An Open-And-Shut Case: Greases for Gear Applications

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Studies of Different Types of Greases in the FZG Back-To-Back Gear Test Rig

For the lubrication of *open gear drives* used in different industrial applications such as cement and coal mills, rotary furnaces, or where the sealing conditions are difficult, *semi-fluid greases* are often used in preference to fluid oils. For girth gear applications the greases are used with a splash or spray lubrication system. The selection of such greases influences pitting lifetime and the load-carrying capacity of the gears, as well as wear behavior.

Investigations have been carried out making comparisons between a fluid oil and different semi-fluid (NLGI 00) grease formulations, varying with regard to base oil viscosity, thickener type and the addition of both liquid and solid additives. The test runs for the determination of the different parameters were performed on FZG back-to-back gear test rigs; the schematic setup of the test rig is shown in Figure 1.

The FZG back-to-back gear test rig utilizes a re-circulating, power-loop principle — also known as a "four-square configuration" in order to provide a fixed torque (load) to a pair of test gears. The test gearbox and drive gearbox are connected through two torsional shafts; one shaft is divided into two parts and contains a load coupling used to apply the load through the use of weights hung on the loading arm.

Depending on the particular tests in question, different test gears and test conditions were selected and details of these are available for the reader interested in articles previously presented by this author (see references). The test runs for the investigation of pitting lifetime and pitting load-carrying capacity were performed on the test rig using splash lubrication. After certain test intervals the flanks of the pinion and wheel were visually inspected for damage. The test results show that gear greases of NLGI 00 consistency exhibit almost the same pitting lifetime as their base oil counterparts. Furthermore, the kinematic viscosity of the base oil shows a significant influence on pitting lifetime of such NLGI 00 grade greases. The addition of a special synthetic graphite to such a gear grease led to a decrease in pitting life and high wear. The test results also show that the pitting load carrying capacity of these greases correlates with the kinematic viscosity of the base oil. Using a higher base oil viscosity, longer pitting lifetime and higher pitting load carrying capacity were achieved. For semi-fluid gear greases, the calculation of pitting load carrying capacity according to ISO 6336 using the viscosity of the base oil correlates well with the practical test results.

The tests to analyze wear behavior of different semi-fluid gear greases were made in the wear test A/2.8/50 on the basis of ISO 14635-3 and ISO 14635-1. Four different wear categories were defined for the 100-hour endurance test and a classification made according to the wear sum on the pinion and wheel.

Generally speaking, almost all investigated lubricants, with the exception of greases containing solid lubricants, show low wear in all test parts. The influence of the base oil viscosity can be seen in that greases with higher base oil viscosities exhibit lower wear. The influence of the concentration of thickener and the type of thickener is almost negligible, but the grease with an aluminum complex soap does show just a very slight higher wear sum compared to its lithium soap-thickened counterpart. A much more significant difference can be seen in the influence of the amount and type of solid lubricant. Greases containing synthetic graphite exhibit much higher wear sums — correlating with the amount of graphite in the grease — compared to the same grease with no solid lubricants. At the end of the step test the grease containing 4.2% graphite shows a three-times-higher wear sum than the base grease. And with a higher amount of graphite — 11.1% —the wear sum increased to a level of eight times higher compared to the grease with no solids. This trend was also confirmed in the endurance test; i.e. — the more graphite, the higher the wear. On the other hand, the grease containing 4.2% of molybdenum disulphide displays comparable wear

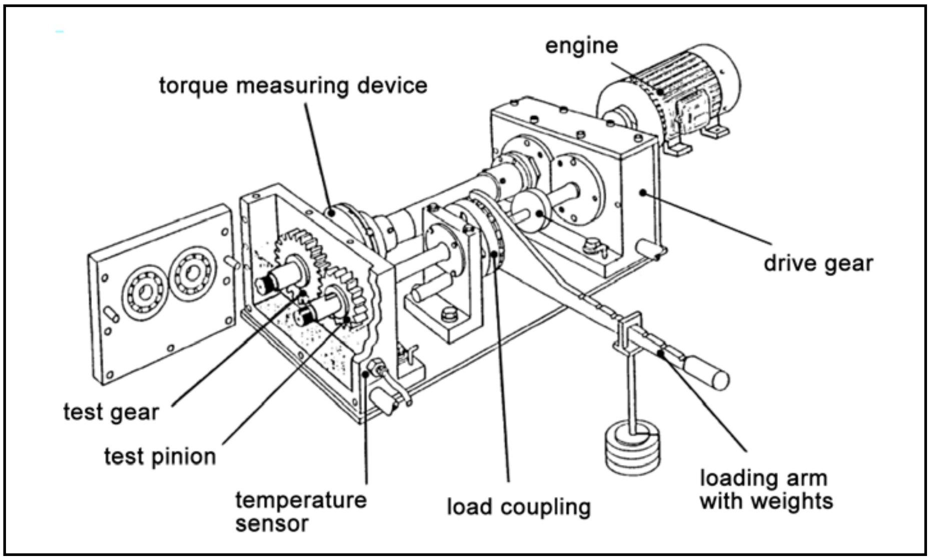

Figure 1 FZG back-to-back gear test rig.

