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NON-INVASIVE MONITORING OF FREE SURFACE FILM LAYER SPREAD USING AN ULTRASONIC CONTINUOUSLY REPEATED CHIRP LONGITUDINAL WAVE

Engine & Drivetrain III

J. Kanja[1], X. Li[1], H. Brunskill[1], A. Hunter[1], R. Dwyer-Joyce[1]
[1]The Leonardo Centre for Tribology, the University of Sheffield

INTRODUCTION

Free surface liquid film layers are seen in various tribology applications such as; condensing liquids, the oil distribution around a gearbox casing, and the oil that forms ahead of an approaching piston ring. Measuring the thicknesses of these films provides information useful for performance control and monitoring. Performing these measurements in-situ can prove to be difficult as films tend to be thin and access often difficult. Reflected ultrasound is a promising way to measure surface films indirectly through a component or vessel. Piezoelectric transducers on a component back face emit ultrasound waves, these waves propagate to the front face and are reflected to the transducer. The magnitude of the reflected wave is dependent on the film thickness at the front face. A pulse-echo ultrasound technique is usually used to perform these measurements. However, as the film becomes thinner, the reflected echoes overlap. In this work, we propose the use of an ultrasonic continuously repeated chirp longitudinal wave to magnify the effect of the film. Multiple reflections occur within the component to form a standing wave whose amplitude spectrum is dependent on the film thickness.

BACKGROUND

High precision free surface film thickness measurement tools such as AFM, SEM and optical interferometry are costly, generally require measurements to be performed ex-situ, and have a requirement for a direct access to the layer of interest. Lower cost, simpler tools currently used include magnetic thickness gauges, wet-film comb gauges and ultrasonic paint thickness probes. Even though they prove to be more practical than the high precision kits, they still require a direct access to the layer of interest and most perform measurements invasively. Where the surface of interest is not readily accessible, indirect measurements can be performed using ultrasound. Ultrasonic waves can penetrate through components to an interface of interest. The reflected echoes are embedded within them information on the conditions at the interface of interest. Usually a pulse-echo technique is applied where the time difference between transmitted wave and the reflected wave is used to calculate the surface layer thickness. For thick surface films a time of flight method is usually used where the time interval between pulses is dependent on film thickness. As the film becomes thinner the echoes overlap and a resonance method is used to calculate the film thickness.

ULTRASOUND FOR NON-INVASIVE IN-SITU MEASUREMENT

Where the surface of interest is not readily accessible, indirect measurements can be performed using ultrasound. Figure 1 shows how piezoelectric transducers can be permanently mounted away from an interface of interest i.e. on the outer surface of the component.

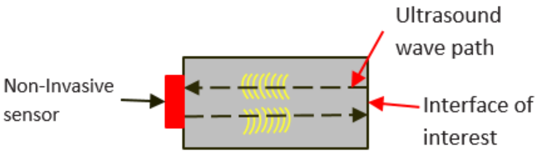

Figure 1. Ultrasound waves reflecting off an interface of interest

High frequency soundwaves (2 – 20MHz) are generated by the transducer. The waves travel through the material reflecting off the interface of interest and back to the same transducer. The reflected wave is detected by the transducers and is digitised for processing.

SIGNAL PROCESSING

In this work, we send a continuously repeated chirp longitudinal ultrasound wave [1]. The waves inside the component superimpose and form a ‘standing wave’. Standing wave peaks are observed, and these are formed due to constructive and destructive interferences. The component resonances are observed as peaks in the time domain spectra. The presence of a thin layer shifts the component resonances and some peaks go missing. This is otherwise known as the resonance method [2]. Destructive interference on a component standing wave occurs at frequencies where the film thickness is ¼ of wavelength. Figure 2 shows where resonances are lost due to a surface layer (green dotted ellipse region).

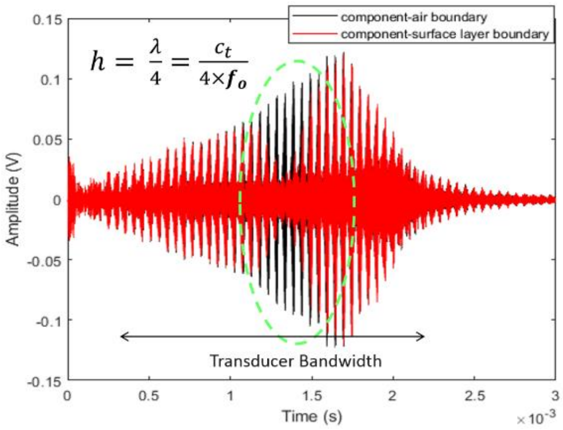

Figure 2. Frequency spectra showing resonances lost due to surface layer (circled in green).

