Absolute Vibration Displacement of Piezoelectric Resonators on Polished Surfaces Measured using Laser Speckle Interferometer

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***Abstract*—We investigated the absolute vibration displacement of a piezoelectric resonator on a polished surface measured using a laser-speckle interferometer. There are various types of piezoelectric resonators, and crystal resonators are mainly used in mobile phones. Laser-speckle interferometry can simplify devices by using a CCD camera, instantly capture an image, and visualize in-plane vibration in about 20 seconds for all pixels. There have been papers on methods for measuring polished surfaces, and we present a development method that uses ultraviolet rays and a correlation function for a laser light source. This method is superior in that the angle of incidence can be freely selected, whereas the angle of incidence must be constant with other methods because an ultraviolet laser is used.**

Keywords—Laser-speckle; Ultraviolet lasers; Polished surface

I. INTRODUCTION

Several methods for plotting the mode shapes of piezoelectric resonators have been developed. When designing resonators or vibration devices, measuring the vibration mode shape is important. Many methods use optical interference, which is the interaction between incident and reflected photons, produced by coherent laser beams[1]. The laser-speckle method, which uses the long coherence of modern lasers, is powerful for visualizing the displacement of deformed shapes. Many techniques have been proposed as a result [2-6]. When a coherent light, such as that from a semiconductor laser, irradiates a surface that has a surface roughness greater than the laser wavelength, reflected photons form a random speckle pattern. Because the speckle pattern is sensitive to changes in the path length, this method can be applied to piezoelectric resonators with minute displacements. When a coherent light such as that from a semiconductor laser irradiates a surface that has a surface roughness greater than the laser wavelength, reflected photons form a random speckle pattern. Because the speckle pattern is very sensitive to changes in the path length, this method can be applied to piezoelectric resonators with minute displacements.

When designing resonators, confirming the reliability of the calculated results is important because the calculation renders many spurious resonances. Comparing the mode shape predicted from analysis and that obtained from experiments is the best method of confirm the results. Therefore, we previously developed methods for visualizing the mode shape that involves combining surface-speckle interferometry and image-processing techniques.

These methods involve irradiating a roughly finished device surface with a visible-collimated laser beam, then the speckle field that is generated on the surface of the device is captured using a charge coupled devices (CCD) camera [3-6]. The mode shapes are obtained from the correlation between the images taken during the resonator-driving and resting phases [6].

We propose an epoch-making method that uses ultraviolet (UV) lasers and a correlation function for a laser light source. This method is superior in that the angle of incidence can be freely selected, whereas the angle of incidence must be constant with other methods because an UV laser is used.

The principle of the proposed method and optical layout and measurement system are described in Section II. The experimental results of measuring a quartz resonators are presented and compared with the results obtained with a previous laser-speckle method in Section III.

II. EXPERIMENTAL METHODS

As shown in Fig. 1, it was determined that a horizontal angle of 16° at a wavelength of 633 nm led to the best laser-speckle interference[5,6]. However, the problem was that laser interference does not occur if the angle deviates from 16° even a little, so a wider range of incident angles was required. Therefore piezoelectric resonators with polished surfaces were measured using a laser speckle interferometer, to determine the in-plane displacement of 1/correlation, making it possible to measure the absolute amplitude of piezoelectric resonators [7,8].

The block diagram in Fig. 2 shows the system for conducting measurements using both the laser Doppler measurement system and laser speckle interferometer[7,8]. We used a method of driving a glass plate with a polished gold surface and applied it to the laser-speckle method by using correlation values, making it possible to measure the absolute amplitude of piezoelectric resonators. A quartz crystal resonator was vibrated arbitrarily with a signal generator.

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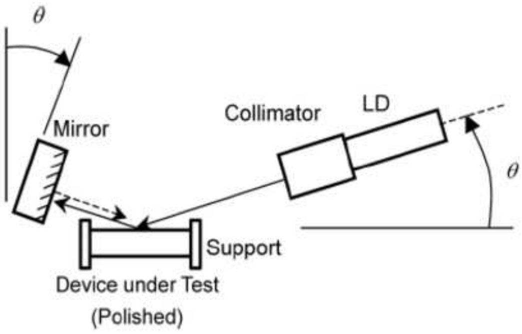

Fig. 1. Optical system for measuring in-plane mode shapes of polished devices[1]. (LD: laser diode)

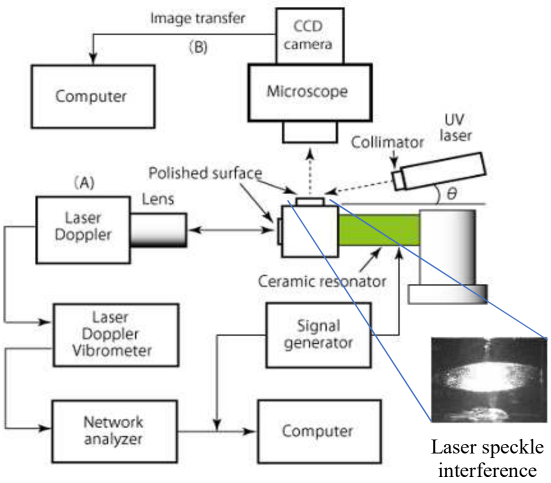

Fig. 2. Calibration system for absolute vibration displacement of polished surface resonance with laser Doppler measurement system (A) and laser-speckle interferometer (B).

