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ORIGINALARBEITEN/ORIGINALS

Transferability of the scuffing load capacity of gear oils determined on spur gears to hypoid gears

Classification of hypoid oils by use of a newly developed scuffing test method

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Abstract

The scuffing load carrying capacity is a decisive design criterion in the development of gears. In addition to the gear geometry, the entire tribological system of the gearbox must also be taken into account. Besides the loads and speeds occuring during the operation of the gears, the lubricant used and its additives have a significant influence on the scuffing load carrying capacity. In particular, hypoid gears show an unfavorable combination of high sliding velocities and high contact stresses in tooth contact with regard to the failure mode scuffing. To ensure safe operation, highly additivated gear oils are generally used in hypoid transmissions. Since it is generally not possible to determine the influence of the lubricant on the load carrying capacity of gears on the basis of physical or chemical oil data alone, experimental test methods are necessary. Due to the high scuffing load carrying capacity of highly additivated hypoid oils, the limits of many test methods are reached. In order to ensure testing highly additivated hypoid oils as close as possible to their application a new hypoid scuffing test was developed. However, since spur gear scuffing test methods can be carried out more quickly and with less resource and effort, the applicability of the spur gear scuffing test S-A10/16.6R/90 to high additivated hypoid oils is investigated. The comparability of the two test methods and the transferability of the scuffing load carrying capacity of a gear oil determined on spur gears to hypoid gears is evaluated in scope of this paper.

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Übertragbarkeit der an Stirnradgetrieben ermittelten Fresstragfähigkeit von Getriebeölen auf Hypoidgetriebe

Klassifizierung von Hypoidölen mittels eines neu entwickelten Fresstests

Zusammenfassung

Die Fresstragfähigkeit ist ein entscheidendes Auslegungskriterium bei der Entwicklung von Getrieben. Bei der Auslegung nach Stand der Technik muss zusätzlich zur Verzahnungsgeometrie das gesamte tribologische System des Getriebes berücksichtigt werden. Neben den auftretenden Belastungen und Drehzahlen nehmen der verwendete Schmierstoff und dessen Additivierung einen maßgeblichen Einfluss auf die Fresstragfähigkeit der Zahnräder. Insbesondere Hypoidräder weisen im Hinblick auf Fressen eine ungünstige Kombination aus hohen Gleitgeschwindigkeiten und hohen Zahnflankenpressungen im Zahnkontakt auf. Um einen sicheren Betrieb zu gewährleisten, werden in Hypoidgetrieben in der Regel hochadditivierte Getriebeöle eingesetzt. Da es im Allgemeinen nicht möglich ist, den Einfluss des Schmierstoffs auf die Tragfähigkeit von Zahnrädern allein anhand von physikalischen oder chemischen Öldaten zu bestimmen, sind experimentelle Prüfverfahren notwendig. Aufgrund der hohen Fresstragfähigkeit von hochadditivierten Hypoidölen stoßen viele Prüfverfahren an ihre Grenzen. Um eine möglichst anwendungsnahe Prüfung hochadditivierter Hypoidöle zu gewährleisten, wurde ein neuer Fresstest unter Verwendung einer Hypoidprüfverzahnung entwickelt. Da Fresstests mit Stirnrädern als Prüfverzahnung schneller, kostengünstiger und mit geringerem Aufwand durchgeführt werden können, wird die Anwendbarkeit des Stirnradfresstests S-A10/16,6R/90 auf hochadditivierte Hypoidöle verfolgt. Die Vergleichbarkeit der beiden Prüfverfahren und die Übertragbarkeit der an Stirnradgetrieben ermittelten Fresstragfähigkeit eines Getriebeöls auf Hypoidgetriebe wird im Rahmen dieser Veröffentlichung bewertet.

1 Introduction

Due to their kinematic conditions, hypoid gears with axle offset have an additional relative movement in the tooth contact in the tooth width direction compared to cylindrical gears or bevel gears without hypoid offset. This leads to a higher overall sliding velocity in tooth contact and consequently to an increased risk of scuffing of hypoid gears. To ensure scuffing-free operation of highly loaded hypoid gears, usually highly additivated gear oils of the API GL-5 classification are used.

Since it is generally impossible to determine the influence of the lubricant on the scuffing load carrying capacity of gears on the basis of physical or chemical oil data alone, experimental test methods are necessary. There are a large number of different test methods for testing the scuffing load carrying capacity of gear oils. However, due to the high scuffing load carrying capacity of hypoid oils, many test methods reach their performance limits. Consequently, only selected test methods are suitable for the experimental investigation of the scuffing load carrying capacity of high additivated hypoid oils. In addition to testing gear oils close to their application, the test methods should be resource-saving, require low amounts of material, energy and oil, and be inexpensive and quick to perform. These requirements are better fulfilled by a spur gear test method than by a hypoid or axle test method. This publication clarifies whether spur gear tests are suitable for testing the scuffing load carrying capacity of high additivated hypoid oils and whether the test results of a spur gear test method can be transferred to hypoid gears. To clarify these issues, among other things, a new scuffing test had to be developed using a hypoid gear.

