Program Digest, 2019 IEEE International Ultrasonics Symposium (IUS)
Glasgow, Scotland, October 6-9, 2019

Development of Novel Tough Hydrophone with Sensor Head with Hydrothermally PZT Film Deposited on The Back Surface of Titanium Conical Front Plate

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***Abstract*—We had developed a tough hydrophone using a titanium front plate and hydrothermally synthesized PZT polycrystalline film. Currently, there are two kinds of hydrophones we are developing, one is a tough hydrophone with a cylindrical front plate, and the other is a tough hydrophone with a conical front plate. These two kinds of hydrophones are not decreased their sensitivity even if they are exposed to a sound field with acoustic cavitation in the ultrasound cleaner for a total of 50 hours. However, there are differences in the scratches on the surface of the front plate. In this study, we observed the behavior of acoustic cavitation bubbles around the tip of the hydrophone using a high-speed video camera and a laser light sheet. In the tough hydrophone with a cylindrical front plate, a cavitation bubble cloud has been adhered to the tip of the hydrophone from the beginning of observation. On the other hand, even with a tough hydrophone with a conical front plate, a cavitation bubble cloud was adhered to the tip of the hydrophone at the beginning of observation. However, when the adhered cavitation bubble cloud collided with another cavitation bubble cloud, we were able to observe behavior the adhered cavitation bubble cloud flows along the shape of the tip of the hydrophone.**

Keywords—hydrophone, the behavior of cavitation bubble, high-speed video camera, front plate

I. Introduction

In recent years, devices using high-intensity ultrasound waves have become widespread in the medical field. Examples thereof include HIFU (High Intensity Focused Ultrasound), sonoporation, and ultrasound elastography. In order to evaluate the performance of ultrasound waves emitted by these devices, it is necessary to measure the sound field using a hydrophone [1]-[9].

However, with a commercially available hydrophone, when a high-intensity sound field is measured, surface electrodes and piezoelectric elements are damaged by high sound pressure and acoustic cavitation, which makes measurement difficult.

Therefore, our laboratory has developed a hydrophone with toughness that does not break even when measuring a high-intensity sound field by using a hydrothermally synthesized PZT polycrystalline film and a titanium material for the front plate [10]-[15]. In this time, it is investigated that the behavior of acoustic cavitation for hydrophones exposed to a high-intensity ultrasound field in the sonochemical reactor where acoustic cavitation occurs using a high-speed video camera for PIV (Particle Image Velocimetry) and a laser sheet.

II. Tough Hydrophones

As shown in Fig. 1, there are two types of tough hydrophones currently under development by our laboratory. Fig.1(a) is a tough hydrophone with cylindrical front plate (hereinafter referred to as a cylindrical hydrophone) in Fig.1 left side. Fig1(b) is a tough hydrophone with conical front plate (hereinafter referred to as a conical hydrophone) in Fig.1 right side.

The front plate of the cylindrical hydrophone is made of titanium, and the acoustic receiving part at the tip is a cylindrical shape with a diameter of 4 mm and a thickness of 3 mm. The front plate of the conical hydrophone has a conical tip (made of titanium), but the tip of the front plate has a flat surface with diameter of 1 mm. Fig. 2 shows the receiving sensitivity measurement system used in our laboratory. Figs.3(a) and 3(b) shows the frequency characteristics of the receiving sensitivity of cylindrical hydrophone and conical hydrophone. The line on the graph means the receiving wave sensitivity before exposure to the ultrasound cleaner and the receiving wave sensitivity after 10, 20, 30, 40 and 50 hours exposure. From these two graphs, it can be seen that the receiving sensitivity of the cylindrical hydrophone and the conical hydrophone do not have a significant difference even after 50 hours exposure. In addition, in the durability test in our laboratory, it has been confirmed that the receiving sensitivity did not decrease significantly even after total exposure time of 50 hours to the high intensity ultrasound field. However, in the cylindrical hydrophone, it is confirmed that the surface of the front plate had scratches that could be attributed to acoustic cavitation after exposure for 25 hours. On the other hand, in the conical hydrophone, no flaws due to acoustic cavitation were confirmed on the surface of the front plate even after 50 hours of exposure (Fig.4).

