Different high-performance gear oils were examined on an FZG back-to-back gear test rig to determine if changeover to these high-performance gear oils could stop micropitting formation which occurred with other industrial gear oils.

By Michael Hochmann and Hermann Siebert
MICROPITTING FORMATION IS OFTEN REPORTED TO OCCUR IN FIELD APPLICATIONS EVEN THOUGH INDUSTRIAL GEAR OILS WITH A HIGH MICROPITTING LOAD-CARRYING CAPACITY ARE USED. SUCH OILS OFFER GOOD MICROPITTING PROTECTION DETERMINED IN THE LOAD STAGE TEST OF THE MICROPITTING TEST ACCORDING TO FVA 54/7 [5], BUT SHOW A LOW ENDURANCE MICROPITTING PERFORMANCE. THEREFORE, THE POSSIBILITY OF STOPPING MICROPITTING FORMATION, WHICH OCCURRED WITH THESE GEAR OILS, WAS INVESTIGATED BY USING HIGH-PERFORMANCE GEAR OILS.

DUE TO ADVANCED ADDITIVE TECHNOLOGIES, THESE HIGH-PERFORMANCE GEAR OILS SHOW A HIGH MICROPITTING LOAD-CARRYING CAPACITY IN THE MICROPITTING LOAD STAGE TEST AS WELL AS A HIGH ENDURANCE MICROPITTING PERFORMANCE.

**MICROPITTING LOAD-CARRYING CAPACITY**

The micropitting load-carrying capacity of gears can be calculated according to ISO TR 15144-1 [4], where the influence of lubricant, operating conditions, and surface roughness is considered with the specific lubricant film thickness. For this purpose, the specific lubricant film thickness of a practical gear is compared with a minimum required specific lubricant film thickness. The latter is the specific film thickness where no micropitting risk is given for a lubricant and can be determined by performing a micropitting test according to FVA 54/7 [5].

**STANDARD MICRO-PITTING TEST**

The micropitting test according to FVA 54/7 [5] consists of a load stage test and an endurance test. Test gears type C-GF run at a circumferential speed of 8.3 m/s and a lubricant temperature of 90°C or 60°C. The load and the test periods are varied.

In the load stage test, the load is increased stepwise from load stage LS 5 to load stage LS 10 with a running time of 16 h per load stage. After the load stage test, an endurance test with a running time of 80 h in load stage LS 8 and 5 x 80 h in load stage LS 10 is performed. The pinion torque and the corresponding Hertzian pressure of the different load stages are given in Table 2.

At the end of the load stage test and the endurance test with the first test gears, the load stage
test is repeated with new test gears to check repeatability. After each test period, the test gears are disassembled and the profile of the tested flanks is measured using a 3D measurement system. In the load stage test, the failure criterion has been reached if the mean profile form deviation due to micropitting exceeds the limiting value of 7.5 µm. The load stage in which the failure criterion is reached is called failure load stage. An overview regarding the classification of test results obtained in the micropitting test is given in Table 3.

Lubricants with a high micropitting load-carrying capacity reach the failure criterion of a profile form deviation of 7.5 µm due to micropitting in load stage ≥ LS 10 of the load stage test. Examples for the evaluation of the micropitting test are given in Fig. 3 and Fig. 4.

In the endurance test, a stagnation of micropitting formation compared with the micropitting area at the end of the load stage test is preferred but not required.

For high-performance gear oil on the basis of polyglycol with a high micropitting performance, a typical test result is given in Fig. 5 showing the profile form deviation due to micropitting. The profile form deviation of the pinion is below the failure criterion for the whole load stage test. In the endurance test, the profile form deviation stagnates compared with the step test.