2 Failure mode scuffing

The following description of the failure mode scuffing is from the publication [1] by the authors of this paper. "Scuffing is a type of spontaneous damage in which the tooth flank surfaces are welded due to an excessively high local temperature occurring during tooth contact. The relative movement of the tooth flanks of the pinion and wheel causes immediate separation of the welded surfaces. The resulting scuffing marks always develop in the direction of the sliding velocity and occur in the corresponding flank areas of the pinion and wheel. Given a pinion and wheel made of the same material, the partner undergoing positive sliding gains material, and the partner undergoing negative sliding loses material [2, 3].

Figure 1 shows an example of scuffing failure at a hypoid gear flank. It can be seen that the scuffing marks are oriented in the direction of the sliding velocity.

Metallographic examinations of flank areas with scuffing show that friction martensite with an underlying tempering structure is present at the surface. This suggests high temperature exposure above the austenitizing temperature of about 800 °C, with subsequent quenching and rehardening [3].

In addition to geometrical gear dimensions and gear set operating conditions, lubrication conditions also have a relevant impact on the failure mode scuffing. To avoid scuffing,

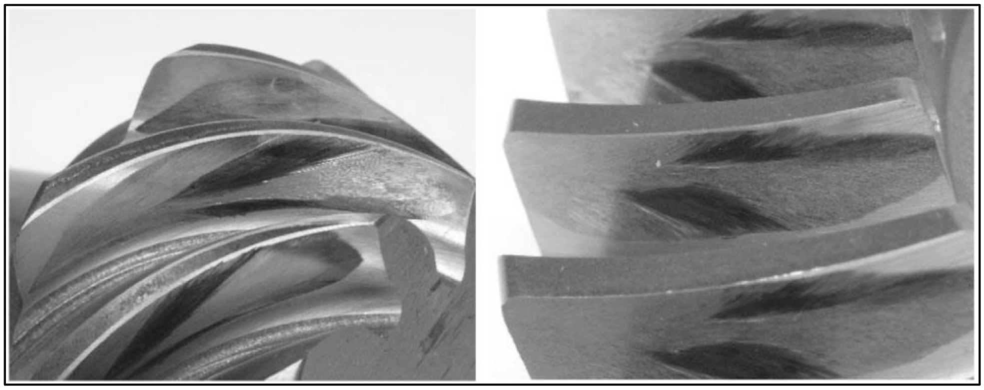

Fig. 1 Scuffing marks at the drive flank of a hypoid gear [4]

metallic contact between sliding elements must be averted. Increasing oil viscosity facilitates separation of the tooth flanks during tooth contact. However, an increase in oil temperature causes a drop in oil viscosity, and thus an increase in the risk of scuffing. To increase the scuffing load carrying capacity of a gear oil, extreme pressure additives (EP) are therefore added to the oil. When the additives are activated by appropriate contact temperatures, they form a tribological protective layer that prevents metallic contact between the tooth flanks. This increases the scuffing load carrying capacity of the gear [4].

Experience shows that the scuffing load capacity of a gear oil increases with rising anti-wear (AW) and EP additive concentration [5]. Gear oils of classification API GL-5 should be used for hypoid gears subjected to highly loaded/shock conditions [6].

The current, internationally accepted calculation method for determining the scuffing load carrying capacity of bevel and hypoid gears is ISO/TS 10300-20 [7]. This method is based on research project FVA 519 [8]. An elementary input variable is the scuffing load carrying capacity of the gear oil represented by the permissible contact temperature, which can only be determined experimentally" [1].

3 Test methods to determine the scuffing load carrying capacity of hypoid gear oils

In the current state of the art, there are a large number of different test methods which allow a statement on the scuffing load carrying capacity of a lubricant. Exemplary oil testing devices are the Timken-Device, Almen-Wieland-Device, Reichert-Friction wear scale, Four-Ball-Device, lfE-Lubrimeter, Pin-Disc-Device or various gear test rigs (FZG, IAE, Ryder gear test rig). Wirtz [9] showed in experimental investigations that no correlation can be established between results on simple testing machines and the behavior of the lubricants in tooth contact [5]. Thus, it can be seen that, when testing different lubricants, the test method can have a fundamental effect on the results and their transferability to the respective practical application [10]. The verification of the scuffing load carrying capacity of gear oils should be tested according to their application on the machine element gear. An overview of possible test methods, some of them have already been standardized, is listed below:

