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Impact of high pressure and shear thinning on journal bearing friction

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ABSTRACT

For the study of mixed lubrication in journal bearings, this paper employs a combined experimental and simulative approach. Extensive measurements on a journal bearing test rig with a low viscosity 0W20 multi-grade lubricant provide a solid basis which is complemented by experimental lubricant data that is measured under high pressure and high shear rates. In this paper, this data is used to investigate the impact of the piezoviscous effect and the non-Newtonian lubricant properties on the friction power losses in journal bearings over a wide range of dynamic loads and shaft speeds.

In particular, this work seeks to predict the friction power losses for journal bearings under both moderate (50 MPa peak load) and high dynamic loads (100 MPa peak load) using the recently presented accurate numerical method (Allmaier et al., 2011 [1], Allmaier et al., 2013 [2]). From the direct comparison to the experimental data a key finding is that the simulation conforms very closely to the measured data. To be more exact, the agreement lies within the measurement uncertainty.

Following this result, the influence of the often neglected piezoviscous effect and the non-Newtonian lubricant rheology is investigated. We conclude that both the piezoviscous effect and the non-Newtonian behaviour are essential to describe the lubrication with multi-grade lubricants in journal bearings. Only the consideration of both properties describes the experimental data very accurately over the entire range of operating conditions studied.

1. Introduction

Journal bearings have been the focus of research for a very long time. From simplified analytical approaches (e.g. [3]) to extensive thermoelastohydrodynamical simulations (e.g. [2,4]) a large number of works have investigated specific questions involving this seemingly simple element. Consequently, we do not reproduce an extensive lists of general references here, but refer to the extensive lists of references in the previous works [1,2,5,6].

Furthermore, it is important to note that the methods to calculate the friction power loss due to the shearing of the oil film have come a long way. Especially the scientific works comparing theoretical approaches directly to experimental data are particularly noteworthy. Early papers presented well chosen approximations and applied them to simplified conditions [7] or used basic numerical evaluations of the Reynolds equation [8]. Recent publications by the authors extended these efforts and presented a numerical technique that is able to predict the friction power loss from full film lubrication to (weak) mixed lubrication under high dynamic loads [1,2,6]. It is worthwhile to mention that this approach requires only two easily measurable temperatures and no iterative adjustments to experimental data are necessary.

Central to these works is the consideration of the complex rheological properties of the lubricant [5] and the inclusion of a physically derived contact model together with a realistic surface contour of the journal bearing [9]. The following work builds on these previous works and extends them to multi-grade lubricants with strong non-Newtonian behaviour. In addition, the methodology is generalized to journal bearings without 180° oil supply groove as they are used as e.g. big end bearings in internal combustion engines.

Besides the scientific interest, the consumer demand and the increasingly strict environmental legislation are strong motivations in the industrial and automotive sector to develop engines that are more energy efficient. About 10% of fuel energy is needed to overcome friction in conventional engines, to which friction in journal bearings contributes up to 44% [10]. One way to reduce friction in journal bearings is the application of low viscosity engine oils [10–12]. While the hydrodynamic losses are decreased by reducing the lubricant viscosity [13,14], the appearance of

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metal–metal contact (mixed lubrication) becomes more likely and increases the risk of premature failure of the journal bearing due to seizure or wear. This poses a great challenge which is further intensified by high mechanical and thermal loads in modern internal combustion engines with ever increasing high power densities.

To explore the potential of reducing friction power losses in journal bearings and to design more efficient engines, reliable simulation methods which are proven by measurements are required.

To address this task, extensive measurements on a journal bearing test rig with controlled ambient conditions provide a solid basis. It is the aim of the present work to predict the friction power losses for journal bearings under moderate (50 MPa peak load) and under high dynamic loads (100 MPa peak load) using the recently presented generic numerical method [1,2] in direct comparison to the experimental data. Oil viscosity is the key parameter to describe lubricated contacts and is considerably sensitive to pressure [15] and shear rate [16,17]. Therefore, the influence of the often neglected piezoviscous effect and the non-Newtonian lubricant rheology are investigated.

2. Lubricant rheology

The lubricant used for this investigation is a fully formulated low-viscous 0W20 hydrocarbon engine oil. Previous works [1,2,5,6] investigated monograde lubricants that do not show a strong non-Newtonian behaviour. In this work the investigated lubricant is a multi-grade lubricant as they are commonly used in the automotive sector. The present work investigates also the influence of its strong non-Newtonian behaviour.

The main properties of the lubricant including the density and the viscosity at various conditions are given in Table 1.

The dynamic oil viscosity was measured at different temperatures as shown in Fig. 1.

