Actas do Simpósio AIMETA,
Viena, Setembro de 2001,

GREASE LUBRICATION MECHANISMS - FATIGUE FAILURES OF GREASE LUBRICATED CONTACTS

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SUMMARY

Grease lubrication is applied to almost every situation, especially for rolling bearing lubrication. Usually, a rolling bearing fails by fatigue, when a spall is formed and it comes out of the contact surface. As it is well known, spalling is prone to appear in heavily loaded EHL contacts. Its presence depends essentially on the Hertzian pressure, thus the maximum shear stress. The depth of the cracks is similar to the depth of maximum shear stress. Crack initiation is also dependent on the lubrication conditions, namely on the specific film thickness Λ. Values of Λ greater than 3 virtually eliminate spalling, whereas values closer to 1 (or even smaller) tend to promote it. The concept of specific film thickness or lubricant parameter Λ, however, has a limited application if one is dealing with grease lubrication. Prediction of fatigue, in general, and spalling in particular, should be handled with caution.

The main objective of this work is the experimental evaluation of fatigue failures in a pure rolling hertzian contact lubricated by grease. A comparative study with the base oils is done. The experimental work is performed with a two disk machine, adapted for grease lubrication. The procedures are described and the results obtained with a base oil and a grease are shown. Also, a critical analysis is performed.

Keywords: Grease; Fatigue Failures; Elastohydrodynamic Lubrication, Rolling Bearings.

1 INTRODUCTION

Spalling is a type of fatigue failure associated with loss of material and the formation of cracks. These cracks would have the depth of some tenths of a millimetre (around 200 μm) and the approximate overall dimensions of the Hertzian contact (usually under 6 mm^2) [1].

This failure appears in a sudden way, generally after some millions of stress cycles, with the material giving away before the undermining of the surface and originating the spall. This undermining is the result of the gathering of many subsuperficial cracks, eventually causing the surface to collapse.

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The main objective pursued in this work is the further understanding of the spalling phenomenon, namely in what concerns the differences between oil and grease lubrication. In other words, one is trying to assess to what extent does the induction of spalling depends on the lubrication mechanism, clearly different with grease and oil lubrication; one is seeking to know if the spalls in both cases present similar morphologies, or if relevant and formal discrepancies are noticed.

In order to evaluate this, spalling was induced in test specimens. Both oil and grease lubrication were used. The operating conditions in the test apparatus resembled those present in a ball bearing.

Surface failures originating from each of the lubrication mechanisms could then be observed.

2 EXPERIMENTAL APPARATUS

The equipment used to simulate rolling bearing conditions was a twin disk machine, mainly consisting of two parallel shafts in which the disks are placed. The shafts are both driven by the action of a single synchronous electric motor, via two rubber strings. The polies on which the rubber strings work may have different sizes, thus permitting various slipping or pure rolling conditions.
The load carried by the disks is pneumatically controlled.
The rolling speed is imposed by the motor.
An overall view of the twin disk machine is given in Fig.1.

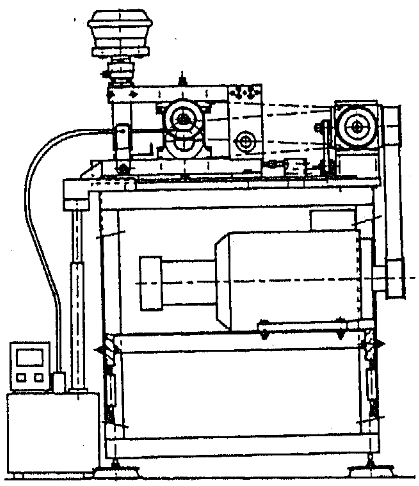

Fig.1: Overall view of the twin disk machine

The machine was at first solely for oil lubrication. The oil is pumped into the convergent, allowing fully flooded lubricating conditions. Moreover, the oil is circulated and filtered. Its temperature is set and monitored.

The specifications of the disks used as test specimens can be seen in Fig.2.

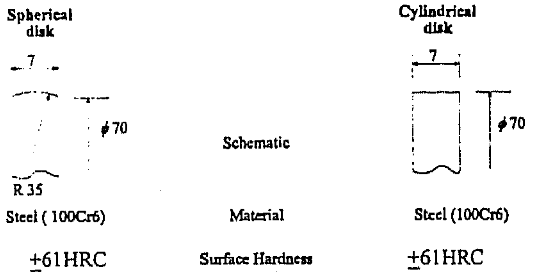

Fig.2– Test specimens

The upper disk has a spherical shaped surface, whereas the lower one is cylindrical in shape

For grease lubrication the apparatus was modified in order to simulate a contact similar to the one existing in a rolling bearing, where there is no permanent relubrication. The new geometry can be seen in Fig.3.