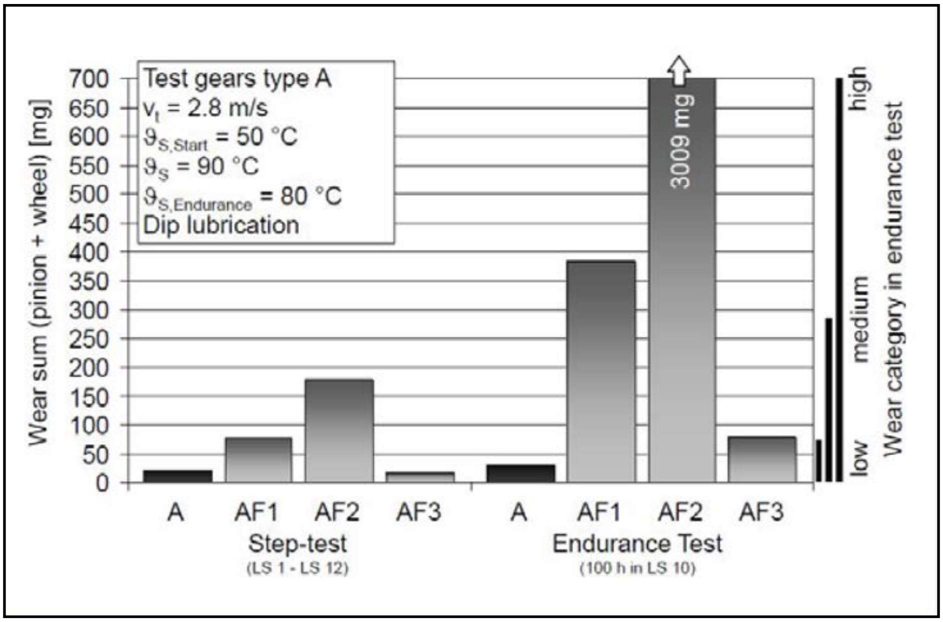

Figure 2 Wear behavior — influence of amount and type of solid lubricant.

A: Aluminum complex base grease
AF 1: Base grease + 4.2% graphite
AF 2: Base grease + 11.1% graphite
AF 3: Base grease + 4.2% molybdenum disulphide

to the base grease after the step test, and only slightly higher wear after the endurance test.

In a different context, for the lubrication of small, enclosed geardrives used in electrical tools or in medical applications, as well as for the lubrication of small gearboxes in difficult sealing conditions, stiffer greases are preferred, often of NLGI 1 or 2 grade consistency. The selection of grease type and the filling level influence efficiency, load-carrying capacity and heat transfer in a gearbox.

Investigations were performed with different greases of NLGI 1 and 2 consistency using different thickener types, lithium complex, aluminum complex, calcium complex and polyurea. Three types of base oils, all with kinematic viscosities approximately 100 $\mathrm{mm^2/s}$@40°C, were used, i.e. — paraffinic, naphthenic, and a synthetic polyalphaolefin. All model lubricants were formulated with 4% of a typical EP package for greases.

The tests for the determination of efficiency and load-carrying capacity were, once again, performed on FZG back-to-back test rigs. The influence of different filling levels (e.g. — 40, 50, and 80%) in dip lubrication has been analyzed. Based on the results of comprehensive studies using NLGI 1 and 2 grade greases in the FZG test rig, different lubrication supply mechanisms — channeling and circulating — have been identified. Whether channeling or circulating occurs depends on various factors such as the interaction of torque, speed, filling level and the type of grease.

Channeling. When the spur gearset starts to rotate, the grease next to the gearset is immediately discarded and does not return to that gearset due to the lack of a sufficient replenishment mechanism. A gap is formed between the rotating gears and the grease sump. No fresh grease flows from the sump to the gearset because of its solid consistency. A lack of lubrication and cooling can be observed that can lead to high bulk temperatures in the gears and, finally, to scuffing. Only a small amount of grease participates in the lubrication. Channeling occurs mainly at 40 and 50% filling levels and for stiffer products.

