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INFLUENCES ON THE WEAR BEHAVIOR OF GREASE LUBRICATED GEARS OPERATED WITH DIP AND SPRAY LUBRICATION

TRACK OR CATEGORY

Gears I

AUTHORS AND INSTITUTIONS

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INTRODUCTION

The international standard ISO 14635-3 [1] offers a method to investigate the wear behavior of grease lubricated gears in the FZG back-to-back test rig. This standardized test is run with dip lubrication. Grease thickener, base oil viscosity and lubricant additives are known to have significant influence on the wear behavior. Some studies have also identified the lubrication supply mechanisms 'channeling' and 'circulating' to affect the wear intensity considerably. Large open gear drives, however, are often spray lubricated. It is uncertain, to what extent the test results with dip lubrication apply to spray lubricated gear drives. Within a research project (see acknowledgments) and a Master's Thesis [6], comparative tests have been performed, showing the effects of different lubrication types on the wear behavior of gears. A test rig was modified and the bulk temperature was measured via an infrared sensor. Under nominally equivalent tribological test conditions, spray lubrication has been found to reduce gear wear significantly compared to dip lubrication.

WEAR BEHAVIOR UNDER DIP LUBRICATION AND TEST PROCEDURE ISO 14635-3

The wear behavior of lubricated gears was comprehensively investigated by Plewe [7]. Most of his experiments were performed with hardened gears, lubricated with plain mineral oil. Plewe found, that the wear risk and the wear rate strongly depend on the minimum lubricating film thickness that can be evaluated using the elasto-hydrodynamic theory provided by Dowson and Higginson [3]. The wear rate increases with thinner lubricating film due to high load, low viscosity or slow speed. Plewe also performed a smaller number of experiments with an NLGI 00 flow grease. The fundamental correlation between lubricating film thickness and wear rate applies as well for the grease. But in the range of very thin lubricating films, the grease shows lower wear rates than the oil, whereas for thicker lubricating films the opposite applies.

Further systematical experiments regarding the specific characteristics of grease lubricated gears were carried out by Hochmann [4], [5] and Stemplinger [8], [9]. Hochmann tested NLGI 00 flow greases with different thickener types as well as their base oil in single stage tests under dip lubrication. He found very similar wear rates for the oil and the greases. The wear rates he determined correspond well to the Plewe model but are overall slightly lower than expected, which is probably due to a sulfur-phosphorous additive package his lubricants contained. Stemplinger carried out similar experiments, but with higher consistency greases. In the range of thick lubricating films, he found significantly higher wear rates for high consistency and high viscosity greases than for the base oil or the greases that Hochmann used.

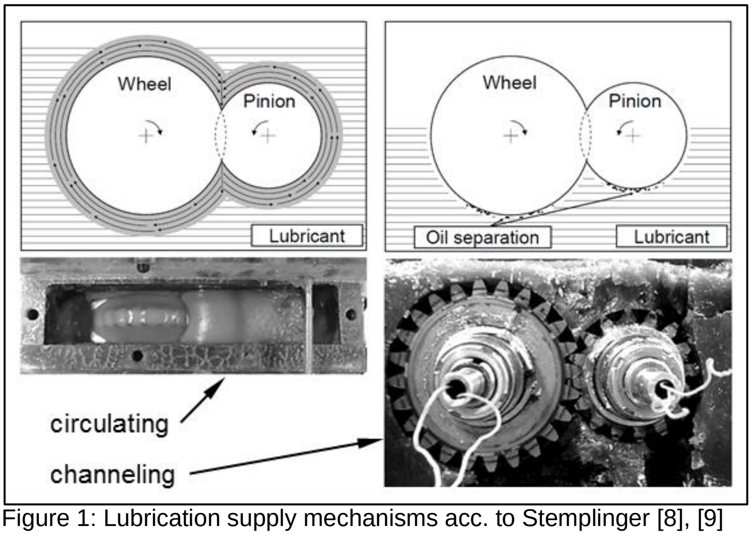

Figure 1: Lubrication supply mechanisms acc. to Stemplinger [8], [9]

These findings could be explained as it was identified, that different lubrication supply mechanisms exist, depending on the lubricant consistency and the operational conditions of the test gears: ‘circulating’ and ‘channeling’ (see Figure 1).

