INTERNATIONAL STANDARD

ISO 14635-2

Second edition
2023-07

Gears — FZG test procedures —

Part 2:
FZG step load test A10/16, 6R/120 for relative scuffing load-carrying capacity of high EP oils

Engrenages — Méthodes d'essai FZG —

Partie 2: Méthode FZG A10/16, 6R/120 à paliers de charge pour évaluer la capacité de charge au grippage des huiles à valeurs EP élevées

Reference number
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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).

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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 14635-2:2004), 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— replacement of ISO 4287 which has been withdrawn and replaced by ISO 21920-2;

— replacement of ISO 4964 which has been withdrawn and similar information can be found in ISO 18265;

— replacement of some bibliography entries which were withdrawn, and changes from dated to undated references;

— subclause 6.2, wording harmonized with the ISO 14635 series;

— Table 2, description "pitch diameter circumferential speed (v_w)" has been replaced by "circumferential velocity at the pitch line" to harmonize the wording with the ISO 6336 series;

— Table 5, insertion of line "Test lubrication volume" to conform to the information in the ISO 14635 series;

— Figure A.1, addition of the figure title.

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 failures which can be influenced by the lubricant in use are scuffing, low-speed wear and the gear-surface fatigue phenomena known as micro- and macropitting. In the gear design process, these gear damages are taken into consideration by the use of specific lubricant and service-related characteristic values. For an accurate, field-related selection of these values, adequate lubricant test procedures are required. The FZG[2)] test procedures specified in this document, ISO 14635-1 and ISO 14635-3 can be regarded as tools for the determination of the lubricant-related characteristic values to be introduced into the load-carrying capacity calculation of gears.

FZG test method A/8,3/90 for the relative scuffing load-carrying capacity of oils described in ISO 14635-1 is typical for the majority of applications in industrial and marine gears. This document is related to the relative scuffing load-carrying capacity of oils of very high extreme pressure (EP) properties, as used for the lubrication of automotive driveline components. Other FZG test procedures for the determination of low-speed wear, micro- and macropitting load-carrying capacity of gears are intended to be added to the ISO 14635 series as further parts.

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

Gears — FZG test procedures —

Part 2: FZG step load test A10/16, 6R/120 for relative scuffing load-carrying capacity of high EP oils

1 Scope

This document specifies a test method based on a FZG four-square test machine to determine the relative load-carrying capacity of high EP oils defined by the gear surface damage known as scuffing. This test method is useful for evaluating the scuffing load capacity potential of oils typically used with highly stressed cylindrical gearing found in many vehicle and stationary applications. It is not suitable for establishing the scuffing load capacity potential of oils used in highly loaded hypoid bevel gearing applications, for which purpose other methods are available in the industry.

NOTE This method is technically equivalent to CEC L-84-02.

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 corresponding flanks of gear teeth*

ISO 14635-1, *Gears — FZG test procedures — Part 1: FZG test method A/8,3/90 for relative scuffing load-carrying capacity of oils*

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, *Standard 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 occur, owing to the absence or breakdown of a lubricant film between the contacting tooth flanks of mating gears, typically caused by high temperature and high pressure

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.

3.2
scuffing load-carrying capacity
⟨of a lubricant⟩ maximum load which can be sustained under a defined set of conditions

Note 1 to entry: It is the minimum load stage at which the failure criterion given in Clause 4 is reached. See Table 1.

3.3
FZG test condition A10/16,6R/120
test condition where A10 is the particular tooth form of the test gears, according to Tables 2 and 3, 16,6 is the speed at the pitch circle, in metres per second, "R" indicates the reverse direction of rotation (wheel drives pinion) and 120 is the initial oil temperature in degrees Celsius, from load stage 4 onward in the oil sump

3.4
failure load stage
load stage reached when the sum of the damage to the 16 pinion teeth exceeds 100 mm^2 in total area damaged

Note 1 to entry: See Clause 4 and Table 1.

3.5
high EP oils
lubricants containing chemical additives appropriate for improving their scuffing load capacity

Note 1 to entry: EP = extreme pressure.

Note 2 to entry: These oils typically exceed the limits of the FZG test according to ISO 14635-1.

4 Failure criteria

Risk of scuffing damage varies with the properties of gear materials, the lubricant used, the surface roughness of tooth flanks, the sliding velocities and the load. Consequences of scuffing include a tendency to high levels of dynamic loading owing to an increase of vibrations, which usually leads to further damage by scuffing, pitting or tooth breakage.

