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Dominant grease properties for high-speed spindle bearings

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ABSTRACT – The widespread use of grease lubrication in high-speed spindle bearings has been limited by its insufficient life. An extended grease life is required to meet the increasing demand of machine tool applications. Dominant grease properties are determined to attain longer life at higher speeds for spindle bearings. Part of the process includes rheological pull-off and oil bleeding tests, defining active grease reservoirs. The validation has been successfully carried out in a series of angular contact ball bearing (ACBB) grease life tests. The selected grease that fits the defined parameters has shown long life at speed factor, 2 *million* nd_m.

1. INTRODUCTION

Recent developments in the machine tool industry has strived for high-speed technology in order to increase cutting efficiency. Improved reliability is not the sole focus as the global trend moves towards environmentally friendly and energy-saving measures as previous study [1]. The use of lubricating grease in high-speed spindle bearings offers maintenance-free operation, thus meeting the industry needs. With the right amount of the right grease, the bearing is typically "sealed for life", ensuring long operation without relubrication.

Greased bearings have however a limited life to meet the demanding increase in spindle speed. Lugt [2] stated that severe lubricant starvation is responsible for the limited life in greased bearings. This view is widely accepted, though there is no consensus on the grease lubrication mechanisms. Due to its Non-Newtonian nature, the understanding of grease flow inside the bearing is rather complex. Franken et al. [3] found that the (in) active grease reservoirs in high-speed super precision angular contact ball bearings can be detected by means of fluorescence spectroscopy (also known as spectrofluorometry). These findings contribute to improved understanding of lubricant migration inside the bearing, in particular, for high-speed spindles.

Our focus in the present work is to identify the dominant grease properties to act as active grease reservoirs. Active, in this context, refers to the ability to form stable grease reservoirs, to subsequently release sustained oil to the contacts. The introduction of the right grease in the critical bearing locations results in long life at high speed.

2. METHODOLOGY

Lugt [4] stated that the ability to form stable grease reservoirs is often characterised by its tackiness, which can be defined into two parts: cohesion and adhesion. Cohesion refers to the intermolecular attractive forces to remain together as a single mass while adhesion represents the attraction between two substances. The latter relates to the grease ability to remain on the surfaces to be lubricated.

The most widely used technique, pull-off test, is applied to measure tackiness by means of a commercial rheometer. A defined layer of grease (250 µm) is applied in-between two plates of a defined material. Once the specified gap is reached, the plates are immediately pulled apart while measuring the normal force. The experimental setup is illustrated in Figure 1.

d = diameter of geometry

h = thickness of grease sample

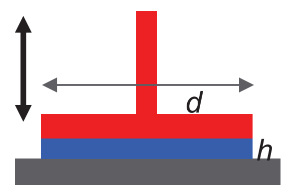

Figure 1 Experimental setup for tackiness test.

Next, the lubricant feed mechanism to the rolling tracks is evaluated by means of static and dynamic oil separation tests. DIN 51817 [5] stated that static oil bleeding is measured by applying a known weight (100 g) on top of a cup filled with grease, where the oil is slowly pressed out through a sieve at the bottom side. The mass of the separated oil from the grease is measured. Dynamic oil bleeding is measured by the in-house test method as previous study [4][3].

The dominant grease properties are then validated in a series of bearing life test. A pair of angular contact ball bearing (i.e., SKF 7008 CE/HCP4A) is mounted in a horizontal cartridge in a back-to-back configuration under an axial pre-load of 310 N. The speed factor equals to approximately 2 *million* nd_m, which is a product of the rotational speed at approximately 37,000 rpm and bearing mean diameter, d_m of 54 mm.

2.1 Materials

In total, four grease candidates are selected as described in Table 1.

A varied composition of thickener and base oil is chosen to verify the dominant grease properties. Three of these are commercially labelled as high-speed greases, characterised by a low base oil viscosity at 40°C. As a comparison, one commercial non-high-speed grease with 10 times higher base oil viscosity at 40°C is also tested.

