to insufficient or breakdown of lubricant film between the contacting tooth flanks of mating gears, typically caused by a combination of high temperature, high pressure and other factors

Note 1 to entry: Scuffing is most likely when surface velocities are high. It can also occur at relatively low sliding velocities when tooth surface pressures are high enough either generally or, because of uneven surface geometry and loading, in discrete areas.

Note 2 to entry: Care should be taken that scuffing does not occur and is polished away before ending the running time at the higher load stages.

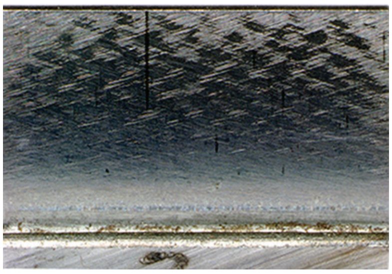
3.2
wear
continuous removal of material occurring when two surfaces roll and slide against one another

3.3
scuffing load-carrying capacity
⟨of a lubricant⟩ maximum load which can be sustained under a defined set of conditions

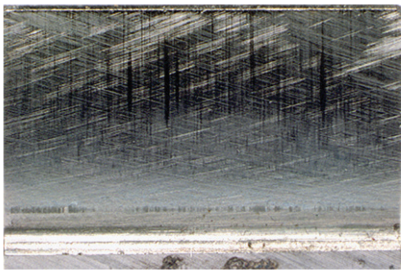
3.4
FZG test condition A/2,8/50
test condition where A is the particular tooth form of the test gears, according to Table 1, 2,8 is the speed at the pitch circle in metres per second (m/s), and 50 is the initial lubricant temperature in degrees Celsius, from load stage 4 onward in the lubricant sump

3.5
failure load stage
load stage reached when the summed total width of scuffing damage on the active flank area of the 16 pinion teeth exceeds one gear tooth width, i.e. 20 mm

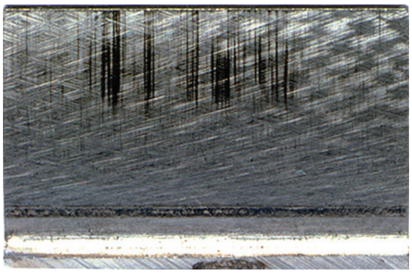
Note 1 to entry: For examples of failure, see Figure 1. Examples of tooth flank changes due to continuous wear are given in Figure 2. Continuous wear is not a failure criterion for the test.



