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INFLUENCE OF SURFACE TOPOGRAPHY ON LUBRICATED CONTACTS BEHAVIOUR

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Summary: *A combination of thin film colorimetric interferometry and phase shifting interferometry has enabled to study the effect of slide-to-roll ratio on the micro-elastohydrodynamic action and asperity-contact mechanism on the real asperity scale. The purpose of this study is to provide some experimental data associated with the behavior of the roughness features in very thin film, real rough surface elastohydrodynamic contacts.*

1. Introduction

It has been generally accepted that in most EHD contacts the surface roughness heights are typically of the same order or even greater than the lubricant film thickness predicted by smooth surface EHD theory. It means that the applied load is shared by both fluid lubricant film and asperity conjunctions. Over the last few decades a large number of papers have been published considering the influence of surface roughness on EHD lubricant films (Cheng, 2002; Spikes & Olver, 2002; Chang, 1995).

Numerical analysis of the behaviour of mixed lubricated concentrated contacts has progressed significantly since early 1980. Nowadays, there are numerical solutions that can provide film thickness distribution within lubricated contacts taking into account topography of real rubbing surface and three dimensional topography data are used as an input. Conversely, there have been only a few attempts to experimentally evaluate a micro-EHD film thickness map for random rough surface (Guangteng et al., 2000; Luo et al., 2001; Křupka et al., 2003) and any detail analysis of film thickness behavior in the vicinity of real asperities has not yet been realized.

Recently introduced advance techniques based on the image analysis of chromatic interferograms (Gustafsson et al., 1994; Cann et al., 1996; Smeeth et al., 1997; Hartl et al., 2001) have enabled to provide the detailed film thickness distribution even under thin film conditions. However, most of these studies have been oriented on the behavior of artificially-produced roughness features in the EHD contact (Guangteng et al., 2000; Félix-Quiñonez et al., 2003; Glovnea et al., 2003). Although excellent film thickness results have been achieved, their application to the real rubbing surfaces is still in nascent.

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In the present study, the micro-EHD film thickness measurements are carried out using two measurements techniques. The phase shifting interferometry is used to measure in-situ initial undeformed shape of a rubbing surface and the thin film colorimetric interferometry enables to compare obtained data with measured film thickness profiles.

2. Experimental apparatus and techniques

The experiments reported here make use of a modified form of experimental apparatus shown in Fig. 1. This is a high-pressure ball on disk tribometer equipped with a microscope imagining system and a control unit.

Figure 1: Experimental apparatus

The principal parts of the test rig are a steel ball and glass disc. The lower part of the ball is submerged in a lubricant reservoir to ensure fully flooded conditions in the contact. For the measurements described here, both contacting surfaces are driven independently to produce any required slide-to-roll ratio. The elastic modulus of the steel ball was 212 GPa and that of the glass disc was 81 GPa. The load used was 26 N, corresponding to a maximum Hertz pressure of 0.49 GPa and a contact radius of 159 μm. The lubricant used was an additive-free, paraffinic base oil maintained at the temperature of 40 ºC. At this temperature this oil had a dynamic viscosity of 0.1 Pa.s and an effective pressure-viscosity coefficient of 23 GPa^{-1}.

The microscope imaging system consists of an industrial microscope, a xenon flash light source, and a high-resolution digital camera. Two configurations of this system are employed. For the ball surface roughness measurements a 20× Mirau interference objective mounted on a piezoelectric positioner is attached to the microscope whereas for the lubricant film thickness measurements a 20× plan achromate objective is used. The xenon flash lamp emitting white light flashes with 2.9 μs full-width half-maximum (FWHM) pulse width is triggered by a signal from the rotary encoder attached to the ball shaft. It ensures that all images are captured at the same ball position where the roughness features of interest are situated. A green spectral filter with a center wavelength of 547 nm is used to convert white light to a monochromatic light source that is needed for the surface roughness measurements and film thickness calibration. The interference patterns are imaged onto three 1360 × 1024 pixel charge-coupled device (CCD) image sensors in color digital camera from where they are read by the computer.

Phase shifting interferometry (PSI) is a well known technique which has been used with great success in a number of commercial optical profilers. The basic idea of this technique is that if the phase difference between the two interfering beams is made to vary in some known manner then, three or more interferograms can be used to determine the phase distribution that is related to the height deviations on the specimen surface. In this paper the phase difference between the beams reflected from the ball surface and the reference mirror built into the Mirau interference objective is changed using the piezoelectric positioner.

