Proceedings of the ASME 2009 International Mechanical Engineering Congress & Exposition
IMECE2009
November 13-19, Lake Buena Vista, Florida, USA

IMECE2009-10160

NEW TECHNIQUE MEASURING FILM THICKNESS FOR TRIBOLOGICAL MACHINES

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ABSTRACT

In the present work, a prototype machine was developed for film thickness measurement for tribological tests. The configuration of the machine was based Block on Ring (BOR) technique. In the current machine, frictional forces and film thickness were measured using load cell and strain gauges, respectively. Calibration was made to determine the real film thickness. Experiments were conducted using the newly developed machine to investigate the film thickness during sliding of UHMWPE against aluminum alloy counterface. The tests were performed at applied loads (1.47 N - 2.94 N). The results revealed that increases the applied load reduces the film thickness which in turn played a main role in controlling the surface characteristics of the polymer.

Keywords: Film thickness, Tribology, Measurement, strain gauge

1. INTRODUCTION

There is growing need in tribology to be able to measure and understand the nature and properties of very thin lubricant films, in rubbing contacts. The endurance of machine elements such as gears, bearings and any other seals relies on the integrity of the lubricant film separating the contact surfaces. If the film fails, these surfaces contact and friction, wear and losses can occur. The thickness of an oil or any other lubricant material, film depends on the lubricant properties, the geometry of the bearing surfaces and the operating conditions [1]. One reason is that the pursuit for smaller, lighter machines combined with improvements in surface-finishing technologies, means that there is a general course towards the use of thinner lubricant films in engineering components [2, 3]. A second important constituent is increasing interest in the development of micro-components such as microelectromechanical systems and information storage retrieval devices that operate at very low contact loads [4]. Clearly an important stage in understanding the behavior of thin lubricant films is to measure their thickness in rubbing contacts and to relate this to the conditions and the properties of the lubricant.

Existing techniques for lubricant-film measurement fall into two categories: electrical methods and optical methods. Early work [5] focused on the determination of the film thickness by measurement of its electrical resistance. In later studies, measurements of the film capacitance [6] founded to be more effective and the use of micro-transducers gave improved resolution [7]. These methods require electrical isolation of the contact elements. The application of optical methods requires either that one of the contact elements is transparent or that it contains a transparent window. Optical interferometry [8] has proved successful in the measurement of elastohydrodynamic films and, more recently, boundary films [9]. The use of lasers to fluoresce a lubricant film has also been used to determine film thickness [10]. However, the requirement for transparency has meant that these methods are rarely used outside the laboratory.

Even though there exist a number of techniques for measuring the thickness of lubricant films greater than 100 nm, based, there are very few methods of measuring nanometer scale thickness lubricant films. Two tools of surface physics, the atomic force microscope and the surface forces apparatus, are able to measure the thickness and physical properties of very thin films on surfaces and have been used with some prosperity to characterize films formed by lubricants [11, 12]. However these techniques differ from lubricated contacts in several important respects, the most essential of which is the way that the film is generated.

2. DEVELOPMENT PROCESS OF THE MACHINE AND EXPERIMENTAL DETAILS

2.1 Fabricated machine

Fig.1 shows a three dimensional view of the new developed machine which was designed with the aid of CATIA software (Computer Aided Three dimensional Interactive Application). Technical specification of the machine is listed in table 1. The main component of the machine are counterface, motor, lubricant container, arm, specimen holder, pivot and strain gauge sensor circuit.

