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Stroboscopic oblique-incidence interferometer for motion visualization of stator of ultrasonic motor.

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Abstract

This paper describes a motion-visualization technique for an ultrasonic motor (USM) by using a stroboscopic oblique-incidence interferometer. Characteristics of USM depend on a vibration mode of a stator which is one of main component of USM. Though there are some visualization techniques of its vibrated mode, it is difficult to visualization. Because the surface of the stator is rough for a light. For visualization such a surface, we focused on an oblique-incidence interferometer. The interferometer is well suited to analyze the rough surface because a scattering at the rough surface is reduced by using an oblique-incidence light. Furthermore, for detecting a vibrated surface, a pulsed light synchronized with stator was used as light source. We have succeeded to detect a periodically movement of fringe patterns of the vibrated stator.

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Keywords: interferometer; obilique incidence; ultrasonic motor; rough surface; stroboscopic method;

1. Introduction

An ultrasonic motor (USM) is driven by a friction force between a rotor and a stator which are main components of the USM. In comparison with electromagnetic motor, the USM is not affected by a magnetic field because of using the friction force. Furthermore, it is compact size and low-speed-high-torque[1]. There have been several studies on new driving methods and new usages of the USM in a field of a robotic engineering. For example, a power assist suit has been developed by using the USM[2]. In these studies, an evaluation for the characteristics of the USM is desirable. Its characteristic depends on a vibration mode of the stator. However, there are few proposed studies about the vibration analysis. Because it has rough surface and the stator is vibrated in ultrasonic frequency with an amplitude of several micrometers. Existing measuring techniques utilize a laser Doppler vibrometer[3] and a stroboscopic phase shift interferometer[4]. By using Laser Doppler vibrometer, a vibrated surface with the ultrasonic frequency has been measured with nanometer resolution. Though it is point-by-point technique, it is necessary to scan for detecting of 2D information. On the other, by using the stroboscopic phase shift interferometer, the surface has been detected by one-shot. However a measurable area is narrow because it consists in a microscope. Furthermore, the surface of the stator was needs to be covered Au layer for fabrication repair. To overcome the

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problems, we focused on an oblique-incidence interferometer[5]. The oblique-incidence interferometer is well suited to analysis for the rough surface because the scattering at the rough surface is reduced by oblique-incidence. Furthermore for detecting a vibrated surface, a pulsed light synchronized with the stator was used as a light source by using an acoust optic modulator (AOM). The purpose of this study is to develop a stroboscopic oblique-incidence interferometer for measurement of the vibrated stator.

2. Principle of oblique-incidence interferometer

Figure 1 shows a principle of an oblique-incidence interferometer which consists of SiO_2, air, and a sample. When the oblique-incident light goes through SiO_2, it is divided into a sample light and a reference light. The sample light is reflected on the sample and incidence into SiO_2 again. A light intensity of the interference light $I(x,y)$ is given by

$$I(x,y) = a_1^2(x,y) + a_2^2(x,y) + 2a_1(x,y)a_2(x,y)\cos\{-k\Delta l(x,y)\}, \quad (1)$$

where a_1 is an amplitude of the sample light, a_2 is an amplitude of the reference light, k is a wave number of the light, and Δl is an optical path difference between the sample light and the reference light. A phase of the interference light $\phi(x,y)$ in eqs. (1) is written by

$$\phi(x,y) = -k\Delta l(x,y) = \frac{4\pi}{\lambda}\Delta h(x,y)\cos\theta, \quad (2)$$

where λ is wavelength of the light, Δh is a thickness between a surface of SiO_2 and a sample surface, θ is the incident angle. By setting θ, the phase ϕ can be measured.

A detected fringe pattern is analyzed by 4 steps phase shift technique. Interference images are detected each time when a predetermined phase amount is shifted about π/2. Using the detected images, the phase can be calculated by

$$\phi(x,y) = \tan^{-1}\frac{I_4(x,y) - I_2(x,y)}{I_1(x,y) - I_3(x,y)}, \quad (3)$$

where $I_n(x,y)$ is intensity of the light detected each time when an optical phase π/2 is shifted, For detecting a vibrated surface, a pulsed light synchronized with the stator was used as a light source.

