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INVESTIGATION OF FILM THICKNESS OF GREASE-LUBRICATED THRUST BEARING: FROM BALL-ON-DISC TO BEARING

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Abstract: *Rolling element bearings lubricated by greases represent the most used mechanical components in industry, thus the total volume of energy required to overcome their friction is enormous. Even small improvements can provide considerable savings. To reach these improvements, it is necessary to understand all the processes in the bearing, and especially those that take place in contacts of rolling elements. So far, most of the research was done on tribometers employing a ball-on-disc configuration. Tests on such devices are easy to perform but differ from conditions of actual bearings in some important aspects such as a contact geometry, presence of cage, number of contacts, spin motion of rolling elements, or action of centrifugal and capillary forces. The aim of this experimental study is to refer about film thickness during the initial running phase of simulated thrust rolling bearing and to reveal some patterns of lubricant behaviour for different conditions and greases. Measurements were carried out on unique apparatus of simulated thrust rolling bearing using optical methods with high speed camera. Results showed that the ball-on-disc configuration does not completely correspond to behaviour of actual bearings, mostly in terms of starvation and replenishment of grease. Multiple contacts in succession of simulated bearing do not tend to starve so rapidly and seriously during experiments as is presented in literature for ball-on disc configuration under similar conditions.*

Keywords: *grease lubrication, EHL, starvation, replenishment, film thickness, rolling element bearing*

1. INTRODUCTION

The main purpose of rolling element bearings is to reduce friction between two parts of different angular velocity. Holmberg et al. reported in 2017 [1] that 23% of total energy consumption is attributed to the operation of these tribological elements due to their wide application across the world. Majority of the rolling bearings operates in the EHL regime. This regime is described as a type of hydrodynamic lubrication where large contact pressure causes elastic deformations of contacting bodies and changes in viscosity of the lubricant [2]. Since the 1950s, a huge progress has been made in field of EHL regime. Satisfactory agreement between predictions and experimental results was reached. However, this achievement is limited to the cases including steady-state conditions, Newtonian fluids, and perfectly smooth surfaces [3].

Almost all rolling bearings (about 95%) are lubricated by greases. Even nowadays, it is still not possible to reliably predict grease behaviour in the bearing contacts as greases have complex (non-Newtonian, thixotropic) rheology. Experimental studies published on grease lubrication were performed mainly on ball-on-disc simulators [4-9] while there is only a few papers involving full-scale bearing simulators [10-13] which were focused principally on resulting bearing torque not on film thickness formed in bearing contacts.

Considering the limited scope of the article and the complexity of grease lubricated bearings, it is impossible to include a qualitative and quantitative description of all the effects occurring in the bearings in one study. The aim of this paper is to provide a fundamental insight into the film thickness trends during the initial running of grease lubricated thrust rolling bearing and to point out the differences with the ball-on-disc simulator, whose results are often misunderstood as the behaviour of grease in actual bearings.

2. MATERIAL AND METHODS

Experiments were performed on a unique apparatus involving 51220 thrust ball bearing, see Fig. 1. One steel washer of the bearing was replaced by a glass (BK7) disk to enable direct optical observation of grease film distribution.

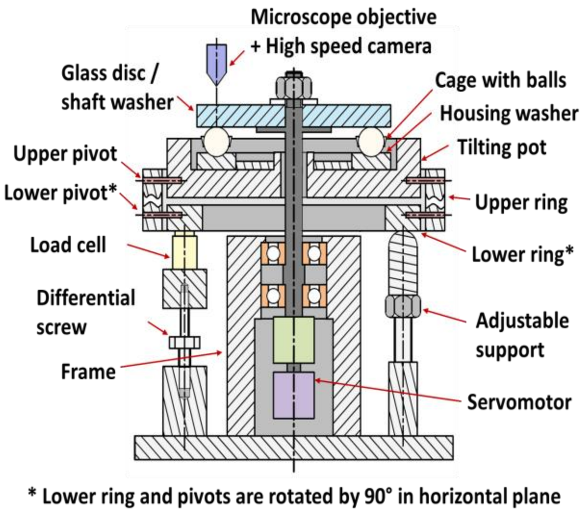

Figure 1. Full thrust ball bearing simulator

Film thickness was evaluated via the method of colorimetric interferometry [14,15]. Experiments were carried out under room temperature. Two industrial greases MOGUL LV 2-3 and LVS 3 were used as lubricants. Details of greases used in the experiments are summarized in Table 1.