In the current machine strain gauges (7) were adhered on flexible plastic prototype and attached in somehow on the lever of the machine. This mechanism can sense any movement in the y-axis direction, in other words sensing the film thickness. During the sliding, when the film presents in the interface, the strain gauges sense the changes, i.e. capture the film thickness. In addition to that a load cell was fixed on the arm to measure the frictional forces at the interface between the specimen (5) and counterface. The pivot (3) is created by drilling a hole through the center of the arm (2) and passing bolt through it, the bolt is also passing through two bearings from each side of the arm, and these bearings are supported by fixed armature. The container (6) was made of transparent material to make the film visible. The specimen holder (4) is a hole of the dimensions (20mm x 30mm, 9mm depth) created on the other end of the arm; two 4mm holes are threaded through the sides of the main hole to allow screws to hold still the specimen. The arm is the most important element of the machine because it holds the load at one of its ends and holds the specimen at the other end, it also cause the deflection of the strain gauges with respect to the film thickness, which make the measurement of the film thickness using the strain gauge possible.

Table 1 Technical specification of the new developed machine.

Motor Speed	94 rpm no load speed
Motor Type	12V DC, stall torque is 9Nm, and stall current is 24A.
Load	1N to 10N
Specimen size	20 mm x 30 mm
Specimen thickness	12 mm to 18 mm

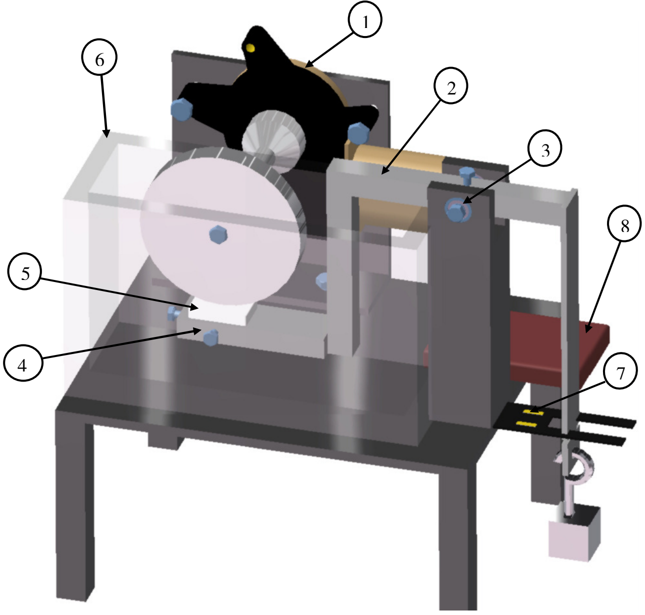

Fig. 1 Three dimensional view of the new machine designed using CATIA software. *1 -Motor, 2- Arm, 3- Pivot, 4- Specimen holder, 5- Specimen, 6- Lubricant container, 7- Strain gauge, 8- Strain gauge sensor circuit*

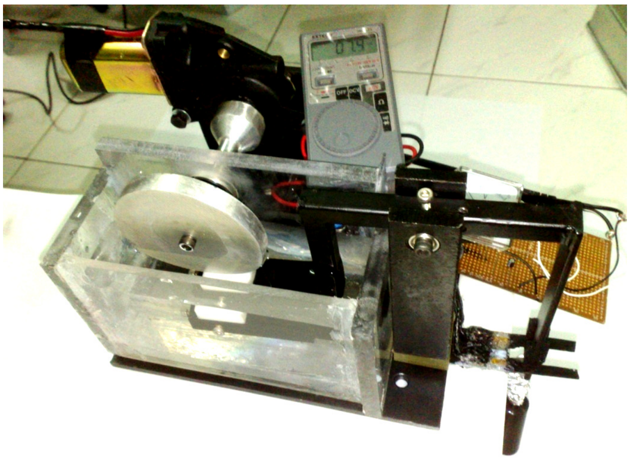

Fig. 2 The newly developed machine

2.2 Measurement and instrument

Wheatstone bridge is used to determine the deflection in the strain gauges resistance. Four strain gauges are used instead of one to increase the sensitivity and the linearity of the circuit, also to eliminate the temperature error. The four strain gauges are attached to a flexible plastic prototype to form the bridge. By placing the strain gauges 2 and 3 on the top of the plastic prototype, it means they are having the same value of resistance. While the strain gauges 1 and 4 are having the same value of resistance, because they are placed on the bottom of the plastic prototype, this arrangement leads the output voltage V_{AB} to be:

