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Optical Interferometric Measurement of Vibration Amplitude in High Power Ultrasonic Tool through Vibration-Synchronized Fringe Counting (II) Simplification of the System

光学干涉縞の同期計数によるパワー超音波振動系の振動振幅測定
(II) 測定系の簡素化

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1. Introduction

For the high power ultrasonic applications such as cleaning, welding, machining, and chemical reactions, vibrations of 20-100 kHz are used. Vibration displacement amplitude ranges from several to several ten µm, and laser Dopper velocimeter (LDV) is commonly used to evaluate vibration system in laboratories [1]. However, there is a demand to reduce the cost of LDV system. Ueha et al. proposed to utilize a simple homodyne interferometer with syncronized counting of fringes [2]. The author tested this concept, and confirmed that it worked with a displacement error of less than sub-microns [3].

In this report, the author try to replace the He-Ne laser to a laser diode to reduce the system cost. The effects of ellimination of temperature control and driving current regulation on the measuremnt quality are investigated.

2. Measurement Principle and Interferometer Configuration

The original setup presented in the author's previous report [3] is shown in **Fig. 1**. It consists of a Michelson homodyne interferometer and a synchronous fringe counting circuit. Light from the laser source is devided into the reference light and the measurement light using a PBS. The later is converted to circular polarized light through a QWP and hits the vibrating object. The light reflected with the object is returend to linearly polarized light, but the polarization is parpendicular to the incident light. Thus, the reflected light is deflected with the PBS to the photo diode via the polarizer. The reference light is reflected with the mirror and travels through the PBS to the photo diode. Both lights are combined at the photo diode, and the phase shift due to the vibration displacement is detected as a result of interference. The ratio of the intensity of the measurement light to the reference light is optimized by rotating the light source polarization. Displacement amplitude of high power ultrasonic vibration systems working at several 10 kHz exceeds µm-range in most cases. The highest displacement amplitude is less than 100 µm. These displacement amplitudes are much higher than the wavelength of the light. Thus, the sign of the electrical output of the photo diode alters so many times as the ratio of the displacement amplitude to a quarter of the light wavelength. The key of the proposed method is to count the interferometric fringes syncronized with the driving signal of the vibration system. This becomes possible when the vibration is continuous.

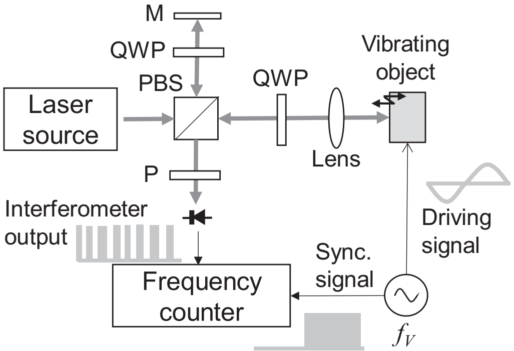

Fig. 1 Homodyne interferometer and synchronized fringe counting circuit for vibration displacement measurement: M, mirror; PBS, polarization beam splitter; QWP, quarter wave plate; P, polarizer.

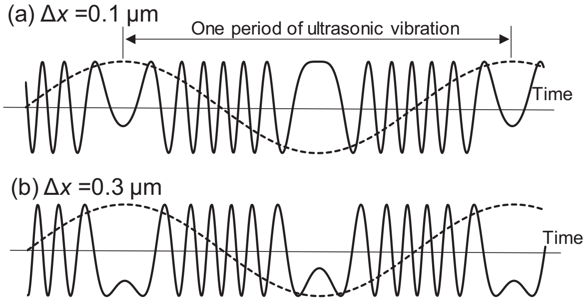

Fig. 2 Simulated interferometric waveforms for the vibration amplitude of 2 µm. Path differences are 0.1 and 0.3 µm.

The AC component of the output of the photo diode can be written with the 0-p displacement u and the frequency f_V of the ultrasonic vibration as

$$i_{AC} \propto \cos 2\pi\left(\frac{2u}{\lambda}\cos 2\pi f_V + \frac{\Delta x}{\lambda}\right), \qquad (1)$$

where λ and Δx are the light wavelength and the initial phase difference between the reference and object lights, respectively. If a He-Ne laser is used as the light source, λ=0.6328 μm. As examples, interferometric waveforms are simulated using Eq. (1) as shown in **Fig. 2** for the peak-to-peak vibration amplitude (=$2u$) of 2 μm. Fringe counting result differs by one depending on the path difference. But the difference does not exceed this value as a theory, and it corresponds to an error of 0.16 μm in the displacement.