As not only the physical properties, but also the chemical composition of a lubricant have strong influence on the wear behavior, it is necessary to determine the performance of a specific lubricant with the help of adequate test procedures. Such tests are best carried out in a testing environment that depicts the conditions in field applications [2]. Consequently, the test procedure acc. to ISO 14635-3 was established to determine the scuffing load-carrying capacity and the wear characteristics of flow greases in a back-to-back gear test rig. The test consists of two parts. The first part is a load stage test with progressively increased torque transmitted from one test gear to the other. If this test is passed without a scuffing damage, an endurance test follows. In this test, the amount of mass loss of the gear set due to wear is monitored over a runtime of 50 hours under constant operational conditions. Using the calculation approach acc. to Plewe, the test result can be introduced into a wear lifetime calculation for gears in an actual application. This standardized test method is quite similar to the experiments carried out by Hochmann and Stemplinger. Thus it must be considered that the unfavorable ‘channeling’ might occur in the test. Moreover, many applications for grease lubricated gears are found in heavy industry sectors with large open gear drives. These drives are typically spray lubricated, which means that grease is precisely sprayed on the tooth flanks with the help of compressed air. In such gear drives, ‘channeling’ and the resulting lubricant starvation are not to be expected.

EXPERIMENTAL PROGRAM, TEST EQUIPMENT AND TEST CONDITIONS

In order to investigate the transferability of ISO 14635-3 wear test results to practical applications, the previous dip lubrication tests performed by Stemplinger were complemented by experiments under spray lubrication. All experiments were performed on an FZG back-to-back gear test rig with center distance a = 91.5 mm. The basic principle of the test rig is described in ISO 14635. For the experiments with spray lubrication, the test gear box was slightly modified, as shown in Figure 2. Fresh lubricant was sprayed onto the driving pinion flanks intermittently while the temperature of the driven wheel was measured continuously.

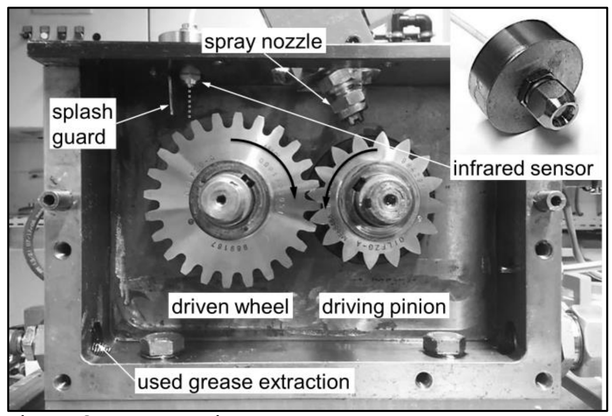

Figure 2: Test gear box

Table 1 shows an overview of the 6 test lubricants. BO and MG1-3 are the same model lubricants, Stemplinger used for his tests. Test results at dip lubrication are therefore directly available. CG1 and CG2 are commercially available high performance greases. Tests at dip lubrication were performed within this work prior to spray lubrication tests.

All tests at dip lubrication were essentially conducted acc. to ISO 14635-3. This means especially, that a test gear set ‘type A’ was loaded with a pinion torque of 372.6 Nm and rotated at a pinion speed of 750 rpm. The runtime was increased to $4.5 \cdot 10^6$ pinion revolutions total for more expressive results. The sump temperature was limited to 80 °C. Due to the absence of a lubricant sump that could have been used to cool the test gears, these operating conditions would have caused overheating and scuffing of the gears at spray lubrication. Thus, the operating conditions for the spray lubrication tests were modified in order to reduce load dependent gear power losses. By specifically reducing both the torque and the speed, it was possible to adjust operating conditions so, that the steady-state temperature of the gears as well as the minimum lubricant film thickness in each spray lubrication test was the same as in the respective dip lubrication test.

