

INFORMATION

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Short Test Procedure to investigate the Lubricant Influence on the Pitting Carrying Capacity of Gears

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DGMK-FZG short duration pitting test

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Summary:

The pitting test method according to FVA 2/IV and its further development according to FVA 371 were developed to determine the lubricant influence on the pitting carrying capacity of gears.

These test methods provide comprehensive information, but they are relatively time-consuming and cost-intensive. An efficient short test procedure, as a screening test to differentiate several lubricants regarding their pitting resistance, was missing so far.

In this research project the DGMK short duration pitting test was developed and tested with lubricants, whose pitting carrying capacity is well known from the existing pitting tests.

The DGMK short pitting test categorizes candidate lubricants regarding their pitting resistance in the load carrying capacity classes low, medium and high. The test procedure requires approx. 2 weeks for this. The determined load carrying capacity classes correlate well with results of the pitting test methods according to FVA 2/IV and FVA 371, although a possible influence of micropitting on the pitting lifetime in the test FVA 2/IV has to be considered.

The DGMK short duration pitting test represents a suitable short test procedure, which differentiates lubricants regarding their pitting carrying capacity with good repeatability and with a shortened test duration. This test procedure is to be seen primarily as a supplement to the existing FVA pitting test methods.

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1 Introduction

Gear flank pitting results from fatigue of the base material with increasing running time. A typical pitting failure is shown in **Fig. 1**.

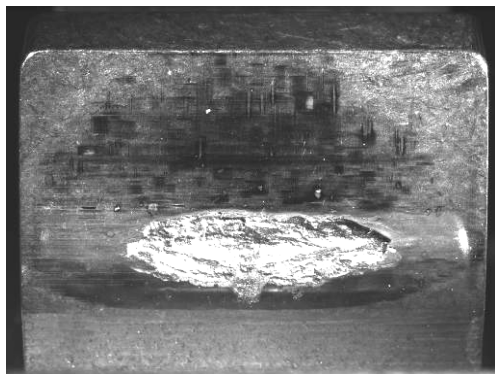


Fig. 1: pitting failure in the short duration pitting test with FVA2+4%A99

Because of the complexity of the influences of additives and base oil, the lubricant influence on the pitting resistance is considered insufficiently in the existing calculation methods. Hence the practical testing of lubricants under defined conditions is necessary. The lubricant test provides important data for the development of lubricants and lubricant additives. The test also demonstrates the suitability of a lubricant regarding its pitting performance for selection by transmission manufacturers and users.

2 Purpose of the test

The DGMK-FZG short duration pitting test (abbreviated as KPTX) /4/ represents a supplement to the available pitting test methods acc. to FVA 2/IV /2/ and FVA 371 /3/, that are used as standard approval tests. The KPTX can be run on any standard FZG test rig with centre distance $a = 91.5$ mm and splash lubrication. The short duration pitting test can be used to determine the influence of lubricants on the pitting resistance. Due to the significantly reduced running time, the KPTX is

an appropriate method for the development of optimized lubricants and additives as well as the rapid evaluation of used lubricants, for example in the case of performance complaints. The KPTX differentiates lubricants regarding their influence on the pitting load carrying capacity and it categorizes candidate lubricants in the pitting resistance classes low, medium and high.

3 Scope of the test

The existing, relatively time-consuming and cost-intensive pitting test methods acc. to FVA 2/IV /2/ and FVA 371 /3/ provide comprehensive information about the pitting carrying capacity of lubricants and their results can be included in the load carrying capacity calculation acc. to DIN 3990 /1/. Therefore these test methods will continue to be used to approve lubricants. But this time and cost effort is neither necessary nor acceptable for all applications. Thus the short duration pitting test is suitable to compare lubricants of the same application, for the development of oil and in the case of performance complaints.

4 Description of the test procedure

The short duration pitting test is a step test running at load stages 9 and 10. The short pitting test categorizes candidate lubricants regarding their pitting resistance in the load carrying capacity classes low, medium and high.