Because of the particular gear design and test loads used, an interference area typically results at the tip of the pinion and root of the mating wheel. This area is usually about 1 mm in length (profile direction) on the pinion and across the entire facewidth. Examples of various levels of distress occurring with this test are shown in Annex A. The effect of the surface distress in these two regions is addressed as follows.

a) For the purpose of the visual rating for scuffing, the top 1 mm near the tip of the pinion is not included in the assessment until the damage extends below that level. The rated damage region is then expressed as the total area scuffed over all 16 pinion teeth (see Figure 1). The failure load stage is reached when the sum of the damage to the 16 pinion teeth exceeds 100 mm^2 in total area damaged.

b) For a valid test, the wheel shall be visually checked for signs of excessive wear after each pass load stage, as this can alter the results of the test. If there is evidence of wear in the dedendum of the wheel, then the gear shall be weighed to the nearest milligram (0,001 g) [see Annex A, Figure A.1 d)].

The test may be considered valid only if the loss in mass of the wheel is ≤ 20 mg: if the loss in mass of the wheel exceeds 20 mg, the test shall not be considered valid.

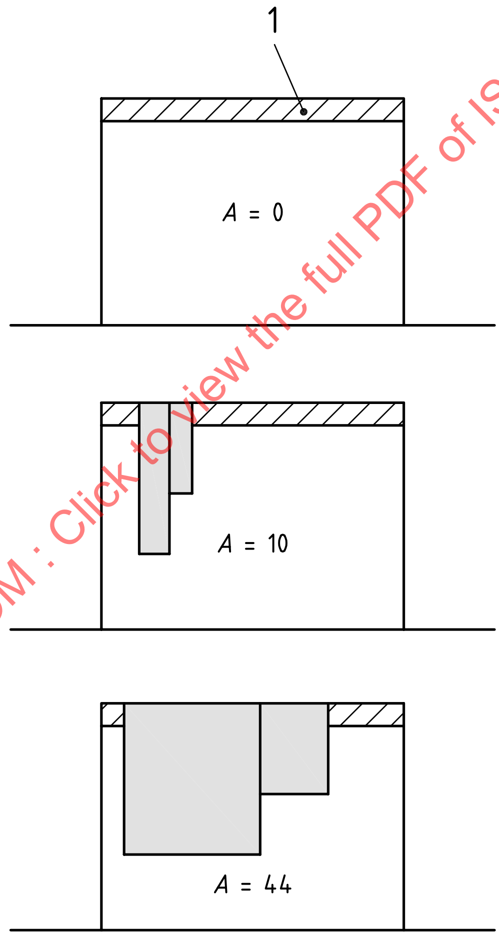
See Table 1.

Table 1 — Test criteria

Pinion failure area A mm^2	**Wheel wear** Δm mg	**Result**
≤ 100	≤ 20	PASS
≤ 100	> 20	INVALID [a]
> 100	Not required	FAIL

[a] No statement on the scuffing load is possible.

Area in square millimetres



Key

1 exclusion zone (1 mm)

Figure 1 — Schematic of distress rating for pinion

5 Brief description of method

5.1 General principle

A set of test gears as defined in Tables 2 and 3 is run with the test lubricant at constant speed for a fixed number of revolutions using dip-lubrication mode. Loading of the gear teeth is increased in steps outlined in Table 4. Beginning with load stage 4, the initial oil temperature is controlled between 117 °C and 123 °C. During the test run of each load stage, the oil temperature is allowed to rise freely. After load stage 5, 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 criteria have been met or when load stage 10 has been completed without meeting the failure criteria.

It is the responsibility of the operator to ensure that all local legislative and statutory requirements are met.

NOTE 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.

WARNING — When the rig is running, there are long loaded shafts and highly stressed test gears turning at high speed and precaution shall be taken to protect personnel.

WARNING — Protection from noise is also highly recommended.

5.2 Precision

The precision of the method has been evaluated according to ISO 5725-2 with two reference oils. The failure load stage of these oils covered the range 5 to 10 inclusive for the step load test.

Values of repeatability, r, and reproducibility, R, as defined in ISO 5725-2, for this test procedures are

r = 1 load stage,

R = 2 load stages.

6 Test materials

6.1 Test gears

A pair of type “A10” test gears with a specification according to Tables 2 and 3 shall be used for testing. Each pair of test gears may be utilized twice for testing, using both tooth flanks as load-carrying flanks.