Each test was paused twice to document the condition of the tooth flanks as well as the mass loss of the test gears. The total mass loss at the end of each test was introduced into the wear calculation acc. to Plewe to determine linear wear coefficients for each lubricant and lubrication method.

Code	NLGI grade	Worked penetration DIN ISO 2137 25 °C / 0.1 mm	Base oil nom. kin. viscosity at 40°C / mm²/s	solid lubricants
BO	-	-	646	-
MG1	0	364	646	-
MG2	0	367	1540	-
MG3	00	431	646	-
CG1	00	430	700	-
CG2	0	380	1050	graphite

Table 1: Overview of the test lubricants

TEST RESULTS, EVALUATION AND CONCLUSION

Figure 3 shows the summarized test results. For each lubricant three linear wear coefficients are shown. The first one represents Stemplinger's test results at dip lubrication acc. to ISO 14635-3 (except CG1 and CG2, which were determined in the present work). The second one represents the newly obtained results from spray lubrication tests. The third supplementary value shows the expected wear coefficient based on Plewe's grease tests. The Plewe flow grease wear curve was extrapolated therefore.

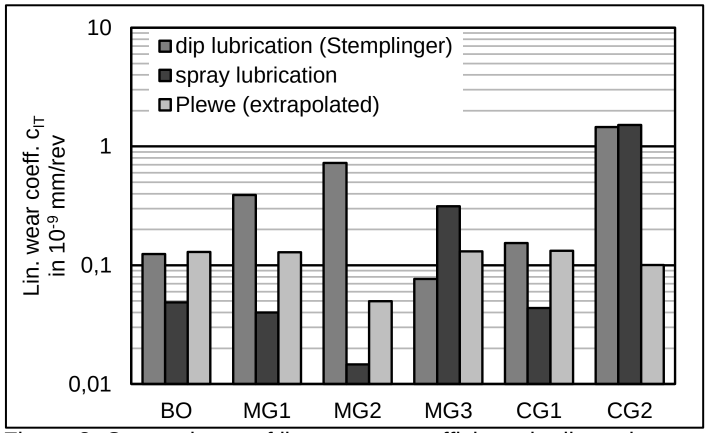

Figure 3: Comparisson of linear wear coefficients in dip and spray lubrication tests and expected coefficients acc. to Plewe [7]

For the higher consistent greases MG1 and MG2, significantly lower wear coefficients are found at spray lubrication compared to dip lubrication. The wear reduction is even higher for the grease MG2 with the highly viscous base oil. The NLGI 00 grease CG1 also shows a significant but less pronounced wear reduction at spray lubrication. This supports the hypothesis, that higher consistent lubricants operated with dip lubrication may promote sliding wear due to a 'channeling' effect. MG3 shows, however, a contrary behavior. Further lubricant analysis showed though, a drastic degradation of this lubricant due to the long storage time between dip and spray lubrication tests. This was not found for the other model greases. CG2 shows comparable and overall high wear in both the dip and the spray lubrication test. It must, however, be considered that this lubricant contains 10% graphite, which is known to promote abrasive wear intensely. The abrasive effect seems to be predominant here. The tests with the base oil BO surprisingly show significantly lower wear in spray lubrication, too. A reason for this might be the fact that in dip lubrication, wear particles can accumulate in the sump and promote abrasive wear. In spray lubrication, fresh and clean lubricant is available at the tooth flanks at all time.

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KEYWORDS

Gears:Open Gears, Lubricant Application/Disposal:Spray Lubrication, Wear:Bench Wear Tests