4.1 Test conditions

Table 1 shows the standard conditions for the short duration pitting test. The oil sump temperature is thermostatically controlled. **Table 2** contains the torque on the pinion and the Hertzian contact stress of the load stages of the test.

running in	
duration	$2.6 \cdot 10^5 \text{ LC}_{\text{Pi}} \approx 2 \text{ h}$
pinion torque	94.1 Nm (load stage 5)
pinion speed	$n_1 = 2250 \text{ rpm}$, pinion drives
oil sump temperature	$\vartheta_{\text{Oil}} = 60 \text{ }^\circ\text{C}$ starting temperature
test run	
pinion torque	load stage 1 $T_1 = 302.0 \text{ Nm}$ (load stage 9) load stage 2 $T_1 = 372.6 \text{ Nm}$ (load stage 10)
pinion speed	$n_1 = 2250 \text{ rpm}$, pinion drives
oil sump temperature	$\vartheta_{\text{Oil}} = 90 \pm 3 \text{ }^\circ\text{C}$
lubrication	splash lubrication; oil level: centre line of the shafts
duration	until reaching of failure criterion (see below), maximally $12.7 \cdot 10^6 \text{ LC}_{\text{Pi}}$ $\approx 98 \text{ h}$ per load stage
failure criterion	pitting area on the most damaged tooth at least 4 % of the active flank (approx. 5 mm^2)
inspection	every $1.8 \cdot 10^6 \text{ LC}_{\text{Pi}} \approx 14 \text{ h}$

Table 1: test conditions of the DGMK-FZG short duration pitting test

load stage	pinion torque T_1 [Nm]	maximal local Hertzian contact stress [N/mm ²]
5 (running in)	94.1	1433
9	302.0	2069
10	372.6	2243

Table 2: load stages of the short duration pitting test

4.2 Test procedure

At the beginning of the running in the oil sump should have a temperature of minimum $60 \text{ }^\circ\text{C}$. Subsequently the temperature has to be controlled at $90 \pm 3 \text{ }^\circ\text{C}$. Before starting the test run an oil sump temperature of $90 \text{ }^\circ\text{C}$ has to be ensured.

The short duration pitting test starts with a running in of 2 hours at load stage 5. Subsequently the actual stage test begins. First of all the gears are tested at load stage 9. The maximum test duration is 12.7 million load cycles on the pinion. If pitting damage occurs during this running time, the test run should be repeated on the reverse gear flank. Should the test gear complete the first load stage without any pitting, the load is increased to load stage 10. The test run continues on the same gear flank. The test is stopped, if a pitting damage occurs or after a maximum running time of 12.7 million load cycles on the pinion.

After the test run, if necessary before increasing the torque, the gears must be removed and the gear tooth flank condition be documented.

4.3 Test gears

The short duration pitting test is run with the same test gears as the FVA-FZG practice relevant pitting test /3/. The gears with the geometry „FZG-C“, type „C-PTX“ used here are optimized regarding sliding velocity. They have flank corrections and are superfinished.

Table 3 shows the gear geometry data.

dimension	symbol	value	unit	
centre distance	a	91.5	mm	
tooth width	b	14.0	mm	
working pitch diameter	pinion	d_{w1}	73.2	mm
	wheel	d_{w2}	109.8	mm
tip diameter	pinion	d_{a1}	82.46	mm
	wheel	d_{a2}	118.36	mm
module	m_n	4.5	mm	
number of teeth	pinion	z_1	16	-
	wheel	z_2	24	-
addendum modification factor	pinion	x_1	0.1817	-
	wheel	x_2	0.1715	-
pressure angle	α	20	°	
	α_{wt}	22.44	°	
helix angle	β	0	°	
reference diameter	pinion	d_1	72.0	mm
	wheel	d_2	108.0	mm
base diameter	pinion	d_{b1}	67.66	mm
	wheel	d_{b2}	101.49	mm
transverse contact ratio	ϵ_α	1.46	-	
tooth modification	pinion: without profile and lengthwise crowning; wheel: tip and root relief $C_a = C_f = 50 \pm 4 \mu\text{m}$, lengthwise crowning $C_b = 30 \pm 3 \mu\text{m}$			

Table 3: gear geometry data of the test gears type C-PTX

Table 4 shows the data concerning the gear material, heat treatment and quality.