6.2 Cleaning fluid

Petroleum spirit conforming to ASTM D 235 shall be used.

7 Apparatus

7.1 FZG spur-gear test rig

7.1.1 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 2 and 3. 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 4, hung on the loading arm.

7.1.2 The test gearbox contains heating elements to maintain and control the minimum temperature of the oil. 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.

7.1.3 The test machine is powered by an electric motor of minimum 7,4 kW at a speed of approximately 2 900 1/min. The direction of drive is reversed (anticlockwise when looking on the motor shaft), i.e. wheel drives pinion, as shown in Figure 3. This is the opposite direction of rotation to that of ISO 14635-1.

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

Table 2 — Details of FZG test gears type A10

Dimension		Symbol	Numerical value	Unit
Shaft centre distance		a	91,5	mm
Effective tooth width	pinion	b_1	10	mm
	wheel	b_2	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	16,6	m/s
Addendum engagement	pinion	e_{a1}	14,7	mm
	wheel	e_{a2}	3,3	mm
Sliding speed at tooth tip	pinion	v_{ga1}	11,16	m/s
	wheel	v_{ga2}	2,50	m/s
Specific sliding at tooth tip	pinion	ζ_{E1}	0,86	
	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	$20,8 \cdot \sqrt{F_{nt}}$ [a]	N/mm^2

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

Table 3 — Manufacturing details of FZG test gears type A10

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

7.2 Heating device

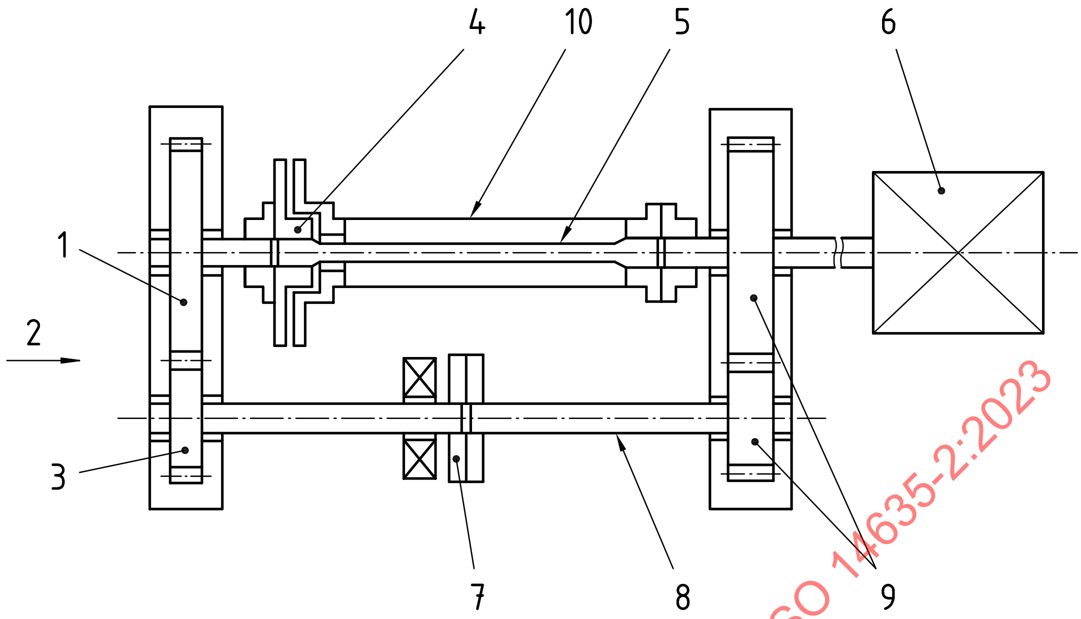
A suitable oven or heating device is required to warm the test gears between 60 °C to 80 °C for assembling on the shafts.

