

## Articles

# The Effect of the Shape of Front Plate of Tough Hydrophone on the Receiving Directivity

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## I. Introduction

In recent years, the use of high-intensity ultrasound has spread in medical field and industrial field. In medical field, high intensity focused ultrasound therapy<sup>1, 2)</sup> and Sonoporation are used widely. High intensity focused ultrasound therapy is a treatment method that irradiates high-intensity ultrasound to cauterize the tumor in the prostate brain. Sonoporation is a treatment that uses acoustic cavitation to make small holes in cells and infect genes or drugs into the cells. In industrial field, ultrasound cleaners and ultrasound dispersers are typical examples. These ultrasound field formed by ultrasound used in medical and industrial fields is desired to measure by a hydrophone.

However, when high-intensity sound field is measured using commercially available hydrophone, the piezo element and surface electrodes are damaged by high sound pressure and acoustic

cavitation. Therefore, our laboratory has been studying a hydrophone that is tough enough not to be damaged even when the hydrophone is used to measure high-intensity ultrasound<sup>3-18)</sup>. Currently, we have developed the tough hydrophone with a cylindrical or conical shaped titanium front plate to avoid from the damage by high intensity ultrasound and acoustic cavitation that does not decreased receiving sensitivity even when the hydrophone measure high intensity sound field for 70 hours.

In this research, we measured the directivity of receiving sensitivity of tough hydrophone to consider the effect of the shape of the front plate on the performance of the tough hydrophone frequency characteristics of receiving sensitivity of tough hydrophone.

## II. Tough hydrophones

Currently, our laboratory develop two types of

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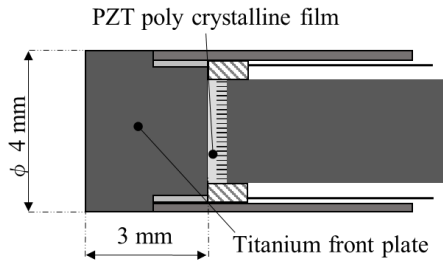
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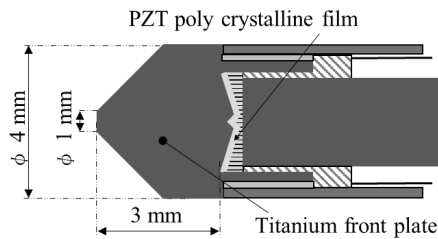
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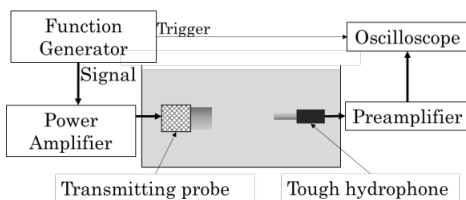
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(a) Structure of cylindrical tough hydrophone

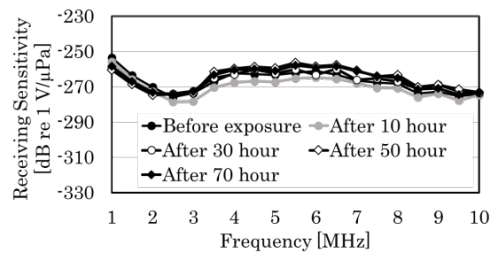


(b) Structure of conical tough hydrophone

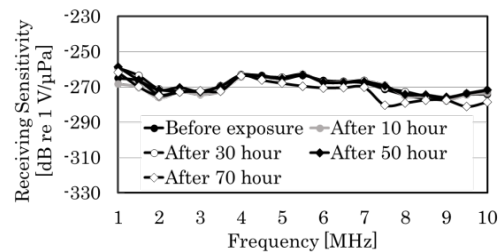
**Fig. 1** Structure of two types of tough hydrophones**Fig. 2** Block diagram of the measurement system for frequency characteristics of receiving sensitivity of tough hydrophone

tough hydrophone with different front plate shapes as shown **Figure 1**. One is tough hydrophone with cylindrical front plate (hereinafter referred to as cylindrical tough hydrophone.), and the other is tough hydrophone with conical front plate (hereinafter referred to as conical tough hydrophone.). Even after a 70 hour durability test in our laboratory, the receiving sensitivity of the two types of tough hydrophone did not decrease.

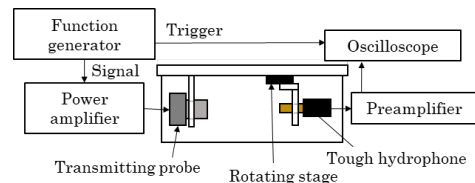
**Figure 2** shows a block diagram of measurement system for the frequency characteristics of receiving sensitivity. A sinusoidal signal with amplitude of 300 mV and 30 cycles in burst was applied to the ultrasound probe for transmission via a power amplifier. The ultrasound waves transmit-



(a) The measured frequency characteristics of receiving sensitivity of cylindrical tough hydrophone



(b) The measured frequency characteristics of receiving sensitivity of conical tough hydrophone

**Fig. 3** The measured frequency characteristics of receiving sensitivity of two types of tough hydrophones**Fig. 4** Block diagram of measurement system for the directivity of receiving sensitivity of two types of tough hydrophones

ted from the ultrasound probe for wave transmission were received by the tough hydrophone. The output signal from the tough hydrophone was observed on an oscilloscope via a preamplifier. The receiving sensitivity was measured from 1 MHz to 10 MHz (0.5 MHz step). Comparing the frequency characteristics of the receiving sensitivity of commercially available hydrophones with those of two types of tough hydrophones, the two types of tough hydrophones did not have flat frequency characteristics as shown **Figure 3**.

