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Development of Grease Film Breakdown Observing Device

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The paper describes a newly developed smart device, which can detect the dielectric breakdown of the grease elastohydrodynamic film formed between a steel ball loaded against a glass disc due to electric discharge, while observing the shape and thickness of the film. The electric discharge between contacting surfaces can be observed as a white flash signal. It is found that the dielectric breakdown voltage increases with the film thickness.

Keywords: electrical pitting, dielectric breakdown voltage, grease, EHL

1. Introduction

Electrical pitting sometimes occurs at the race and ball surface of rolling contact bearings used for ac induction motors. It has been thought that electrical pitting is produced by the dielectric breakdown of lubricating film. Vance and Palazzolo[1)] and Komatsuzaki et al[2)] have suggested that there is an intimate relation between the dielectric breakdown voltage and the film thickness. However, nobody has observed directly where in the elastohydrodynamic lubrication (EHL) conjunction the dielectric discharge occurs. In order to understand electrical pitting phenomenon, the electric discharge phenomenon should be directly detected in the EHL conjunction, while observing the shape and thickness of EHL films.

Optical interferometry is now widely used for measuring the film shape and thickness in model rolling and/or sliding EHL contacts. Hence, a ball-disc machine which uses interferometry to map the point contact geometry has been improved so as to be able to observe directly the electric discharge between surfaces as a flash signal under running conditions.

2. Experimental

2.1. Apparatus

In the conventional optical interferometry device, the contact surfaces are composed of a highly reflective steel ball and a transparent material such as glass and sapphire to visible light. The surface of the transparent material is coated with a thin semi-reflective chromium layer. In order to investigate electrical pitting phenomenon using this device, it is necessary to apply a voltage between contacting materials. However, the electrical resistance of the chromium layer is high, say several kΩ. As shown in Fig. 1, therefore, the chromium layer was covered with an indium tin oxide (ITO) film, which is transparent and has a good conductivity.

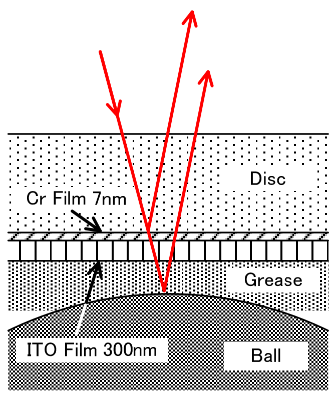

Fig. 1 Newly developed interference method

A schematic diagram of a newly developed experimental apparatus is shown in Fig. 2. The contacting surfaces are composed of a precision stainless steel (SUS440C) ball of 25.4 mm diameter and a glass disc of 180 diameter and 12 mm thickness, whose lower surface is sputtered with a semi-reflecting chromium layer of 7 nm thickness. An indium tin oxide (ITO) film of 300 nm thickness was sputtered onto the chromium layer. The addition of the ITO film to the chromium layer reduced the electric resistance of films from several kΩ to 10Ω.

Electrode brushes made from sintered alloy of 90% Ag were attached to shafts connecting the steel ball and glass disc, respectively, in order to apply the voltage between the surfaces of the steel ball and glass disc. The electrical resistance between the brush and shaft was about 1Ω. A commercially available function generator and a power amplifier were used as a power source.

The duo-chromatic interferometry technique[3] was used to measure the shape and thickness of the EHL film. A xenon-lamp was used as a light source and the fringe pattern was recorded at an interval time of 500 μs and an exposure time of 450 μs with a high speed digital camera attached to a microscope.

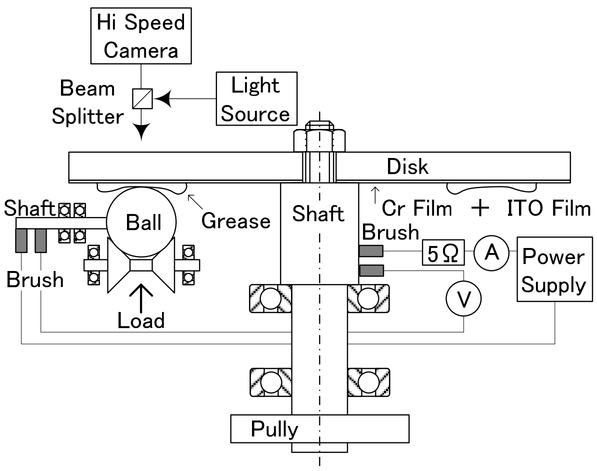

Fig. 2 Schematic view of testing machine

2.2. Experimental procedure

A sample of lithium grease (see Table 1) was evenly applied to the glass disc around the rolling track. The glass disc rotation was started, after the steel ball was loaded against the glass disc. Then, a 100 Hz sine wave voltage with 10 $V_{0\text{-}P}$ under a current limit of 2.7A was applied between the ball and the ITO film. The voltage and current between both surfaces were recorded at a sampling rate of 5 MHz with a memory oscilloscope. Since the steel ball was rotated by the traction force transmitted through the grease EHL film, the recording was started after a steady rotation of the steel ball was attained; the measuring duration was 0.65 seconds. In experiments, a virgin track on the glass disc was always used, but the ball was used several times. The experimental conditions are summarized in Table 2. Under the condition where the voltage was not applied, two surfaces are always completely separated.