- A/8.3/90 acc. DIN ISO 14635-1 [11] and CEC-L-07-095 [12]
- A10/16.6R/120 acc. DIN ISO 14635-2 [13]
- FZG L-42 Test [14]
- S-A10/16.6R/90 [15]
- S-A10/16.6R/110 [16]
- A/10/33.2R/90 [17]
- FZG-Hypoid scuffing test A mod bzw. A/44/Cr [18]
- L42 axle test [19]

With the exception of the L42 test and the A/44/Cr hypoid scuffing test, spur gears are used in all test methods listed. A distinction can be made between stage and shock tests for the spur gear scuffing tests. In stage tests, loads are applied in stages until scuffing occurs or the highest defined load stage is passed without damage. In the shock tests (marked by "S"), the expected failure load stage is applied directly. Depending on whether this load stage is passed through without damage or with the occurrence of scuffing, the result of the test run is a "PASS" or a "FAIL". Due to the missing gear running-in, the shock tests are more critical to scuffing compared to the stage tests. The load stage that the test oil just passes without damage describes the scuffing load carrying capacity of the test oil. Hypoid oils usually have such a high scuffing load carrying capacity that the above-mentioned spur gear step tests reach their performance limits. In the case of using spur gears in the scuffing test method, only shock tests can provide a determination of the scuffing load carrying capacity of such highly additivated gear oils [10, 15, 16].

The A/44/Cr hypoid scuffing test is a step test using the FZG hypoid back-to-back test rig. The hypoid test gear has a hypoid offset of 44 mm. This enables application-oriented testing of hypoid gear oils. Reimann et al. [18]

performed the A/44/Cr hypoid scuffing test with three oils from practical application, two with classification API GL-5 and one with API GL-4. Both gear oils of the classification API GL-5 passed the test without damage. The gear oil of the classification API GL-4 showed a FAIL in load stage 8 due to scuffing.

The current, globally recognized test for examining the scuffing load carrying capacity of highly additivated gear oils with respect to their applicability in highly loaded hypoid gears is the axle test L42. In this test, gear oil is evaluated in an axle test rig at high circumferential speeds and shock loads. The test method is defined in ASTM standard D7452 [19]. To pass the L42 test, the tooth flanks of the test hypoid gear may have a maximum scuffing area, as compared to the average scuffing area of the passed reference oils used to calibrate the test rig. Among other things, passing the L42 test is necessary for the test oil to receive the API GL-5 classification [20].

In summary, the spur gear test method S-A10/16.6R/90, the hypoid gear test method A/44/Cr and the axle test L42 are suitable for testing the scuffing load carrying capacity of hypoid oils. The spur gear test method S-A10/16.6R/90 enables the determination of the permissible scuffing temperature. However, highly additivated hypoid oils can exceed the performance limits of the test method, so a differentiation between hypoid oils is not always possible. Furthermore, due to the different kinematics between spur gears and hypoid gears, application area of highly additivated gear oils of the classification API GL-5, the transferability of the test results has to be checked. The axle test method L42 enables classification of gear oils into the API GL-5 class according to their applicability in highly loaded hypoid gears. A differentiation between gear oils of the classification API GL-5 nor the determination of a permissible scuffing temperature is not possible. The hypoid scuffing test method A/44/Cr enables a determination of the permissible scuffing temperature. However, since gear oils of the classification API GL-5 pass all load stages without damage, a differentiation between gear oils of the classification API GL-5 is not possible. Consequently, the test method is currently not feasible. Thus, no scuffing test method using a hypoid gear is available that enables a quantitative determination of the scuffing load carrying capacity of gear oils based on the permissible scuffing temperature occurring in the scuffing test method. Based on the described facts, a new hypoid scuffing test method was developed to carry out the investigations presented here.

4 Experimental investigations

To clarify the transferability of the scuffing load carrying capacity of a gear oil determined on spur gears to hypoid gears, test results of the spur gear scuffing test method S-A10/16.6R/90, the newly developed hypoid scuffing test method and the standardized axle test method L42 are compared. The standardized test method L42 was performed according to ASTM standard D7452 [19] by the South West Research Institute (USA).