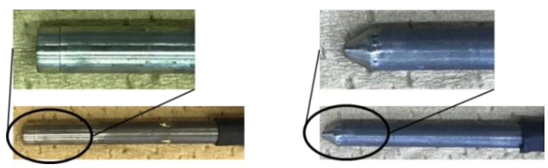


Fig. 1. Our fabricated robust hydrophone (a) Clyndrical hydrophone, (b) Conical hydrophone

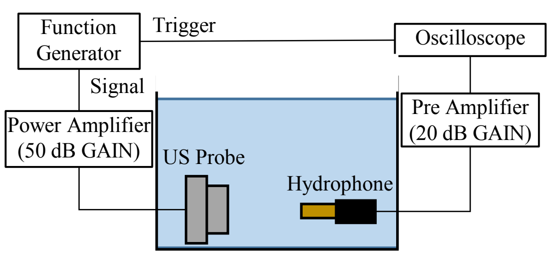
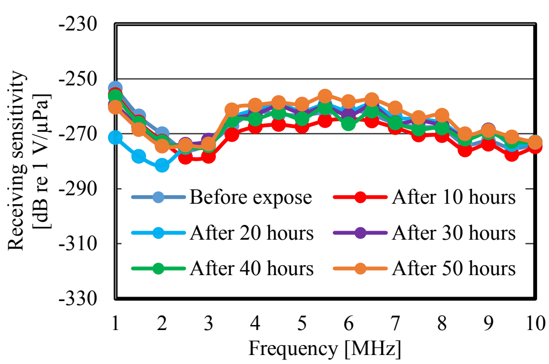


Fig. 2. Receiving sensitivity measurement system used in this study



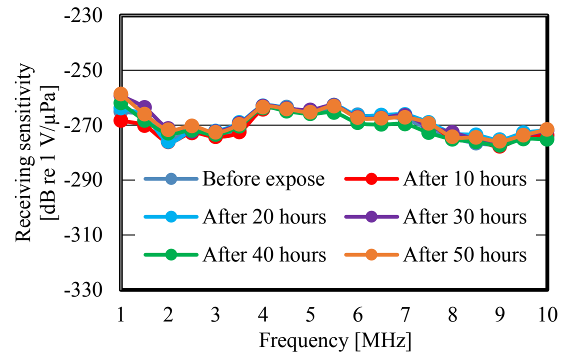


Fig. 3. Frequency characteristics of receiving sensitivity of conical hydrophone.((a) is up side graph, (b) is down side graph)

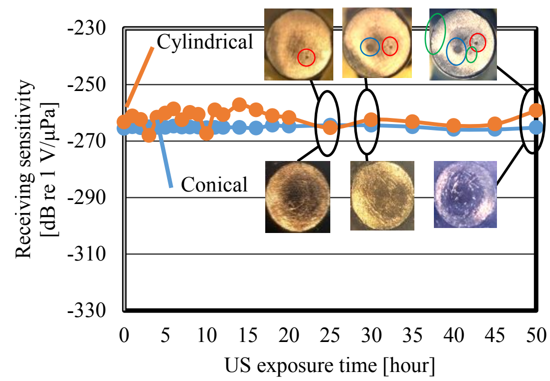


Fig. 4. Relationship between exposure time and receiving sensitivity

III. Experimental Method[16][17]

As shown in Fig.5, a high-speed video camera (K5, Kato Koken) is installed in front of a sonochemical reactor (HSR-301, Honda Electronics) with quartz glass windows on all four sides, and a PIV laser (G5000, Kato Koken) is installed in the vertically to the high-speed video camera.

The hydrophone is placed using a microstage so that the front plate tip of the hydrophone is 4.2 mm above the sonochemical reactor vibration surface.

Fig.6 shows a block diagram of the observation system for the acoustic cavitation behavior. A waveform with a frequency of 23 kHz was output from the function generator (WAVE FACTORY WF1944A, NF CO., Ltd.), and a sinusoidal wave with electric power of 30 W was input to the sonochemical reactor through the power amplifier (POWER AMPLIFIER 2100L, E&I) and impedance matching circuit. The signal received by the hydrophone is output to the oscilloscope (RTO1004, ROHDE&DCHWARZ) via the preamplifier (HUS-20-A, Honda Electronics), and the output waveform the hydrophone is confirmed with the oscilloscope.

Using this system, the behavior of the acoustic cavitation bubble around the tip of the hydrophone on the laser sheet is observed for about 30 minutes.

