SHEAR AND NORMAL STIFFNESS OF MIXED LIQUID-SOLID CONTACTS

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ABSTRACT

When a wave of ultrasound strikes an interface between two bodies some proportion of the wave amplitude is reflected. A rough surface interface with a low real area of contact will reflect more ultrasound. This is the case for both normal and shear modes of ultrasound. If the ‘gaps’ in the contact are filled with liquid, then more of a longitudinal wave is transmitted through the interface. However, the shear wave should remain unaffected, since it is virtually all reflected at a solid liquid boundary. It is the stiffness of the interface that controls the response. Measurements of reflection can readily be used to determine the interface stiffness.

In this work a series of experiments has been performed to measure the reflection of both normal and shear ultrasound from both dry and wet rough contacts. This gives information about the normal and shear stiffness of dry contacts. When the layer is flooded with a liquid the stiffness of the liquid part alone can be deduced. This can be used to determine the film thickness in mixed lubrication. The shear stiffness was found to reduce with the application of a liquid; this is caused by the presence of asperity micro-slip at the interface.

INTRODUCTION

In boundary or mixed lubrication surfaces may not be completely separated by the oil layer. In such conditions, load will be partially supported by the contacting surface asperities and partially by the lubricant film. The proportion of solid contact controls the friction and influences the wear experienced by the machine elements. In this work, ultrasound is used to examine the nature of the mixed liquid-solid contacts under pressure. Shear and longitudinal ultrasonic pulses have been reflected from mixed liquid solid interfaces. The recorded reflections are used to investigate the contact conditions and to determine the proportion of solid contact.

Ultrasound has proved to be a useful method to study the in-situ characterisation of dry [1,2] and lubricated [3] surfaces in contact. The reflection coefficient (the proportion of the wave amplitude reflected), $R$ depends on the stiffness of the interface, $K$ according to a simple spring model:

$$R = \left| \frac{1}{\sqrt{1 + \left(\frac{2K}{\omega z}\right)^2}} \right|$$

where $\omega$ is the angular frequency of the ultrasonic wave ($\omega=2\pi f$), and $z$ is the acoustic impedance of the media either side of the interface. This relationship is applicable for both normal and shear ultrasonic waveforms.

For a mixed liquid solid this stiffness will have two components (see figure 1):

$$K_{\text{total}} = K_{\text{liquid}} + K_{\text{solid}}$$

The liquid part is given by:

$$K_{\sigma} = \frac{B}{h} \quad \text{and} \quad K_{\tau} = 0$$

where, $B$ is the bulk modulus of the liquid and $h$ is the liquid film thickness. The subscripts $\sigma$ and $\tau$ stand for normal and shear respectively. The solid stiffness part is governed by the surface deflection under traction:

$$K_{\sigma} = -\frac{d^2 p}{du_z^2} \quad \text{and} \quad K_{\tau} = -\frac{d^2 q}{du_x^2}$$

where $p$ and $q$ are the normal and shear tractions, and $u_z$ and $u_x$ are the normal and tangential surface displacements.
MEASUREMENT APPARATUS

Figure 2 shows a schematic diagram of the ultrasonic measuring apparatus and the specimens. The contact specimens consist of two aluminium blocks with grit blasted surfaces. The blocks are pressed together in a hydraulic test machine.

A shear wave and longitudinal wave transducers (both 5 MHz center frequency) was bonded to either side of the contact pair as shown. An ultrasonic pulser-receiver (UPR) was used to pulse the transducers. This pulse reflects back from the interface and is received by the same transducer. The recorded voltage is then captured by the UPR and stored as a waveform on a digital oscilloscope. The amplitude of the reflected signal is divided by that of the incident signal to produce the reflection coefficient. This is processed using the spring model to obtain the stiffness.

The specimens were initially assembled together dry, a few loading cycles were applied to remove any plasticity. The reflection was then determined at a series of applied loads. The contacts were then unloaded (to a very low load) and oil applied to the interface. The subsequent loading is then on an elastic mixed liquid solid interface.

RESULTS & DISCUSSION

Figures 3 and 4 show the interface stiffness for the dry and wet cases in both longitudinal and shear configurations.

The longitudinal stiffness is increased by the addition of oil; the oil layer has an inherent normal stiffness. However, the shear stiffness is reduced. This is caused by micro-slip occurring at the interface. The oil reduces the surface friction and so more slip occurs at the asperity contacts; thus reducing the shear stiffness of the interface.

By integrating the longitudinal stiffness result it is possible to deduce the variation in the gap between the surfaces. If this gap is assumed to be full of liquid then the liquid stiffness can be deduced. This is added to the solid stiffness to produce the combined stiffness. This is plotted on figure 3; the result agrees qualitatively with the measured stiffness results.

CONCLUSIONS

Ultrasound reflection can be used to determine the normal and tangential stiffness of wet and dry contacts. In a wet contact the normal stiffness is increased but the tangential stiffness is reduced over the same dry contact. This is caused by the reduced friction resulting in increased lateral slip at the asperity contacts. It is possible to separate the wet and dry contributions and so determine the proportion of dry contact occurring in mixed lubrication.

REFERENCES