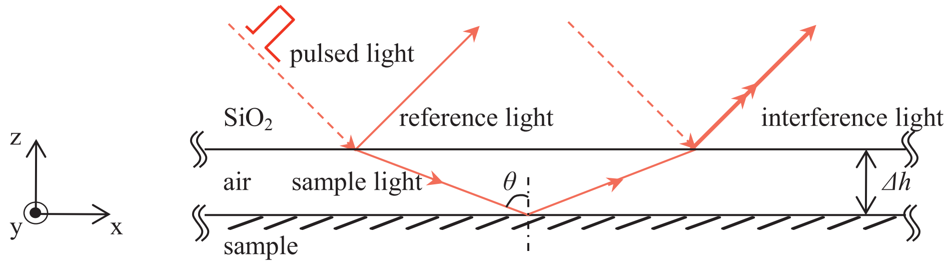


Fig.1 Principle of oblique-incidence interferometer.

3. Experimental setup of stroboscopic oblique-incidence interferometer

Figure 2 shows an experimental setup of the stroboscopic oblique-incidence interferometer. It consists of an electrical circuit part for synchronization between the stator and the pulsed light, and an optical part for interference. In the electrical circuit part, master oscillator supplied a reference signal for the light synchronized with the stator, and two sinusoidal signals for driven the stator. By using an AOM, a continuous light is changed to the pulsed light. Two sinusoidal signals from the master oscillator, E_A and E_B, are amplified by two amplifiers, respectively. Then the stator is driven by the signals. In the optical part, a prism is used for a SiO_2 layer for reducing a size of the optical part. A light source is a He-Ne laser (λ=594.1nm). The pulsed light changed by the AOM is reflected at a mirror for controlling an incident angle and into the prism. Part of the light goes through the prism for the sample light. The sample is set on a PZT stage for 4 steps phase shift technique. The reflected light from the bottom of the prism and the sample light creates an interferogram. The interference light is detected by a CMOS camera.

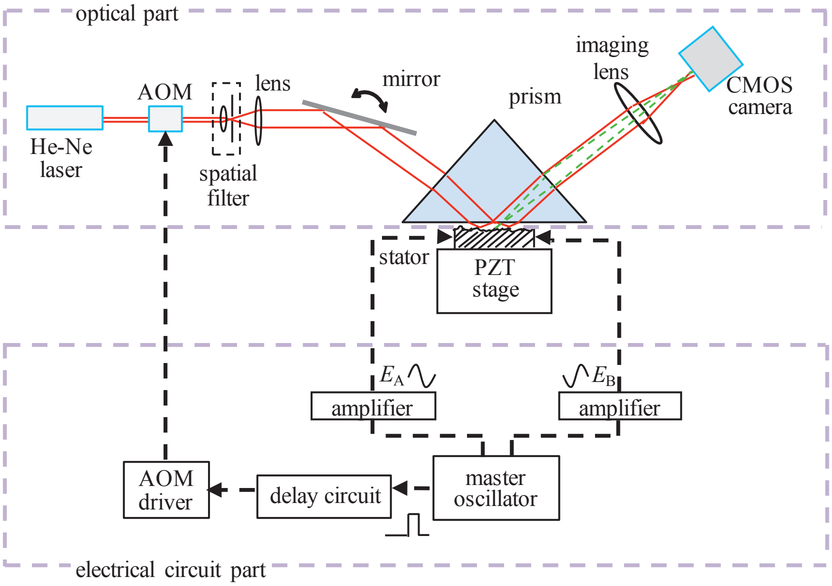


Fig.2 Experimental setup of stroboscopic oblique-incidence interferometer.