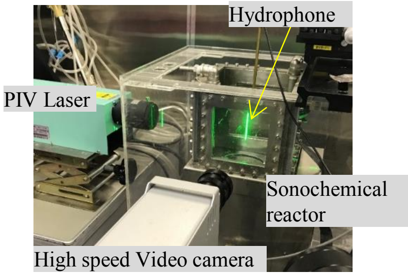


Fig. 5. Observation system using acoustic cavitation behavior high-speed video camera and laser light sheet

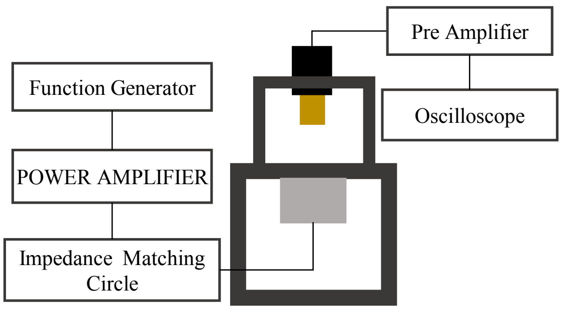


Fig. 6. Block diagram of observation system for the acoustic cavitation behavior

IV. Results and Discussions

When the cylindrical hydrophone was observed for about 30 minutes, as shown in Fig. 7, we could observe the situation that the cavitation bubble cloud continuously adhered to the hydrophone's sound receiving surface and front panel and outer sheath connection from the beginning. As described in Section 2 of this article, the cylindrical hydrophone is exposed to a high-intensity ultrasound field in the sonochemical reactor where acoustic cavitation bubbles are generated. From this the front plate surface is damaged. This seems to be due to the cavitation bubble cloud that continued to adhere to the front plate.

Fig.8 shows the waveforms measured during the observation. Since the cavitation bubble cloud was continuously adhered to the tip of the hydrophone from the start of observation to the end of observation, this waveform is the received waveform of the hydrophone when the cavitation bubble cloud is adhered to the hydrophone.

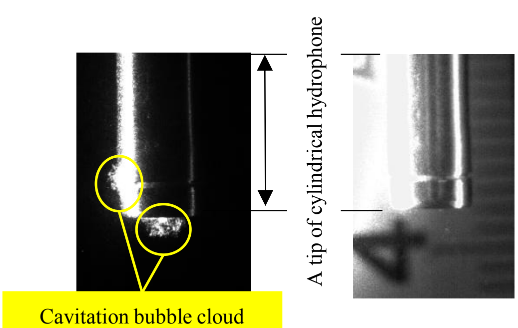


Fig. 7. Observation photograph of the cylindrical hydrophone

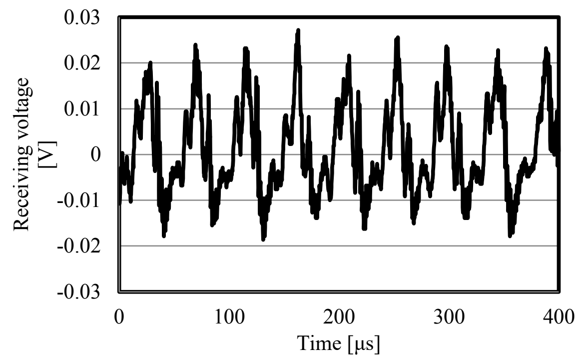


Fig. 8. Received waveform when cavitation bubble cloud is adheres to cylindrical hydrophone

On the other hand, when observing the conical hydrophone, a cavitation bubble cloud adheres to the tip at the beginning of the observation, but another cavitation bubble cloud collided with it after about 5 minutes as shown in Fig.9. As a result, the cavitation bubble cloud which was adhering to the surface of the hydrophone was observed to flow upward along the sheath side of the hydrophone. Observation was continued for 30 minutes passed.

After 30 minutes, after the cavitation bubble cloud had disappeared away from the hydrophone as shown in Fig. 10, the cavitation bubble cloud only collided with the hydrophone twice, however, it did not adhere to the front plate and it was observed to the flow along the shape of the front plate. The received waveforms at this time are shown in Fig.11 and Fig.12. Fig.11 shows the received waveform when the cavitation bubble cloud is not adhering to the hydrophone, and Fig.12 shows the received waveform when the cavitation bubble cloud collides with the hydrophone. Comparing the two received waveforms, it can be seen that when the cavitation bubble cloud collides with the hydrophone, the received waveform becomes larger than when the cavitation bubble cloud does not adhere to the hydrophone. It is considered that this is because the received waveform changes in a pulse shape due to the impact when the cavitation bubble cloud collides.