![Fig. 3: Pinion type C-GF with measurement of the profile, nearly no micropitting failure.](image)

![Fig. 4: Pinion type C-GF with measurement of the profile, micropitting failure in the range of the failure criterion.](image)
MODIFICATION OF THE STANDARD MICROPITTING TEST

The aim of research is whether changing from oils with low endurance micropitting performance to oil with high endurance micropitting performance can stop micropitting formation. Therefore the standard micropitting test according to FVA 54/7 [5] was modified. For oil with a high micropitting load-carrying capacity, but low endurance performance, a load stage test and an endurance test are performed with the first test gears. After the repeated load stage test with new test gears, an oil change is made. The subsequent endurance test is conducted to find out whether a product with a high micropitting load-carrying capacity in the load stage test as well as a high endurance performance can stop micropitting formation. The oil temperature is set to 60°C compared to an oil temperature of 90°C, the lubricant film thickness in the gear mesh is higher, but the formation of a reaction layer on the tooth flank surfaces is more difficult. The latter is more critical regarding the formation of micropitting.

TEST EQUIPMENT

The test runs conducted to determine whether micropitting can be stopped by using high-performance gear oils were performed on a FZG back-to-back gear test rig [3]. The schematic setup of the FZG back-to-back gear test rig is shown in Figure 6.

The FZG back-to-back gear test rig utilizes a re-circulating power loop principle, also known as a foursquare configuration, in order to provide a fixed torque (load) to a pair of test gears. The test gearbox and drive gearbox are connected with two torsion shafts. One shaft is divided into two parts and contains a load coupling...
used to apply the torque (load) through the
use of weights hung on the loading arm.
A separate oil aggregate contains heating
and cooling elements to control the oil
temperature as required by the operating
test conditions. Before the oil is injected
into the gear mesh of the test gears, it is
filtered with a 10µm filter.
In order to investigate if micropitting can
be stopped, test gears type C-GF of the
standard micropitting test according to FVA
54/7 [5] are used. The geometrical data
and manufacturing details of the test gears
type C-GF are shown in Table 4 and Table 5.

LUBRICANTS TESTED
A specialty lubricant manufacturer’s goal is
to supply industrial gear oils on the basis
of mineral oil, polyalphaolefin, or polyglycol
showing a high micropitting load-carrying
capacity of failure load stage ≥ LS 10 in the
load stage test as well as a stagnation of
micropitting formation in the endurance
test according to FVA 54/7 [5] by selection of advanced additive technologies.
See also Fig. 5. These industrial gear oils
show excellent micropitting protection not
only at an oil temperature of 90°C, but
also at a lower oil temperature of 60°C,
and the advanced additive technologies
can react on the surface of the tooth
flanks and protect them against micropit-
ting formation.

Fig. 6: FZG back-to-back gear test rig.

Fig. 7: Stopping micropitting by using a high-perfor-
mance gear oil (mineral oil).
Additionally, the tests questioned whether micropitting formation occurred with other gear oils and whether changing to high-performance gear oils can stop micropitting. The oil data of the tested gear oils are shown in Table 6 and Table 7. Both the high-performance gear oils and the reference oil are of ISO VG 320 and possess a high micropitting load-carrying capacity according to FVA 54/7. All tested gear oils are specified according to DIN 51517 [2], which includes the minimum requirements for industrial gear oils and is similar to AGMA 9005 [1]. For the reference oil, the micropitting load-carrying capacity was only tested at an oil temperature of 60°C because at this oil temperature, it was to be investigated if micropitting formation can be stopped. See also Fig. 7, Fig. 8 Fig. 9.

<table>
<thead>
<tr>
<th>lubricant</th>
<th>chemistry of the base oil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>viscosity of the oil type and amount of additives</td>
</tr>
<tr>
<td>tooth flank surface</td>
<td>roughness</td>
</tr>
<tr>
<td></td>
<td>surface texture</td>
</tr>
<tr>
<td>operating conditions</td>
<td>normal and frictional load</td>
</tr>
<tr>
<td></td>
<td>circumferential speed</td>
</tr>
<tr>
<td></td>
<td>temperature</td>
</tr>
</tbody>
</table>

Table 1: Influences on the micropitting load-carrying capacity.
TEST RESULTS

For reference oil with a high micropitting load-carrying capacity, but low endurance performance, a load stage test and an endurance test were performed with the first test gears according to FVA 54/7 [5]. The reference oil always showed the test result GFT-high at the end of the load stage test. But in the subsequent endurance test, micropitting formation increased. The endurance test was finished due to pitting formation. Then the load stage test was repeated for the reference oil using new test gears. All repeated test runs of the reference oil showed a good repeatability compared with the first load stage test of this oil. See Fig. 7, Fig. 8, and Fig. 9.