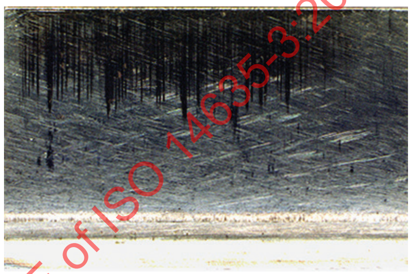
a) Marks, no failure



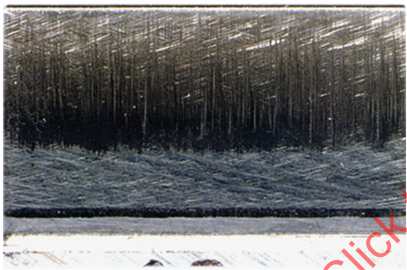
b) Marks, no failure



c) Approx. 5 mm failure marks

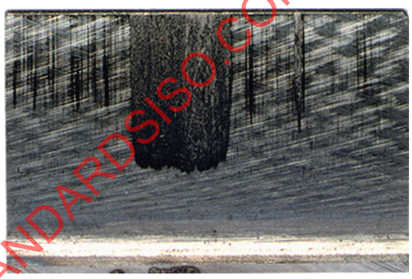


d) Approx. 15 mm failure marks

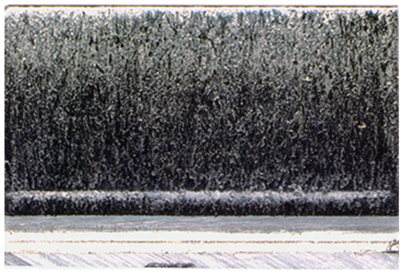


e) 20 mm failure marks

f) Approx. 2 mm failure marks



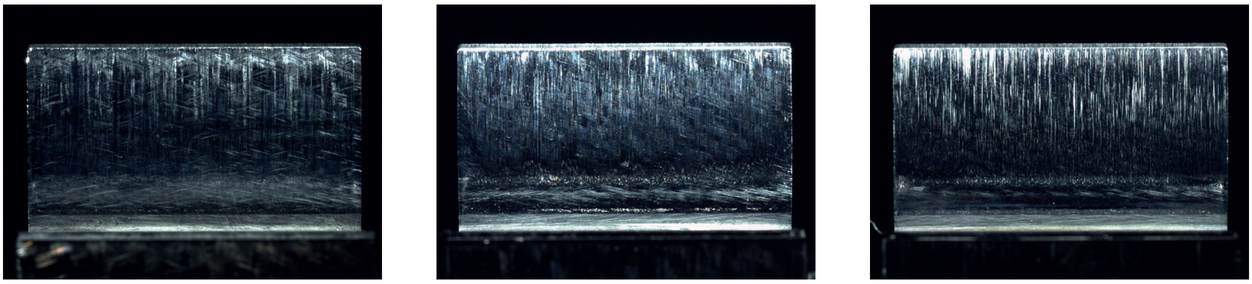
g) Approx. 6 mm failure marks



h) 20 mm failure marks

NOTE This figure describes the typical pinion tooth flank changes occurring in FZG scuffing type tests. Changes in the original surface condition (criss-cross grinding) can be described by their physical appearance. One and the same type of flank damage can be described in different places in the world by using different terminology (e.g. “scuffing”, “scoring” and “severe wear”). In order to avoid misinterpretation of the pinion tooth flank changes occurring during the test, typical examples of non-failure and failure are given.

Figure 1 — FZG A-type gear tooth face changes (flank damages)



a) Light wear b) Medium wear c) Severe wear

Figure 2 — FZG A-type gear tooth flank changes due to continuous wear

4 Brief description of method

4.1 General

A set of test gears as defined in Clause 5, Tables 1 and 2, weighed to the nearest 0,001 g before the test, is run with the test lubricant at constant speed for a fixed number of revolutions in dip lubrication mode. Loading of the gear teeth is increased in the steps outlined in Table 3. Beginning with load stage 5, the initial lubricant temperature is controlled between (50 ± 3) °C. During the test run of each load stage, the lubricant temperature is allowed to rise freely. After load stage 4, the weight loss of the gear set is determined to the nearest 0,001 g and the pinion tooth flanks are inspected for surface damage. For each subsequent load stage, the pinion tooth flanks are inspected for surface damage at the end of each load stage and any changes in appearance are noted. A test is considered complete when either the failure criterion has been met or when load stage 12 is run without meeting the failure criterion. If load stage 12 is reached without meeting the failure criterion, the gear set weight loss is determined to the nearest 0,001 g.

4.2 Precision

Values of repeatability, r, and reproducibility, R, as defined in ISO 5725-2, are not valid for this test procedure. However, experience suggests that similar methods (see ISO 14635-1) are expected to be representative.

Values for ISO 14635-1 are indicated below.

r = 1 load stage

R = 2 load stages

NOTE The above precision results apply to the range of failure load stages 5 to 12.

5 Test materials

5.1 Test gears

A pair of type "A" gears with a specification according to Table 1 and Table 2 shall be used for testing. Each pair of test gears may be used twice for testing, using both tooth flanks as load-carrying flanks.

5.2 Cleaning fluid

Petroleum spirits conforming to ASTM D 235 shall be used.

Table 1 — Details of FZG test gears type A

Dimension		Symbol	Numerical value	Unit
Shaft centre distance		a	91,5	mm
Effective tooth width		b	20	mm
Working pitch diameter	pinion	d_{w1}	73,2	mm
	wheel	d_{w2}	109,8	mm
Tip diameter	pinion	d_{a1}	88,77	mm
	wheel	d_{a2}	112,5	mm
Module		m	4,5	mm
Number of teeth	pinion	z_1	16	
	wheel	z_2	24	
Profile-shift coefficient	pinion	x_1	0,853 2	
	wheel	x_2	-0,50	
Pressure angle		α	20	°
Working pressure angle		α_w	22,5	°
Circumferential velocity at the pitch line		v_w	2,8	m/s
Addendum engagement	pinion	e_{a1}	14,7	mm
	wheel	e_{a2}	3,3	mm
Sliding speed at tooth tip	pinion	v_{ga1}	1,85	m/s
	wheel	v_{ga2}	0,42	m/s
Specific sliding at tooth tip	pinion	ζ_{E1}	1,86	
	wheel	ζ_{A2}	0,34	
Specific sliding at tooth root	pinion	ζ_{A1}	- 0,52	
	wheel	ζ_{E2}	- 5,96	
Hertzian contact pressure		p_c	$14{,}7 \cdot \sqrt{F_{nt}}$ [a]	N/mm^2

[a] F_{nt} = normal tooth load in N (see Table 3).