4.1 Test equipment

The testing machines used are a back-to-back hypoid gear test rig and a back-to-back spur gear test rig. Figure 2 shows both test rigs. Both test rigs operate according to the principle of a closed power circuit. On the hypoid test rig, the power circuit consists of two hypoid gears, the test gear set and the slave gear set, connected to a spur slave gear set by means of two parallel shafts. On the spur gear test rig, two spur gears, the test gear set and the slave gear set, connected by two parallel shafts, form the power circuit. A defined torque is applied at both test rigs by use of a mechanical load clutch. The torque applied to the pinion of the test bevel gear set and to the wheel of the spur test gear set is measured using strain gauges that are mounted on the torsional shafts. The electric motor only injects the

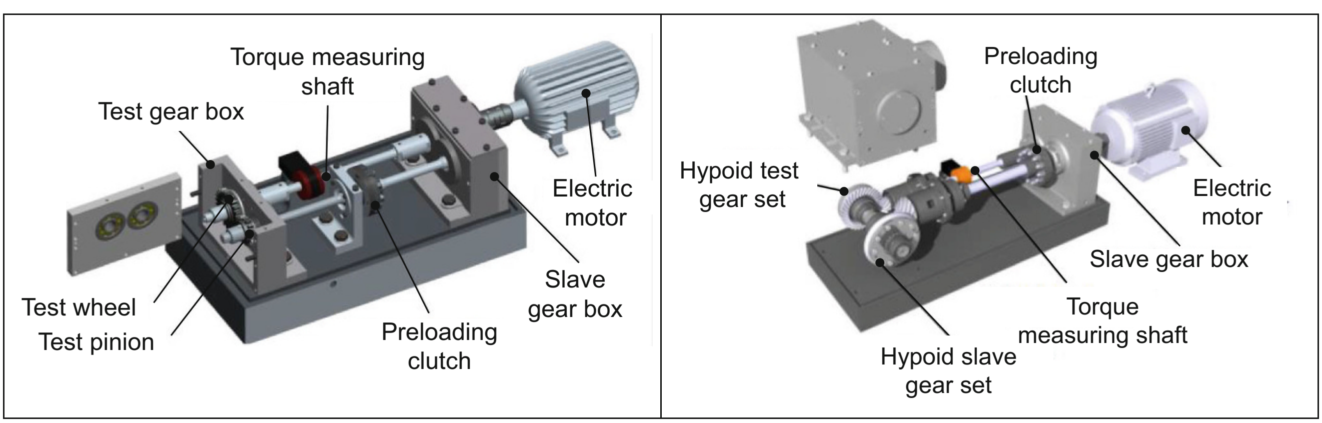

Fig. 2 Setup of a back-to-back spur gear and hypoid gear test rig according to [21, 22]

Table 1 Basic geometry data of the spur test gear A10 and hypoid test gear G44

Test gear name			A10	G44
Center distance/hypoid offset	a	mm	91.5	44
Shaft angle	Σ	°	0	90
Teeth ratio	z_1/z_2	–	16/24	9/34
Mean normal module	M_{mn}	mm	4.5	4.19
Face width	b_1/b_2	mm	10/20	36.9/26
Normal pressure angel	α_{nD}/α_{nC}	°	20	13.2/26.8
Helix angle/Mean spiral angel	β_{m1}/β_{m2}	°	0	49.5/16.5
Profile shift coefficient	x_{hm1}/x_{hm2}	–	0.85/–0.50	0.45/–0.45

Table 2 Test gear oils

Designation	Result in L42
Oil 1	FAIL [a]
Oil 2	PASS
Oil 3	FAIL
Oil 4	PASS

[a] acc. to manufacturer. The test was not performed

power losses induced by the components of the back-to-back test rigs. Both test rigs offer the possibility of injection or dip lubrication as well as a combination of both types of lubrication. The oil temperature in the gearboxes can be regulated.

The spur gear type A with a tooth width of 10 mm (A10) and the hypoid gear G44 are used as test gears. Table 1 provides an overview of the gear geometry. The spur test gear A10 is standardized in DIN ISO DIN ISO 14635-2 [13]. It has a high profile shift to provoke high sliding velocities in the tooth contact. The hypoid test gear G44 has already been used in the research project FVA 411 [23]. It is charactarized by a large hypoid offset to provoke high sliding velocities in the tooth contact. The risk of scuffing increases with increasing sliding velocity in the tooth contact.

Four different gear oils based on mineral oil were used as test oils. Table 2 provides an overview of the oils examined. Neither the composition nor the type of the additive is known for oils 1 and 2. Oils 3 and 4 are based on the standard oil FVA 3 with different concentrations of the EP additive “Anglamol 99”. Oil 3 shows a concentration of 4% Anglamol 99, and oil 4 contains 6.5% Anglamol. Oil 2 and oil 4 are classified according to API GL-5 and had passed the L42 test. Oil 3 failed in the L42 test and shows scuffing resistance comparable to that of an API GL-4 oil. According to the manufacturer, oil 1 should be assigned to the API GL-3/4 class. Consequently, it was assumed that oil 1 would fail the L42 test.

4.2 New hypoid scuffing test method

The new test method allows a differentiation between gear oils of the categories API GL-4 and GL-5 as well as a differentiation within the category API GL-5. In addition, a determination of the permissible scuffing temperature is possible. The development of the test method is described in detail in [1]. The new test method consists of a gear running-in, followed by the main test phase and finally the test evaluation. The FZG back-to-back hypoid gear test rig is used as test device. The coast flank is the active tooth flank and the wheel drives the pinion. The test oil is used in both the main test phase and in the gear running-in.