4. Experimental result

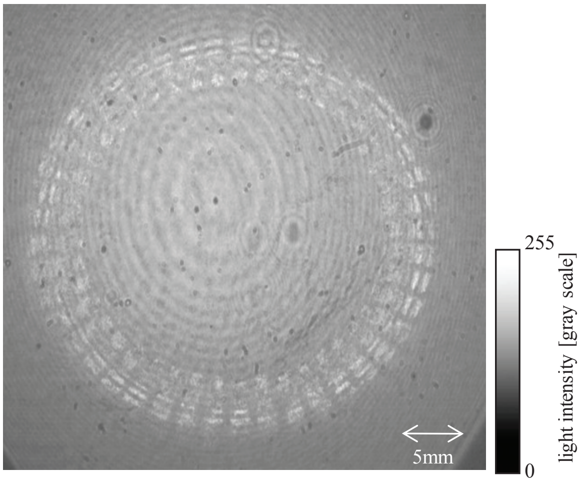
Before analyzing a vibration mode, we have confirmed to observe an interferogram of the vibrated stator. The two sinusoidal signals for driving the stator had a phase difference about $\pi/2$. The amplitude was 110 V with 50 kHz. Figure 3(a) shows an interferogram without synchronization. Its contrast was low because the interferogram was average of amplitude of the vibrated stator. Figure 3(b) shows an interferogram synchronized with the stator. Its contrast is well for analysis because of synchronization between the stator and the pulsed light. The interferogram shown in fig.3(b) has been confirmed that there is a possibility to analyze a surface profile of the vibrated stator by using the stroboscopic oblique-incident interferometer.

We have attempted to detect a phase information of the vibrated stator. Figure 4 shows a calculated phase distribution by using 4 steps phase shift technique. The result shows that detecting position of the phase distribution is on the circle aligned tooth on the stator. And these slope are similar to each other. Figure 5(a) shows a wrapped phase distribution of a dashed area in fig.4. Then after phase unwrapping, a surface profile of the stator was determined using eq.(3) as shown in fig.5(b). The stator has down slope away from an outside. Height of the slope is 2.0μm.

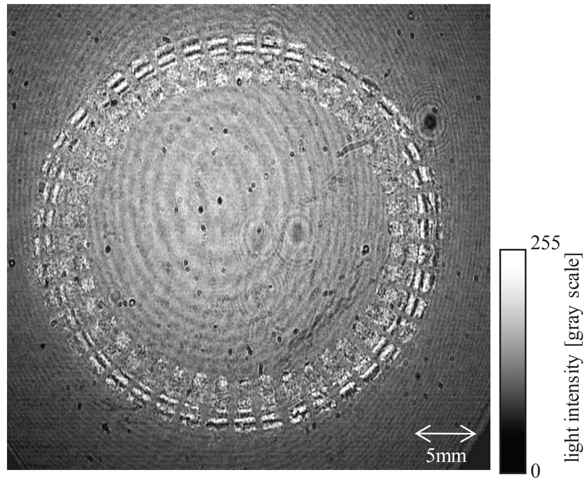
For a vibration-mode analysis, antinodes of the vibrated stator were detected. Phase difference between E_A and E_B was set to 0 degree for a standing wave. When using the pulsed light synchronized without the stator, a contrast of the fringe pattern was low. However, in the area of antinodes, contrast was well for analysis. Figure 6 shows time dependent behaviors of displacements. Figure 6(a) shows analysis points and antinode areas. There are ten antinodes. In fig.6(b), the points of the stator have periodic displacement and the amplitude of the stator is 392 nm. A phase difference between A and B was about 72 degrees. And there was a point at one-fifth position between the antinodes as shown in fig.6(a). The detected phase difference was good agreement with the measured points.

5. Conclusion

A motion-visualization technique for an ultrasonic motor by using a stroboscopic oblique-incidence interferometer has been developed. Using pulsed light synchronized with the stator, the contrast of the fringe pattern was high for phase analysis. And by phase analysis, the stator has slope of 2.0μm. In addition using the pulsed light synchronized without the stator, the ten antinodes were detected. An amplitude of the stator was 392nm by time-resolved analysis. It was confirmed that the stroboscopic oblique-interferometer is useful for analysis of a vibrated stator.



(a) unsynchronized interference image.



(b) synchronized interference image.

Fig. 3 Interference images of vibrated surface of the stator.

