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Uncertainty Source of Active Element Diameter Measurement for Hydrophone Sensitivity Calibration
ハイドロホン感度校正における アクティブエレメント有効径測定の不確かさ要因

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1. Introduction

A technique for hydrophone sensitivity calibration up to 40 MHz using focused ultrasound has been investigated at the National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology (NMIJ, AIST)[1]. The calibration is significantly influenced by the spatial averaging of ultrasound pressure on a hydrophone active element. The effect of such spatial averaging on focused field can be derived quantitatively using a theoretically derived sound pressure and an element size[2,3].

In the previous experiment, it was confirmed that the effect should be corrected by appropriating not nominal element size but measured effective one, because there was a hydrophone that had a large difference between the nominal and effective element sizes[1]. Therefore the uncertainty estimation of the element size measurement is important for the hydrophone sensitivity calibration.

The element size measurement from a hydrophone directivity needs a given element shape, however, the shape of an effective element is expected to be different from the apparent geometry[1]. Therefore the method assuming the circular element and deriving the effective diameter should be applied in practice. In this case, the variation of effective diameter measurement turns out an uncertainty source contributing to the estimation of the spatial averaging effect. The variation with the measured directions on a hydrophone active element is investigated in the article.

2. Principle of measurement

The process for measuring the effective diameter of a hydrophone's active element used in the experiment is described in the international standard IEC 62127-3:2007[4]. The theoretical directional response, assuming a circular hydrophone active element, is expressed by

$$D(\theta) = \frac{2J_1\left(ka\sin\theta\right)}{ka\sin\theta}, \quad (1)$$

$$k = 2\pi f / c, \quad (2)$$

where a, θ, f and c are the radius of the active element, the angle between the acoustical axis and the vector normal to the active element surface, the ultrasonic frequency, and the sound velocity, respectively. $J_1()$ is a first-order Bessel function of the first kind. If θ_3 and θ_6 are respectively the angles that satisfy $D(\theta_3) = 0.7$ (-3 dB) and $D(\theta_6) = 0.5$ (-6 dB), then the -3 dB and -6 dB radii of the active element, a_3 and a_6, are expressed from eqs. (1) and (2) as

$$a_3 = \frac{1.62}{k\sin\theta_3}, \quad (3)$$

$$a_6 = \frac{2.22}{k\sin\theta_6}. \quad (4)$$

The effective radius a_e is derived as the mean of a_3 and a_6. When it is considered that these measured radii indicates the element dimension for the direction perpendicular to the rotational at angle ϕ as shown in **Fig. 1**, the relational expression of a_e, a_3 and a_6 is shown as functions of ϕ.

$$a_e(\phi) = \frac{a_3(\phi) + a_6(\phi)}{2}. \quad (5)$$

The conclusive effective diameter $2a_{Eff}(\phi)$ is determined as the sum of $a_e(\phi)$ for two orthogonal rotational axes in IEC 62127-3:2007.

$$2a_{Eff}(\phi) = a_e(\phi) + a_e(\phi - 90°). \quad (6)$$

3. Experimental method

The hydrophone(CPM04, PAL), shown in Fig. 1, is a membrane hydrophone with an 80-mm-diameter piezoelectric polyvinylidene fluoride (PVDF) film printed electrodes on both sides. A line electrode is printed from the edge to the center of the PVDF film on one side. The line electrode has a circular part 0.4 mm in diameter as shown in the micrograph of **Fig. 2**. On the opposite side, almost the entire surface of the PVDF film is

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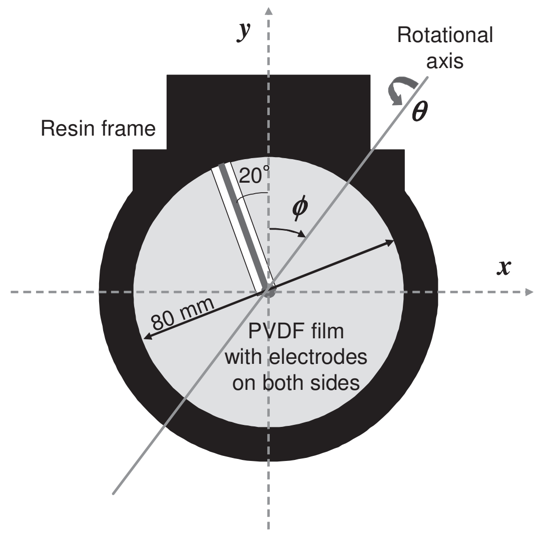

Fig. 1 Schematic illustration of the membrane hydrophone.