Since R_{SG1} $=R_{SG1}$ and R_{SG1} $=R_{SG1}$, hence

$$V_{AB} = \left(\frac{R_{SG1} - R_{SG2}}{R_{SG1} + R_{SG2}}\right) V_{CD} \qquad (1)$$

When the plastic prototype is flat, the initial resistance value of all strain gauges is 120 Ω, which means V_{AB} is 0Ω. When force is applied on the plastic prototype, the resistance value of stain gauges 1 and 4 increases and the resistance values of the strain gauges 2 and 3 decreases with the same ratio, this leads V_{AB} to slightly increase. The deflection of the resistance values of the strain gauges varies from 0.01 to 1.5Ω, which is very small deflection; hence the deflection of voltage value of V_{AB} is also very small (in mV). To increase the voltage value of V_{AB}, two stages of inverting operational-amplifier are connected to the bridge output voltage V_{AB}, the gains of the amplifiers are calculated as below

$$V_{o1} = -\frac{R_{f1}}{R_a} V_{AB} \qquad (2)$$

and,

$$V_{out} = -\frac{R_{f2}}{R_b} V_{o1} \qquad (3)$$

,

By substituting the values of R_{f1}, R_{f2}, R_a, R_b (as shown in the circuit diagram) and V_{AB} in the above equation V_{out} can be calculated as

$$V_{out} = \left(\frac{R_{SG1} - R_{SG2}}{R_{SG1} + R_{SG2}}\right) 880 \qquad (4)$$

Finally, an analogue low-pass filter is added to the output voltage of the circuit to reduce the voltage fluctuations caused by high-frequency noise. The value of the frequency can be determined by using the formula below:

$$f_o - \frac{1}{2\pi RC} = 16\ Hz \qquad (5)$$

2.3 Experimental procedure

Calibration test is preformed to make it possible to represent the film-thickness (mm) in terms of output voltage (mV), where the output voltage values were read from the voltmeter and the oscilloscope under different displacements of the film-thickness (0-1mm). The output voltages were read at every 0.1mm, and they were presented against lubricant film thickness as shown in Fig.4.