The running-in is carried out at a pinion torque of 100 Nm and a pinion rotational speed of 120 rpm. This leads to a maximum local contact stress of 1689 N/mm² and a maximum local sliding velocity of 0.32 m/s or a sliding velocity of 0.28 m/s at the contact point with the minimum local scuffing safety. A total of 150,000 load cycles are performed on the pinion during the running-in. The oil temperature is controlled to 90 °C during running-in. After the running-in procedure, the oil is changed to remove wear particles.

The operating conditions of the main test phase are summarized in Table 3. The new test method is a stage test. Each load stage is driven for 10 min at an oil start temperature of

Table 3 Operating conditions of the new hypoid test method [1]

Load stage	Torque at pinion in Nm	Max. local contact stress in N/mm²	Further test conditions	
1	34	1182	*Driving gear*	Wheel
2	46	1310		
3	61	1440	*Active tooth flank*	Coast side
4	79	1561		
5	100	1689	*Rotational speed at pinion*	4550 rpm
6	124	1812		
7	152	1935	*Load cycles at pinion*	45,500
8	183	2043		
9	217	2130	*Lubrication type*	Dip lubrication
10	254	2224		
11	295	2318	*Amount of oil*	Approx. 7 liters
12	339	2406		
13	386	2481	*Oil start temperature*	90 °C
14	436	2548		

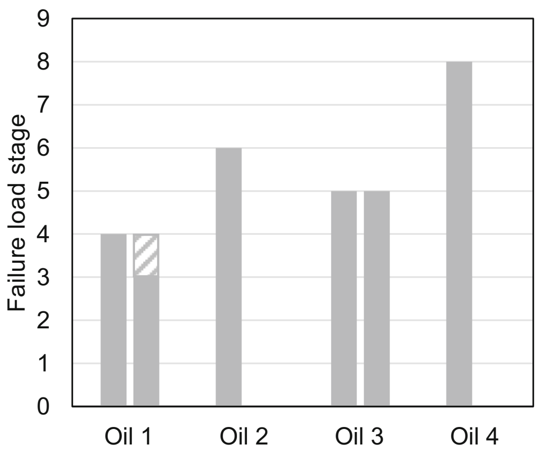

Fig. 3 Experimental results of the new hypoid scuffing test method according to [1]

90 °C. The oil temperature is not controlled during the test run and can escalate freely. Dip lubrication with an immersion depth of 0.14 in relation to the outer pitch diameter of the wheel is applied as lubrication type. Local maximum sliding velocities about 12.1 m/s or sliding velocities about 10.4 m/s at the contact point with the minimum local scuffing safety occur across the load stages.

After each load stage, a photographic documentation of the tooth flanks is made to evaluate the test run. The evaluation is carried out on the wheel flanks, since the camera does not have sufficient access to photograph the entire pinion flank in the gearbox. This is permissible because scuffing is a damage to both gears. If the scuffing area exceed at least 5% of the contact pattern under load, the load stage is defined as the failure load stage. The development of this failure criterion as well as the evaluation of the contact pattern and scuffing area is discribed in detail in [1].

A total of 6 tests were carried out using the test oils. Figure 3 summarizes the test results. The test results have already been published in [1] by the authors of this paper. "According to the API GL classification, oil 1 (API GL-3/4) showed the lowest failure load stage, followed by oil 3 (API GL-4) and oils 2 and 4 (both API GL-5), which showed the highest failure load stage. In one test run using oil 1, no flank documentation of sufficient quality was available for evaluating the third load stage, so the failure load stage could have been either three or four. In Fig. 3, this fact is indicated by a shaded bar. A repeat test was performed in each case using oils 1 and 3. An equal failure load stage was determined. Based on the test results shown, oils that can pass at least load stage five without damage were presumed to have the scuffing load carrying capacity of an API GL-5 oil. However, further tests will be necessary in order to confirm this statement" [1].