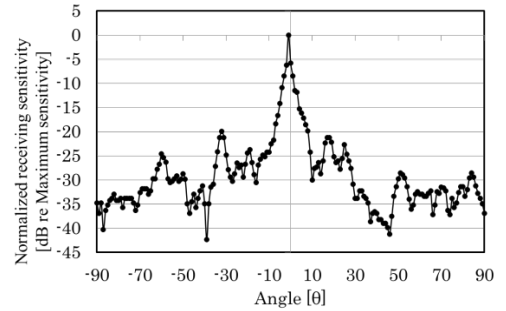
**Figure 4** shows a block diagram of measuring system of the directivity for receiving sensitivity

of tough hydrophone<sup>19, 20</sup>. The tough hydrophone was fixed to fixing jig, and fixing jig was fixed to rotating stage. The tip of the tough hydrophone was placed on the central axis of the rotating stage. The burst signal with amplitude of 300 mV, 30 cycles at 5.0 MHz, and applied to the ultrasound probe for transmission via a power amplifier. The ultrasound waves transmitted from the ultrasound probe were received by the tough hydrophone. The ultrasound probe for transmission (Harrisonic 13-0506-R) was in the water immersion type ultrasound probe with diameter of piezo element of 0.375 inch and operation frequency of 5.0 MHz. The output signal of the tough hydrophone was observed on an oscilloscope via a preamplifier. Measurement interval of the directivity was measured for each 1 degree.

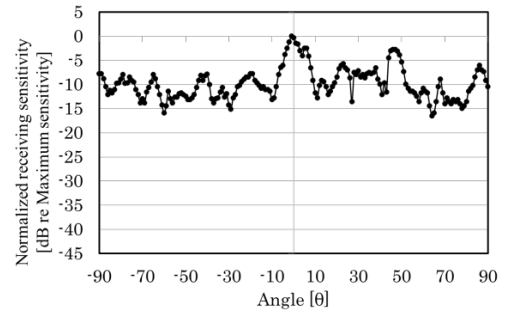
### III. Measurement of directivity of receiving sensitivity<sup>19, 20</sup>

**Figure 5** and **Figure 6** show the measured directivity of receiving sensitivity of two types of tough hydrophone. The output voltage from the tough hydrophone observed on the oscilloscope was normalized with the maximum output voltage from the tough hydrophone. Also, the receiving sensitivity of the cylindrical tough hydrophone is -267 dB at 5.0 MHz, and the receiving sensitivity of the conical tough hydrophone at 5.0 MHz is -265 dB at the center angle (0 degree).

In the case of the cylindrical tough hydrophone, the receiving sensitivity dropped by -6 dB from the maximum voltage at -2 degree and 0 degree. At -4 degree and 2 degree, the receiving sensitivity dropped by -10 dB from the maximum voltage. The minimum sensitivity was -42 dB at -39 degree. In the case of the conical tough hydrophone, the receiving sensitivity dropped by -6 dB from the maximum voltage at -6 degree and 8 degree. In addition, the decrease in receiving sen-



**Fig. 5** The measured directivity of receiving sensitivity of cylindrical tough hydrophone



**Fig. 6** The measured directivity of receiving sensitivity of conical tough hydrophone

sitivity was -10 dB even if the voltage deviated from the maximum voltage by 10 degrees. The minimum sensitivity was -16 dB at 64 degree.

### IV. Conclusions

The directivity of receiving sensitivity of two types of tough hydrophones showed significant differences. The directivity of receiving sensitivity of cylindrical tough hydrophone is low, and the receiving sensitivity decreases by -6 dB if it deviates from the maximum voltage by 1 degree and by -10 dB if it deviates by 3 degree. The directivity of receiving sensitivity of conical tough hydrophone is higher, and the receiving sensitivity decreases by -6 dB if it deviates from the maximum voltage by about 7 degree. Furthermore, the receiving sensitivity of the conical tough hydrophone dropped by only -16 dB, even if deviated significantly from

the direction showing maximum voltage.

As mentioned above, the directivity of the receiving sensitivity of the cylindrical tough hydrophone and those of the conical tough hydrophone were significantly different. This is considered to be related to the shape of front plate of tough hydrophones. The tip diameter of front plate of conical tough hydrophone is 1 mm and gradually increases from the tip toward the rear. Therefore, the conical tough hydrophone is easier to receive from the lateral signal than the cylindrical tough hydrophone. As that reason, the directivity of receiving sensitivity of two types of tough hydrophones is considered to be significantly different.

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