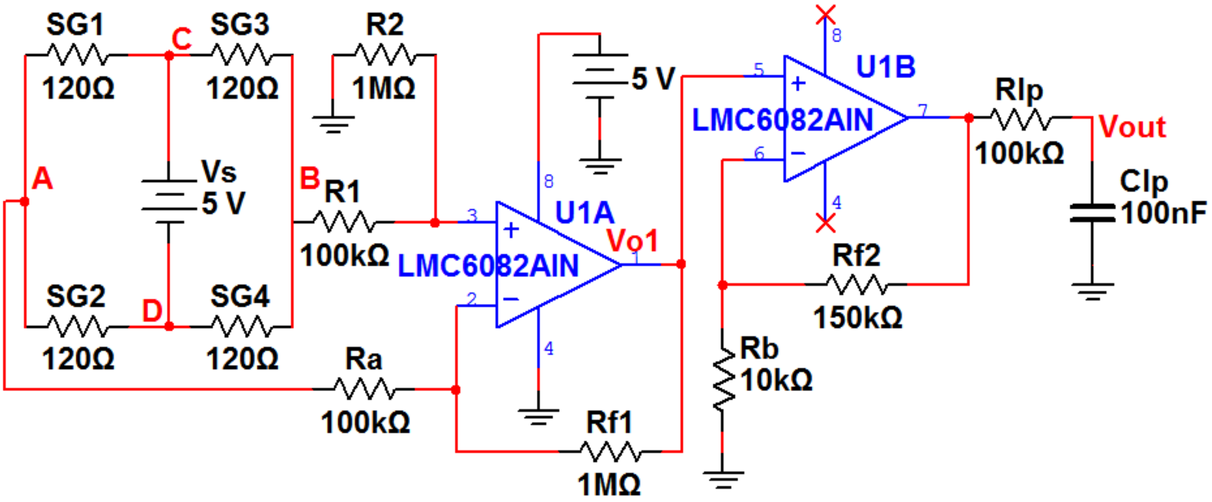

Fig. 3 Schematic diagram of Strain Gauge sensor circuit

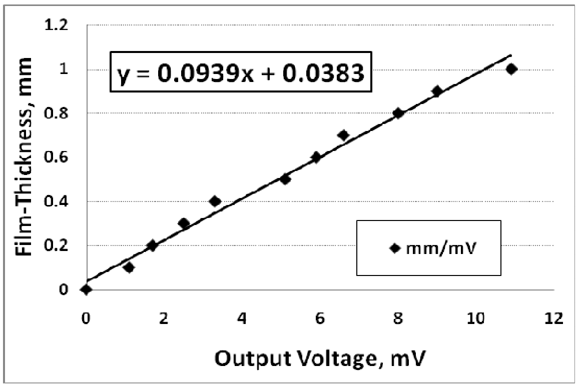

Fig. 4 Film thickness vs. output voltage relation

Experimental tests were conducted on prepared samples of Ultra High Molecular Weight Polyethylene (UHMWPE) to verify the lubricant film thickness measurement setup. Material properties of the selected polymer are listed in table 2. Virgin surface of the UHMWPE is shown in Fig. 5. The tests were conducted at different applied loads of 1.47-2.94N. The lubricant fluid used in the current work is tap water. The tests were performed for 10 minutes and the lubricant films were recorded for every minute.

Table 2 Material Properties of UHMWPE

Material Properties	UHMWPE
Density, g/cm^3	0.93
Tensile strength, N/mm^2	20
Hardness, Shore D	63
Melt temperature DSC, °C	133-135
Coefficient of linear expansion, 23-80 °C	≈2*10^-4 /K

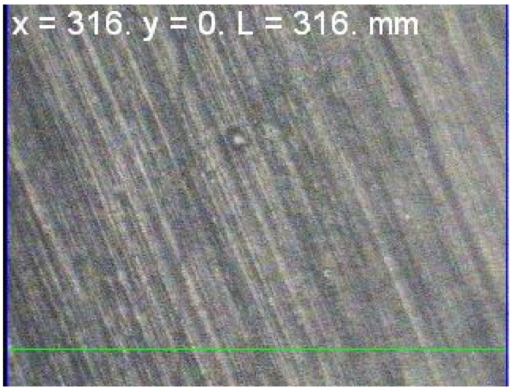

Fig. 5 micrograph of the virgin UHMWPE surface

3. RESULTS AND DISCUSSION

3.1 Machine Calibration

Fig. 4 shows the Output Voltage of the strain gauge sensor circuit at different values of the film thickness. In general, there is a tendency of increasing the film thickness with the increase of output voltage. Besides, it can be said that the increase of the output voltage is linear with the increase of the film thickness, and the linearity relation can be presented from the slop equation as bellow:

$$\mathbf{L} = 0.0939\,\mathbf{V} + 0.0383$$

Where **L** is the film-thickness in millimeters and **V** is the output Voltage in mill volts.

3.2 Film thickness test

For the measurement of lubricant film-thickness, water was used as a lubricant, and the rotation speed was constant for all the tests. The relation between the film thickness against duration for different loads, is presented in Fig. 6, which shows the film-thickness against the duration of the test, the loads were used in the test from lighter to heavier (1.47-2.94N). There is obvious increase of the film thickness value with respect to time, because the wear is causing damage to the contact surfaces which increases the gap (film-thickness) between the contact surfaces. This behavior can affect the lifetime of the machine negatively. The relation between the film thickness and the applied force is disproportional; the heavier load the smaller the film-thickness. This is due to the applied gravitational force which pushes the specimen toward the counterface and increases the friction and wear between the contact surfaces.

