ASIATRIB 2002International Conference
JEJU ISLAND, KOREA

APPLICATION OF FFT-BASED ANALYSIS TO CONTACT CONDITION PREDICTION FOR TRIBOLOGICAL SURFACE DESIGN

I. H. SUNG, H. S. LEE, and D. E. KIM

Department of Mechanical Engineering, Yonsei University
134 Shinchon-dong, Seodaemun-gu, Seoul 120-749, KOREA

In this paper, the frictional behavior according to the contact geometry was investigated using a micro-tribotester built inside a Scanning Electron Microscope (SEM) and an Atomic Force Microscope (AFM). FFT (Fast Fourier Transform) analysis for friction was conducted as a method to interpret the contact condition. From the experimental results, it could be concluded that the relative dimensions and distribution of contact asperities on the surface could be predicted by the power spectrum and main frequency in the FFT analysis of the friction signal.

Keywords : Asperity, Contact Geometry, FFT (Fast Fourier Transform), Micro-grooved Surface

1. INTRODUCTION

Numerous researches on the frictional behavior with respect to the contact geometry between two surfaces have been performed in various aspects including contact area and contact potential [1-4], since the basic understanding of the relationship is important to improve the life and durability of machine elements. However, the fundamental mechanism or quantitative analysis of the friction induced by contact geometry is still ambiguous. This may be due to the fact that the frictional behavior between two surfaces can be affected by various surface properties such as surface energy, hardness, degree of contamination, and environmental conditions, even though the contact geometry is similar [5-7]. Nevertheless, the need for friction and stiction control by surface geometry modification has been steadily increasing, especially for micro-parts in micro-systems or high vacuum condition where conventional fluid lubrication is not applicable. For this purpose, micro-structured surfaces with special geometries such as bumps or micro-grooves have been investigated [8,9].

Micro-structured surface is effective in reducing friction and stiction due to contact area reduction and trapping of the particles produced by wear or contamination [10,11]. The optimum geometry of the micro-structured surface from the tribological viewpoint, however, still needs to be solved. On the other hand, in order to design and optimize the surface geometry for friction control, it is essential to analyze the multi-asperity contact condition. Since it is difficult to control the distribution and size of the asperity in the experimental investigation of multi-asperity contact, most of the previous works have been limited to numerical analysis and simulation [12,13].

The objective of this research was to investigate the frictional behavior according to the contact geometry with the aim to design micro-structured surface which has optimum tribological characteristics. Especially, FFT analysis of the friction signal was performed to interpret the contact condition. In this work, a ball with sub-mm diameter and micro-grooves with various widths and spacings which were fabricated on a silicon surface. In the experiment, the ball and the micro-grooved surface served as an asperity and multi-asperity surface, respectively. They were used to investigate the frictional behavior with respect to the geometry of surface asperities.

2. EXPERIMENTAL DETAILS

In order to observe and visualize the frictional interaction, a pin-on-disk type micro-tribotester was designed and built to fit inside a Scanning Electron Microscope (SEM). A consistent environment could be maintained for all experiments by the vacuum condition (10^{-5} torr) inside the SEM chamber. Using this set-up, the instantaneous frictional force between the pin and the disk could be measured with high precision, and at the same time, the pin-disk contact point could be observed as the sliding took place. The normal load between 10~50 mN and the sliding speed of 1~6 μm/s were applied.

As for the pin material, a AISI E52100 (KS STB2) ball with hardness of HV700 and a diameter of 500 μm was used and modeled as a single asperity. For the contact between multi-asperities, three balls were assembled in a triangular configuration and used as the pin. Microgrooves with various geometries (3~20 μm width and spacing, 1.5 μm height) fabricated on the Si (100) surface were used as disk specimens. The definitions of the width (w), spacing (s), and height (h) are illustrated in Fig. 1.

