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Open voltage measurement for reciprocity calibration of hydrophone using insert voltage technique

相反定理に基づくハイドロホン感度校正のための
挿入電圧法を用いた開放電圧測定

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1. Introduction

A hydrophone sensitivity calibration system using laser interferometry from 0.5 MHz to 20 MHz has been developed for establishing ultrasonic standard of our country at NMIJ, AIST.[1)] The calibration service was started in 2005. However the calibration in further wide frequency range is required for an accurate measurement of broadband ultrasonic waves like a pulse.[2)] Consequently, an expansion of the calibration frequency range is now carried on.[3,4)] For a treatment of low frequency side, a system using reciprocity technique shown in IEC 60565[5)] from 100 kHz to 1MHz is developed.

A relational expression between end-of-cable open-circuit sensitivity and transmitting response to current of an ultrasonic transducer given by reciprocity theorem is used in the calibration. So output of reciprocal transducer receiving ultrasonic wave must be measured as open voltage. Because a voltage drop by electrical impedance of the transducer affects the output voltage into equipment for voltage measurement, both electrical impedances of the transducer and input to the equipment is necessary to obtain open voltage as described in IEC 60565.[5)]

Meanwhile, insert voltage technique is used to reciprocity calibration of microphone in audible acoustic standard for open voltage measurement.[6)] An advantage of this technique is unnecessary to measure frequency response of the aforementioned electrical impedances separately. Therefore the availability of the proposed technique for the sensitivity calibration of hydrophone to measure ultrasound is investigated.

2. Principle of Reciprocity Calibration

Three ways of ultrasonic transmitting and receiving using projector (P) and reciprocal transducer (T) and hydrophone (H) for reciprocity calibration are shown in **Fig. 1**. Electrical transfer impedances $|Z_{PH}|$, $|Z_{PT}|$ and $|Z_{TH}|$ (Ω) are derived by dividing amplitudes of output voltage U_{PH}, U_{PT} and U_{TH} (V) by those of input current I_{PH}, I_{PT} and I_{TH} (A), respectively. d_1, d_2 and d_3 (m) are ultrasonic propagation distances. Then, sensitivity of H, M_H (V/Pa) is obtained by

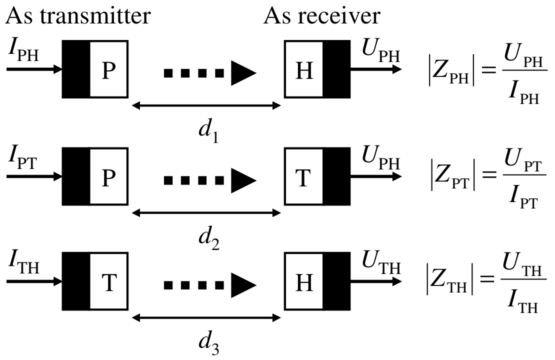

Fig. 1 Ultrasonic transmitting and receiving for reciprocity calibration.

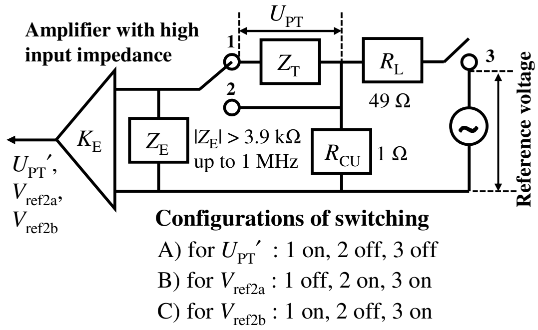

Fig. 2 Electrical circuit for insert voltage technique.

$$M_H = \sqrt{\frac{2d_1 d_3}{\rho f d_2} \frac{|Z_{PH}||Z_{TH}|}{|Z_{PT}|}}, \quad (1)$$

where ρ (kg/m^3) and f (Hz) are density of water and ultrasonic frequency, respectively.