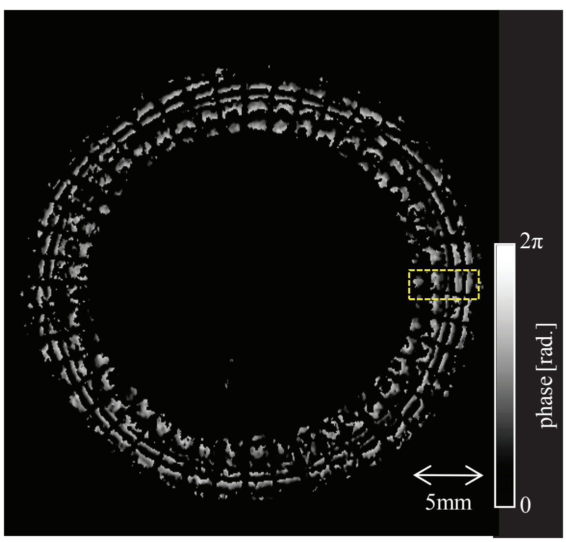
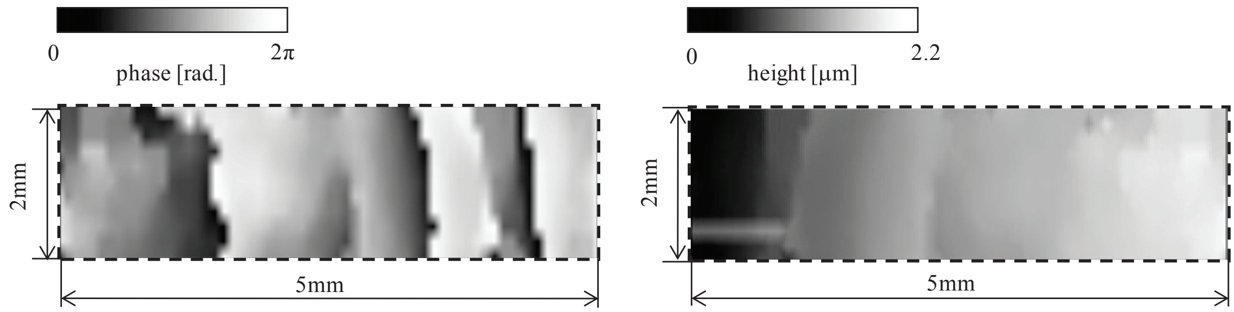
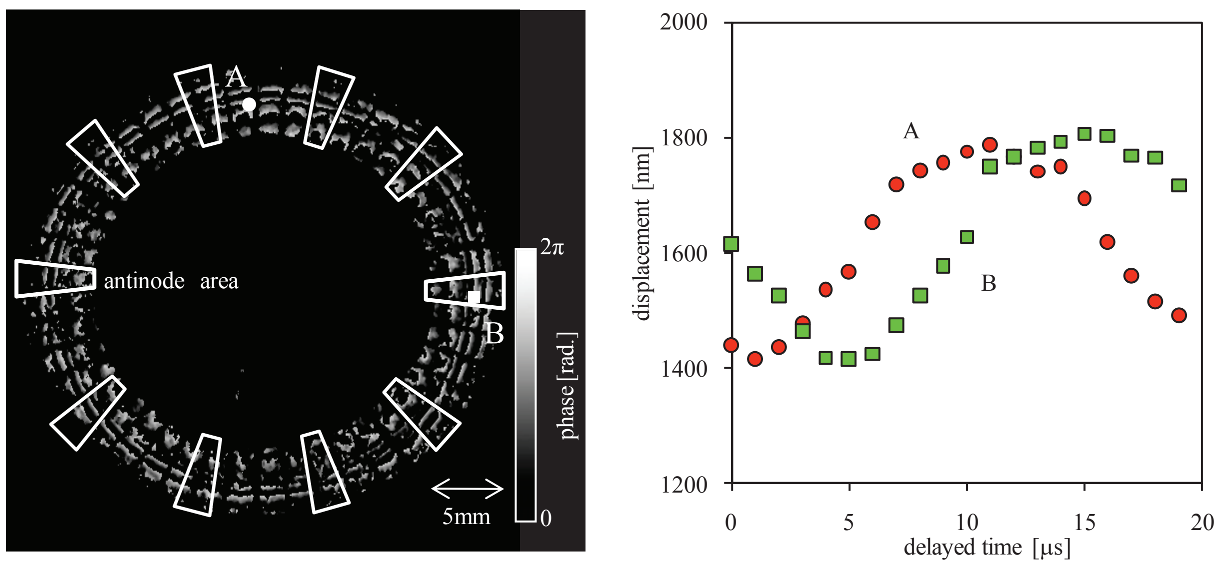


Fig. 4 Phase distribution of the stator.



(a) wrapped phase. (b) surface profile of the stator.

Fig. 5 The surface profile of the stator.



(a) analysis points on the stator. (b) time-dependent displacement of the stator.

Fig. 6 Comparison of time-dependent displacement of the stator.

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