METHOD

1. Measurements from a solid Surface Layer during removal

A polyimide layer bonded to a steel block was ground off using an industrial grinding wheel rotating at 2500 rpm. Micrometre readings and continuous wave ultrasound thickness calculations were performed at every grind pass (Figure 3).

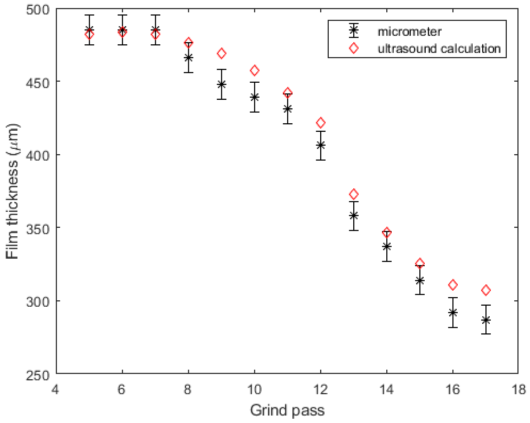

Figure 3. Surface film thickness comparison between micrometre readings and ultrasound calculations.

2. Measurements from a liquid film during spreading.

Continuous ultrasound waves methodology was used to detect and monitor the local film thickness of isopropanol on an aluminium surface due to spreading and evaporative conditions at room temperature. The sample was introduced after 5 seconds from the start of the test. At this time the film thickness was 140μm. This is represented in Figure 4. The film thickness then rose sharply to 380μm and then began to steadily drop up to 18μm. At this point in time the isopropanol that was remaining on the surface instantaneously evaporated.

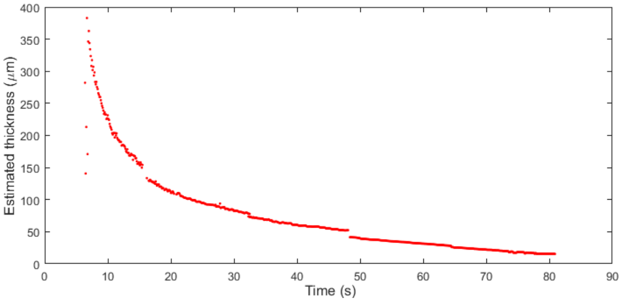

Figure 4. A plot showing ultrasonic local film thickness estimation of isopropanol sample as it spreads and evaporates from an interface of interest.

The technique was also applied to detect and monitor the local film thickness of a base oil on an aluminium surface due to spreading conditions only at room temperature. Figure 5 shows the localised film thickness change of base oil as it is introduced on the surface and as it spreads. Base oil has a much greater viscosity than isopropanol and this directly proportional to the time it takes to for the local film thickness to drop and this can be seen in Figure 4 and Figure 5. Isopropanol took 82 seconds to spread out and evaporate from the surface whereas base oil was still spreading even after 9 minutes.

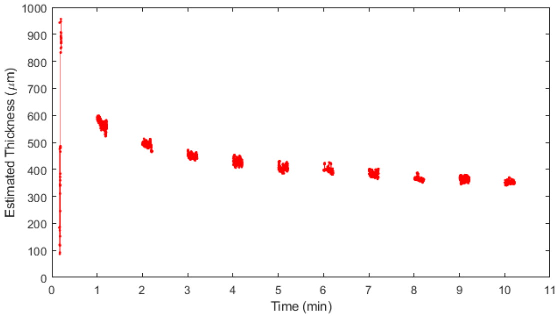

Figure 5. A plot showing ultrasonic local film thickness estimation of a base oil sample as it spreads across an interface of interest

Conclusion

This work illustrates the application of a continuous ultrasound wave methodology to detect and monitor surface layers for various test conditions.

References

[1] R. Mills, R. S. Dwyer-Joyce, And M. Marshall, ‘Continuous Wave Ultrasound for Analysis of a Surface’, 29-Jun-2017.
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Keywords
Surface layer; thickness; ultrasound; continuous waves; engine and drive train; wear;