3. Insert Voltage Technique

In order that the reciprocity of T is available for the calibration of H, U_{PT} must be measured as end-of-cable open-circuit voltage. The electrical circuit and configurations of switching A)–C) for measuring U_{PT} using insert voltage technique are shown in **Fig. 2**. Z_T, Z_E, R_{CU}, and R_L (Ω) are electrical impedance of T, input impedance of an amplifier with gain K_E, and two known resistances, respectively. When T receives an ultrasound from P

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and switches of the circuit are configured to A), the amplitude of output voltage from the circuit U_{PT}' (V) is shown as

$$U_{PT}' = \frac{K_E |Z_E|}{|Z_E + Z_T + R_{CU}|} U_{PT} . (2)$$

Then the ultrasonic radiation is turned off and a reference voltage with a certain amplitude is inserted to the circuit. The ratio between output voltage amplitudes V_{ref2a} and V_{ref2b} (V) with switching configurations B) and C) are shown as

$$K_{open} = \frac{V_{ref2a}}{V_{ref2b}} = \frac{|Z_E + Z_T + R_{CU}|}{|Z_E + R_{CU}|} . (3)$$

When R_{CU} is enough smaller than $|Z_E|$, U_{PT} is derived from eqs. (2) and (3) as

$$U_{PT} = \frac{K_{open}}{K_E} U_{PT}' . (4)$$

Although the amplifier gain K_E is unknown, the effect of K_E is canceled in the derivation of electrical transfer impedance $|Z_{PT}|$. It is because I_{PT} is measured from a voltage on a shunt resistance inserted in series in P that is detected through the identical amplifier.

4. Experiment

Sensitivity of an ultrasonic transducer V303 (Panametrics) with diameter of 13 mm and center frequency of 1 MHz as H is calibrated using the same type transducer or V318 (Panametrics) with diameter of 19 mm and center frequency of 0.5 MHz as T in the experiment. P used in each calibration is same type of T.

Frequency responses of K_{open} for the two types of T measured in the calibration are clearly different as shown in **Fig. 3**. Because K_{open} operates as a correction value for removing the effect of voltage drop at T in the measurement of open voltage U_{PT}, the variation of the calibrated sensitivities by the correction using K_{open} is investigated. Deviations of the sensitivity of H calibrated with V318 from that with V303 as T are shown in **Fig. 4**. It is confirmed that the deviation is decreased by the correction using K_{open}.

Large deviation at low frequency would be caused by the effect of ultrasonic reflection from side surfaces of water vessel in the calibration system as expected from our previous investigation.[7)]

5. Summary

Open voltage measurement using insert voltage technique for reciprocity calibration of hydrophone from 100 kHz to 1 MHz is proposed. As the result of comparing sensitivities calibrated using ultrasonic transducers with different electrical impedance as T, it is confirmed that K_{open} derived using insert voltage technique can correct the output voltage amplitude of T affected by its own voltage drop.

Improvement of the reproducibility of the calibration at low frequency is an issue in future. Additionally, we intend to estimate the uncertainty of the calibration.

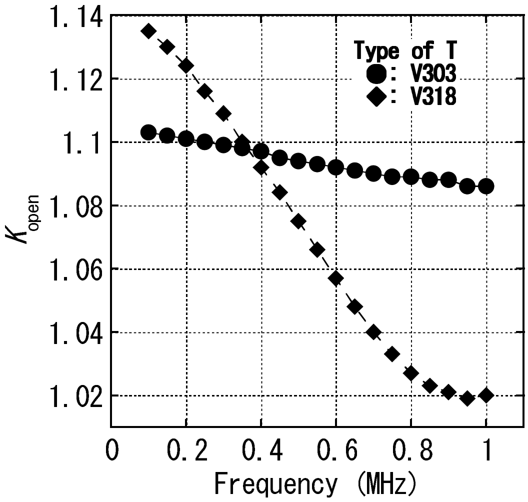

Fig. 3 K_{open} for two types of T.

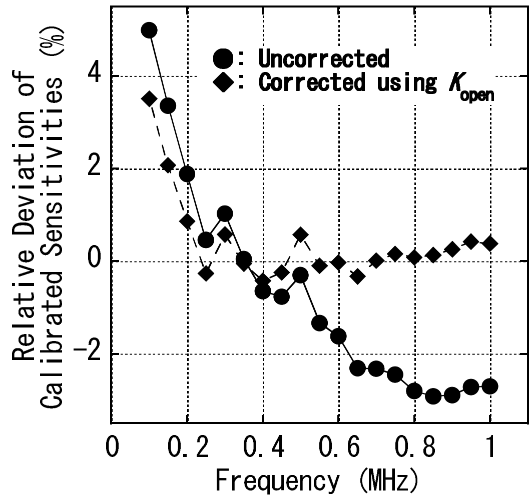

Fig. 4 Relative deviation of H sensitivity calibrated using V318 from that using V303 as T.

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