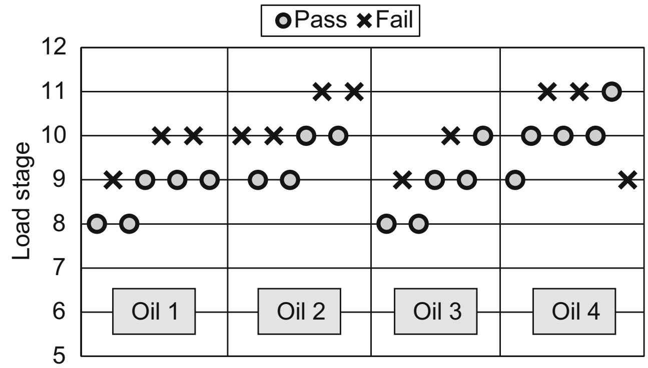

Fig. 4 Experimental results of the spur gear test method S-A10/16.6R/90

4.3 Spur gear scuffing test method S-A10/16.6/R90

Following the state of the art, the spur gear test method S-A10/16.6R/90 is recommended for investigating the scuffing load carrying capacity of an API GL-5 gear oil [10, 15]. The spur gear type A10 is used as test gear. The test procedure is carried out according to FVA 243/I [15] using the FZG back-to-back spur gear test rig. The test procedure corresponds to the test procedure of the step test described in DIN ISO 14635-2 [13], with the exception that the expected failure load stage is driven directly in the shock test S-A10/16.6R/90. If a "PASS" is reached, the next higher load stage is driven using a new spur test gear. If a "FAIL" occurs, one load stage lower is used. The load stages are documented in DIN ISO 14635-2 [13]. The test load stage is run at a wheel speed of 2880 rpm with the wheel driving the pinion for approx. 7.5 min. The oil start temperature is 90 °C. The oil temperature is not regulated during the test run and can escalate freely. Dip lubrication is applied as lubrication type. If one tooth flank of the test gear shows a damage greater than 10 mm in the sum of all scoring and scuffing marks in the tooth width direction, the test run counts as a "FAIL".

Eight valid test runs were carried out using test oils 1, 2 and 4 and seven valid test runs using test oil 3. Figure 4 summarizes the test results. Each dot or cross represents one test run. The cross indicates a "FAIL" and the point a "Pass" as test result.

5 Evaluation of the experimental investigations

The evaluation of the test results is based on the limit scuffing temperature of the test oils. It can be calculated based on the load stages determined in the experimental investigations.

The local scuffing calculation method according to Klein [4, 24] is used to evaluate the hypoid test results. This

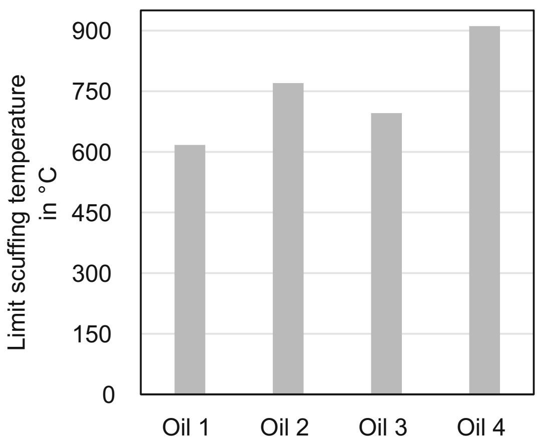

Fig. 5 Calculated limit scuffing temperature of the new hypoid scuffing test method

calculation method also forms the basis for the development of the standardized calculation method according ISO/TS 10300-20 [7]. Based on a manufacturing simulation and a tooth contact analysis under load, carried out here using the software BECAL [25], the local contact temperatures of the G44 hypoid test gear can be calculated. The maximum local contact temperature is the critical variable for scuffing and is used as a comparative variable with the spur gear test method S-A10/16.6R/90. Figure 5 shows the calculated limit scuffing temperatures of the test oils determined in the new hypoid scuffing test method.

The limit scuffing temperature for spur gears can generally be calculated according to the calculation method of the maximum contact temperature according to Blok [26], standardized in ISO/TS 6336-20 [27], or according to the integral temperature according to Michaelis [3], standardized in ISO/TS 6336-21 [28]. Depending on the calculation method, different limit scuffing temperatures are determined for the spur gear test method S-A10/16.6R/90. However, this is correct because the respective calculation method is applied to the conditions of the failure load stage and defines the temperature calculated for this as the limit scuffing temperature [10]. Additionally, a friction coefficient is required to determine the limit scuffing temperature. Depending on the friction coefficient approach, deviations in the limit scuffing temperatures can be calculated.

To be consistent in comparison to the evaluation of the hypoid test results, the calculation approach for determining the limit scuffing temperature according to ISO/TS 10300-20 [7] is used to evaluate the spur gear test results. This approach is also based on the contact temperature method and on the friction coefficient approach for spur gears according to Klein [8]. Consequently, the results of the spur gear test method S-A10/16.6R/90 are comparable with those of the new hypoid scuffing test method. Due to the difference in the absolute value of the friction coefficient for bevel gears and for spur gears, deviations in the calculated limit scuffing temperature for the spur gear and for the hypoid gear test results are to be expected.