7.3 Revolution counter

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

7.4 Balance

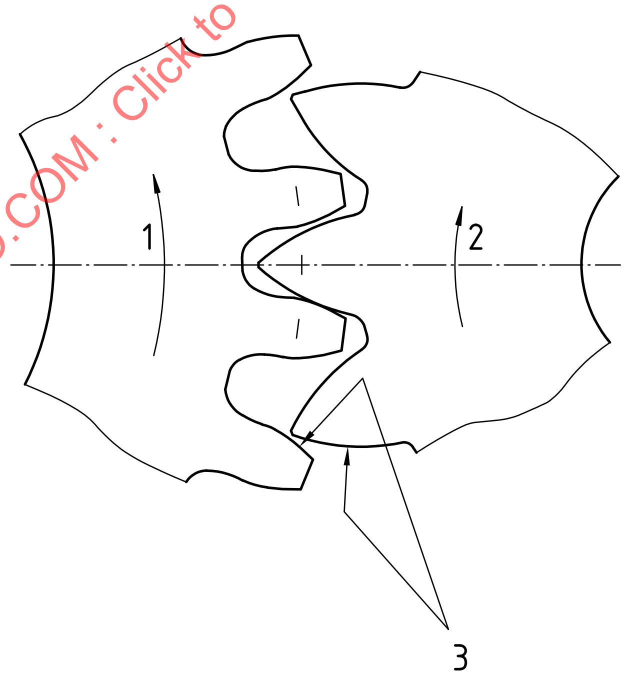
A suitable balance of a minimum weighing capacity 1,3 kg and with accuracy to the nearest to 0,001 g shall be used to determine the mass of the test wheel.



Key

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

Figure 2 — Schematic section of the FZG gear test machine



Key

1 test wheel
2 test pinion
3 active tooth flank

Figure 3 — Mounting of the FZG test gears of type A10 (view A in Figure 2)

8 Preparation of apparatus

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

8.2 Clean the test gears in petroleum spirit and air dry, using protective gloves.

8.3 Visually inspect the test gears for corrosion, rust or any other damage. Reject the gears if so damaged.

8.4 Weigh the wheel to the nearest 0,001 g.

8.5 For easier mounting, heat both the test gears and bearing races to between 60 °C and 80 °C with the heating device.

8.6 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.

8.7 Switch drain cock to the CLOSED position.

8.8 Fill the test gear box with nominal 1,25 l of test oil.

8.9 Plug in the heater.

8.10 Fit and secure the top cover to the test gear box.

8.11 Apply load stage 12 in accordance with ISO 14635-1 using the 0,5 m radius position for 2 min to 3 min without running the motor, in order to bring the test gears and the clearances in the system into the correct working position.

9 Test procedure

9.1 Apply the first load stage (see Table 4). Using the conditions given in Table 5, start the motor, switch on the heater and run for 21 700 motor shaft revolutions (approximately 7,5 min). Repeat the process for load stages 2 and 3.

9.2 At the start of load stage 4, ensure that the oil temperature in the test gear box is between 117 °C and 123 °C, in accordance with Table 5.

9.3 At the end of load stage 4, inspect the test pinion for damage, without removing the test gears. Record the tooth condition, using the examples in Figure 1 and Annex A as a guide. If the damage criterion is not reached, the test is continued.

9.4 If the test is continuing to the next higher load stage, ensure that the oil temperature in the test gearbox is between 117 °C and 123 °C. This may be accomplished through the use of appropriate heating or cooling of the test gear box. When the temperature is between 117 °C and 123 °C, the test may be continued. Ensure that cooling devices are turned off during the test.

9.5 Continue the test with stepwise increased load stages (Table 4), inspecting all the test pinion teeth after each stage, and cooling to between 117 °C and 123 °C, as specified in 9.4, before applying the next higher load stage.

9.6 Continue with the procedure until the failure load stage according to Clause 4 is reached, but if insufficient damage (< 100 mm^2 scuffing) occurs, terminate the test at the end of load stage 10.

9.7 If the machine is shut down at the end of a load stage for any reason during a test for a period of time before the test is completed and the test oil temperature drops below 117 °C, carry out the following steps before resuming the test.

a) Apply load stage 1, start the motor, switch on the heater and run until the oil temperature reaches 117 °C to 123 °C.

b) Stop the motor, switch off the heater and apply the next load stage in the test sequence after the load stage at which the machine was shutdown.

c) Continue the test according to 9.5 and 9.6, respectively.

9.8 If the failure criteria according to Clause 4 is not reached at the end of load stage 10, weigh the test wheel to the nearest 0,001 g and calculate the loss of mass, Δm.