Table 1. Details on used lubricants

Grease	LVS 3	LV 2-3
Base oil	mineral	
Base oil viscosity at 40 °C (mm^2/s)	110	50
Thickener	Li soap	
NLGI grade	3	2-3

Load of 20 N per ball contact was applied in the experiments performed on bearing simulator while 35 N was used on a ball-on-disc simulator (for more details on this simulator, see Ref. [15]) to ensure the same contact pressure. For comparison of starved and fully flooded (FF) film thicknesses, a film thickness of grease LVS 2-3 under FF conditions was estimated by means of Hamrock-Dowson film thickness formulas [16].

3. RESULTS AND DISCUSSION

Firstly, experiment with LV 2-3 grease was conducted on the ball-on-disc simulator for entrainment speed ranging from 0.05 to 0.8 m/s under FF conditions.

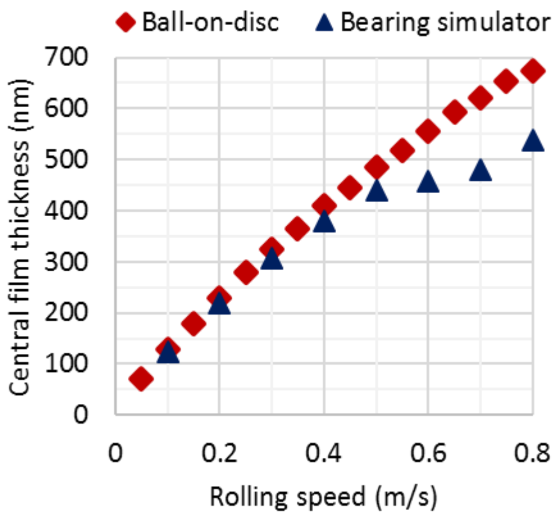

Figure 2. Central film thickness of LV 2-3 grease on ball-on-disc (fully flooded) and bearing simulator (2 g of grease)

Figure 2 compares the thickness curve from the ball-on-disc with the thicknesses obtained on bearing simulator. Before tests, 2 g of grease were applied on the disc. Film thickness was measured after 10 minutes of running at each speed. Film thickness in the bearing contacts was very close to the FF conditions at speeds up to 0.5 m/s where more pronounced starvation occurred. Beyond this point, bearing replenishment mechanisms ceased to be sufficient and were overcome by loss mechanisms causing reduction in film thickness by 20%.

For the same bearing conditions at fixed speed of 0.5 m/s, where a more pronounced deviation from FF thickness was found, a time test lasting 3 hours was curried out to study a development of film thickness during this period. Results for LV 2-3 and LVS 3 are shown in Fig. 3.

