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# Performance analysis of journal bearings using ultrasonic reflection

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ABSTRACT

One method that shows potential for non-invasive oil film measurement is the use of ultrasonic reflection. In the current work, ultrasonic transducer is coupled to the outside of a bearing and a wave transmitted through the bearing shell. The wave is partially reflected when it strikes an oil film. Experiments were conducted to study ultrasonic reflection coefficient technique in plain journal bearing. Measurements of multiple reflection coefficients were recorded and used to map the viscosity profiles, oil-film thickness and bearing cavitation. In addition, an alternative method using the reflection coefficient phase from film thickness measurement was used for verification. The results revealed that the evaluation of phase method is slightly lower compared to that of the amplitude method. The film thickness profile obtained in the converging region agreed well with classical hydrodynamic predictions.



## 1. Introduction

In journal bearings applications, viscosity is the most important property of the lubricant that affects bearing performance. Measurement of fluid viscosity in bulk is easy with different types of viscometer. Due to the limitation of utilising these devices to measure the lubricant viscosity inside the journal bearing where the lubricant exist in a very thin layer, however, other techniques are required to be applied to measure viscosity inside journal bearings. Ultrasonic approach is a non-conventional approach which is to measure the fluid viscosity. Greenwood and Bamberger [1] reported the use of shear wave reflection at the solid-fluid interface for online measurement of viscosity but the approach has not been extended to measure the viscosity in plain bearings. In recent work, Kasolang and Dwyer-Joyce [2] measured the viscosity in thin layers between parallel plates by using shear reflection coefficient. There have been many studies found in the literature related to ultrasonic reflection coefficient measurement [3–6]. They used ultrasonic reflection coefficient technique to conduct tribological studies on coating materials and measurements of their properties. Maintaining an adequate film thickness around the journal circumferences at all times have been the main concern in tribological community [7]. Thin film is produced due to the pressure build-up between the journal and bearing shell. Fluid film bearings rely on the formation of relatively thick film between the journal and the bush, it occurs when opposing bearing surfaces are completely separated by a lubricant film. A number of methods to monitor the performance of plain bearings have been developed in the past and their differences essentially lie in the choice of the monitoring parameter such as lubricant contamination, vibration, temperature, friction and wear [8–12].

One method that shows potential control of hydrodynamic journal bearings based on oil-film thickness measurement is suggested by Roy Chowdhury [13]. The proposed method monitors the journal bearing so that an adequate film thickness is maintained at all times as this is desired. However, this technique is useful commonly in industrial applications especially in large installations such as power plants, rolling mills etc. Moreover, the displacement sensor has a much lower accuracy. It can only measure movement of the journal in one direction. It cannot accommodate deflection of the bearing (which occurs in most automotive type journal bearings). Also ultrasound can measure down to smaller film thicknesses (as low as 100 nm)—beyond the resolution of displacement sensors.

Chapkov et al. [14] developed a point contact model to predict the film thickness incorporating a shear-thinning rheological model. The model is applicable solely for elastohydrodynamic lubrication in rolling bearings. Glavatskih et al. [15] developed an eddy current transducer with an active compensation for changes in sensor temperature to simultaneous monitoring oil film thickness and temperature in bearings. Of late, techniques for local oil film thickness measurement in bearings suffer from serious drawbacks. According to a comprehensive review done by

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**Nomenclature**

| | |
|---|---|
| $c$ | speed of sound in medium ($ms^{-1}$) |
| $C$ | radial clearance of bearing (m) |
| $D$ | journal diameter (m) |
| $h$ | interface thickness (mi) |
| $h_{min}$ | minimum film thickness (mi) |
| $i$ | square root of $-1$ (dimensionless) |
| $K$ | interface stiffness (GPa $\mu m^{-1}$) |
| $L$ | bearing length (m) |
| $R$ | complex reflection coefficient (dimensionless) |
| $S$ | Sommerfeld number (dimensionless) |
| $z$ | acoustic impedance of medium ($kgm^2$ s $\times 10^6$) |
| $e$ | bearing eccentricity (m) |
| $\eta$ | dynamic viscosity (Pa s) |
| $\rho$ | density (kg $m^{-3}$) |
| $\theta$ | angle (rad) |
| $\Phi$ | reflection coefficient phase (rad) |
| $\omega$ | angular frequency of pulse (rad) |
| $1$ | solid material before thin film layer (dimensionless) |
| $2$ | solid material after thin film layer (dimensionless) |

Dwyer-Joyce [16], one method that shows potential for non-invasive oil film measurement without extensive modification to the components is the use of ultrasonic technique.

