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Primary calibration of hydrophones up to 40 MHz in ultrasonic far-field using optical interferometry
光干渉法による遠距離音場でのハイドロホン校正（40 MHz への拡張）

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1. Introduction

Recently, high frequency ultrasound above 20 MHz is used to improve image resolution in medical ultrasound. To guarantee patient safety and to assess the equipment performance, the radiated sound pressure amplitude is evaluated using calibrated hydrophones. Hydrophones are practically calibrated using ultrasonic far-field from 0.5 MHz to 20 MHz [1-3]. However, hydrophone calibration using ultrasonic far-field is difficult at the frequencies above 20 MHz because of the large ultrasonic attenuation [4-6].

In this study a 1 mm radius transducer was developed to achieve ultrasonic far-field at 50 mm propagation distance at 40 MHz. A coplanar membrane hydrophone was calibrated from 10 MHz up to 40 MHz with a 1 MHz frequency interval using ultrasonic far-field. The calibration results were compared with the National Physical Laboratory (NPL) calibration results.

2. Experimental Methods

The hydrophone amplitude sensitivity $M(f)$ is given as

$$M(f)=\frac{V_{\mathrm{h}}(f)}{p(f)}=\frac{V_{\mathrm{h}}(f)}{2\pi f\rho c U(f)}, \qquad (1)$$

where f is the ultrasound frequency. $V_{\mathrm{h}}(f)$, $p(f)$, and $U(f)$ respectively signify the hydrophone output voltage amplitude, the incident plane wave sound pressure amplitude and the incident plane wave ultrasound displacement amplitude. ρ and c respectively denote the water density and the sound velocity in water.

Fig. 1 portrays a block diagram of the hydrophone calibration system. A water tank was filled with degassed and distilled water. Water temperature was monitored using a thermometer to determine the water density and the sound velocity in water. Regarding hydrophone calibrations, a tone burst ultrasound generated using a transducer was observed at almost identical positions using a stabilized Michelson interferometer and a hydrophone to be calibrated.

A 1 mm radius plane poly vinylidene fluoride – trifluoroethylene (PVDF-TrFE) transducer generated the tone burst ultrasound with the pulse duration of 10 μs. The transducer has a nominal center frequency of 40.3 MHz and a nominal -6 dB band width of 28 MHz. The propagation distance was 50 mm. The frequency dependence of the sound pressure amplitude was measured at the detection point using the interferometer. The transducer effective radius was evaluated with the least-squares method at 20 MHz and 40 MHz.

A 5-μm-thick polyethylene terephthalate (PET) film with a 300 nm gold coating on the interferometer side surface was used as the pellicle, which was acoustically transparent and optically reflective.

Signals from the interferometer and the hydrophone were amplified using a RF amplifier, averaged from 100 times to 2000 times to increase the signal-to-noise ratio and were recorded using a 12-bit digitizer. Hydrophones were calibrated in the frequency range from 10 MHz up to 40 MHz with a 1 MHz frequency interval.

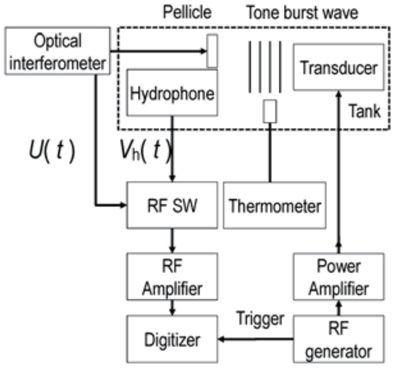

Fig. 1 The block diagram of the hydrophone calibration system using optical interferometry.

3. Results

The tone burst ultrasound generated from the transducer was observed using the interferometer. **Fig. 2** shows the frequency dependence of the incident sound pressure amplitude at the detection point. The measured values ranged from 20 kPa to 60 kPa.

The directional responses of the transducer were measured using the interferometer to evaluate

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the effective radii of the transducer. **Fig. 3** presents the experimental and the curve-fitting results. The effective radii of the transducer at 20 MHz and 40 MHz were 0.85 mm and 0.88 mm, respectively. The effective radius of 0.88 mm at 40 MHz and the 50 mm propagation distance meet far-field condition.