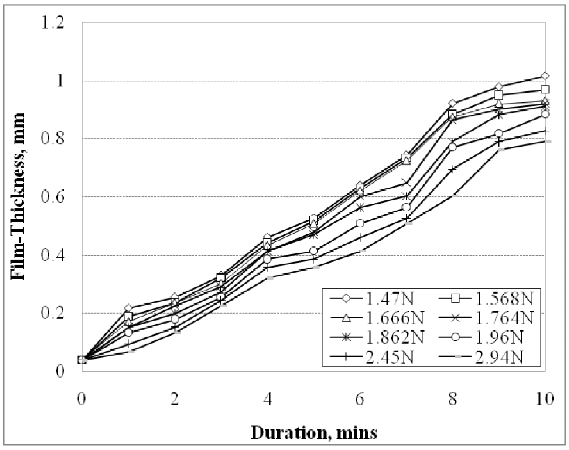

Fig. 6 Film thickness against time of lighter region of loads

The worn surface of the UHMWPE material after the tests is presented in Fig. 7 at low and high applied loads. At lower applied load, 1.47 N, there are no remarkable damages on the surface. In other words, there is less contact between the asperities in the rubbing area. This could indicate that in presence of the water, there was lifting process preventing the contact of the bodies. This leads to very low friction coefficient and removal of materials. On the other hand, Fig. 7b shows scars and grooves on the surface of the polymer. This is due to the contact of the polymer with the counterface. In addition to that, there could be a film transfer onto the counterface which led to increase the roughness of the track. The figure can explain the experimental results obtained on the film thickness. At small film thickness, at higher load, there is contact between the asperities showing scars and damages on the soft body (polymer).

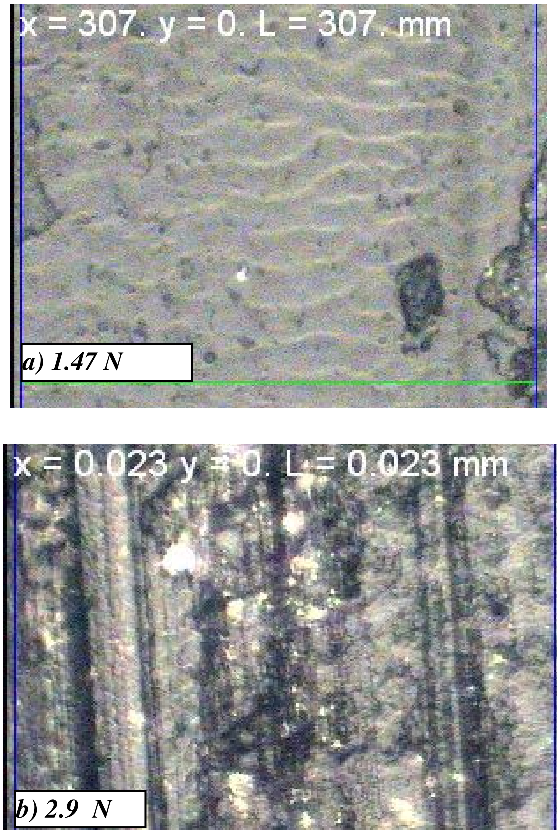

Fig. 7 Micrographs of the worn surface at different applied loads.

4. CONCLUSION

It can be concluded that the new technique is capable to measure film thickness during wet adhesive tests. The experiments revealed; that the higher the applied load the smaller the film thickness. Optical microscopy images revealed that at small film thickness UHMWPE surface is highly damaged compared to larger film thickness. It can be also concluded that using four strain gauge in Wheatstone bridge result in linearity between output voltage and strain gauges resistance deflection.

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