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Table 1 Grease candidates for high-speed spindle.

Name	Base oil visc. 40°C	Thickener type	Base oil type	NLGI class
HSS-1	25	Lithium complex	PAO + Ester	2
HSS-2	23	Barium complex	Ester	2
HSS-3	22	Polyurea	PAO + Ester	2
HSS-4	220	Polyurea	PAO	2

3. RESULTS AND DISCUSSION

Due to the large centrifugal forces acting on the grease in high-speed operation, grease is often pushed away from the contacts. Therefore, grease needs to stabilise and remain as reservoirs, determined by its cohesive and adhesive properties. Achanta et al. [6] found that cohesion within the grease network is mainly dictated by the thickener.

Adhesion, on the other hand, is not only governed by grease composition, but also by the surface counterpart. For this reason, tackiness is measured using two different surfaces, aluminium and steel. Only the results on steel surfaces are shown in Figure 2 as these are the most relevant for bearings.

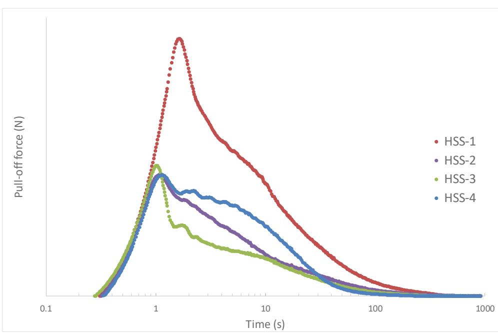

Figure 2 Pull-off force vs. time on steel plates.

HSS-1 grease shows higher tackiness, indicated by the largest force required over time to separate the grease from the mating surfaces. The non-high-speed HSS-4 grease is second.

Next, the ability of the grease reservoirs to release oil is studied. Figure 3 shows the separated oil from the grease when subjected to centrifugal forces over time.

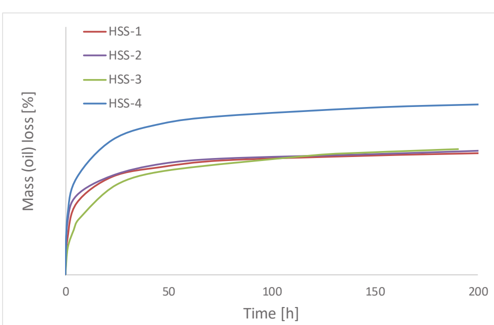

Figure 3 Dynamic oil bleeding (centrifugal force).

These greases have been successfully tested on high-speed test rig as shown in Figure 4.

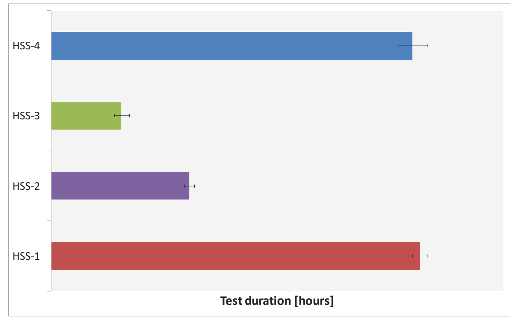

Figure 4 Test duration in high-speed test rig.

HSS-1 ran longer than other high-speed greases, which can be attributed to its high tackiness and controlled bleeding behaviour. Despite of having a high base oil viscosity, HSS-4 showed comparable long time to HSS-1, indicating that this parameter may be less dominant than tackiness and oil bleeding properties. In this case, high oil bleeding helps to provide sufficient film thickness.

4. CONCLUSION

The combination of rheology and oil bleeding tests led to an understanding of key grease properties. Grease with high tackiness and controlled oil bleeding has been successfully validated to attain longer test duration at high speeds. The base oil viscosity might have less dominating impact on grease life for high speed.

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