Table 2 — Manufacturing details of FZG test gears type A

Material	Case-hardening steel with restricted hardenability to 2/3 of the lower scatter band. Material composition: C = 0,13 % to 0,20 % Mo = max. 0,12 % Si = max. 0,40 % Ni = max. 0,30 % Mn = 1,00 % to 1,30 % Al = 0,02 % to 0,05 % P = max. 0,025 % B = 0,001 % to 0,003 % S = 0,020 % to 0,035 % Cu = max. 0,30 % Cr = 0,80 % to 1,30 %
Heat treatment	The test gears are carburized and case hardened. The case depth at a hardness of 550 HV10 shall be 0,6 mm to 0,9 mm. The surface hardness after tempering: 60 HRC to 62 HRC, core strength in tooth root centre: 1 000 N/mm^2 to 1 250 N/mm^2 (determined in accordance with ISO 18265 based on Brinell hardness). Retained austenite should be nominally 20 %.
Gear accuracy grade	Q5 according to ISO 1328-1:1995
Arithmetic roughness of flanks *Ra*	*Ra* is separately determined for left and right flanks, measured each at three flanks per gear across the centre of the tooth parallel to the pitch line; measuring parameters according to ISO 21920-2: measured length l_t = 4,8 mm, cut-off length λ_c = 0,8 mm; velocity v_t = 0,5 mm/s, using a skid.
	Average roughness (relating to manufacture batches of a minimum of a 100 gear sets) Pinion: *Ra* = 0,35 µm ± 0,1 µm Gear: *Ra* = 0,30 µm ± 0,1 µm
	Maximum roughness (average of three measurements according to the described method and valid for 95 of 100 tested gears). Pinion and gear: *Ra* = 0,5 µm
Grinding	Maag criss-cross grinding (15° method), 154 1/min of generating stroke drive
Flank modification	None

6 Apparatus

6.1 FZG spur gear test rig

6.1.1 The FZG spur gear test machine utilizes a recirculating power loop principle, also known as a four-square configuration, to provide a fixed torque (load) to a pair of precision test gears. A schematic view of the test rig is shown in Figures 3 and 4. The slave gearbox and the test gearbox are connected through two torsional shafts. Shaft 1 contains a load coupling used to apply the torque through the use of known weights defined in Table 3 hung on the loading arm at the 0,5 m notch.

6.1.2 The test gearbox contains heating elements for maintaining and controlling the minimum temperature of the lubricant. A temperature sensor located in the side of the test gearbox is used to control the heating system as required by the test operating conditions.

NOTE The heating elements typically have a maximum heat density of 3 W/cm^2 to 5 W/cm^2 for minimizing thermal degradation of the test lubricant.