After the repeated load stage test for the reference oil, an oil change to high-performance gear oil on basis of mineral oil with a high micropitting load-carrying capacity as well as a high endurance micropitting performance was conducted. This oil change to a high-performance mineral gear oil using advanced additive technologies stopped micropitting formation compared with the reference oil. This shows that these advanced additive technologies can react at the surface of the tooth flanks after an oil change and build up a new improved reaction layer. Further micropitting formation was stopped and the micropitting area stagnated. See Fig. 7.

The oil change to high-performance gear oil on the basis of polyalphaoelfin with a high micropitting load-carrying capacity as well as a high endurance micropitting performance can also stop the micropitting formation compared with the reference oil. The reason for the stagnation of the micropitting areas are, again, the advanced additive technologies in

<table>
<thead>
<tr>
<th>Load stage</th>
<th>Pinion torque, T₁ Nm</th>
<th>Hertzian pressure, p₁ N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS 5</td>
<td>70.0</td>
<td>795.1</td>
</tr>
<tr>
<td>LS 6</td>
<td>98.9</td>
<td>945.1</td>
</tr>
<tr>
<td>LS 7</td>
<td>132.5</td>
<td>1093.9</td>
</tr>
<tr>
<td>LS 8</td>
<td>171.6</td>
<td>1244.9</td>
</tr>
<tr>
<td>LS 9</td>
<td>215.6</td>
<td>1395.4</td>
</tr>
<tr>
<td>LS 10</td>
<td>265.1</td>
<td>1547.3</td>
</tr>
</tbody>
</table>

Table 2: Load stages of the micropitting test.

<table>
<thead>
<tr>
<th>Description</th>
<th>Failure load stage</th>
<th>Micropitted area</th>
<th>GF-class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low micropitting load-carrying capacity</td>
<td>≤ LS 7</td>
<td>Sometimes more than 50%</td>
<td>GFT-low</td>
</tr>
<tr>
<td>Medium micropitting load-carrying capacity</td>
<td>LS 8 - LS 9</td>
<td>About 30%</td>
<td>GFT-medium</td>
</tr>
<tr>
<td>High micropitting load-carrying capacity</td>
<td>≥ LS 10</td>
<td>Less than 20%</td>
<td>GFT-high</td>
</tr>
</tbody>
</table>

Table 3: Classification of test results of the micropitting test.
this high-performance polyalphaolefin gear oil. Even after an oil change, these advanced additive technologies can react at the surface of the tooth flanks and build up a new improved reaction layer. See Fig. 8.

Finally, also high-performance gear oil on the basis of polyglycol with a high micropitting load-carrying capacity as well as a high endurance micropitting performance can stop micropitting formation after an oil change compared with the reference oil due to the advanced additive technologies. See Fig. 9.

All endurance tests for the high-performance gear oils on the basis of mineral oil, polyalphaolefin, and polyglycol were stopped after the same running time as the reference oil but without any pitting formation.

## CONCLUSIONS

High-performance gear oils on the basis of mineral oil, polyalphaolefin, or polyglycol show a high micropitting load-carrying capacity of failure load stage \( \geq \text{LS 10} \) in the load stage test as well as a stagnation of micropitting formation in the endurance test according to FVA 54/7 [5] by selection of advanced additive technologies.

The new test results showed that high-performance gear oils using advanced additive technologies can react at the surface of the tooth flanks after an oil change and stop further micropitting formation. The micropitting area, which occurred with other gear oils, stagnates after changeover to high-performance gear oils. Therefore, these high-performance gear oils are strongly recommended to stop micropitting formation in field applications.

## REFERENCES

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