Statistical Measurement of Real Contact Area on the Basis of Image Intensity Histogram

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The area of real contact is one of the most important factors governing friction and its characteristics under non-lubrication conditions including some lubrication conditions except hydrodynamic lubrication regime. The purpose of this paper is to propose the simple practical method for real contact area measurement that uses visualized contact zone images. The target contact zone was visualized using LED polarized interferometry. Under the condition of non-lubricated static Hertzian contact between a sapphire plate and a plano-convex or a lenticular lens made of PMMA, a statistical measurement of the real contact area was carried out by using image intensity histograms. The results are as follows: (1) The Gaussian distribution characteristics at the lowest region of the intensity histogram distribution were obtained, and the size of the domain as extracted through Gaussian distribution fitting was in good agreement with the theoretically obtained Hertzian contact area. By using the right and left symmetricalness of Gaussian distributions, it was possible to statistically measure the size of the domain, that is, the real contact area, in a straightforward manner. (2) It was suggested to measure the real contact area statistically by using the proposed method, which is capable of detecting gaps of the order of nanometers without requiring a threshold value for binarization. (3) In the case of a rough model surface when using a lenticular lens, the results agreed with the theoretical results for the Hertzian contact area as obtained by performing background correction. Thus, the effectiveness of measuring the real contact area by using Gaussian distribution fitting was demonstrated.

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1. Introduction

The area of real contact is one of the most important factors governing friction and its characteristics under non-lubrication conditions including some lubrication conditions except hydrodynamic lubrication regime. The authors have carried out a trial of measurement of the real contact area with threshold method using polarized white light interferometry [1]. The method needs threshold intensity of image for binarization to extract the area of real contact. And this threshold had many problems including unspecified relations between the gap clearance and the real contact area, and its meaning and effectiveness.

In this paper, two-beam optical interferometry that interference intensity is according to theoretical behavior was adopted. If it regards zero gap clearance as the area of real contact, it can visualize the area and satisfy the measurement conditions of (a) sliding condition, (b) high resolution and (c) lubricating condition. The purpose of this paper is to propose the simple statistical method for real contact area measurement using visualized contact zone images.

2. Experimental

The visualizing system for real contact zone with a stereomicroscope [1] was used. The system constructed with a 12-bit monochromatic camera (1,344 x 1,024 pixels) and a high power white LED (representative wavelength λ=440 nm) which has low coherence as illuminating light. Taking into account of experiments under lubricating conditions, a sapphire plate (diameter of 30 mm, thickness of 2 mm) which have a high refractive index, n=1.768, was used for a mating transparent plate. For lower specimens made by PMMA, a plano-convex lens or a lenticular lens (observing field area of 2.69 mm^2) which simulated as a rough surface were used. The experiment was carried out changing normal load under non-lubricating static condition.

3. Measurement of real contact area

An example of the interference images acquired for both of lenses are shown in Fig. 1. Newton rings to become the area of real contact appear at the center zone (Fig.1 (a)). The intensity value can be simulated by optical theory by the two-beam interference. The intensity histogram of the acquisition image was shown in Fig. 2. For the plano-convex lens, its distribution has two remarkable peaks divided into background distribution area and lower intensity distribution area (i.e. the area of real contact). The lower intensity distribution was admitted that it was almost Gaussian distribution as an experimental fact.

To extract real contact area, the method that is fitting this intensity histogram to Gaussian distribution and necessary no threshold value for binarization was examined. Synthetic separation method on the basis of the general curve-fitting method was applied taking adjacent complex Gaussian distribution divided into Gauss 1A and Gauss 1B. The result was shown in Fig. 2(a). For the left-half of the lower intensity histogram, Gaussian distribution, Gauss 1A, accords with an experimental value precisely. If a half of the right side histogram was compared to the superimposed distribution of Gauss 1A and Gauss 1B, the residual error is very small. All areas of this complex Gaussian distribution domain, Gauss 1AB, are the real contact area decided statistically. The problem of determination of threshold value for binarization of images is can be avoided. In addition, it is thought that Gauss 1B is produced by un-uniform illumination.

4. Result of real contact area of smooth or rough model surfaces

Interference images of contact zone between a plano-convex lens and a sapphire plate under Hertzian contact at changing normal loads were acquired. The comparison of the Gaussian distribution fitting domain area with theoretical Hertzian contact area is performed. Figure 3 shows the result of the real contact area at varying normal loads. The area extracted from complex Gaussian distribution, Gauss 1AB, is good agreement with the area by the Hertzian theory at all normal loads tested in the figure. The result extracted from only Gauss 1A is estimated to be a little. From these results, it is demonstrated that the real contact area could measure statistically using image intensity histogram without requiring a threshold value for binarization. However, the difference between the result of statistical method and binarized method using eye-viewing threshold value of 400 is small because the contact condition is in the smooth surface.

Interference images for a model rough surface were acquired at changing normal loads. In comparison with the plano-convex lens, the right and left symmetricalness of the distribution at the peak center intensity value is weak in the model rough surface. Un-uniform illumination was corrected by background correction operation using the next equation.

Corrected intensity = Raw intensity - reference intensity + 1500 -------- (1)

The reference image intensity is based on the image of load of zero. And, the real contact area is calculated by domain area of this distribution afterward. The left half of the Gaussian distribution at each loads condition was in good agreement with corrected actual measured intensity distribution. This estimated area by corrected Gaussian distribution almost agrees with the theoretical Hertzian contact area at all experimental normal loads.

5. Conclusions

The area of real contact was visualized using a gray scale of 12-bit camera and LED polarized light interferometry. The real contact area measurement using a Gaussian distribution fitting to intensity histogram of light interference image was suggested. Under the condition of non-lubricated static Hertzian contact, the effectiveness of statistical method for measurement of the real contact area without requiring a threshold value for binarization was demonstrated.

REFERENCES

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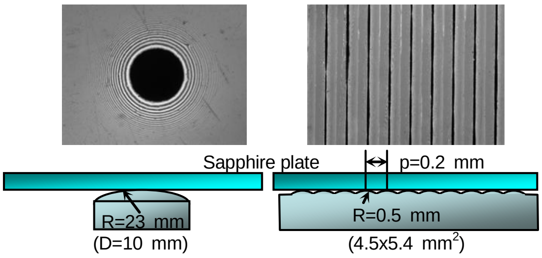

(a) Plano-convex lens (b) Lenticular lens

Fig. 1 Simplified lower test specimens

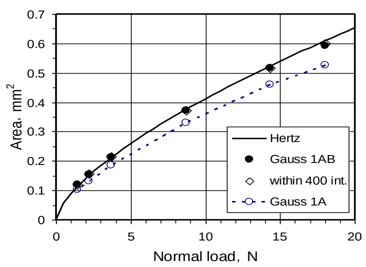

Fig. 3 Estimated real contact areas (plano-convex lens)

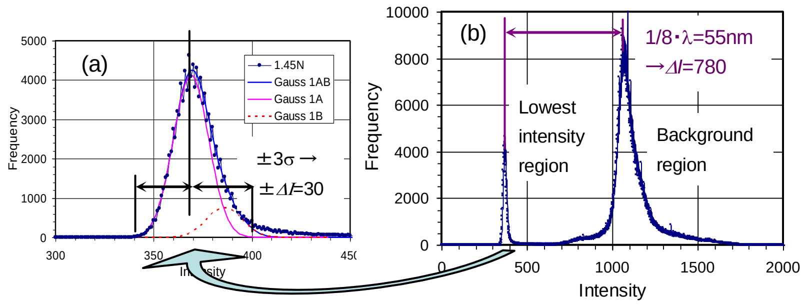

Fig. 2 Fitting Gaussian distribution to the intensity histogram (plano-convex lens, W=1.45 N)