6.1.3 The test machine is driven at 500 1/min ±3 % by an electric motor giving sufficient torque to carry out the test.

6.1.4 A check list for maintenance of the FZG gear test rig is given for information in Annex C.

6.2 Heating device

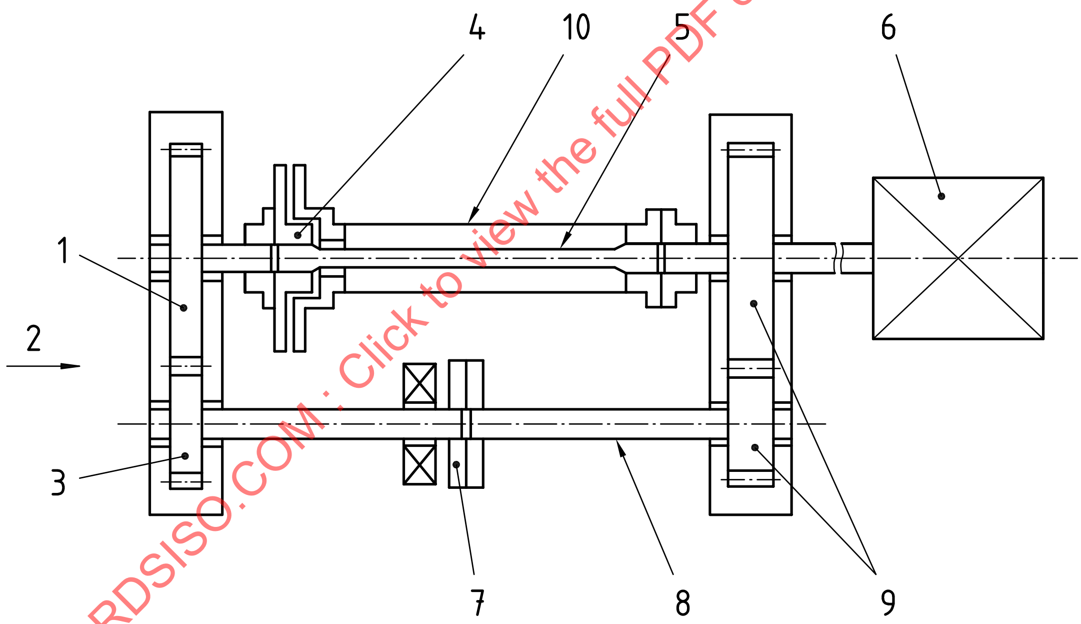
A suitable oven or heating device is required to warm the test gears between 60 °C to 80 °C for assembling on the shafts.

6.3 Revolution counter

A suitable counter shall be used to control the number of revolutions during each load stage of the test. The counter should be capable of shutting down the test machine at the appropriate number of revolutions of the pinion.

6.4 Weight measurement

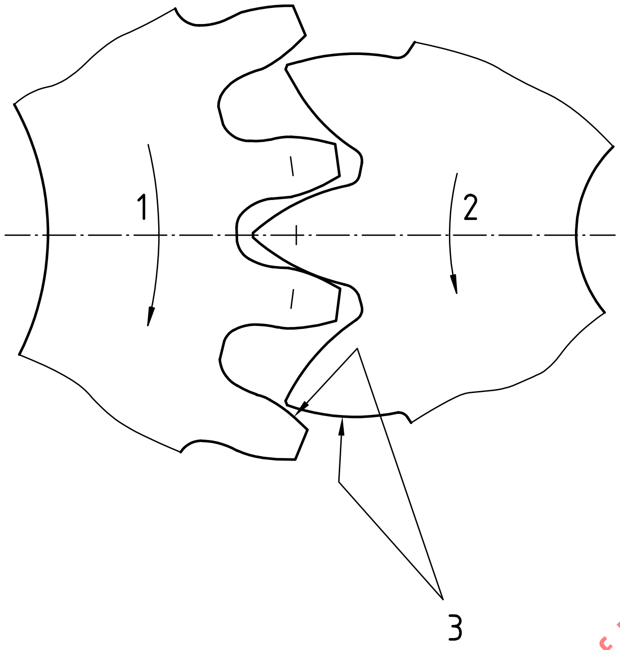
A suitable balance of 1,3 kg min. weight capacity with reading to the nearest 0,001 g shall be used to determine the weight of the test wheel.



Key

1	test wheel	6	drive motor
2	view A	7	load coupling
3	test pinion	8	shaft 1 (two pieces)
4	torque measuring coupling	9	slave gears
5	shaft 2 (torsion shaft)	10	torsion shaft outer tube

Figure 3 — Schematic section of the FZG gear test machine



Key

1 test wheel

2 test pinion

3 active tooth flank

Figure 4 — Mounting of the FZG test gears type A (view A of **Figure 3**)

7 Preparation of apparatus

7.1 Flush the test gear case twice with petroleum spirit, ensuring that the bearings are clean of any previous lubricant, and air dry with a water-free air line.

If the previous lubricant tested contained any solid lubricant particles such as graphite or MoS_2, the test machine shall be completely disassembled and cleaned carefully.

7.2 Mark the test pinion and test wheel as shown in Figure 4.

7.3 Clean the test gears in petroleum spirit and air dry. After cleaning, use gloves to handle gears.

7.4 With the unaided eye, inspect the gears for corrosion, rust or any other damage. Reject the gears if so damaged.

7.5 Weigh the pinion and the wheel each to the nearest 0,001 g.

7.6 Heat both the gears and bearing races to between 60 °C and max. 80 °C using an appropriate heating device.

7.7 Assemble the test gear box (except the top cover) with the test pinion on shaft 1 (right-hand side) and the test wheel on shaft 2 (left-hand side) as shown in Figure 3. Ensure the test pinion and test wheel are correctly aligned, i.e. no offset. Also ensure that the locating marks are positioned as shown in Figure 4.

