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Friction torque in thrust ball bearings lubricated with polymer greases of different thickener content

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ABSTRACT

In this work a series of experimental tests were performed in thrust ball bearings lubricated with polymer greases. The tested greases were formulated with the same base oil but different thickener content. A multi-purpose lithium thickened grease was also tested as reference.

The friction torque was measured at constant temperature and load, while varying the rotational speed. The coefficients of friction under boundary and full film lubrication were numerically calculated through the optimization of a rolling bearing friction torque model to the experimental measurements. The results show that the higher the thickener content, the smaller is the friction torque generated by the lubricating greases, phenomenon which was found to be especially important at low speeds and low specific film thickness.

1. Introduction

About 90% of all the rolling bearings are grease lubricated [1]. Despite this fact, there is very little work on the grease lubrication mechanisms which rule the film thickness formation and friction torque in rolling bearings. Most analytical tools to predict film thickness and friction in grease lubrication only take into account the base oil properties and generally disregard the grease formulation, i.e., the type of thickener, its content or its interaction with the base oil, the additive package, etc. Furthermore, the base oil properties are often used to predict film thickness [2–4] and rolling bearing friction torque [5], even though for many grease formulations, the grease shows very different characteristics than the base oil and even the oil bled by the grease during work might have significantly different properties than the original base oil [6].

According to Cann et al. [7,8], the grease lubrication mechanisms after the churning phase depend mainly on bearing type, operating conditions and grease properties where base oil oxidation, thickener degradation, and anti-wear/boundary properties will all play a role. Still, the available rolling bearing torque loss models do not take into account different grease formulations (thickener type and concentration) which may influence the torque measurements and it only considers the base oil properties to predict the friction torque of rolling bearings lubricated with grease.

Very recently, in single ball-on-disc tests, the thickener influence on the film thickness and friction was addressed by several authors [9–12]. Either by influencing the bleed-oil release, by changing the grease rheology/consistency or by directly contributing to the film thickness at low speeds, it has been observed experimentally that the thickener type and content are very important for the lubricant film formation. However, there is still very little work published on how the friction is affected, especially in full bearing tests.

Therefore, this work intends to analyse the friction torque behaviour of this recent and still poorly studied type of lubricating greases formulated with polypropylene (PP) thickener and how the different thickener content reflects in the rolling bearing friction torque. The tests were performed in a rolling bearing test rig using thrust ball bearings, running over different rotational speeds at constant load and controlled temperature.

2. Materials and methods

2.1. Tested greases

Four greases were tested in this work: M1, M2, M3 and MLi. The greases' main properties are shown in Table 1. Experimental batches of polymer greases were specifically manufactured for this

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work. All the polymer greases were formulated with the same poly-alpha-olefin (PAO) base oil. Grease MLi was formulated with a mixture of two different grades of PAO and some ester to facilitate the saponification reaction. Regarding the thickener, greases M1–M3 were formulated with polypropylene (PP) while MLi was formulated with lithium complex (LiX). Greases M1, M2 and M3 were formulated with different thickener content, respectively, 11%, 13% and 15%. Since lithium thickened greases are the most common lubricating greases in the market, MLi was tested as a benchmark. None of the greases has additives in its formulation.

2.2. Rolling bearing assembly and test procedures

The bearings friction torque tests were performed to evaluate the generated friction torque of each grease. The tests were performed in a modified four-ball machine, using a rolling bearing assembly in the place of the typical four-ball arrangement, shown in Fig. 1. This procedure has been developed by Cousseau et al. [13] and also used by other authors [14–16].

The tests were conducted applying an axial load of $P \approx 7000$ N, while varying the rotational speed stepwise from 100 to 3250 rpm and assuring that the temperature was kept constant. Each test was performed on a new 51107 thrust ball bearing from SKF® (marked with numbers 3–5, in Fig. 1). Each rolling bearing was lubricated with 2 ml of grease (about 30% of the rolling bearing's free volume). Care was taken to assure that the initial grease distribution was as uniform as possible between tests. Table 2 summarizes the operating conditions.