material	16MnCr5 acc. to DIN EN 10084
heat treatment	case carburized
core strength	1000 – 1300 N/mm ²
surface hardness	59 – 63 HRC
case depth	0.8 – 1.0 mm
at limit hardness	550 HV 1
content of retained austenit	< 30 %
gear quality	5 acc. to DIN 3962, part 1
roughness R_a of tooth flanks	$0.1 \pm 0.05 \mu\text{m}$ measured in involute direction acc. to DIN 3969, part 1
grinding method	form grinding with adjustable corund disks (Samputensili)
superfinishing	superfinishing acc. to SMS-Vibration-Superfinishing procedure of the company Schnarrenberger GmbH

Table 4: manufacturing processes of the test gears type C-PTX

4.4 Test stand

For the short duration pitting test the FZG test gear rig (loaded mechanically or hydrostatically) with splash lubrication is used.

4.5 Assembly of test gears

As with the established pitting test methods FVA 2/IV /2/ and FVA 371 /3/ the gear (24 teeth) is mounted on the motor shaft. The pinion (16 teeth) is the driving gear.

4.6 Failure criterion and classification in pitting resistance classes

The test run is stopped, when the pitting area exceeds 4 % of the active flank of one tooth (approx. 5 mm²). The classification of the candidate lubricant into the pitting resistance class low, medium or high depends on the torque at which pitting damage occurs (**Table 5**). A completed test with a pitting area smaller than the failure criterion can be rated as failure.

pitting resistance class acc. to the KPTX	moment of pitting damage
pitting resistance low	pitting failure during testing at load stage 1 (during $12.7 \cdot 10^6$ LC _{Pi} at load stage 9)
pitting resistance medium	no pitting during testing at load stage 1, pitting failure during testing at load stage 2 (during $12.7 \cdot 10^6$ LC _{Pi} at load stage 10)
pitting resistance high	no pitting during the whole test procedure

Table 5: classification in pitting resistance classes according to the KPTX

5 Documentation of the results

The number of completed load cycles on the pinion and the pitting resistance class shall be documented. If micropitting occurs the micropitted area should be noted as a % of the whole flank area. The gear damage after every test run should be documented as follows:

- a photograph of the most damaged tooth flank as well as photographs of one undamaged tooth flank of both the pinion and the wheel.

It is also recommended that a profile measurement along the involute and across the flank of three undamaged tooth flanks of both pinion and wheel be recorded.

6 Result of the reference lubricant Shell Spirax MA 80W

The test runs with the reference oil Shell Spirax MA 80W were stopped due to typical scallop shaped pitting at load stage 10 after an average running time of 3 million LC_{Pi}. Thus this lubricant reaches the pitting resistance class medium. There was no micropitting found.

7 Comparability of the results of the DGMK-FZG short duration pitting test

The DGMK-FZG short duration pitting test categorizes candidate lubricants regarding their pitting resistance in the load carrying capacity classes low, medium and high. The result of the existing FVA pitting test methods is the pitting lifetime for 50 % failure probability. Results of gear oils from the market place investigated in this research project show a good correlation between the achieved pitting resistance classes of the KPTX and results of the existing FVA pitting test methods. As in the practice relevant pitting test acc. to FVA 371 /3/ the tested gear flanks of the KPTX show no micropitting. This is due to the superfinishing of the test gears type C-PTX. Due to the C-PT gears ($R_a = 0.2 \dots 0.4 \mu\text{m}$) used in the test FVA 2/IV /2/ the possible influence of micropitting on the pitting lifetime has to be considered when comparing test results.

8 Literature

- /1/ DIN 3990: Tragfähigkeitsberechnung von Stirnrädern. Dezember 1987.
- /2/ FVA-Informationsblatt zum Forschungsvorhaben 2/IV „Pittingtest“. 1997.
- /3/ FVA-Informationsblatt zum Forschungsvorhaben 371 „Praxisnaher Pittingtest“. 2006.
- /4/ Hergesell, M.: Entwicklung eines Kurzzeit-Pittingtestes zum Einfluss des Schmierstoffs auf die Grübchentrugfähigkeit von Stirnrädern. Abschlussbericht zum DGMK-Vorhaben 623, 2006.