7.8 Switch drain cock in the CLOSED position.

7.9 Fill the test gear box with a nominal 1,25 l of test lubricant.

7.10 Plug in the heater.

7.11 Fit top cover to the test gear box.

7.12 Apply load stage 12 using the 0,5 m radius position (see Table 3) for 2 min to 3 min, without running the motor, in order to bring the test gears and the clearances in the system into correct working position.

8 Test procedure

8.1 Apply load corresponding to stage 1 (see Table 3). Start the motor, switch on the heater and run for 21 700 revolutions of the motor (approximately 45 min), according to Table 4.

8.2 Stop the motor and apply the load for stage 2. Restart and run according to Table 4 for 21 700 revolutions of the motor. Repeat for load stage 3 and load stage 4.

8.3 At the end of load stage 4, remove the lubricant from the unit and save. Visually inspect the pinion for damage. Record the tooth condition, using the examples in Figure 1 as a guide.

8.4 Disassemble and weigh the pinion and the wheel, each to the nearest 0,001 g.

8.5 Re-assemble the test gear box according to 7.7 to 7.12. Ensure that the pinion teeth are immersed in the test lubricant. If needed, add a small amount of the same lubricant.

8.6 Before starting the next higher load stage, ensure that the lubricant temperature in the test gearbox is (50 ± 3) °C. This can be accomplished through the use of cooling water or by using the procedure given in 8.8.2. When the temperature reaches (50 ± 3) °C turn off the cooling water and continue the test. The cooling water shall be turned off during the test.

8.7 Continue the test with the next load stages (see Table 3). Visually inspect all the pinion teeth after each stage, ensuring the lubricant temperature is (50 ± 3) °C before applying the next higher load stage. Continue the test until the failure load stage according to 3.5 is reached. If the failure criterion is not reached, terminate the test at the end of load stage 12.

8.8 Determine the failure load stage by summing the flank damages on all the test pinion teeth.

8.8.1 If the failure criterion is not reached, continue the test with the next higher load stage up to a maximum of load stage 12.

8.8.2 If the machine is shut down at the end of a load stage beyond load stage 4 for a period of time before the test is completed and the test oil temperature drops below 47 °C, carry out the following before resuming the test.

a) Apply load stage 1, start the motor, switch on the heater and run until the lubricant temperature reaches (50 ± 3) °C.

b) Stop the motor, switch off the heater and apply the next load stage in the text sequence. Continue the test according to 8.6 and 8.7, respectively.

8.9 If the test is terminated after load stage 12 without reaching the failure criterion, weigh the test pinion and the test wheel each to the nearest 0,001 g and determine the weight losses during the test.

An additional test procedure can be found in Annex B. If the test is terminated at or before load stage 12 because the scuffing fail criterion/limit has been reached, then the test gears need not be weighed.

Table 3 — FZG load stages

Load stage No.	Pinion torque N·m	Normal tooth load N	Hertzian stress at pitch point N/mm^2	Total work transmitted by the test gears up to the end of load stage kW·h	Load coupling loaded with:
1	3,3	99	146	0,19	H_1
2	13,7	407	295	0,97	H_2
3	35,3	1 044	474	2,96	$H_2 + K$
4	60,8	1 799	621	6,43	$H_2 + K + W_1$
5	94,1	2 786	773	11,8	$H_2 + K + W_1 + W_2$
6	135,5	4 007	929	19,5	$H_2 + K + W_1 + W_2 + W_3$
7	183,4	5 435	1 080	29,9	$H_2 + K + W_1 + W_2 + W_3 + W_4$
8	239,3	7 080	1 223	43,5	$H_2 + K + W_1 + W_2 + W_3 + W_4 + W_5$
9	302,0	8 949	1 386	60,8	$H_2 + K + W_1 + W_2 + W_3 + W_4 + W_5 + W_6$
10	372,6	11 029	1 539	82,0	$H_2 + K + W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7$
11	450,1	13 342	1 691	107,0	$H_2 + K + W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7 + W_8$
12	534,5	15 826	1 841	138,1	$H_2 + K + W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7 + W_8 + W_9$