Before the limit scuffing temperature of the test oils determined in the spur gear test method can be calculated, a failure load stage needs to be determined from the test results. In the research project FVA 243 I [15], in which the spur gear test method S-A10/16.6R/90 was developed, an evaluation according to the enhanced staircase method according to Hück [29] is recommended for determining the failure load stage. A prerequisite for the application of the enhanced staircase method is a constant stair step. However, since the limit scuffing temperature does not increase linearly over the load stages, application of the enhanced staircase method to the limit scuffing temperature is not possible. On the other hand, an application to the load stage number itself, as it was also handled in the research project FVA 243 I [15], is possible. Thus, an average failure load stage can be determined and the limit scuffing temperature can be inferred. It should be noted that considering a number of tests smaller than 10, only a rough estimation of the mean value of the failure load stage is possible without determining the confidence level according to the enhanced staircase method.

Due to the small number of tests and the determination of the limit scuffing temperature by the calculation of an average load stage according to the enhanced staircase method, the extended modified Probit [30] method was also used as a statistical evaluation method. The extended modified Probit method [30] is particularly suitable for the experimental determination of the fatigue strength of machine elements with a small number of tests. One advantage of the method is that an evaluation is possible even if the step change is not constant. Thus, the spur gear test results can be evaluated directly with respect to the limit scuffing temperature. In accordance with the enhanced staircase method, a normal probability distribution of the test results is assumed in the extended modified Probit method.

Figure 6 shows the evaluation of the test results according to the extended modified Probit method. The rhombs represent the experimentally determined failure probabilities for the respective limit scuffing temperatures of the spur gear test method S-A10/16.6R/90. A linear regression in the Gaussian network is used to determine the limit scuffing temperature for 50% failure probability.

The determined limit scuffing temperatures for 50% failure probability according to the extended modified Probit method can be compared to the limit scuffing temperatures according to the enhanced staircase method.

Figure 7 shows the comparison. Except for oil 2, the enhanced staircase method determines lower temperatures. For oil 2, the same limit scuffing temperature is calculated by both evaluation methods because the failure load stage

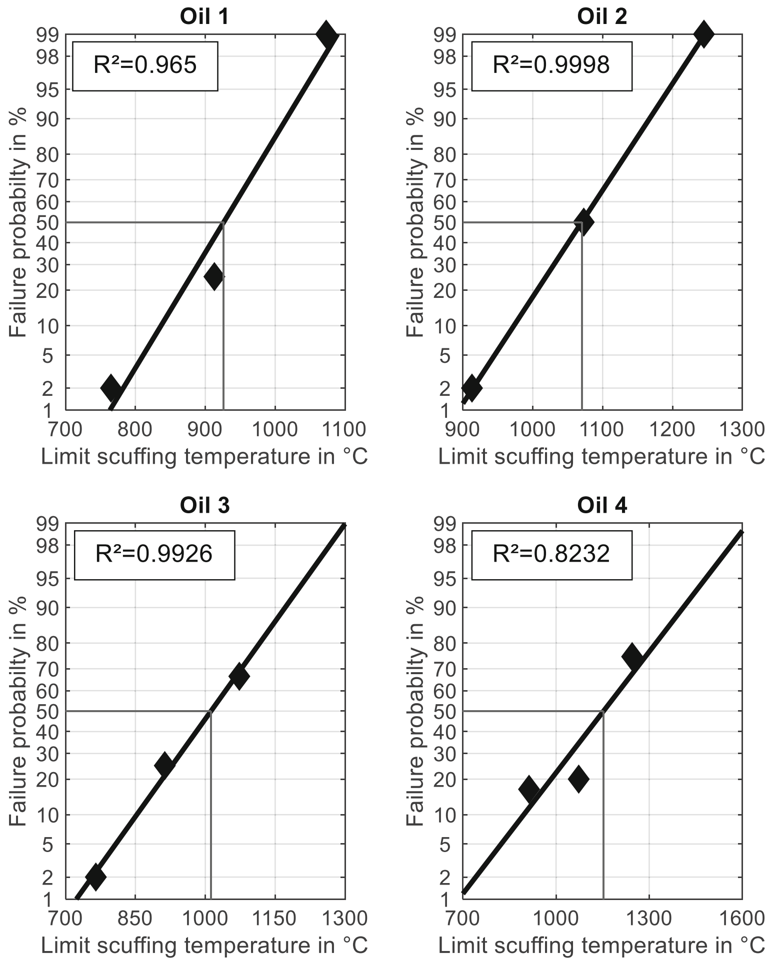

Fig. 6 Evaluation of the spur gear test results using the extended modified Probit method

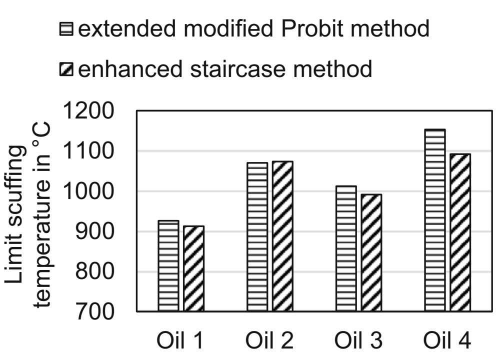

Fig. 7 Calculated limit scuffing temperature of the spur gear test method S-A10/16.6/90

corresponds to load stage 10 and not between the load stages of the spur gear test method S-A10/16.6R/90.