The thin film colorimetric interferometry (TFCI) technique used in this study for film thickness measurement is fully described by Hartl et al. (2001). In this technique, the digitized chromatic interferograms are after transformation from RGB to CIELAB color space converted to the film thickness map using appropriate color matching algorithm and color/film thickness calibration curves. They are obtained from Newton rings for flooded static contact formed between the smooth steel ball with a roughness of 5 nm rms and the chromium coated glass disc. TFCI is routinely employed for the study of thin lubrication films and it has been used for the measurement of film thickness below 60 nm without silica spacer layer. It is possible by the considerable improvement of the calibration process that provides color/film thickness dependence in the form of empirically fitted functions instead of discrete look-up table. This approach enables to eliminate the spacer layer which thickness estimation has a strong influence on the accuracy of measured film thickness values.

3. Results and discussion

Ball surface area of the same topography is used to evaluate the effect of slide-to-roll ratio on the mixed lubricant performance of the point EHD contact. The mean surface velocities used are very low, the lubricant film is thin, so that the contacting surfaces are not completely separated.

Figure 2 show chromatic interferograms converted into gray scale for slide-to-roll ratios of 0, − 0.2, − 0.5 and − 1. The mean surface velocity is fixed at 0.0044 m/s. Figure 3 depicts the corresponding midplane film thickness profiles in the direction of motion. It can be seen that when sliding is present, both long and short wavelength components of the roughness are largely flattened.

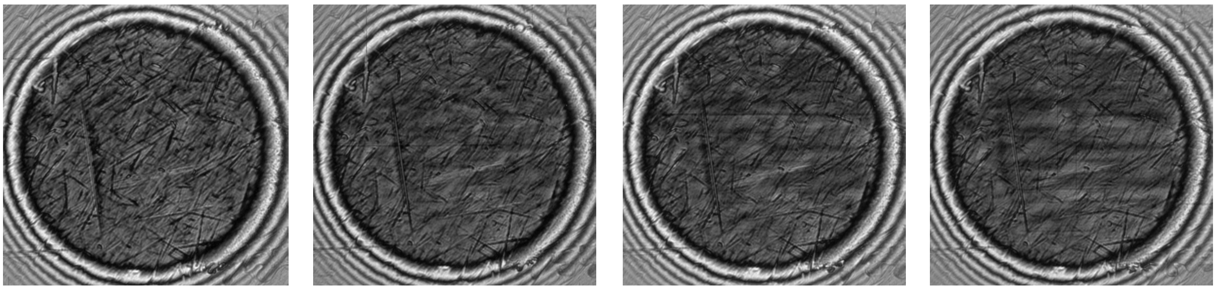

Figure 2: Interferograms in gray scale for slide-to-roll ratios of 0, − 0.2, − 0.5 and − 1.