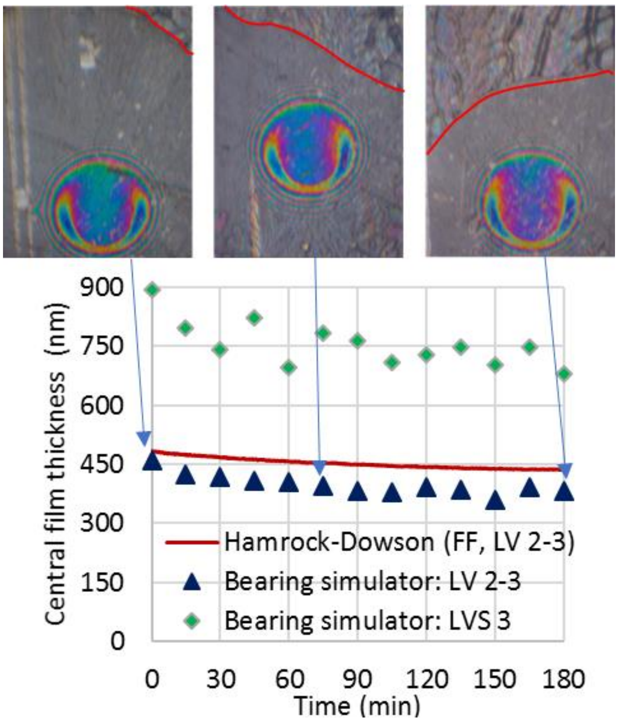

Figure 3. Film thickness development of LV 2-3 and LVS 3 at 0.5 m/s, 20 N/contact and corresponding interferograms with highlighted film meniscus

Measured film thicknesses of LV 2-3 are accompanied by corresponding interferograms of the circular contact and Hamrock-Dowson estimation of film thickness under FF conditions. The estimated thickness was calculated according to immediate conditions in the bearing thus it was reduced during the test as temperature increased in the bearing. The total temperature rise by 3 °C caused drop in the estimated film thickness by 10%. However, overall reduction in the measured film thickness of LV 2-3 was 17% with evident presence of film meniscus (air/lubricant interface) in front of the contact. The meniscus fluctuated (especially in the case of LVS 3 grease as seen in film thickness variations) and slightly approached to the contact during the time test. Nevertheless, it did not influence the film thickness significantly. The most distinctive decline in film thickness occurred during the first 30 minutes of bearing running for both the greases.

All these observations suggest that most of the film reduction in bearings is given due to temperature rise rather than by starvation itself during initial phase of its running. On the other hand, similar conditions was previously studied by Cann [4] on ball-on-disc simulator where a grease-lubricated circular contact without artificial replenishment began to starve very quickly and seriously despite precisely controlled temperature. For this reason, there seems to be a strong discrepancy in the results obtained on the ball-on-disc and full bearing simulators.

Further, more comparable experiments were performed to exclude influences of different lubricants, conditions, and experimental methodologies employed in this and Cann's study [4] on the discussed results. Film thickness behaviour of grease LV 2-3 was assessed at three rolling speeds of 0.1, 0.3, and 0.5 m/s on both simulators (ball-on-disc and full bearing) under starved conditions. In both the cases, 2 g of grease were applied on the disc before each test and no artificial mechanism of contact replenishment was involved.

It was observed that significant starvation occurred immediately after the start of the test on ball-on-disc simulator (see Figure 4) for all the speeds. Reduction of film thickness by about 80% from FF value to a certain stable level took only 30 seconds for speeds of 0.3 and 0.1 m/s where the film meniscus got at the contact boundary. It is worth noting that the film development differs for the high speed of 0.5 m/s where film thickness fluctuated dramatically and meniscus position was often out of the observable area. The average film thickness decline was around 65% compared to FF conditions. More pronounced, even if unstable, mechanism of replenishment was triggered by this speed.