The trends of the scuffing load carrying capacity of the test oils is the same for both evaluation methods. According to the API classification of the test oils, oil 1 (API GL-3/4) has the lowest scuffing load carrying capacity, followed by oil 3 (API GL-4). Oils 2 and 4 (both API GL-5) have the highest scuffing load carrying capacities. Based on the test results shown, oils with a failure load stage of at least 10 are presumed to have the scuffing load carrying capacity of an API GL-5 gear oil.

6 Comparison of the test results of the spur gear test method S-A10/16.6R/90 and the new hypoid scuffing test method

Figure 8 compares the test results of the spur gear test method S-A10/16.6R/90 evaluated according to the enhanced staircase method and the extended modified Probit method to the test results of the new hypoid scuffing test method. Since there is a difference in the absolute values of the limit scuffing temperatures due to the different calculation methods for spur and hypoid gears, the relative limit scuffing temperatures, related to Oil 1, were used as a reference to clarify the comparison. Considering the influence of the selected calculation methods and test scatter, both test methods, the spur gear test method S-A10/16.6R/90 and the new hypoid scuffing test method, show the same tendencies between the test oils with regard to their scuffing load carrying capacity. This confirms that the scuffing load carrying capacity of gear oils determined by the spur gear

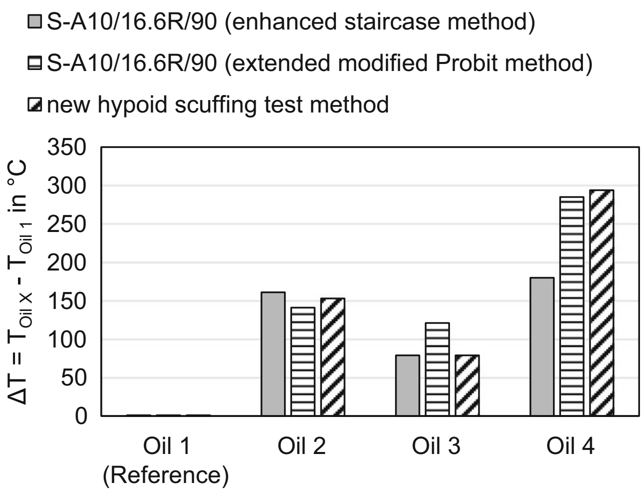

Fig. 8 Calculated limit scuffing temperature of the spur gear test method S-A10/16.6/90

scuffing test method S-A10/16.6R/90 can be used within the calculation of the scuffing load carrying capacity of hypoid gears.

7 Summary and Conclusion

Since it is generally not possible to determine the influence of the lubricant on the load carrying capacity of gears on the basis of physical or chemical oil data alone, experimental test methods are necessary. Due to the high scuffing load carrying capacity of highly additivated hypoid oils, the limits of many test methods are reached. In order to ensure testing highly additivated hypoid oils as close as possible to their application a new hypoid scuffing test was developed. However, since spur gear scuffing test methods can be carried out more quickly and with less resource and effort, the applicability of the spur gear scuffing test S-A10/16.6R/90 to high additivated hypoid oils is investigated. The research question was if the scuffing load carrying capacity of gear oils determined on spur gears can be applied to hypoid gears. Therefore, four gear oils were experimentally investigated, using the spur gear test method S-A10/16.6R/90 and the new hypoid scuffing test method. To evaluate the test results, a limit scuffing temperature was determined. The choice of calculation method and the statistical evaluation methods used are discussed in detail in the paper. A comparison of the limit scuffing temperatures of the test oils determined using the spur gear scuffing test method S-A10/16.6R/90 and the new hypoid scuffing test shows that the scuffing load carrying capacity of gear oils determined on spur gears can be applied to hypoid gears. For sustainability reasons, it is recommended to use the spur gear test method S-A10/16.6R/90 to obtain a classification in API GL-4 or -5. For a differentiation of high additivated hypoid oils within the API GL-5 classification with regard to their scuffing load carrying capacity, the spur gear test method can reach its limits. Consequently, the new hypoid scuffing test method is then recommended to determine a limit scuffing temperature for the test oils with such a high scuffing load carrying capacity.

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Conflict of interest A. Drechsel, J. Pellkofer and K. Stahl declare that they have no competing interests.

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