The tests were conducted under controlled operating temperature. This temperature is measured very close to the upper raceway using a thermocouple (number III in Fig. 1), which is associated with a digital PID controller, allowing to adjust and maintain the operating temperature steady through the activation of two electrical resistances, symmetrically applied to the bearing house. The assembly chamber is permanently submitted to air-forced convection, by action of two fans with 50 mm in diameter, which enables the evacuation of some generated heat.

A run-in period of at least 15 h at 500 rpm preceded each test, for roughness smoothing and grease distribution (churning phase). Following the run-in period, the electrical resistances were turned on and the temperature fixed at 60 °C. The friction torque was then measured for each speed step after the operating temperature was stabilized (smaller than 1 °C variation in a time

Table 1
Tested greases' properties according to the manufacturer.

Grease reference		M1	M2	M3	MLi	Units
Thickener type		Polypropylene			Lithium complex	–
Thickener content		11	13	15	17.5	%
Worked penetration (ISO 2137)		290	269	249	288	10^{-1} mm
NLGI		2	2	3	2	–
Base oil nature			Poly-alpha-olefin (PAO)			–
Base oil viscosity (ASTM D445)	40 °C		48		179	mm^2/s
	100 °C		8		21	

Table 2
Operating conditions for the rolling bearings tests.

Parameter	TBB 51107
Mean diameter (mm)	43.5
Number of rolling elements	21
Height (mm)	12
Rotational speed (rpm)	Stepwise from 100 to 3250
Temperature (°C)	60, 80, 110
Axial load (N)	7000 (≈ 2.3 GPa)

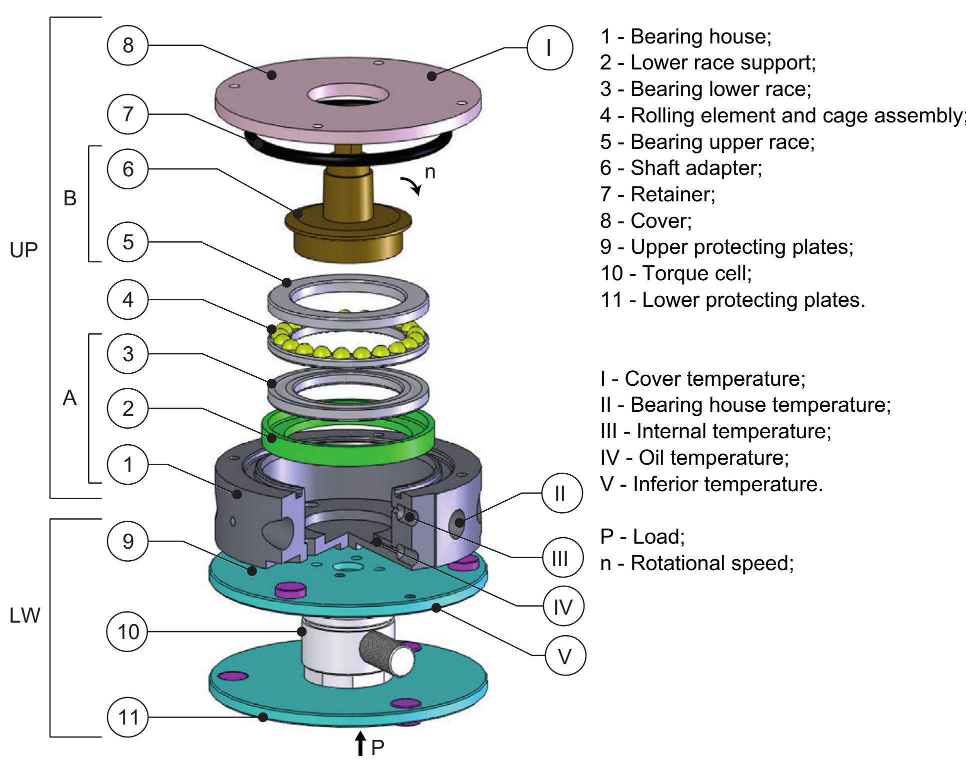

Fig. 1. Rolling bearing assembly. Note: Numbers from 1 to 13 are related to the assembly components. Numbers from I to V are referred to the thermocouple locations.