Thus, in the present study, ultrasonic measurements of multiple reflection coefficients are extended to a practical application in a journal bearing. The reflection data is used threefold; firstly to determine the viscosity, secondly to monitor the film thickness profile; and thirdly to observe the bearing cavitation. Static measurements of shear reflection coefficients are carried out at several locations around the journal bearing. Thereafter, the amplitude reflection coefficient data were converted to viscosity values and compared with an earlier work done by Kasolang et al. [17]. The oil film thickness was determined from both the amplitude and the phase of the reflected signal. These two approaches were then compared with a theoretical solution.

## 2. Experimental details

To demonstrate the reflection coefficient technique around journal bearings circumference, the ultrasonic equipment used in this study is shown in Fig. 1, which was also described elsewhere [18]. The main components are a computer, an ultrasonic pulser receiver (UPR), a digitizer (oscilloscope) and a transducer. The UPR generates short duration voltage pulses, which excite the transducer causing it to resonate, thus sending the required ultrasonic pulse to the medium. The transducer operates in a pulse-echo mode (see Fig. 2).

The transducer converts electrical signals supplied by UPR into a mechanical vibration. When the pulse encounters the boundary, it is partially reflected and received by the same transducer. The reflected pulse is converted to voltage by the transducer, amplified by the UPR, digitised by the oscilloscope and then passed through the computer for processing. A series of LabView routines control the operation of the hardware and the subsequent processing of the received signals. The journal test rig was modified by preparing a hole on the journal and the shear transducer assembly was then fixed by pressing it into the hole (Fig. 3). The protruding part of the Perspex plug was machined in order to follow the contour of the journal. The journal bearing was then measured and the new measurements were tabulated. Oil temperature was recorded using K-type thermocouples at the oil supply hole and at the outlet of the bearing as illustrated in Fig. 4. The terminal ends of the sensors were connected to electronic controller for processing the signal before displaying on PC. The oil temperature measurements were used to adjust the lubricant viscosity for theoretical calculations of film thickness. It was found during the experiments performed in this study that the error in the temperature of the oil film about $\pm 0.5\,^{\circ}C$. At the beginning of the experiment, the oil was supplied and the journal bearing was lightly loaded. The speed of the journal bearing was slowly increased to the desired value. Then, the full load was

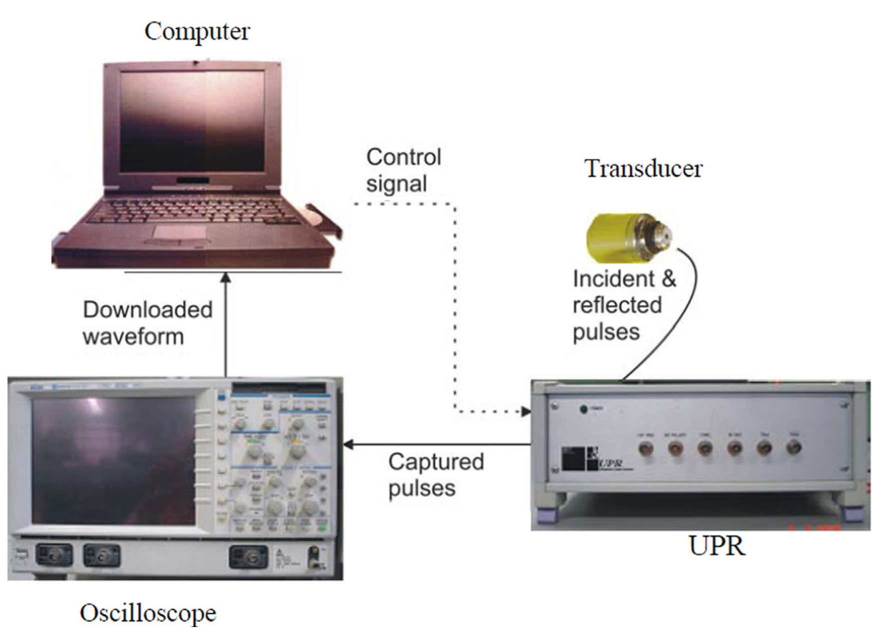


**Fig. 1.** Schematic diagram of ultrasonic kit and system layout.