By placing a crystal resonator on a polished surface on the laser-speckle interferometer, an equivalent 1/correlation could be obtained, then vibration displacement was obtained, as shown in Fig. 3. This is for when the glass plate and crystal oscillator are the same material.

III. EXPERIMENTAL RESULTS

In Figs. 2 and 3, the angle-of-incidence and wavelength of the laser were 10° (reference to the horizontal direction) and 377 nm, respectively. The laser Doppler measurement system was used to measure the vertical direction of the glass plate, and the laser-speckle interference was expressed as a correlation obtained from vibration displacement measurements.

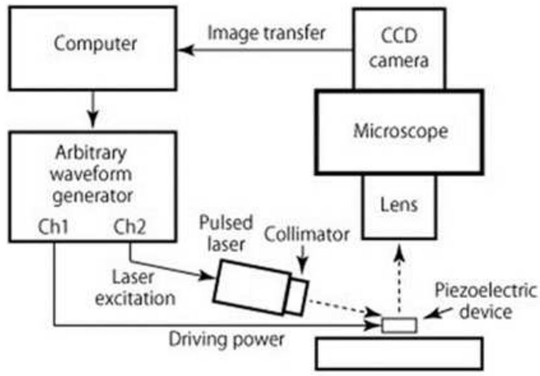

Fig.3. Schematic of measurement system.

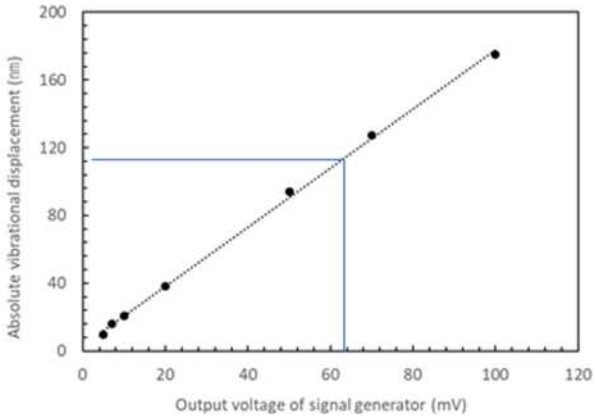

Fig. 4. Calibration system for absolute vibration displacement of polished surface resonance in laser Doppler measurement system and laser speckle interferometer.

Figure 4 shows the vibration displacement and output voltage of the signal generators obtained using the system in Fig. 2.

The sample in the figure clearly shows an almost linear response. This is because the maximum deflection width of a piezoelectric resonator is 120 nm, and a voltage less than 0.06 V (60 mV) is considered effective.

The measurement results of the polished surface are shown in Fig. 5, in which the incidence angle was 10° and the wavelength of the laser was 377 nm. The laser-speckle interference is the result of the large amount of reflection. An average value was obtained from 200 measured values. The 1/correlation coefficient was confirmed to be linear around 30 to 22 on the polished surface of a stress compensated cut (SC-cut) quartz crystal unit.

An SC-cut crystal resonator was vibrated at +8 dBm with a signal generator, and when the resonator was partially viewed (50 × 50 pixels), an absolute vibration displacement of 115 nm

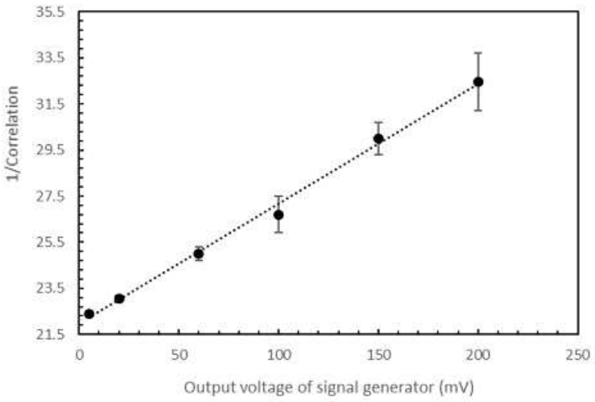

Fig. 5. 1/correlation vs. output voltage of signal generator using laser-speckle interferometer using the results in Fig. 3.

was obtained. Since the vibration was conducted at +8 dBm, an absolute vibration-displacement of less than 1.5 nm was obtained at -30 dBm, which was judged to be appropriate for the vibration.

IV. CONCLUSIONS

A UV laser with a short wavelength of 377 nm was introduced into the laser-speckle method. First, a 377-nm ultraviolet laser was used to measure the vibrational displacement of a glass plate with a mirror surface of gold. By combining the laser Doppler measurement system and laser speckle interferometer, we succeeded in measuring the absolute vibration displacement of the thickness vibration of an SC-cut crystal oscillator with a mirror surface. Since the entire oscillator contains parts that do not interfere with speckle, the central part was reduced to 50 x 50 pixels.

A 1/correlation of around 25.3 was obtained, and when this was plotted in Figs. 4 and 5, approximately 115 nm was obtained. The excitation power was relatively high, 8 dBm (≈ 6.3 mW: 50 Ω), and the power obtained with a normal oscillator is about -30 dBm (= 0.001 mW), so the absolute displacement was 1.5 nm or less.

Future work will involve using different gold mirror surfaces (glass plate and crystal oscillator), so the obtained results will change slightly. The accuracy is low because speckle interference occurs or does not occur in the entire oscillator. Therefore, we will consider more accurate measurement methods.

V. ACKNOWLEDGEMENT

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