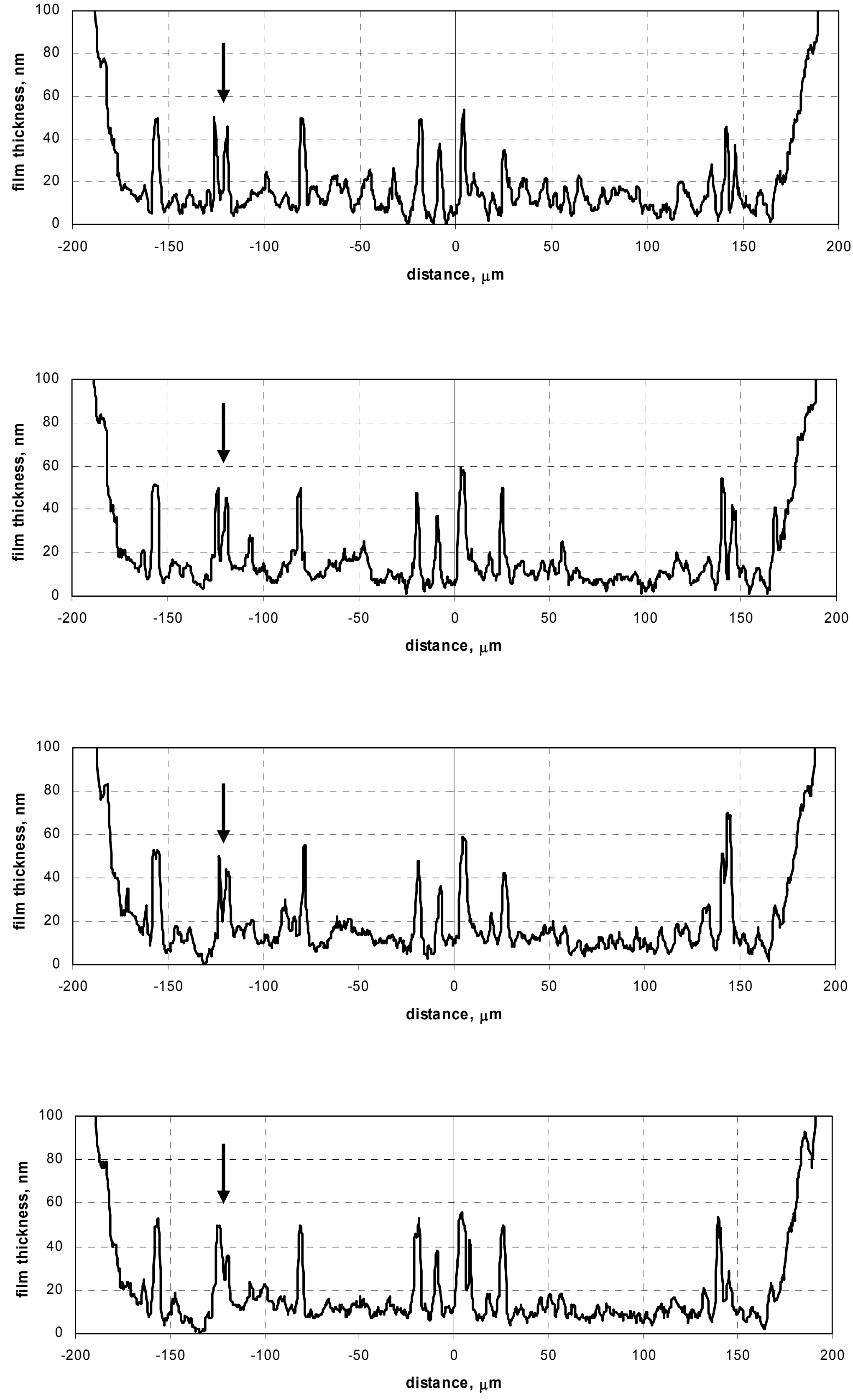

Figure 3: Film thickness profiles for slide-to-roll ratios of 0, − 0.2, − 0.5 and − 1.