Circulating. In some cases, especially at high filling levels, a second, different lubricant supply mechanism can be observed. When the gears rotate, part of the grease in the sump rotates at a lower speed than the gears and, from time to time, fresh new grease flows from the sump in the direction of the gears. Compared to the situation with channeling, better lubricant supply to the gears, better cooling and thus lower bulk temperatures in the gears and higher sump temperatures can be observed. In total, more grease participates in the lubrication mechanism. Circulating occurs mainly at a filling level of 80%.

In general, the field of possible operating conditions with respect to load-speed combination is restricted by limited heat removal from the gears and, therefore, only high-speed, i.e. — low torque, low speed — high torque and medium speed — medium torque are possible operating conditions, thus limiting transmittable power without immediate scuffing failures. A lubrication-optimized, internal geometry of the housing without edges and corners, one which is tight-fitting to the gears, can improve heat transfer. And heat removal can, of course, be improved by cooling fans on the exterior of the gearbox.

Lubrication supply, efficiency and load-carrying capacity are somewhat influenced by the filling level. As a mini-

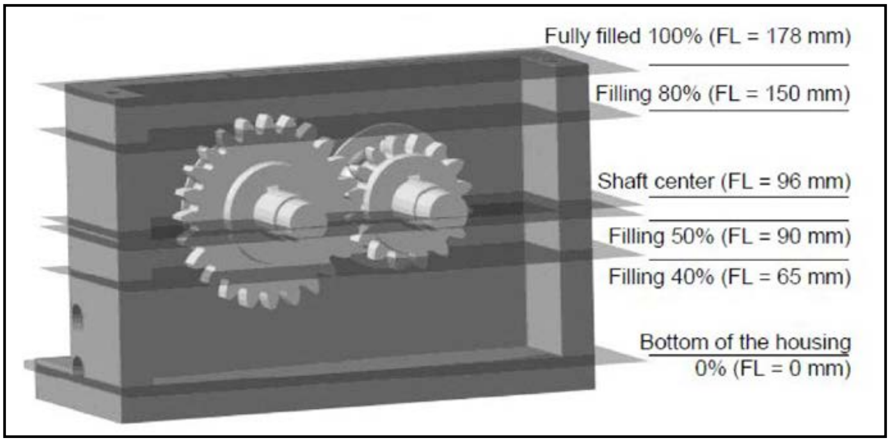

Figure 3 Filling of test gearbox.

mum filling level, it is necessary that all the gears are dipped into the lubricant. At the other extreme, a maximum filling up to 90–95% of the free volume in the gearbox is possible. A fully filled gearbox will leak due to the thermal expansion of the lubricants. A filling level of "shaft center" is a good compromise between low no-load losses, sufficient cooling, and adequate lubricant supply. When channeling occurs, low no-load losses, low sump temperatures, and high bulk temperatures can be observed with a high risk of wear and scuffing. On the other hand, circulating results in high no-load losses, better heat removal and thus lower bulk temperatures and higher sump temperatures.

When it comes to the optimal lubricant choice, the synthetic base oil shows advantages for frictional behavior and load-carrying capacity, whereas the naphthenic base oil cannot be recommended; the thickener type influences the lubricant supply to a minor degree. Lithium complex and aluminum complex greases show high oil separation and thus a good supply for channeling and circulating. Calcium complex shows the lowest oil separation of the greases and thus a lack of lubrication. Polyurea greases show the highest load-carrying capacity, the lowest frictional losses in the gear contact and good, high-temperature performance.

References:

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2. Stemplinger, J.-P., K. Stahl, B.-R. Höhn, K. Michaelis, H.-P. Otto and M. Hochmann. "Wear Behavior of Grease-Lubricated Gears," 2012, *ELGI–European Lubricating Grease Institute, 24th Annual General Meeting*, München.
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It Ain't Black — but It Works

The implementation of modern tribology offers substantial savings in wear, energy and, not least — money. According to Peter Jost in his presentation to the 2013 World Tribology Congress in Turin, "New materials and new technologies are cascading upon the world, but their tribological benefits are often not recognized by the end-users." Which is a pity, because there is so much to be gained by utilizing already-available lubrication technologies, not to mention the potential for developing new products with a focus on functionality rather than specification. Existing specifications are, in fact, often an impediment to progress; this is a dilemma for any new (lubricant) technology. Current specifications describe the old best practice products with emphasis on "old" — and, in many cases — reject a new and better product; new products need new specifications.