Table 1 Properties of grease used

Base Oil	Mineral oil	
	Kinematic Viscosity	130 mm^2/s (40°C)
		12.2 mm^2/s (100°C)
Thickener	Lithium	
Worked Penetration	276	

Table 2 Experimental conditions

Room Temperature	21 ± 1 °C
Humidity	50-70 %RH
Rolling Velocity	350 mm/s
Contact Load	39.2 N
Hertzan Pressure	Max 0.54 GPa, Mean 0.36 GPa
Hertzan Diameter	0.37 mm
Calculated Film Thickness[4]	Central 0.88 μm, Minimum 0.53 μm

3. Results and discussion

Figure 3 shows the representative results, where the current and voltage for 50 ms after the start of measurements are shown. If the surfaces are completely separated by the grease film, the current does not flow across the film. However, it should be noted that the current flows about ten times within 50 ms. This fact means that the electrical discharge or dielectric breakdown occurs. Figure 4 shows the interferogram at around 25 ms. It can be seen that there are two white colored flash signals, which correspond to the positions where the dielectric breakdown of the grease occurs. The minimum film thickness occurs at the horseshoe shaped constriction region and its value is 0.53 μm. The measured central film thickness is 1.0μm. It should be noticed that the flash signals do not occur at the horseshoe shaped constriction region but at a film thickness of 0.94 μm. Figure 5 shows an enlarged detail view around at 25 ms of Fig. 3 for an examination. The voltage just before the dielectric breakdown is 9.8 V. This voltage will be defined as the dielectric breakdown threshold voltage. Immediately the voltage changes, the current, whose maximum value is about 100 mA, flows for about 10 μs; Two times change in the voltage and current seems to correspond to the two white spots shown in Fig. 4.

At 550 ms after the start of measurements, oil starvation occurred so that the overall film thickness reduced to about half. Although the current flows more frequently, the incidence of the flash signal remained unchanged. Within 650 ms the flash signals more than 100 times were observed. Figure 6 summarizes the relation between the film thickness and dielectric breakdown threshold voltage. The symbols ◎ and ○ denoted in Fig. 6 show the film thickness at the position where the flash signal appears under fully flooded and starved conditions, respectively. The central and minimum film thicknesses are indicated as an error bar. It should be noted that the minimum dielectric breakdown threshold voltage for the grease used in this study is about 4 V. It should be also noticed that the film thickness at the position, where the flash signal is detected, roughly increases with increasing dielectric breakdown threshold voltage. Within the limits of experiments, the flash signal never occurred at the position where the minimum film thickness appeared.

