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Measuring Lubricant Viscosity In-Situ Using Ultrasound

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Ultrasound is used to measure the reflection coefficient at a solid/liquid interface, and determine lubricant viscosity. Viscosity is measured at the area of contact or withing an oil film, where temperature, pressure, and shear rate can be extreme. These extreme conditions can be found in many industrial applications.
Models are developped to correlate the reflection coefficient and the viscosity.

Keywords: viscosity, in-situ, ultrasounds, reflection coefficient

1. Introduction

Being able to monitor lubricants in-situ represents time and money savings, making ultrasonic technology particularly adapted in industry.

2. Test Apparatus and Data Acquisition

2.1. Apparatus

Shear transducers are used to send and receive ultrasonic waves. They are instrumented onto a solid surface, so that the studied area is in direct line of sight. A thin solid layer, called the matching layer, is bonded between the solid and the lubricant. Its role is to reduce the mismatch between the acoustic impedances of the solid and the lubricant [1].

2.2. Data Acquisition

The ultrasonic wave travels through the layers, and is both transmitted and reflected at the matching layer/lubricant interface.

Two measurements are performed: one with a lubricant, and one with a reference (Figure 1).

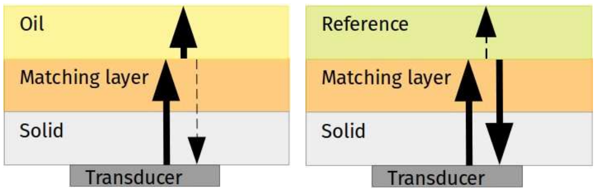

Figure 1: Oil and reference measurements using an ultrasonic wave.

The reflection coefficient RC, is the lubricant signal divided by the reference signal.

$$RC = \frac{frequency\, domain\, signal_{lubricant}}{frequency\, domain\, signal_{reference}} \quad (1)$$

2.3. Calibration

A calibration of the rig, under fixed conditions, is performed using lubricants of known viscosity. The reflection coefficient of each fluid is measured, and then correlated to the viscosity. The data points are fitted with a decreasing logarithmic curve: this is the calibration curve of the rig.

It is now possible to deduce the viscosity of unknown lubricants under the same conditions, by measuring their reflection coefficient and using the calibration curve.

3. Reflection Coefficient Models

Another way to calibrate the apparatus is to use theoretical models. Some models are based on a 2-layer system (Greenwood model [2]), while others (Newtonian and Maxwell models [3]) take into account the matching layer. They all link the reflection coefficient and the frequency, at a defined viscosity. They can be modified so as to correlate the reflection coefficient and the viscosity, at a defined frequency. The obtained curve is the theoretical calibration of the apparatus.

The models are compared to one another, and to experimental data (Figure 2). The accuracy of the models is based on the understanding of the parameters. Each layer is defined by a thickness and a material, itself defined by a density, and a shear velocity.

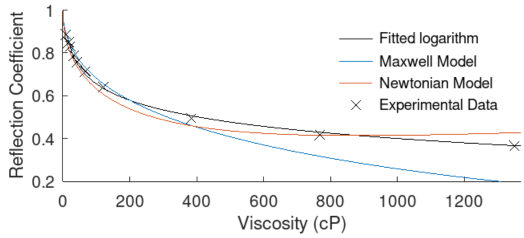

Figure 2: Experimental and theoretical calibrations.

4. Impact of Temperature, Pressure, and Shear Rate

In the lubricated contact of a machine element the conditions can be high temperature, pressure, and shear. The oil behaves very differently in a contact than it does under ambient conditions. The test apparatus has been used to explore how the ultrasound wave is affected with the lubricant at elevated temperature, pressure, and shear rate.

5. References

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