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Film thickness decay and replenishment in point contact lubricated with different greases: A study into oil bleeding and the evolution of lubricant reservoir

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ABSTRACT

Six different types of greases were tested on the ball-on-disc test rig under starved condition. Both the central film thickness and the cross section film thickness profile were analyzed to better understand the mechanism of grease starvation. In-situ Monitoring of lubricant reservoir was achieved by using a high-resolution camera. Results showed that a new reservoir would re-form after a period of operation after the contact lost its initial grease reservoir under starved condition. The higher oil bleeding ratio of grease, the larger re-formed lubricant reservoir would be. A turning point on the central film thickness curve was found, which was due to the loss and re-formation of the lubricant reservoir.

1. Introduction

Grease is widely used in bearings and gear systems. In some cases, for examples under high-speed and lightly-loaded condition, lubricant will be enough to maintain fully flooded lubrication. However, in most other cases, especially under low-speed and heavy-loaded condition, grease will be pushed out of the contact gradually. Thus, the contact will be working in starvation.

Researches were carried out on studying the behaviour and mechanism of grease starvation since very early. Wilson [1] observed this phenomenon in a rolling bearing in 1979. Zhu and Neng [2] then measured the large decrease of film thickness in a starved grease lubricated point contact. From the 21st century to now, the mechanism of grease lubrication has been widely studied. But people now understand fully flooded grease lubrication better than starved grease lubrication. The diversity of chemical composition and different physical/chemical changes during operation make the mechanism of grease starvation more difficult to study. Though it is complicated, many significant findings were presented in the past decades. Cann [3] studied the relationship between starved film thickness and different temperatures on the ball on disc test rig, using lithium greases. It was found that for a low thickener concentration lithium grease, film thickness decreased faster at higher rolling speed and with higher base oil viscosity, while reflow was stronger at lower speed and higher temperature. And it was not always true when using a high thickener concentration grease. Cann [4] also found that, for lithium grease, starvation was more severe with higher thickener concentration and base oil viscosity. Hurley et al. [5] studied the film thickness behaviour of thermally aged lithium greases, and they claimed that moderately aged greases give higher film thickness than both the fresh grease and heavily aged grease. Couronné et al. [6] tested the change film thickness of different kinds of greases as a function of speed by using a ball on disc test rig. They smeared an initial layer of grease and added no more during the test. Results showed that for the 4 tested greases, 2 out of them showed increase and then decrease in film thickness, and the transition speed differed with different grease type. The other two showed no increase in film thickness at all but were constant with speed. Baly et al. [7] measured averaged film thickness in a complete bearing by a capacitance method and found that sometimes the film thickness recovered at higher speed due to the replenishment during the operation. Cousseau et al. [8] measured the friction torque of several kinds of greases in thrust bearings and found that starvation happened in the test would increase sliding torque, but decrease rolling torque. At the same time, researches were carried out specially for improving replenishment. Cann and Lubrecht [9] found that the loading–unloading process would contribute to lubricant replenishment. She then studied the grease friction coefficient using MTM which could model bearing operation condition and found that semi-starvation could be self-improved when greases were sheared or heated

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replenish the track [10]. Damiens et al. [11] optimized the cage clearance of a modeled bearing structure to prevent starvation. Nagata et al. [12] found that lateral vibration would promote grease reflowing back to the contact. Huang et al. [13] found that slide-roll ratio would also contribute to grease replenishment by influence the grease distribution along the rolling track.

According to Lugt [14], high consistency grease would help to “maintain lubricant reservoir adjacent to the rows of rolling elements” in a bearing. The concept “lubricant reservoir” here was referred to the local lubricant gathering or staying around the contact or along the rolling track as a result of capillary force and tackiness. Åström et al. [15] showed the typical butterfly shape of oil reservoir and discussed its importance to starved oil lubrication. Cann et al. [4,16] studied the mechanism of starved grease lubrication and pointed out that oil would release from grease reservoir to lubricate the contact. IR analysis showed that this was mainly base oil containing little thickener.

The researches above were mainly focused on the film thickness and friction measurement inside a grease lubricated contact. Despite some studies on oil and grease reservoir, few studies were about the change of grease reservoir and its influence on starved film thickness. In this paper, six different types of greases were studied under pure rolling condition. The loss and re-formation process of the lubricant reservoir around the grease lubricated point contact was recorded by a high-speed camera. The behaviours of lubricant reservoir and film thickness were analyzed together to make a better understanding of the mechanism on starved grease lubrication.