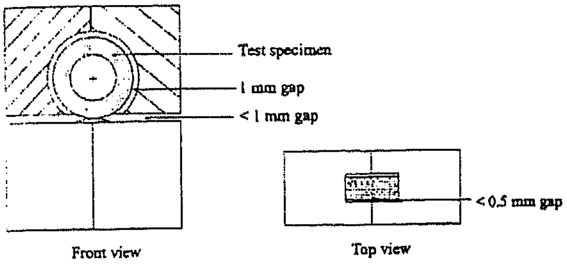

Fig.3 – Apparatus for grease lubricated contacts

So, the original oil supply system was suppressed, for it was not suitable for grease lubrication.

As it can be seen and in order to keep the grease in the contact area, the disks were nearly sealed off, by means of a set of restraining parts, specifically conceived for it. This ensures that the grease doesn't leave the surroundings of the disks, but does not grant a fully flooded condition. The space enclosed by the device is filled with grease in the beginning of the test and no further supply is attempted.

3 EXPERIMENTAL PROCEDURE

Fatigue phenomenons may take several forms, namely pitting, micro-pitting or spalling. In this study, spalling was the elected form of fatigue, although other forms might have been present. Spalling is critical in heavily loaded EHL contacts, such as ball or roller bearings or gear teeth. Thus, the Hertzian pressure was set to 2 GPa [3]. The operational parameters may be seen in the table below (Table 2).

Rotational speed ω	3200 r.p.m.
Linear speed v	1,73 m·s^{-1}
Load P	1800 N
Maximum Hertzian pressure p	2 GPa

Table 2 – Operational parameters

The range of lubricants included one base mineral oil (30cSt at 40,0 °C), without additives, and one grease made using the same oil as its base oil. The nature of the soap is Lithium, with a soap content of 7%. The NLGI grade is 0 and the dropping Point 187°C. The visual aspect is smooth [4].

The surface hardness of the discs is 61 HRC. On the spherical disks surfaces, two indentations were made, in order to induce the fatigue phenomena around those indentations.

Also the surface roughness of the disk was measured transversal and longitudinal directions of the disks. The results can be observed in the next Table.

	Set of discs nr.1		Set of disks nr.2	
	Spherical disc	Cylindrical disc	Spherical disc	Cylindrical disc
Rt	16,267	5,047	9,617	4,460
Ra	1,897	0,530	1,260	0,497
Rk	4,320	1,697	0,690	1,590
Rq	2,743	0,680	2,233	0,633
Rpk	2,203	0,767	2,197	0,497

Table3 – Transversal roughness

	Set of discs nr.1		Set of discs nr.2	
	Spherical disc	Cylindrical disc	Spherical disc	Cylindrical disc
Rt	3,713	2,650	3,540	3,110
Ra	0,523	0,343	0,443	0,437
Rk	1,707	0,913	1,347	1,253
Rq	0,667	0,443	0,573	0,543
Rpk	0,517	0,443	0,460	0,443

Table 4 – Longitudinal roughness

Using the correlation factor, it can be seen that the predominant roughness direction is transversal.

After measuring the roughness of the surfaces, the specific film thickness of the lubricated contact was determined for each of the tests performed. The values obtained are shown in Table 5.

	Test 1	Test 2
Minimum film thickness h_m	2.8491E-7	2.8491E-7
Composite roughness σ	2.8260E-6	2.3210E-6
Minimum specific film thickness $\Lambda=h_m/\sigma$	9.28E-2	1.130E-1

Table 5 – Characteristics of the contact

Each test had duration of 10 million cycles. During the tests the indentation area was observed and its dimension was measured by means of a video microscope.

4 EXPERIMENTAL RESULTS

The first test was made with the base oil. In Fig.4 and Fig.5 it can be seen the indentation area and the surrounding surface after 3,5 million cycles and 10 million cycles.

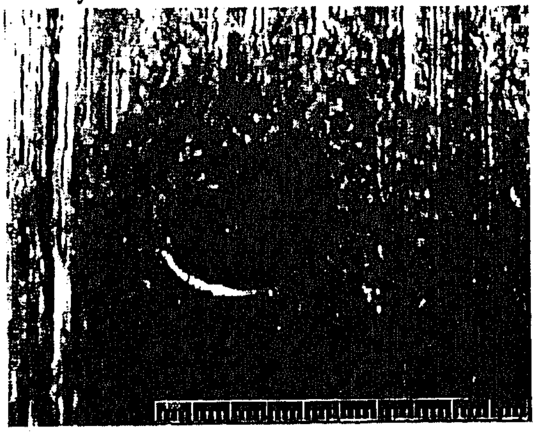

Fig.4 – Indentation area after 3.5 million cycles (oil lubrication)

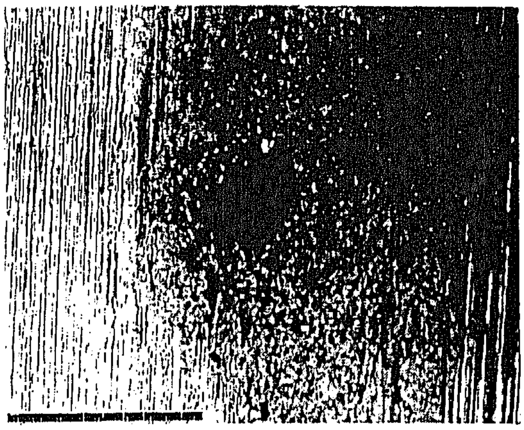

Fig.5 – Indentation area after 10 million cycles (oil lubrication)

As it can be observed in the pictures that the surface area of the indentation augmented significantly. Also it can be seen that the surface suffered a micro-pitting phenomena, with plastic deformation.