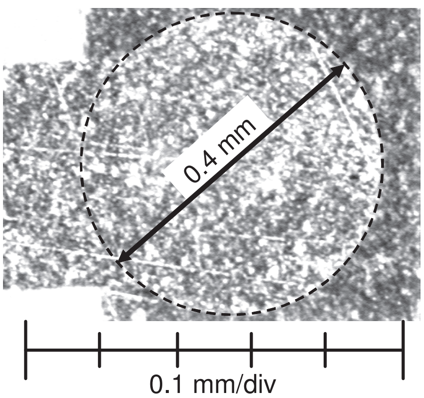

Fig. 2 Micrograph of the hydrophone active element.

covered by the electrode.

The directional response of the hydrophone for deriving $a_e(\phi)$ is measured by receiving a 5 MHz ultrasonic wave radiated from a plane-circular transducer 12.7 mm in diameter, with a 270 mm propagation distance for each incident angle θ of 1° step. The measurement range of ϕ is 180° by 5° step.

4. Results and Discussion

Measurement values of $a_e(\phi)$ obtained as points on the polar coordinate are converted to the orthogonal *x-y* coordinate of Fig. 1 and plotted in **Fig. 3**. In addition to the result that the effective diameter of membrane hydrophone is larger than the geometric one determined by electrode patterns as reports in refs. 1 and 5, it is revealed that the effective one lengthens along the electrode line deposited on membrane by compared with the superimposed electrode patterns scaled from Fig. 2.

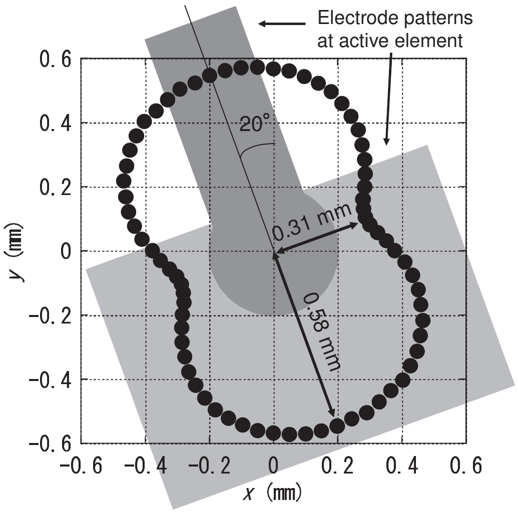

Fig. 3 Measurement results of effective radii $a_e(\phi)$ plotted on *x-y* plane and scaled electrode patterns at the hydrophone active element.

The average and the variation range of measured diameter $2a_e(\phi)$ in the experiment are 0.96 mm and 0.56 mm. On the other hand, those of the conclusive effective diameter $2a_{Eff}(\phi)$ in eq. (6) are 0.96 mm and 0.13 mm. Therefore $2a_{Eff}(\phi)$ derived from two values of $a_e(\phi)$ for arbitrary and mutually orthogonal ϕ can obtain the average effective diameter by the minimal measurement. However, in order to estimate the variation range of an effective diameter by minimal measurement, the relation between values of $a_e(\phi)$ and electrode patterns should be clarified. To confirming the relation, it is intended to measure $a_e(\phi)$ for other types of hydrophone.

Moreover, it is expected that the figure connecting the points on Fig. 3 indicates the more accurate shape of the effective element than the circular one. Therefore, it is intended to estimate the uncertainty of the correction factor of the spatial averaging for the hydrophone sensitivity calibration by comparing the correction factors derived assuming the active element shapes as the figure and circles with diameters in the range of measurement variation.

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