In grease-lubricated contacts it is accepted wisdom that thickener works only as a reservoir for the lubricant (the oil) that leaks out of the "sponge" into the contact zone and, after passing the zone, re-enters the grease matrix. We have now come to the conclusion that this theory does not fully correspond with reality. The thickener in soap-based greases contributes extensively to the formation of a lubricating film and, in some cases, the film can be twice as thick as it would have been when using an oil of the same viscosity as the base oil of the grease. We also found that at very high-contact pressures the friction decreased as the amount of thickener increased. The theoretical basis of calculations currently used for evaluating the thickness of a lubricating film do not consider the influence of the thickener and are therefore not applicable to lubricating greases. The Kappa value for greases is almost always higher than can be calculated for the base oils. At the same time, it is known that the tendency of the thickener to adhere to a metal surface is greater than that of an oil, which led us to postulate that it would be better to try to attach the additives to the thickening agent instead of dissolving them in the base oil. These new types of products have been designated "functional soaps."

Functional soap-based greases have performed successfully in open gear applications in the mining and cement industries, as well as in traction motor gears on railway locomotives (even in Norway under frozen Arctic conditions). Even when used as semi-fluid gear greases they meet the specifications for most open gear applications, high adhesion to the surfaces; good pumpability; excellent corrosion inhibition; and extremely high load-carrying capacity (4-ball weld load > 7500N), FZG test > stage 12). In everything — *but* the stipulated content of solids! The advantages of excluding the solid particles are attractive to the end user if they can be convinced that a product that is not black will actually do the job. There is no build-up of solids in the gear teeth, thus reducing vibration and noise and, for the ambitious maintenance engineer, the surfaces are visible and can be monitored using, for instance, a stroboscope. And, the fact that the greases are not black has even some cosmetic advantages like, in the wind power industry, where it not considered environmentally attractive to see black oil running from the turning gears down on to the ground.

Harbour Crane
(Courtesy Bert Schenk, Lubricoat BV)

Mining Example/Case Study

One practical example from the mining industry is the use of such a product in ore processing and, in particular, rotary kilns. This functional soap was introduced in a kiln where the gear was in such bad condition that a replacement had been ordered. The gear had a diameter of about nine meters and was running at a speed of 2 rpm. The result, after about three months, was that the wear had been reduced dramatically to an acceptable level and, at the same time, the surface roughness had remarkably improved.

In addition to the mining industry, these products have been used with excellent results. Other examples are the lubrication of turning gears on wind turbines and even the swivel gears on large harbor cranes. According to Bert Schenk, Lubricoat BV, in the Netherlands, “This type of grease has been used successfully on the open gears of a slewing bearing of a floating bulk crane in the harbor of Amsterdam.” He had received a phone call from the construction engineer of the company who built the crane to check the lubrication of the open gears because there was significant wear on the gear teeth. When he climbed the stairs of the crane to take a look at the open gears, he observed silver-grey grease on the open gears. “The pinion gear had a very rough surface and the gears of the slewing bearing were smooth,” says Schenk. “In this particular case the hardened surface of the teeth on the pinion was discovered to be four times harder than the teeth on the slewing bearings, which were much softer. The harder pinion wheel was more or less ‘grinding’ on the softer slewing bearing. So the silver-grey color was caused by all the metal ‘wear’ particles in the grease. In addition, after recalculation of the gear geometries it seemed that the teeth did not have the right dimensions, so the teeth surfaces needed to be increased (for lower surface pressure). But remarkably, there was no pitting on the surface of the teeth, which had very smooth surfaces. This proved that the grease had lubricated perfectly during this grinding process. The customer is still using this grease because, even in extreme overload situations, it has proved to do its work.”

Crane Gears
(Courtesy Bert Schenk, Lubricoat BV)

Yet another version, based on synthetic base oils, has been tested with great success on the traction motor gears of diesel electric locomotives.

The problem with these gears is that they originally were designed for oil lubrication. However, the seals are so poor that when oil is used, it is thrown out of the oil sump along the shaft. That is why most traction motor gears of today are grease-lubricated. Grease lubrication, however, has never worked satisfactorily — especially in winter. The types of greases predominantly used in such applications have been traditional bitumen-based lubricants with an addition of solid lubricants; e.g. — graphite and molybdenum disulphide. In winter these types of lubricants become very hard and elastic; they do not flow back down into the oil sump, but instead stay in the roof of the gearbox where they are thrown up by the gears. The PAO-based functional soap copes with the extreme loads and shock loads that occur in these spur gears as a result of rail joints and irregularities of the wheels caused by locked brakes. Still, the product remains smooth and fluid at very low temperatures and the re-flow to the oil sump is secured.

For more information, please visit: *www.axelch.com/wordpress/wp-content/uploads/2013/06/White-or-Black-Blues.pdf*

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