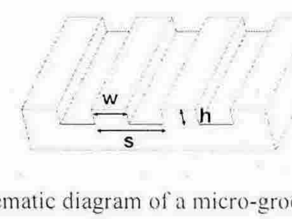

Fig. 1 Schematic diagram of a micro-grooved surface

3. RESULTS AND DISCUSSIONS

Fig. 2 shows the friction coefficients for multi-asperities (balls) sliding on 5 μm and 10 μm micro-grooved silicon surface at 20 mN normal force and 1.5 μm/s sliding speed. From these figures, it can be seen that the frictional behaviors are different with respect to the groove spacing. This result suggests that the frictional behavior is largely dependent on the local contact geometry between the two surfaces. Also, the degree of friction variation is dependent on the geometric ratio which is defined as the relative size of the pin diameter with respect to the groove width. From these observations, it can be concluded that the contact geometry of the counter surface sliding on a micro-structured surface should be carefully designed in order to obtain the micro-structured surface with optimum tribological performance.

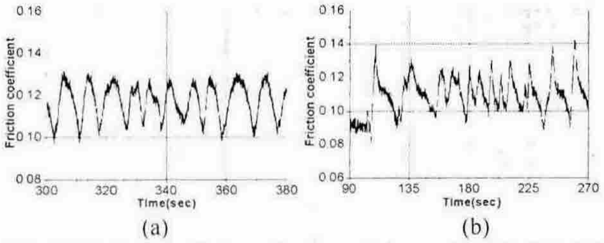

Fig. 2 Friction coefficients for for multi-asperities (balls) slid against (a) 5 μm and (b) 10 μm micro-grooved surfaces

FFT spectra of the friction coefficients for a single asperity and multi-asperities sliding on 5 μm multi-grooved silicon surface are shown in Fig. 3. In the case of the contact with a single asperity, the main frequency was about 0.15 Hz and its power was below 10^{-9}. This main frequency value is in good agreement with the value of 0.15 (=1.5/10) which can be derived from the sliding speed and the groove spacing. On the contrary, in the case of the contact with multi-asperities, more peaks showed up in the frequency spectrum and the power of the main frequency was smaller than that of the contact with a single asperity, which was in the order of 10^{-10}. These results are attributed to the difference in the main frequencies of the friction signals obtained by each asperity (ball). Namely, when the multi-asperities come into contact with the micro-grooved surface simultaneously, the friction signals of each asperity may be superposed and their main frequencies may show different values with lower power.

In summary, the power spectrum of the friction coefficient reflects the number and the geometric ratio of asperities which are in contact. Also, the frequency spectrum indicates the relative distribution of the surface asperities.

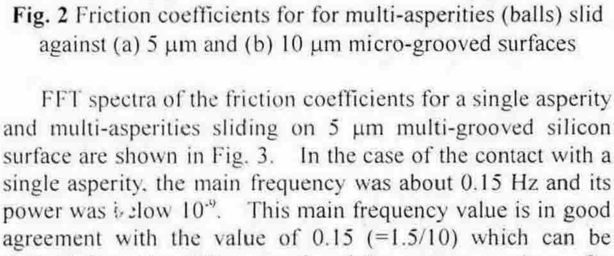

Fig. 3 FFT spectra of the friction coefficients for (a) a single asperity (ball) and (b) multi-asperities (balls) sliding on 5 μm micro-grooved surface

4. CONCLUSIONS

In this work, the frictional forces between micro-grooved surfaces and balls modeled as the surface asperities were measured using a micro-tribotester which was built inside a SEM. Micro-grooves with various dimensions were fabricated on the silicon surface to investigate the frictional behavior with respect to the change in the geometrical contact condition. From the results of the experiments and simulations, it was found that the friction for multi-asperities could be determined by superposition of the signals from single asperity experiments. Thus, FFT analysis could be a useful method for predicting the contact condition such as the relative size and distribution of surface asperities within the contact. The results of this work can be utilized in the design for the micro-structured surface which has optimum tribological characteristics.

5. ACKNOWLEDGEMENT

This research, under the contract project code MS-02-342-01, has been supported by the Intelligent Microsystem Center (IMC; http://www.microsystem.re.kr), which carries out one of the 21st century's Frontier R&D Projects sponsored by the Korea Ministry of Science & Technology.

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