2. Material and methods

2.1. Lubricants

Six different types of greases were specially formulated in lab environment by Shenzhen Hecheng Lubricant Material Co. Ltd. Four lithium greases were made through the same manufacturing process. Other two kinds of greases were none-soap greases and were designed to be compared with lithium grease. All greases were non-additive greases. The composition and properties of these greases are shown in Table 1. Each of the greases was named accordingly to its thickener and base oil type: LiP4 was PAO4 thickened lithium soap; LiP8 was PAO8 thickened lithium soap; LiDE was di-ester thickened lithium soap; LiPE was polyol ester thickened lithium soap; SiP8 was PAO8 thickened silica, and UP8 was PAO8 thickened diurea.

2.2. Grease reservoir observation and film thickness measurement

The tests were carried out on a ball-on-disc test rig, as shown in Fig. 1. The steel ball was loaded against the chromium-coated disc. The radius of the ball and the rolling track was 6.35 mm and 75 mm, respectively. The maximum Hertzian contact pressure was 0.68 GPa and the Hertzian contact radius was 0.22 mm. The shaft passing through the centre of the ball was fixed pointing to the rotating centre of the disc to reduce the effect caused by spinning [17]. The roughness of the ball and the disc were 7 nm and 3 nm, respectively. Before each test, a 0.1 mm thickness grease layer was evenly spread on the chromium coated glass disc, which was achieved and checked as follows.

A bar fixed on a lifting platform with the resolution of 0.02 mm was used to smear a very thin layer evenly on the lower surface of the disc when it rotated. Then, stop the motor and load the ball against the disc. A static reservoir could be observed though the microscope and the radius R of which was determined by the thickness of the pre-smeared grease layer. The thicker grease layer it was, the larger reservoir it would form. It was calculated from Pythagorean Theorem that R was about 1.25 mm when the grease layer was 0.1 mm’s thick. If R was not 1.25 mm, unload the ball and slightly adjust the thickness of grease layer while the disc was rotating to make sure it was evenly changed. Check and adjust R by repeating the steps described above until it met the requirement. The size of R was carefully checked at any 3 points on the disc to make sure the grease was evenly spread. And the radius deviation of the static grease reservoir was carefully controlled within ± 0.02 mm.

Then, the ball and disc were both driven to rotate. The changes of grease reservoir and the interferograms were recorded. Film thickness was calculated based on the principle of two-beam interferometry. *The tested speeds were* 100 mm/s, 250 mm/s and 500 mm/s. And the test would be stopped either when the disc was scratched or an equilibrium state was achieved. Both the ball and the disc were cleaned successively with acetone, ethanol and deionized water, and then dried before a new test. Each test was repeated 2 times. *The test temperature was* 22 °C.

3. Results

3.1. Starved film thickness

Film thickness was measured along the cross section of the contact which was perpendicular to the moving direction. Fig. 2 shows the film thickness profile of LiP4 when operating at 250 mm/s.

Table 1
Physical properties of the tested greases.

Designation	LiP4	LiP8	LiDE	LiPE	UP8	SiP8
NLGI grade[a]	2	2	2	2	2	2
Thickener[a]	Lithium*	Lithium*	Lithium*	Lithium*	Diurea**	SiO_2
Base oil[a]	PAO4	PAO8	Diester	Polyol Ester	PAO8	PAO8
Base oil viscosity[a]						
40 °C (cSt)	17	46	26.3	138	46	46
100 °C (cSt)	4.1	8.0	5.3	17.6	8.0	8.0
Static oil bleeding ratio[b] **(w/w)**	3.5	3.7	2.7	1.9	2.5	6.0
Dynamic oil bleeding ratio for 6 h (V/V)	28.2	19.4	5.7	0.3	16.4	33.2
1/2 Penetration[b] **(mm)**	151	151	150	145	139	141

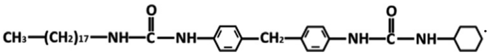
The method of static and dynamic oil bleeding ratio measurement is shown in Appendix A.

[a] Provided by the grease supplier.

[b] Tested by Shell (Shanghai) Technology Ltd.. The 1/2 penetration test was the 60 times worked penetration.

* Lithium: lithium 12-hydroxy stearate+lithium stearate.

** Diurea:



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