Table 4 — FZG load stages

Load stage No.	Pinion torque N·m	Normal tooth load N	Hertzian stress at pitch point N/mm^2	Load coupling loaded with:
1	3,3	99	206	H_1
2	13,7	407	417	H_2
3	35,3	1 044	670	$H_2 + K$
4	60,8	1 799	878	$H_2 + K + W_1$
5	94,1	2 786	1 093	$H_2 + K + W_1 + W_2$
6	135,5	4 007	1 314	$H_2 + K + W_1 + W_2 + W_3$
7	183,4	5 435	1 527	$H_2 + K + W_1 + W_2 + W_3 + W_4$
8	239,3	7 080	1 730	$H_2 + K + W_1 + W_2 + W_3 + W_4 + W_5$
9	302,0	8 949	1 960	$H_2 + K + W_1 + W_2 + W_3 + W_4 + W_5 + W_6$
10	372,6	11 029	2 176	$H_2 + K + W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7$

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_7 = weights for weight loading

Table 5 — Test conditions

Duration of each load stage:	21 700 revolutions of the motor (approx. 7,5 min)
Motor rotational frequency:	2 910 1/min ±3 %
Direction of rotation:	Anticlockwise [a]
Test lubrication volume:	1,25 l ± 0,05 l
Initial oil temperature at start of load stage 4 and each subsequent load stage:	(120 ± 3) °C

[a] The direction of the rotation of the gears is shown in Figure 3.

10 Reporting of results

Report the load stage and the corresponding pinion torque at which the failure load stage occurred, according to Clause 4. State the test conditions as A10/16,6R/120. If the test was completed without failure, report “Failure load stage greater than 10” and give the loss in mass of the test wheel, expressed in milligrams. If the test is terminated owing to scuffing before load stage 5 was reached, report "Failure load stage less than 5". For examples of different cases of test validity, see Table 6.

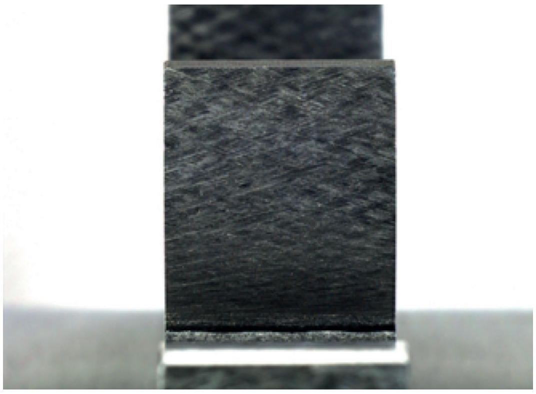
Table 6 — Example results for test conditions

Example	1	2	3
Failure load stage	8	> 10	—
Wheel mass loss after LS 10	—	16 mg	30 mg
Valid test	Yes	Yes	No

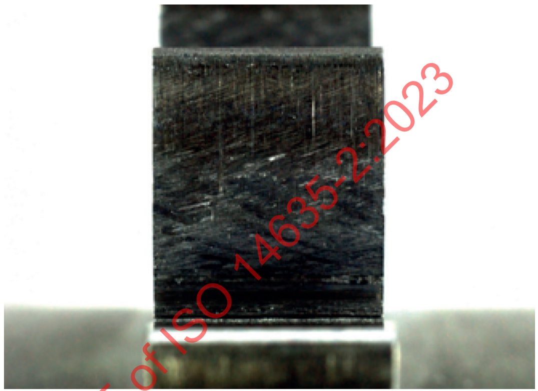
The changes may also be recorded photographically. Any corrosion or deposits should be recorded in the test report (see Annex B).

Annex A
(informative)

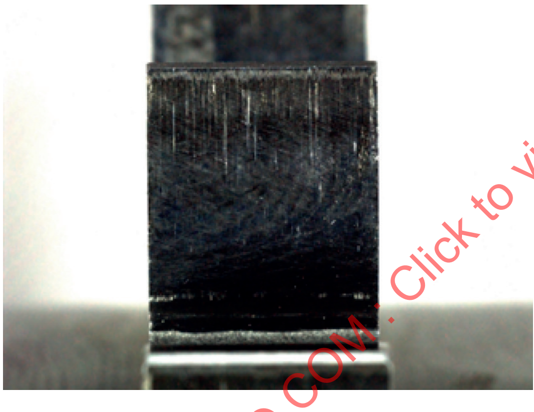
FZG A10-type gear tooth face changes (flank damages)