For numerical reasons in practical applications it is more convenient to use empirical equations in the simulation instead of using the experimental data directly. Vogel's equation [18] is used here to describe the dependency of viscosity η from temperature in this paper:

$$\eta(T) = A \cdot e^{B/(T+C)}, \tag{1}$$

where T (°C) is the temperature, and A (mPa s), B (°C) and C (°C) are constants determined by curve fitting of the measurement results; Table 2 lists the values of these constants. Fig. 1 shows the measured viscosities at various temperatures and the corresponding curve obtained from Vogel's equation.

The lubricant viscosity under high pressure was measured using a quartz viscometer at the TU Clausthal. A piezoelectric sensor is excited to mechanical oscillation by applying an alternating voltage [19–21]. A particular benefit of this method is the minor temperature increase because the applied electric power is very low. Further, viscosities can be investigated for pressures up to 10 000 bar. The measured pressure viscosity relation of the

Table 1
Basic properties of the tested 0W20 lubricant.

Density at 40 °C	832.5 kg/m^3
Dyn. viscosity 40 °C	37.5 mPa s
Dyn. viscosity 100 °C	6.8 mPa s
HTHS-viscosity[a]	2.7 mPa s

[a] The HTHS-viscosity is defined as the viscosity at high temperature (150 °C) and high shear rate (10^6 1/s).

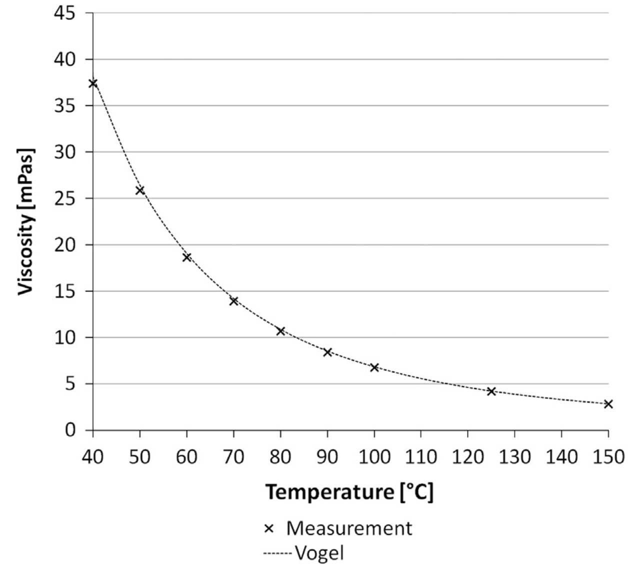

Fig. 1. Viscosity temperature dependence of the tested 0W20 lubricant at ambient pressure. The measured data are shown as crosses and the displayed curve is obtained from Vogel's equation, Eq. (1), with the parameters in Table 2.

Table 2
Parameters for Eqs. (1)–(3) derived from the experimental data.

A	0.0516 mPa s
B	1127.6 °C
C	130.7 °C
α	0.00095 1/bar
r	0.53 (–)
m	0.79 (–)
K	7.9 e – 8 s

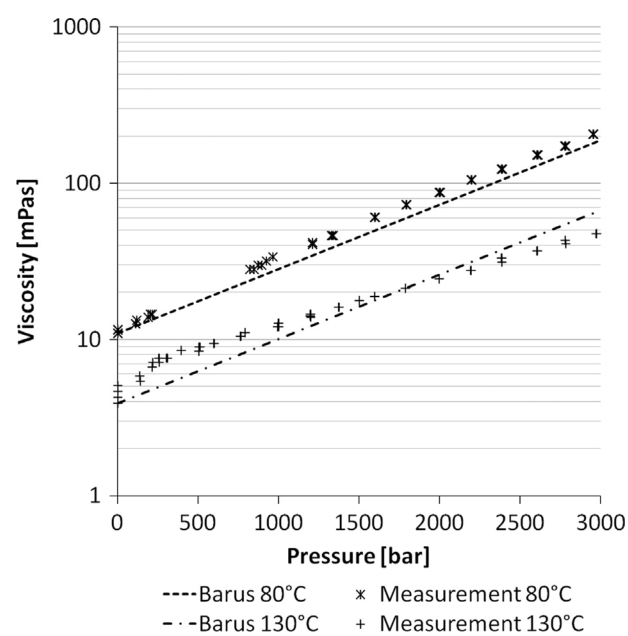

Fig. 2. Viscosity pressure dependence of the tested 0W20 lubricant. The measured data for 80 °C and 130 °C are shown as crosses and pluses, respectively. The displayed curve is obtained from Barus' equation, Eq. (2), with the parameters in Table 2.