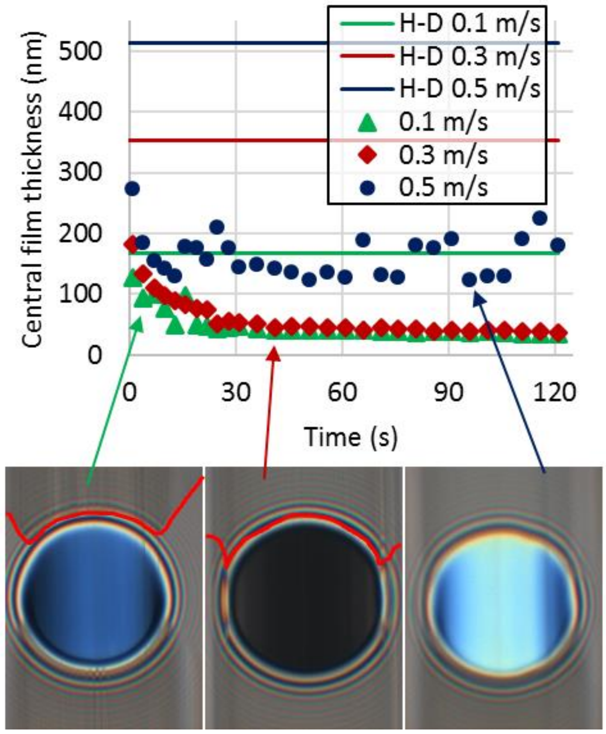

Figure 4. Film thicknesses of LV 2-3 measured on ball-on-disc simulator (symbols) with corresponding FF estimations (lines)

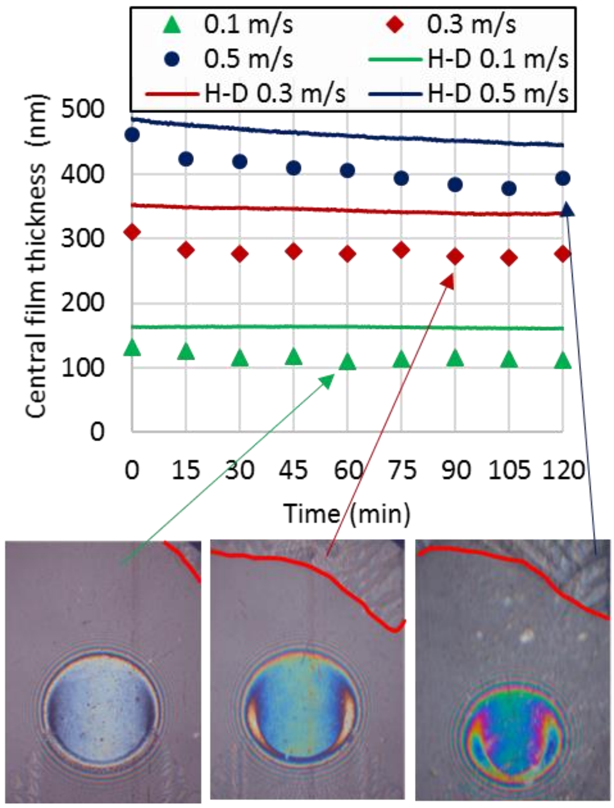

Figure 5. Film thicknesses of LV 2-3 measured on bearing simulator (symbols) with corresponding FF estimations (lines)

Notwithstanding, specific origin of this phenomena is unknown. No substantial changes were detected in lubricant temperature or test rig vibrations that could accelerate refilling of contact running track by the lubricant.

Compared to the ball-on-disc results, starvation was very mild on bearing simulator despite the much longer duration of the tests (2 hours), as illustrated in Figure 5. Starvation led to a decrease in film thickness by approximately 50 nm regardless of used speed. Relative decreases in thicknesses were 30, 18.5, and 11.5% of FF values for individual speeds sorted from the lowest to the highest. A temperature rise in the bearing was responsible for one-third of the decline.

4. CONCLUSIONS

The present work was focused on the comparison of film thicknesses formed in the contacts of grease-lubricated thrust rolling bearing and ball-on-disc simulator under various conditions.

It was shown that thrust bearings are capable to maintain a film thickness close to the fully flooded conditions (without severe starvation) according to bearing speed, even though they are lubricated by greases. Not negligible part of the film thickness reduction in bearings can origin from bearing heating rather than from starvation process, especially during the first hours of bearing running. On the contrary, if no artificial replenishment mechanism is involved in the ball-on-disc simulators during tests with greases, significant starvation usually takes place within a few seconds when film meniscus reaches the contact boundary.