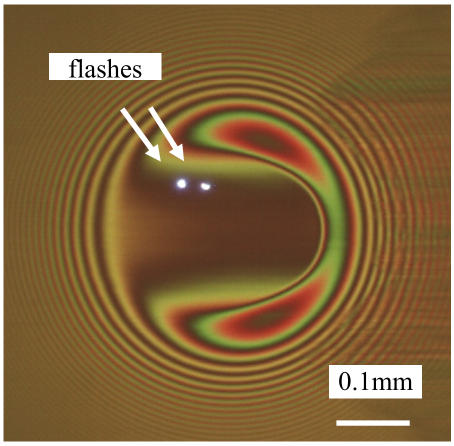

Fig. 4 Interferogram showing flash signal caused by electric discharge

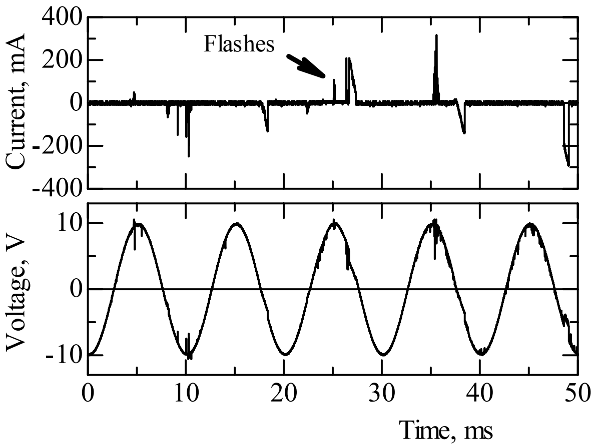

Fig. 3 Waveforms of current and voltage

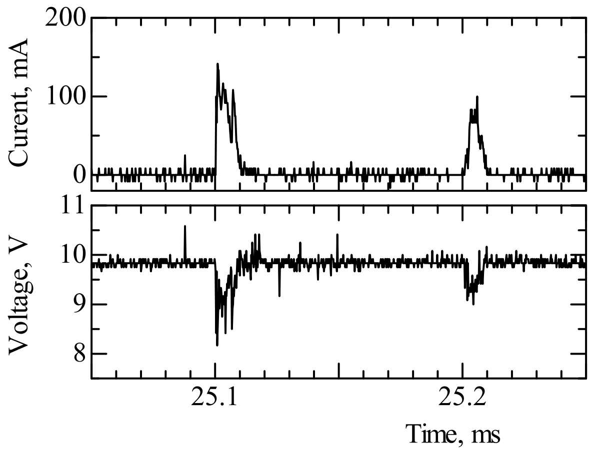

Fig. 5 Magnified waveforms of current and voltage

There was the case where the flash signal was not detected although the current flows. In such cases, it was observed that a cloudy shadow passed through the EHL conjunction. Figure 7 shows the interferogram showing the cloudy shadow, and the corresponding waveforms of current and voltage are shown in Fig. 8. It can be seen from Fig. 7 that the cloudy shadow appears at the position of the minimum film thickness at about 49 ms. The current flowing duration is several hundred μs, which is longer than the flash duration time of several μs. The current are several hundred mA, which is larger than the electric discharge current of several ten mA. Further study is necessary to understand the generation of such a cloudy shadow.

Figure 9 shows pits appeared on the steel ball surface. Each pit (black part) is accompanied with a discoloring region in its surrounding. Note that there are many pits since the photograph is taken after the experiments.

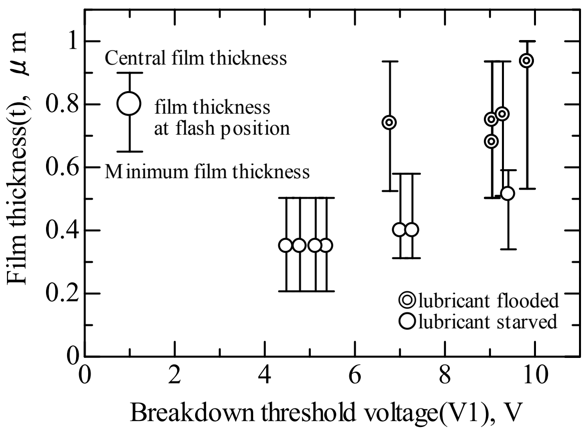

Fig. 6 Relationship between film thickness and dielectric breakdown threshold voltage

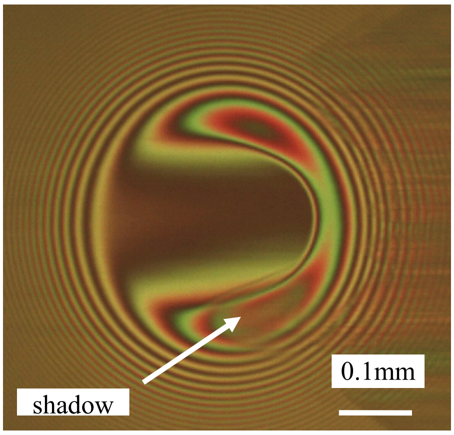

Fig. 7 Interferogram showing cloudy shadow

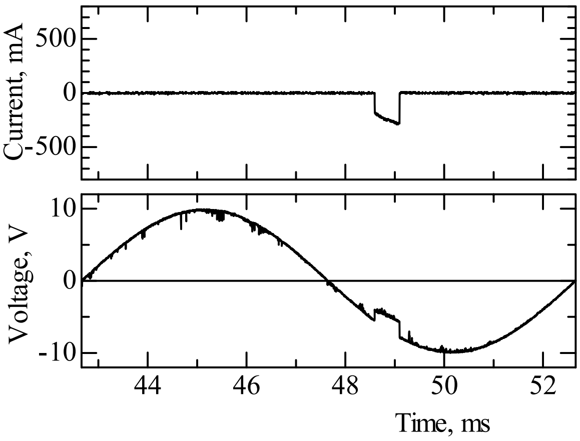

Fig. 8 Waveforms of current and voltage

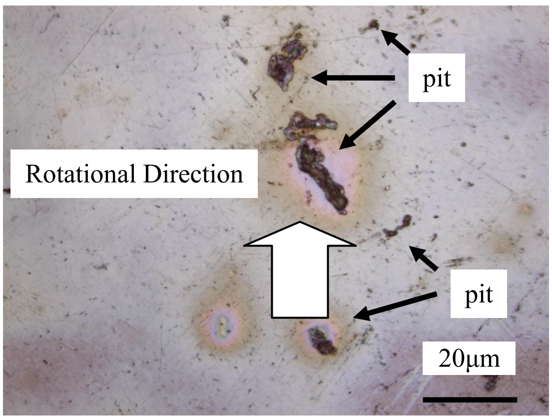

Fig. 9 Pits appeared on the ball

4. Conclusions

The technique of optical interferometry has been extended so that it can observe the dielectric breakdown phenomenon, which occurs in the point contact EHL conjunction lubricated with grease, as a white flash signal, together with the dielectric breakdown threshold voltage, the dielectric breakdown position and the corresponding film thickness.

It has been found that the dielectric breakdown voltage increases as the film thickness increases.

5. Acknowledgments

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6. References

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