Weight hangers shall be applied to the 0,5 m radius position.
H_1 = load lever H_1 (light)
H_2 = load lever H_2 (heavy, 0,5 m notch)
K = weight support rod
W_1 to W_9 = weights for weight loading

Table 4 — Test conditions

Duration of each load stage:	21 700 revolutions of the motor (approx. 45 min)
Motor rotational frequency:	500 1/min ± 3 % [a]
Direction of rotation:	Clockwise [a]
Test lubricant volume:	1,25 l ± 0,05 l
Lubricant temperature at start of load stage 1:	Ambient
Initial lubricant temperature at start of load stage 5 and each subsequent load stage:	(50 ± 3) °C (shall be preset on temperature-controller)

[a] The direction of the rotation of the gears is shown in Figure 4.

9 Reporting of results

Report the load stage and the corresponding pinion torque at which the failure occurred, in accordance with 3.5. State the test conditions as A/2,8/50. If the test was completed without failure, report “Failure load stage greater than 12” and report the weight losses determined for the test pinion and the test wheel. If the test was terminated due to scuffing before load stage 5 was reached, report “Failure load stage less than 5”.

A typical report sheet is given in Annex A.

Calculate the specific weight loss, Δm_{sT}, in milligrams per kilowatt hour [mg/(kW·h)], using the formula

$$\Delta m_{sT} = \frac{\Delta m_{12} - \Delta m_4}{131{,}67}$$

with

Δm_{12} is the weight loss of test pinion and test wheel in milligrams after load stage 12;

Δm_4 is the weight loss of test pinion and test wheel in milligrams after load stage 4.

If the specific weight loss is below 0,2 mg/kW·h, report “Below 0,2 mg/kW·h”.

Annex A
(informative)

Test report

Company Name *Company Logo*

ISO 14635-3

Gears — FZG test procedure

Part 3: FZG test method A/2,8/50 for relative scuffing load-carrying capacity and wear characteristics of semi-fluid gear greases

TEST REPORT

Lubricant: ....

Origin: ....

FZG Test No.: ....

FZG Test Gear Set No.: ....

TEST RESULT:

Failure load stage: ....

Pinion torque T_1 at failure load stage: ....N·m

Specific weight loss: ....mg/(kW·h)

Individual losses:

		Pinion	Wheel	Pinion + Wheel
Weight loss	after load stage 4, Δm_4, mg	....	....	....
	after load stage 12, Δm_{12}, mg	....	....	....

Remarks:

....

....

Date: Signature:

Annex B
(informative)

Additional test procedure for the investigation of extended wear characteristics of the lubricant

B.1 General

For semi-fluid gear greases which have a load-carrying capacity of over load stage 12 according to the test procedure specified in this document, an additional endurance test can be recommended. The lubricant temperature is not controlled during the test.

B.2 Test procedure

B.2.1 Assemble the test gear box using the same gear set and flanks that completed load stage 12 according to 7.7 to 7.12. Ensure that the pinion teeth are immersed in the test lubricant. If needed, add a small amount of the same lubricant.

B.2.2 Apply load stage 10 using the test conditions for motor speed, direction of rotation and test lubricant volume given in Table 4. Lubricant temperature at start shall be ambient temperature.

B.2.3 Set the revolution counter to 1 500 000 revolutions of the motor, (approximately 50 h).

B.2.4 Set the temperature control to limit the lubricant to (80 ± 3) °C max.

B.2.5 Start the motor. The heating device for the test gear box shall be in position “Off”.

B.2.6 At the end of the test, inspect the test pinion for tooth flank changes. Record the tooth condition, using the examples in Figure 2 as a guide.

B.2.7 Weigh the pinion and the wheel each to the nearest 0,001 g and determine weight loss Δm_{10} during the test.

B.3 Reporting results

Report the weight loss of test pinion and test wheel (Δm_{10} + Δm_{12}) and report the specific weight loss Δm_{sE}.

$$\Delta m_{sE} = \frac{\Delta m_{10} - \Delta m_{12}}{1\,463} \text{ mg/(kW}\cdot\text{h)}$$

Weight loss during test:

		Pinion	Wheel	Pinion + Wheel
Weight loss	after load stage 12, Δm_{12}, mg	…………	…………	…………
	after load stage 10, Δm_{10}, mg	…………	…………	…………

Annex C
(informative)

Checklist for maintenance of FZG gear test rig

C.1 How to recognize malfunction

C.1.1 Distribution of scuffing marks

Frequently, an indication that the machine requires maintenance is given by the distribution of scuffing marks across the face width of every tooth and around the circumference after every gear-oil test.