From the above results it is evident that the consequences of grease starvation and replenishment mechanisms obtained on the ball-on-disc simulators cannot be directly transferred and applied to the actual bearings since these systems are very different from this point of view. Therefore, the use of full bearing simulators rather than ball-on-disc seems to be a more appropriate way to clarify the mechanisms of grease lubrication of actual bearings.

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REFERENCES

[1] K. Holmberg, A. Erdemir: Influence of tribology on global energy consumption, costs and emissions, Friction, Vol. 5, No. 3, pp. 263-284, 2017.
[2] G. Stachowiak, A. W. Batchelor: *Engineering tribology,* Butterworth-Heinemann, 2013.
[3] T. Lubrecht, D. Mazuyer, P. Cann: Starved elastohydrodynamic lubrication theory: application to emulsions and greases, Comptes Rendus De L Academie Des Sciences Serie Iv Physique Astrophysique, Vol. 2, No. 5, pp. 717-728, 2001.
[4] P.M. Cann: Starved grease lubrication of rolling contacts, Tribology Transactions, Vol. 42, No. 4, pp. 867-873, 1999.
[5] T. Cousseau, M. Bjorling, B. Graca, A. Campos, J. Seabra, R. Larsson: Film thickness in a ball-on-disc contact lubricated with greases, bleed oils and base oils, Tribology International, Vol. 53, pp. 53-60, 2012.
[6] S. Hurley, P.M. Cann, H.A. Spikes: Thermal degradation of greases and the effect on lubrication performance, Tribology for Energy Conservation, Vol. 34, pp. 75-83, 1998.
[7] P.M.E. Cann, A.A. Lubrecht: Bearing performance limits with grease lubrication: the interaction of bearing design, operating conditions and grease properties, Journal of Physics D-Applied Physics, Vol. 40, No. 18, pp. 5446-5451, 2007.
[8] B. Damiens, A.A. Lubrecht, P.M. Cann: Influence of cage clearance on bearing lubrication, Tribology Transactions, Vol. 47, No. 1, pp. 2-6, 2004.
[9] P.M. Cann, A.A. Lubrecht: The effect of transient loading on contact replenishment with lubricating greases, Transient Processes in Tribology, Vol. 43, pp. 745-750, 2004.
[10] P.M. Cann, M.N. Webster, J.P. Doner, V. Wikstrom, P. Lugt: Grease degradation in R0F bearing tests, Tribology Transactions, Vol. 50, No. 2, pp. 187-197, 2007.
[11] T. Cousseau, B. Graca, A. Campos, J. Seabra: Friction torque in grease lubricated thrust ball bearings, Tribology International, Vol. 44, No. 5, pp. 523-531, 2011.
[12] D. Goncalves, S. Pinho, B. Graca, A.V. Campos, J.H.O. Seabra: Friction torque in thrust ball bearings lubricated with polymer greases of different thickener content, Tribology International, Vol. 96, pp. 87-96, 2016.
[13] D.N. Olaru, M.R.D. Balan, A. Tufescu, V. Carlescu, G. Prisacaru: Influence of the cage on the friction torque in low loaded thrust ball bearings operating in lubricated conditions, Tribology International, Vol. 107, pp. 294-305, 2017.
[14] M. Hartl, I. Krupka, M. Liska: Elastohydrodynamic film thickness mapping by computer differential colorimetry, Tribology Transactions, Vol. 42, No. 2, pp. 361-368, 1999.
[15] M. Hartl, I. Krupka, R. Poliscuk, M. Liska, J. Molimard, M. Querry, *et al.*: Thin film colorimetric interferometry, Tribology Transactions, Vol. 44, No. 2, pp. 270-276, 2001.
[16] B.J. Hamrock, D. Dowson: Isothermal Elastohydrodynamic Lubrication of Point Contacts: Part III - Fully Flooded Results, Journal of Lubrication Technology-Transactions of the Asme, Vol. 99, No. 2, pp. 264-276, 1977.