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Development of a hydrophone calibration system based on the reflection method using optical interferometry
光干渉法を用いた反射法によるハイドロホン校正装置の開発

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1. Introduction

A combination of an optical interferometer and a pellicle, featuring an almost flat frequency response and a small active element, is used for hydrophone calibration [1,2,3,4]. Two conventional methods exist for the technique: the transmission and the reflection method. The transmission method features easy alignment, but it requires correction for the acousto-optic effect. The reflection method shows almost twofold sensitivity for normally incident ultrasound. No correction for the acousto-optic effect is necessary. However, it is prone to perturbation by mechanical vibration and bubbles at the water–pellicle interface [5]. Moreover, it requires some alignment modification during calibration, for example, topping up with water before the measurement using the hydrophone [4]. For this study, we solved the problems and developed a hydrophone calibration system based on a new reflection method with an air-backed pellicle. The calibration results of a membrane hydrophone using the conventional transmission and the developed methods were compared and discussed in a frequency range from 1 MHz to 20 MHz.

2. Experimental methods

Figure 1 presents a sketch of the conventional transmission and the new reflection methods. Because only the pellicle is arranged in the transmission method, ultrasound travels in water, passes through the pellicle, and interacts with the probe beam of the interferometer. Both ultrasonic displacement and the acousto-optic effect are observed there. Therefore, a correction using the effective refractive index of water is necessary. Meanwhile, because an air layer is introduced behind the pellicle in the reflection method, ultrasound waves traveling through the water are reflected almost perfectly at the pellicle–air interface. The waves do not interact with the interferometer probe beam. The method is therefore useful at almost identical alignment with the transmission method, and twofold ultrasonic displacement is visible.

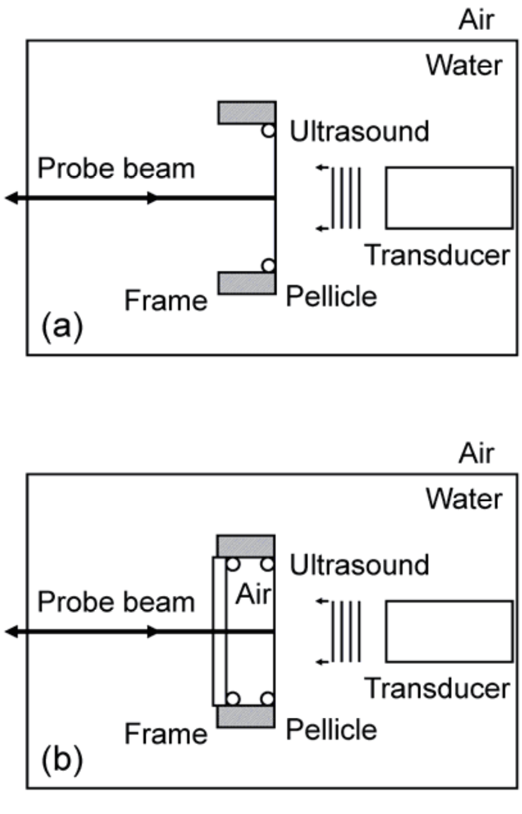

Fig. 1 Two methods for underwater ultrasound detection using a combination of an optical interferometer and pellicle; (a) Conventional transmission method and (b) Developed new reflection method with an air-backed pellicle.

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Regarding hydrophone calibrations using the two methods, a tone burst ultrasound from a transducer was observed at almost identical positions using a combination of a path-stabilized Michelson interferometer and a pellicle and a hydrophone to be calibrated. The pellicle, which is acoustically transparent and optically reflective, follows the ultrasonic motion. Its displacement is measured using the interferometer. The ultrasonic pressure is derived from the measured displacement under a plane wave assumption. The hydrophone is calibrated by measuring the output voltage corresponding to the known acoustic pressure. A stabilized He–Ne laser (wavelength = 633 nm) was used as the interferometer probe beam. A 1-µm-thick polyester film with a 300 nm gold coating was used as the pellicle. The normalized transducer – detection point distances were 1.5–15. The water temperature was 23 °C±0.5 °C. A commercial membrane hydrophone was calibrated using the two methods in the frequency range from 1 MHz to 20 MHz. Relative standard deviations of the measured displacement were also evaluated.

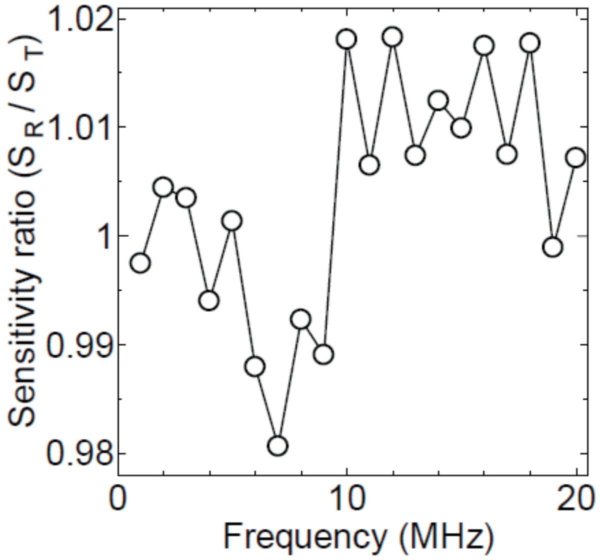

Fig. 2 Comparison of the sensitivity of a membrane hydrophone using the two methods. S_R: The sensitivity measured using the reflection method. S_T: The sensitivity measured using the transmission method.

3. Results and discussion

The calibration results obtained using each of the two methods were compared. **Figure 2** shows that the sensitivity differences between the two were within 2%. Relative expanded uncertainties of the calibrations are 6 % – 9 % in the frequency range. Therefore, calibration results well agreed. **Figure 3** shows the relative standard deviations of the measured displacements for the two methods. The values were around 0.5 %; they were not so different at less than 15 MHz. However, the values greater than 15 MHz obtained for the transmission method increased more rapidly than those for the reflection method.

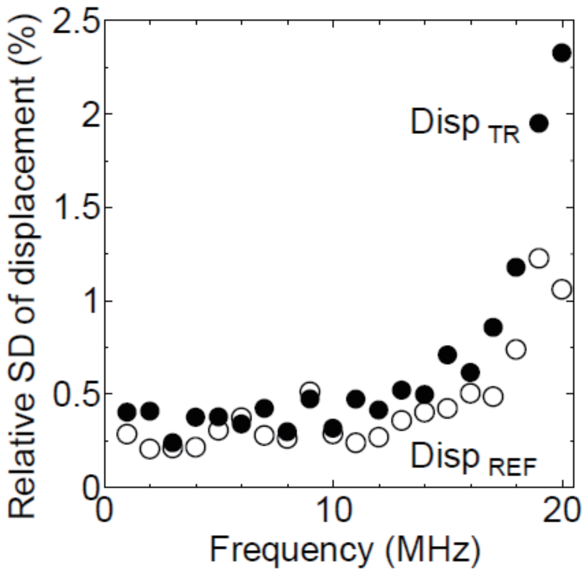

Fig. 3 The relative standard deviations of the measured displacement for the two method. $Disp_{TR}$: Transmission method. $Disp_{REF}$: Reflection method.

4. Conclusion

A hydrophone calibration system based on the new reflection method using a combination of an optical interferometer and an air-backed pellicle was developed and validated. The calibration results obtained using the new method agreed well with those obtained using the conventional method. The developed system provides more stable high-frequency measurements than the conventional one.

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