The next pictures represent the contact of the disks in the grease lubricated test.

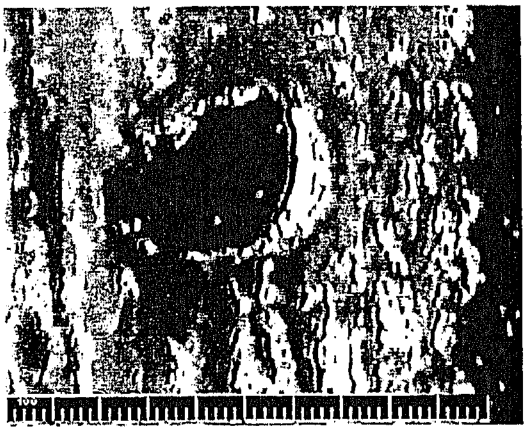

Fig.6 – Indentation area after 3,5 million cycles (grease lubrication)

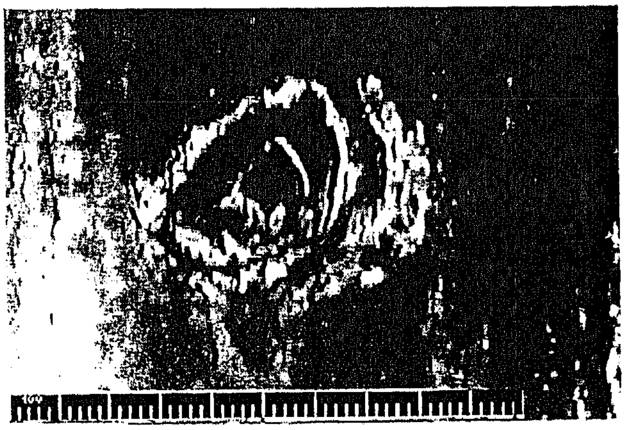

Fig.8 – Indentation area after 10 million cycles (grease lubrication)

As it can be seen, the deformed area is not regular. It can be noticed that the plastic deformation is more important. Also, a spall was prone to appear as it was observed at the microscope.

At the end of each test a ferrographic analysis was performed to the lubricants: The results can be seen in the next teble.

	Oil 30cST@40°C	Grease7% Li
Dilution	1	0,1
DL	76,6	41,4
DS	14,2	13,7
CPUC	90,8	551,0
ISUC	5665,9	15262,7

Table 6 - Comparison of Fatigue Wear Particles for both Tests using Direct Ferrography

The analysis show a more severe wear for the grease lubricated contacts, with a greater number of larger particles. For oil lubrication it was noticed the existence of numerous ferrous particles of small dimension, typical of normal wear. For grease lubrication it was seen the existence of numerous ferrous particles of important dimension, typical of severe wear

5 CONCLUSIONS

The tests were performed with one grease and its base oil. The analysis of the experimental results show that the surfaces of the grease lubricated contact suffered more surface damage then the ones lubricated by the base oil.

The number of cycles of the tests, ten million, was not enough to observe the detachment of a spall, but in the case of the grease lubricated contact it could be observed that one spall was near to come out of the surface.

It was observed that the grease lubricated contact suffered more micro-pitting then the oil lubricated one. That can be explained by the fact that the contact was not fully flooded as it was with the oil lubrication.

The presence of micro-pitting can be easily explained by the value of Λ that in the oil lubricated case was around 0,1. It means that the tests were performed at the boundary lubrication regime. In the grease case the real value of Λ should be even smaller because of the starvation effects [5].

BIBLIOGRAPHY

[1] Silva, Pedro; "Influência da rugosidade no comportamento à fadiga de um contacto Elastohidrodinâmico"; Master Thesis; FEUP 1997 (in portuguese);

[2] Berthe, Daniel; "Les effets hidrodynamiques sur la fatigue des surfaces dans les contacts hertziens"; PhD Thesis; INSA-Lyon 1974 (in french);

[3] Webster, M. N.; Norbart, C. J.; "An Experimental Investigation of Micropitting Using a Roller Disk Machine"; Tribology Transactions, vol. 38, 1995;

[4] Vergne, Philippe; Blettner, Grégory; "Lubricating greases, correlation between composition and rheology"; Eurogrease, Nov./Dec. 1998;

[5] Cann, P. M., "Starvation and Reflow in a grease-lubricated elastohydrodynamic contact", Tribology Transactions, pp. 698-704, 1996