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An experimental and signal analysis workflow for detecting cold-induced noise emissions (cold squealing) from porous journal bearings

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ABSTRACT

We employ a variant of the joint time-frequency analysis (JTFA) for identifying transient, temperature-dependent noise emitted from porous journal bearings operated at temperatures between −40 °C and 0 °C. This phenomenon, called “cold squealing”, is difficult to reproduce in laboratory environments, as it requires a suitable (and typically system-specific) resonator to occur. We systematically tested real-world bearings impregnated with various oils on a custom-designed experimental rig, fitted with a coolable sample holder and a vibration sensor, over a range of rotational speeds. By analyzing temperature-differential JTFA signal maps, we succeeded in detecting transient cold-squealing as well as ranking the bearing lubricants according to their low-temperature quiet running properties.

1. Introduction

In the automotive industry, components such as brakes as well as bearings used in windshield wipers, power window lifts, fans, and air conditioners can emit unpleasant noises under certain operating conditions, which usually leads to customer complaints or even product recalls.

A journal bearing is a simple and cheap mass-production machine element, which operates paired with a matching shaft of a drive. Porous journal bearings are produced from metal powders by sintering, and their resulting porous structure is later impregnated with a lubricant like a sponge [1,2]. The permanent oil circulation between the bearing’s porous seat and the lubrication gap gives them the advantage of “life-time lubrication”, i.e., they are functional for their entire service life of typically 3000–10,000 h [3,4]. Due to their flexibility in design and maintenance-free operation, they are very often used in industrial applications where an external supply of oil is not possible. Providers of automobile parts wish for smoothly running bearings, in particular the prevention of so-called “cold squealing” at temperatures below −20 °C, so choosing the right combination between bearing material and lubricant is crucial. On the other hand, the full functionality and the service life of the bearing in the temperature range from −40 °C to +120 °C must be kept, since operation has to remain possible in cold regions as well as in the hot engine compartment [5,6]. References [2,7] reported the occurrence of noise in porous journal bearings when certain types of lubricants are used, but their tests focused on high-temperature operation only. Numerous lubricants have frequently failed in terms of quiet operation, especially at low temperatures.

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The motivation for this work stems from an automobile parts manufacturer commissioning one of its lubricant providers to formulate a new porous bearing lubricant to fulfill a set of requirements including the ones mentioned above. Out of the handful of novel laboratory formulations, some were already discarded in-house by the lubricant manufacturer due to inadequate evaporation and/or static oil aging results. One more candidate formulation had to be discarded due to poor tribological performance at high temperature. Therefore, two new formulations remained that had to be tested for the most beneficial low-temperature properties.

While there is some literature available on brake squeal and ways to reduce it [8–10], cold start squealing of clutches [11] or engines [12], as well as more general work on friction-induced vibration, chatter, and squeal [13], the phenomenon of cold squealing bearings is relatively unstudied. Annoying as the latter may be, it is relatively difficult to consistently reproduce it in laboratory experiments, which impairs the studying of its origins.

It is generally understood that cold squealing is a friction-induced resonance phenomenon in the sense that a positive feedback between rapidly changing friction forces in the bearing and vibrational motion of the shaft may excite eigenmodes of the surrounding components, which in turn are emitted as airborne sound waves with sufficient acoustic pressure [14]. The origin of the rapid change in friction conditions is caused by a sudden transition from boundary or mixed to hydrodynamic lubrication, e.g., because of a cold, highly viscous bearing lubricant.

Most tribometers available for testing the performance of porous bearings are relatively stiff and do not feature an appropriate resonator, which means that the measuring and analysis approach must be able to detect transient or even inaudible noise emissions. In this work we will present such an approach based on the measurement of structure-borne noise as well as methods borrowed from voice analysis. We will exemplify our approach by ranking five porous bearing lubricants according to their cold-noise performance, which eventually led to the commercialization of the best-performing lubricant.

2. Model tribometers and experimental procedure

In this section we will introduce the two test devices that we used to experimentally reproduce the cold squealing phenomenon. The first one, a rheometer, was chosen because it allows isothermal testing, so that the point at which cold squealing occurs can be located via manual tweaking of the rotational speed. The second one, a custom-designed tribometer, performs rotational speed ramps after an initial cooling, so that the temperature varies due to the friction energy dissipation in the bearing.

Preliminary studies were carried out on a stress-controlled rotational rheometer with air bearings, the Physica MCR 301 by Anton Paar, see Fig. 1(a). The tribocell constituting its core is a ball-on-plate model system. The ball (diameter 12.7 mm) is pressed against three plates with an angle of 45° to the vertical axis and 120° between each other, thus creating three point contacts, see Fig. 1(b). While the ball rotates or oscillates, the torque and normal forces are recorded. The temperature can be regulated with Peltier elements positioned in the cap and the bottom. This setup offers a temperature range of −40 °C to +200 °C at a precision better than 0.1 °C. Reaching −40 °C from room temperature can be achieved in approximately 10 min. The rotating speed can be adjusted between 10^{-7} and 3000 min^{-1}, the torque measurement resolution is

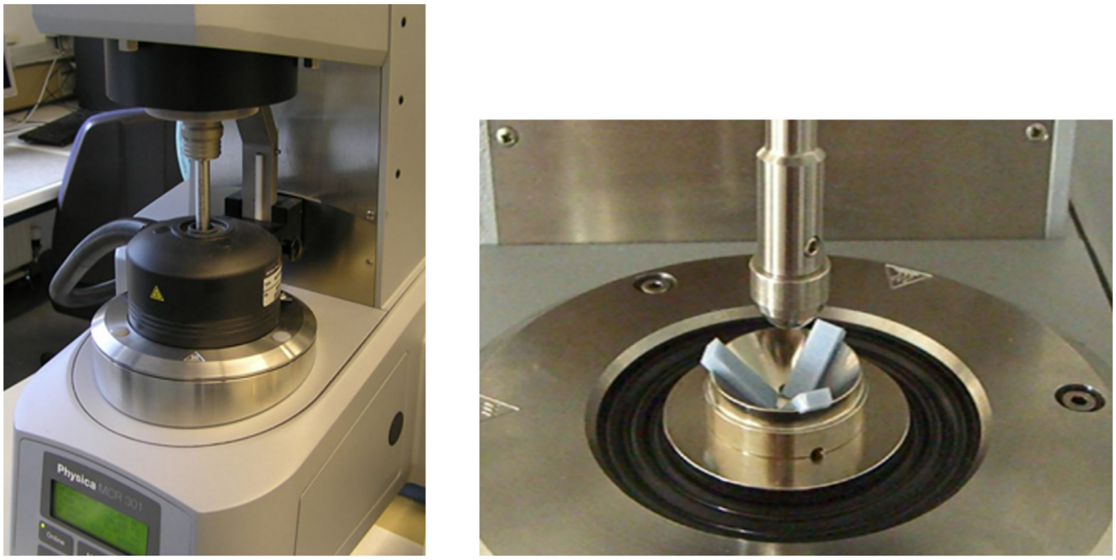
(a) (b)

Fig. 1. The Physica MCR 301 rheometer by Anton Paar. (a) In operation with Peltier cap. (b) The ball-on-plate geometry of the tribocell with three blocks of plastic in the positions where the porous plates are held in place by a clip (not shown) during testing.