3. Measurement System with Laser Diode

Light source in **Fig. 1** was replaced with a cost-effective commercial laser diode (RLD65MZT ２, ROHM), which was designed for DVD-R/CD drives (650 nm and 5 mW/ typ.). At the same time, interferometer was simplified as shown in **Fig. 3**. It is common that the temperature of the laser diode is regulated using a Peltier unit, a temperature sensor, and a controlling circuit within ±0.01°C for interferometer applications. The driving current is also controlled at a constant value.

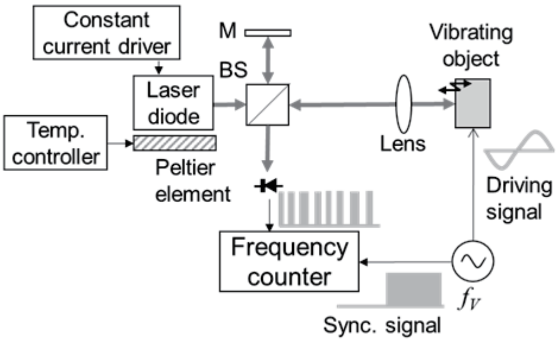

Fig. 3 Measurement system using laser diode and simplified optics: BS, non-polarized beam splitter.

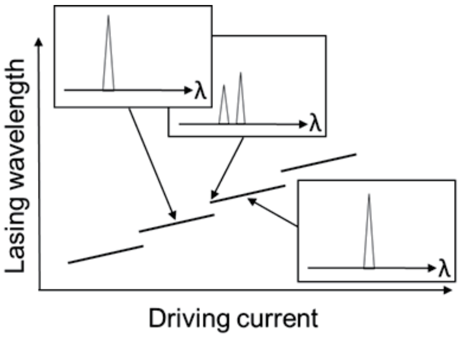

Fig. 4 Conceptual description of characteristics of Fabry-Perot laser diode.

4. Effects of Temperature and Driving Current Controls for Laser Diode on Measured Results

To reduce the system cost, the circuits related to the laser diode is investigated. First, the temperature control was turned off, and the measurement quality was examined. No significant effect on the measured displacement amplitude was observed although the fringe pattern drifted. In a strict manner, the lasing wavelength shift due to the temperature change will reflect on the measured results. But there will be little effect on the results if the measurement is done around room temperature.

Second, the driving current was changed, and the interferometer output was observed. As illustrated in **Fig. 4**, lasing wavelength of typical Fabry-Perot laser diode slightly increased in roughly proportional to the driving current, but there are step-like variations called ‘mode hop.’ The laser output spectrum exhibits single peak in the middle of the slope, while multiple peaks are observed around the hop. The quality of the interferometer output became worse as shown in **Fig. 5 (a)** if the laser diode was operated around the hop. But, even under this condition, we could measure the vibration amplitude through the fringe counting.

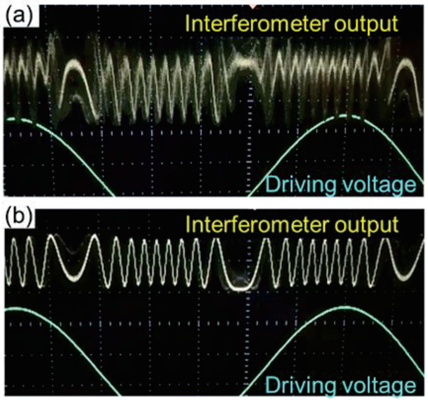

Fig. 5 Interferometer outputs: (a), laser diode is operated near the hop; (b), at the current between the hop.

3. Conclusions

A homodyne fringe counting interferometer was studied for amplitude measurement of ultrasonic vibrations. To reduce the cost, simplification of the optical system and the light source was tried.

References

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2. S. Ueha, T. Nakamura and E. Mori, Ultrasonics, pp.41-42, Jan., 1983.
3. K. Nakamura, Proc. USE2018, 1P4-9, 2018.