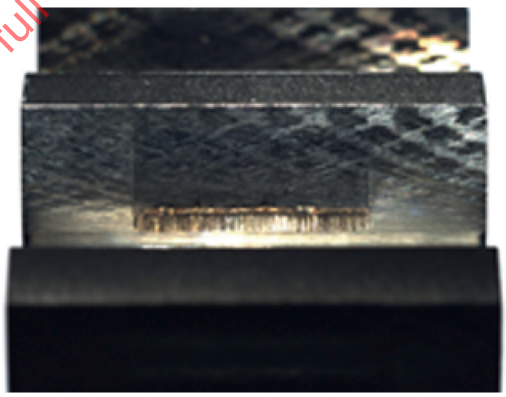
a) New pinion flank



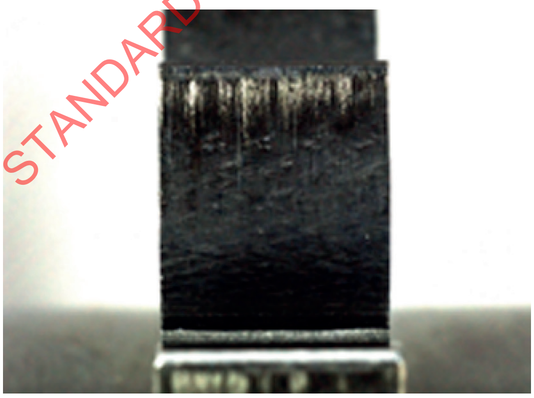
b) No failure



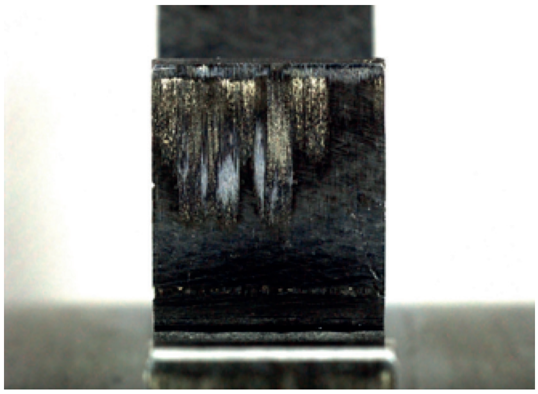
c) No failure



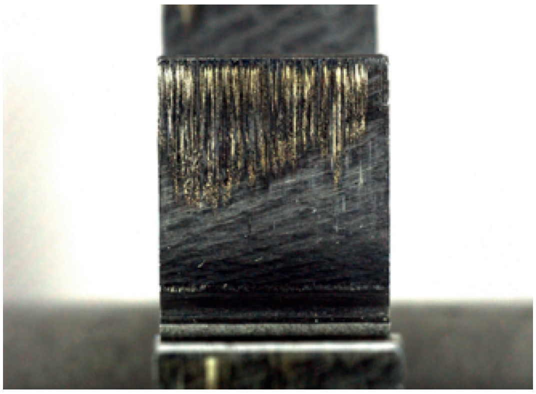
d) Wear mark in wheel dedendum: test invalid if mass loss > 20 mg



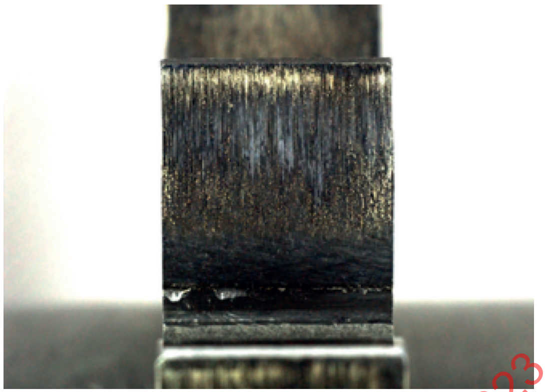
e) A = 16 mm²



f) A = 40 mm²



g) A = 45 mm²



h) A = 70 mm²

Figure A.1 — FZG A10-type gear tooth face changes (flank damages)

Annex B
(informative)

Typical FZG test report sheet

Company Name *Company Logo*

ISO 14635-2

Gears — FZG test procedure

Part 2: FZG test method A10/16, 6R/120

TEST REPORT

Lubricant: ....

Origin: ....

FZG Test No.: ....

FZG Test Gear Set No.: ....

FZG Test Gear Flank: ....

TEST RESULT:

Valid test (Yes/No): ....

Failure load stage: ....

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

Wheel mass loss at end of load stage 10: ....mg

Remarks:

....

....

Date: Signature:

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 of maintenance of the machine being required 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 facewidth 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 the scuffing mark distribution for perfect running operation, as well as 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 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