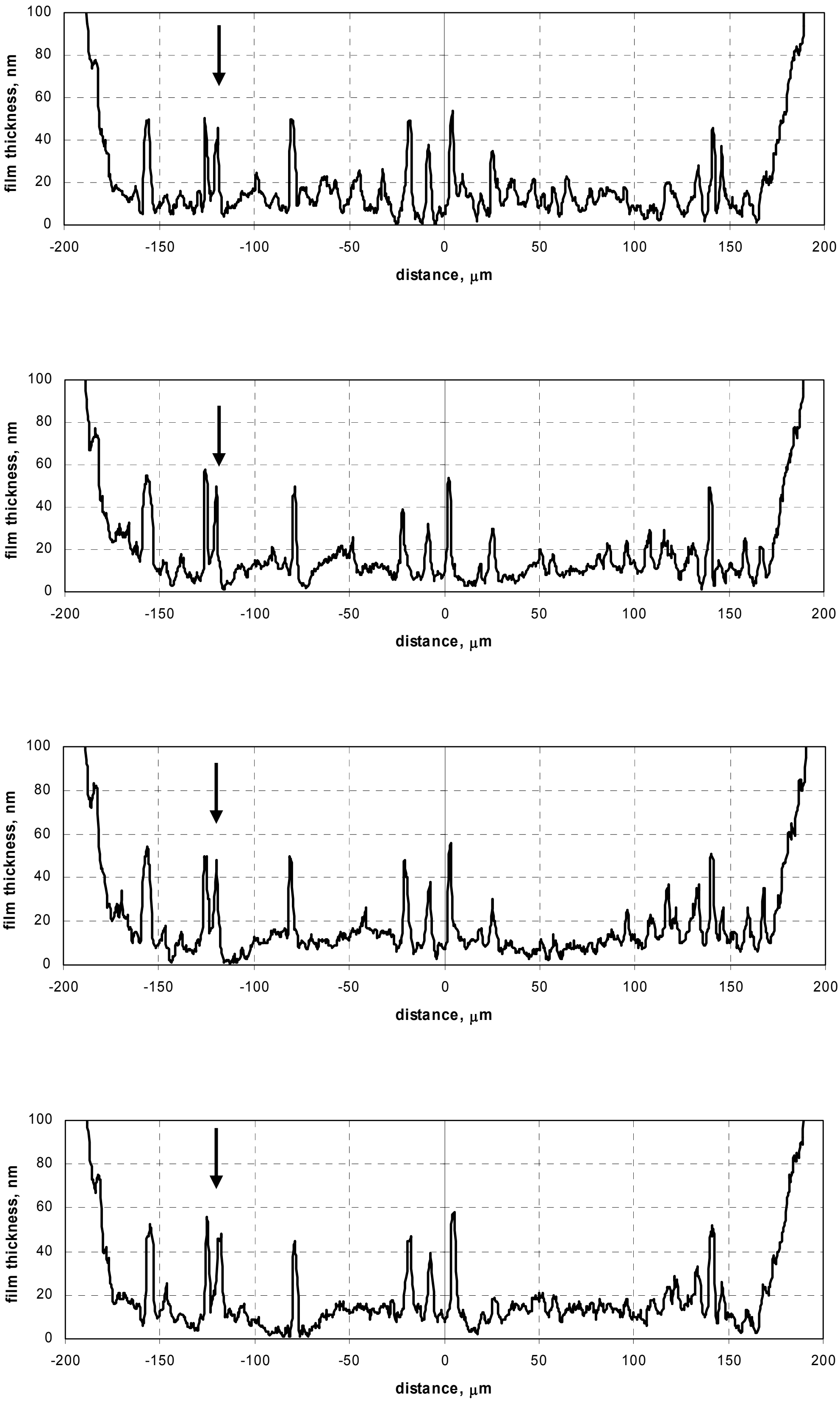

Figure 5: Film thickness profiles for slide-to-roll ratios of 0, 0.2, 0.5 and 1.

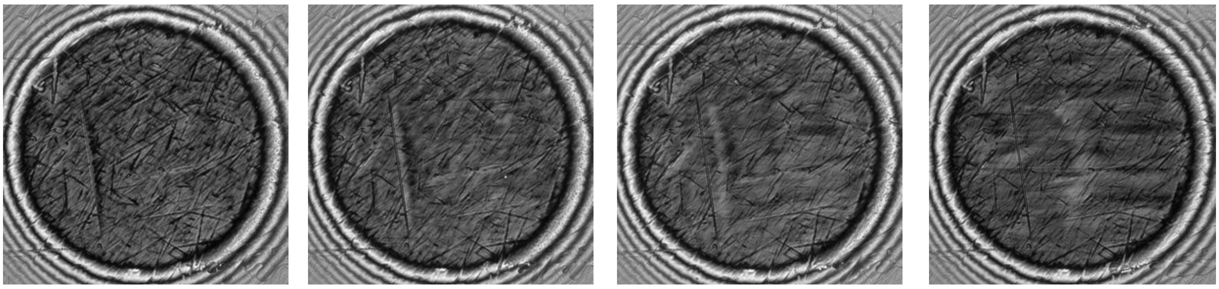

Figure 4: Interferograms in gray scale for slide-to-roll ratios of 0, 0.2, 0.5 and 1.

Figure 4 show chromatic interferograms converted into gray scale for slide-to-roll ratios of 0, 0.2, 0.5 and 1. The mean surface velocity is again fixed at 0.0044 m/s. Figure 5 depicts the corresponding midplane film thickness profiles in the direction of motion.

It can be observed from Figs. 2 to 5 that the film thickness profiles are changed complicatedly, compared with the case of the isolated artificially-produced roughness features. This is because the real surfaces have a complex topography that consists of asperities with various amplitudes and wavelengths. Each of them responses differently in a contact according to the operating conditions and the orientation of the roughness pattern. To be able to find some regularity in the local film thickness fluctuations, two closely-spaced transversely oriented grooves momentarily −110 μm distant from the center of the Hertzian contact are taken as a base. Their position in the film thickness profiles is indicated by the downward arrow. The smaller of two grooves is approximately 70 nm deep while the larger is approximately 80 nm deep. Their total width is about 9.5 μm. By focusing on the changes in film thickness created by the grooves, it can be seen that there are some similarities between the behavior of the real and artificially-produced roughness features. Positive slide-to-roll ratio results in significant changes in film thickness distribution and the local film thickness reduction can be found ahead of the grooves and the length of this reduction increases with increasing slide-to-roll ratio. When the slide to roll ration reaches the value of 1, the local fluctuation in film thickness associated with the groove influences the film thickness distribution in the vicinity of another groove located downstream.

4. Conclusions

This paper presents a study of the effect of slide-to-roll ratio on the micro-EHD lubrication of the roughness features of different scale in very thin film, real rough surface EHD contact conditions. Roughness features represented by two closely-spaced transversely oriented grooves in a real, random, rough surface have been examined in detail by means of advanced optical interferometry techniques. Obtained results indicate the presence of either a boundary film less than 1 nm thick or some solid-like contact in front of roughness features when the disc is moving faster than the ball (positive slide-to-roll ratios). No such a local film thickness reduction can be found for negative slide-to-roll ratio conditions.

5. Acknowledgment

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