A coplanar membrane hydrophone with a 0.2 mm radius active element was calibrated using optical interferometry in the frequency range from 10 MHz up to 40 MHz with a 1 MHz frequency interval. The calibration results were compared with the NPL calibration results, which have the relative expanded uncertainties of 7 % at 10 MHz, 11 % at 20 MHz, 12 % at 30 MHz and 15 % at 40 MHz. **Fig. 4** presents the results. The results of this study were one-run measurement and the NPL results are the average of four measurements. The differences between the results of this study and the NPL calibration results were 2.3 % at 10 MHz, 3.3 % at 20 MHz, 5.9 % at 30 MHz and 11 % at 40 MHz. The results of this study were smaller, but the differences were within the uncertainties stated by the NPL.

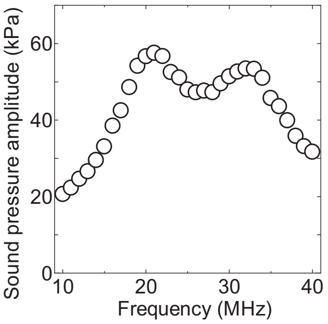

Fig. 2 Frequency dependence of the incident sound pressure amplitude measured using the interferometer. Sound source was the 1 mm radius plane PVDF-TrFE transducer. The propagation distance was 50 mm.

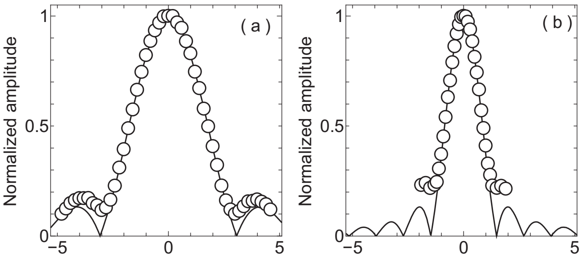

Fig. 3 The directional responses of the 1 mm radius plane PVDF-TrFE transducer measured using the interferometer: (a) 20 MHz and (b) 40 MHz. The propagation distance was 50 mm. The solid line shows the curve-fitting result to derive the effective radius. The effective radii at 20 MHz and 40 MHz were 0.85 mm and 0.88 mm, respectively.

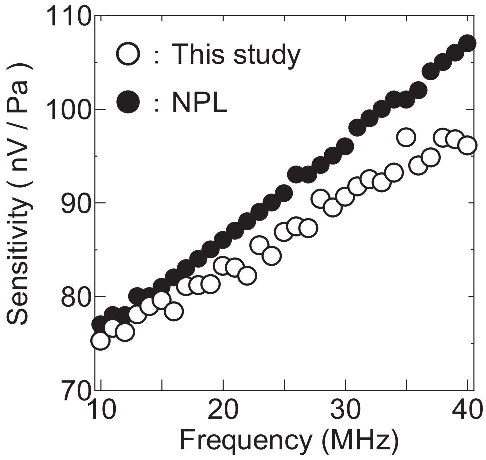

Fig. 4 The amplitude sensitivity of a coplanar membrane hydrophone with a 0.2 mm radius active element: (○) This study , (●) The NPL calibration results. The relative expanded uncertainties are 7 % at 10 MHz and 15 % at 40 MHz.

4. Conclusions

A 1 mm radius plane PVDF-TrFE transducer was developed to calibrate hydrophone at high frequencies in ultrasonic far-field using optical interferometry. The transducer featured a frequency range from 10 MHz up to 40 MHz and an effective radius about 0.9 mm at 40 MHz. A coplanar membrane hydrophone with a 0.2 mm radius active element was calibrated in the frequency range from 10 MHz up to 40 MHz with a 1 MHz frequency interval. The calibration results were compared with the NPL calibration results. The results of this study were smaller than the NPL results, but the differences were within the uncertainties stated by the NPL. Further studies will be carried out to evaluate the calibration uncertainties and to investigate the discrepancy of the calibration results.

References

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