Thus, unlike the cylindrical hydrophone, the effect of the cavitation bubble cloud adhering to the front plate tip of the conical hydrophone is very small.

For this reason, it is thought that no flaws were found on the front plate surface even after 50 hours of exposure in the high-intensity ultrasound field in the sonochemical reactor where the acoustic cavitation bubbles of the conical hydrophone is generate.

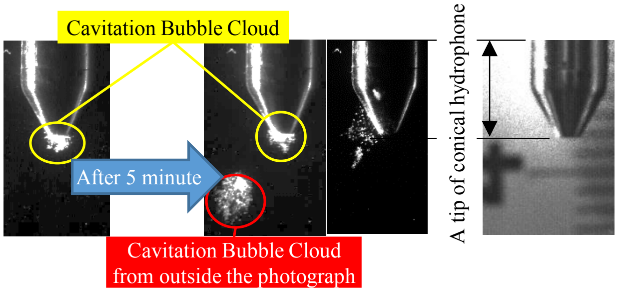


Fig. 9. Observation photograph of the conical hydrophone

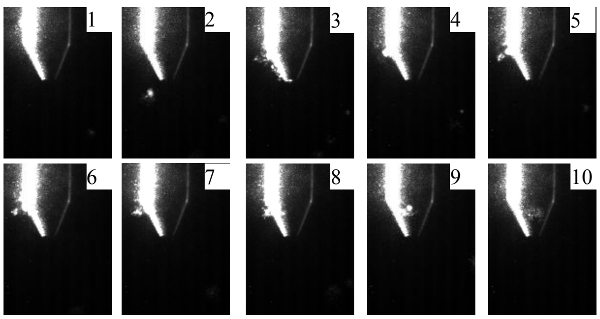


Fig. 10. Continuous photo when a cavitation bubble cloud collides with the conical hydrophone (Interval between each photo: 5 ms)

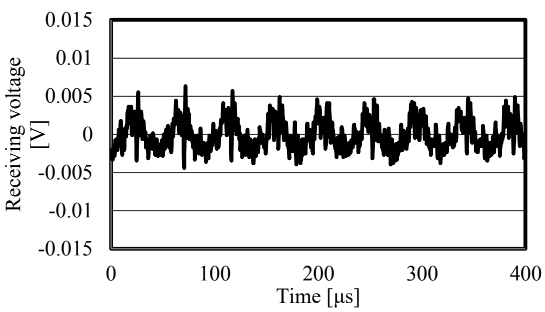


Fig. 11. Waveform before cavitation bubble collides with conical hydrophone

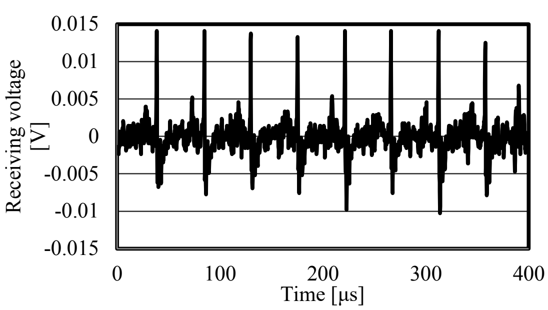


Fig. 12. Waveform when cavitation bubble collides with conical hydrophone

V. Conclusions

From the experimental results, it is confirmed that there is a change in the behavior and generation of cavitation bubbles due to the difference in the shape of the hydrophone front plate. It is found that the conical shape of the front plate is less affected by the cavitation bubble cloud. It is also found that cavitation bubbles are likely to gather at uneven portions such as the connecting portion between the front plate and the outer sheath.

From the observation results of the conical hydrophone, we could find that the hydrophone received a pulsed signal when the cavitation bubble cloud collided.

VI. Future Work

In this experiment, the observation time was only 30 minutes, so there was a difference in the information obtained from the observation results of the cylindrical hydrophone and the conical hydrophone. Therefore, we will conduct the same observation experiment for a longer time using the same system as this observation system, and verification will be continued.

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