Uneven distribution of scuffing marks across the face width indicates uneven load distribution, and, because of elastic deformations, this is more likely at low load stages than it is at high load stages. Figure C.1 shows scuffing marks distribution for perfect running operation, as also for misalignment and tumbling error indicating the malfunction.

C.1.2 Tooth contact pattern

From time to time (e.g. after every twentieth test), or after indication of load maldistribution, the contact pattern should be checked either by using soot or Prussian blue. Under no-load conditions, the tooth contact pattern should be uniformly distributed and should cover 70 % or more of the active flank area.

C.1.3 Tests with reference oil

From time to time (e.g. after every fortieth test), a duplicated scuffing test with a minimum of one of the two reference oils for the test is recommended. Deviations from the typical scuffing load stage of the reference oil, high scattering between the two tests and regular increase or decrease of scuffing load stage as compared to former reference oil tests can indicate a malfunction.

Organizations such as CEC, the Coordinating European Council for the Development of Performance Tests for Fuels, Lubricants and Other Fluids, have defined reference oils for comparison testing.

C.1.4 Other indications

Noise and vibrations, temperatures, bearing play, wear, etc. should be checked.

C.2 Parts that need maintenance

C.2.1 Test gear box

C.2.1.1 Shafts

Bearings shall have a light shrink fit on the shafts. Bearings shall not slide on or off the shaft at same (ambient) temperature of bearing and shaft. Indication of a slack fit are circumferential wear or even scoring marks on the shaft and the inner diameter of the bearing when the inner race of the bearing slides on the shaft during operation.

Gears shall have a slight shrink fit on the shafts. They shall not easily slide on or off the shaft at same temperature of gear and shaft. Possible slight fretting corrosion on the shafts is not harmful and can be polished off the shaft using e.g. a chrome polish. Tangible wear marks on the shaft cannot be tolerated.

Hard-chromed shafts tend to show spalling in the vicinity of the keys. Spalling up to approximately 5 mm width all along the key can be tolerated.

A tangible wear groove under the shaft seal leads to leakage even when seals are replaced.

C.2.1.2 Bearings

Bearings shall have an adequate small amount of play. Bearing life is normally not limited by pitting but by excess wear.

Bearings shall have a slight shrink fit on the shaft (see also C.2.1.1) and a slide fit with small clearance in the bore (see C.2.1.5).

C.2.1.3 Keys

Keys shall not be worn or show any plastic deformation. They should fit into the shaft with a small clearance; tilting of the key in the shaft is not allowed.

C.2.1.4 Spacer rings

The spacers between bearings and gears should be hardened and plane-parallel ground. These faces shall not show fretting or scoring marks, grooves or burrs.

Due to the bearing configuration, hubs or spacers that are too wide can cause a compressive force in the bearings.

Check if shafts of unloaded machine are easily turnable; check inner races of bearings for axial thrust. Check the temperature in the oil sump after every load stage of standard test A/8,3/90; normally 90 °C is not exceeded in the first six load stages.

C.2.1.5 Gear box and front cover

The outer race of the bearing in the gear box and front cover shall have a sliding fit with no detectable radial clearance.

The sealing surface (front and top, gear box and cover) shall be flat without burrs or scratches. It is essential not to trap dirt particles during mounting.

All threads in the gear box shall be in good condition.

C.2.1.6 Seals

In case of leakage, check seals and seal race on the shafts (see C.2.1.1). Seals shall not slide on the shaft with the key groove unprotected; otherwise the sealing lip will possibly be destroyed.

C.2.2 Connecting shafts and flanges

C.2.2.1 Load coupling

The two halves of the load coupling shall be easily twistable against each other. If this is not possible, check the centring pin in the shafts, the faces of the load coupling and the T-slot guidance of the bolts. Remove fretting corrosion and lubricate parts if necessary.

Tighten bolts using a torque indicating wrench set to $T = 100$ N · m. Replace broken bolts immediately. Do not operate rig with missing bolts.

C.2.2.2 Torque measuring device

Easy twisting with low friction shall be possible. Check the bearing in measuring coupling:

