Form measurement of hand-scraped surfaces using an Abramson oblique-incident interferometer

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This study presents application of an oblique-incident interferometer for three-dimensional measurement of the rough surface form finished by hand-scraping. Hand-scraping is one of finishing utilized for the sliding parts of the machine tools or the surface plates of the precision measuring instruments. In general, the finishing of the hand-scraped surfaces is evaluated by engineer's blue testing, however, it often requires an expert skill and hard work. To realize the quantitative evaluation of the finishing and automation of fabrication, three-dimensional measurement of fine form of the hand-scraped surface will be necessary. In this study, an Abramson interferometer has been applied for the surface form measurement of the hand-scraped surface. The measurement time and measurement accuracy of the developed oblique-incident interferometer were compared with a commercially available vertical-incident interferometer. The developed oblique-incident interferometer allows non-contact measurement of the rough surface with shorter measurement time.

1. Introduction

Hand-scraping is one of an important surface finish method, which are widely used for the sliding parts of the machine tools and surface plate of the precision measurement instruments. The hand-scraping is carried out by the skilled craftsman, so the acquirement of the hand-scraping skill becomes problem in the Japanese machinery industry. In general, the quality of the hand-scraped surface is evaluated based on the transfer of pigment by rubbing the workpiece against a pigment-coated reference surface plate. For that reason, the finish quality of the hand-scraped surface is evaluated qualitatively, and the surface form and surface properties are not often measured quantitatively.

In our previous research [1, 2], an oblique-incident interferometer based on Abramson type interferometry has been developed for the surface form measurement of the hand-scraped surface. Since the rough surface is consisted by the hand-scraping, it is useful to measure the surface form using the oblique-incident interferometer, which can easily obtain reflected light on the rough surface. However, the hand-scraping marks are several μm depth, which often results in overcrowded interference fringes. To avoid the overcrowded of the interference fringes, the oblique-incident interferometer using a near-infrared laser was developed and its feasibility for the surface form measurement was evaluated in this study.

2. Experimental method

Figure 1 shows the principle of the Abramson interferometry. A right-angle prism (RAP) is used as both a beamsplitter and a reference surface of the interferometer. The hypotenuse of the RAP is mounted to be faced to the measured surface. A part of the laser beam incident on one surface of the RAP is reflected by the bottom of the RAP and become a reference light. The laser beam transmitted through the bottom of the RAP is reflected on the measured surface and is incident the RAP again as measuring light. The measuring light and reference light overlap at the bottom surface of the RAP, and the interference fringes are generated. The distance, h, between the bottom of the RAP and the measured surface is expressed by the following equation,

$$h = \frac{m\lambda}{2\cos\theta} \quad (1)$$

where, θ is incident angle of the measuring light, m is the fringe order, λ is the wavelength of the measuring light. Therefore, the sensitivity, S,

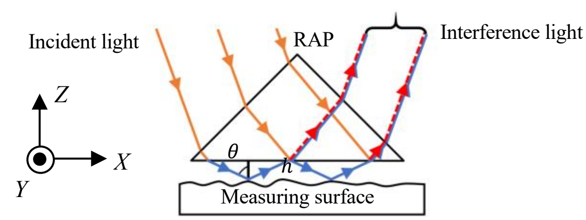


Fig.1 Principle of Abramson type oblique-incident interferometer

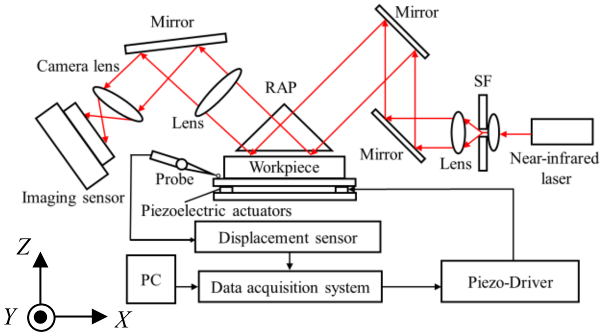


Fig. 2 Set-up of an oblique-incident interferometer

of the interference fringe can be expressed as follow.

$$h = \frac{\lambda}{2\cos\theta} \quad (2)$$

As shown in Eq. 2, the fringe sensitivity can be reduced by using the measuring light with a longer wavelength, and as a result, interference fringe interval can be increased. In this research, a near-infrared laser with a wavelength of 880 nm was employed as the light source of the interferometer.

Figure 2 shows the configuration of the phase-shifting oblique-incident interferometer. A five-step phase-shifting method was introduced to calculate the surface form based on the interference fringes. The phase-shifting of the interference fringes was achieved by moving the measured surface along the *Z*-direction with the piezoelectric actuators. The phase distribution, $\phi(x,y)$, was calculated by applying following Eq. (3) to five interference fringe images I_1 to I_5, which were taken by shifting the interference fringe phase by $\alpha = \pi/2$.

$$\phi(x,y) = \tan^{-1}\left\{\frac{2[I_2(x,y) - I_4(x,y)]}{2I_3(x,y) - I_5(x,y) - I_1(x,y)} \cdot 2\sin\alpha\right\} \quad (3)$$

The interference fringe images were captured by an imaging sensor through a tilt-shift camera lens (TS-E90 F2.8L macro, Canon). According to the phase distribution, $\phi(x,y)$, the surface form can be calculated by the following equation.

$$h(x,y) = \frac{\lambda}{4\pi\cos\theta}\phi(x,y) \quad (4)$$

3. Experimental method and results

To confirm the feasibility of the form measurement by the oblique-incident interferometer using the near-infrared laser, the flat surface of the gauge block was measured.

Figure 3 shows the photograph of the interference fringe images generated on the gauge block. The incident angle of the measuring light is estimated to be 67.0°. Higher-order interference fringes with different from the carrier frequency were observed in the captured images. The phase of these high-order interference fringes did not change with the displacement of the gauge block in the *Z* direction. Therefore, it was confirmed that the higher-order interference fringes were not caused by the interference between the bottom of the RAP and measured surface. The higher-order interference fringes in the captured images were removed by a digital filter using two-dimensional Fourier transform, and the surface form of the gauge block was calculated using Eq. (4).

Figure 4 shows the calculated surface form of the gauge block. Figure 5(a) shows the cross-sectional profile of A-A' line shown in Fig. 4. On the other hand, figure 5(b) shows the cross-sectional profile of the same location measured by the non-contact contour measuring instrument (NH-3S, Mitaka Kohki). The root mean square roughness

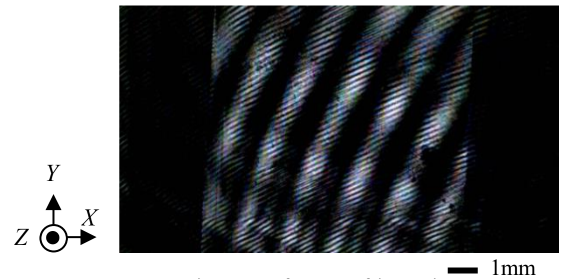


Fig.3 Interference fringes image

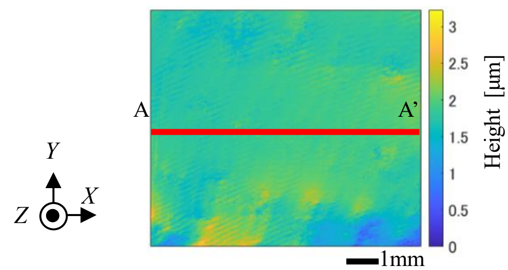
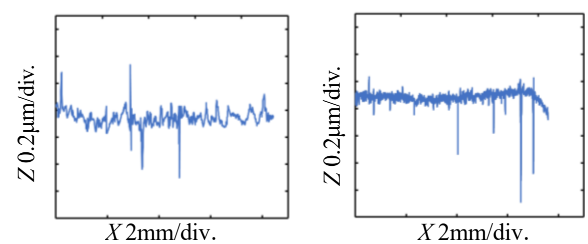


Fig.4 Calculated surface form of the gauge block



(a) Interferometer (b) NH-3S

Fig.5 Cross-sectional profile of A-A' line

R_q of the cross-sectional profiles measured by the oblique-incident interferometer and the contour measuring machine were evaluated to be 0.14 μm and 0.06 μm, respectively. It was assumed that the R_q of the oblique-incident interferometer increased due to the higher-order interference fringes.

3. Conclusions

In this study, an oblique-incident interferometer using a near-infrared laser has been developed for the surface form measurement. To evaluate the feasibility of proposed method, the surface form of the gauge block was measured and compared with the non-contact contour measuring instrument. As future works, we will apply the developed oblique-incident interferometer for the measurement of the rough surface consisted by the hand-scraping.

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