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Study on Relationship between Acoustic Cavitation Bubbles Behavior and Output Signal from Tough Hydrophone Using High-speed Camera

高速度カメラによる音響キャビテーションバブルと堅牢型ハイドロホン出力の同時観察

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1. Introduction

Recently, ultrasound treatment methods, such as high intensity focused ultrasound (HIFU) are increasingly used in medical applications such as tumor therapy. We have developed a tough hydrophone consisting of a titanium front plate that can withstand cavitation and a hydrothermally synthesized lead zirconate titanate (PZT) thick-film vibrator deposited on the back-side of the titanium-plate acoustic surface[1)] for the acoustic characterization of HIFU field. Our developed tough hydrophone resisted damage in a high-pressure field (15 MPa) when placed at the focal point of a concave HIFU transducer, which was driven in sinusoidal continuous-wave (CW) mode with up to 50 W of power input to the sound source[2)]. The hydrophone was found to be suitable for HIFU fields, even though it has a flat-shape tip of 3.5 mm diameter. Because the generation of acoustic bubbles in a high-intensity ultrasound field cannot be avoided, the influence of having the tough hydrophone in the field were investigated using visualization of the spatial distribution of acoustic bubbles around the focal point of the HIFU transducer by using high-speed camera, with the aim of achieving accurate and precise evaluation of acoustic fields. The simultaneous recording of acoustic bubble movements and the hydrophone signal was not observed in our previous studies[3)]. Therefore, we studied on relationsip between acoustic cavitation bubbles behavior and output signal from tough hydrophone in this study.

2. Experiment

A diagram of the experimental arrangement used to measure acoustic bubbles in a high-intensity acoustic field by using high-speed camera is shown in **Fig. 1**. An ultrasound source was a single-element concave focused transducer, with

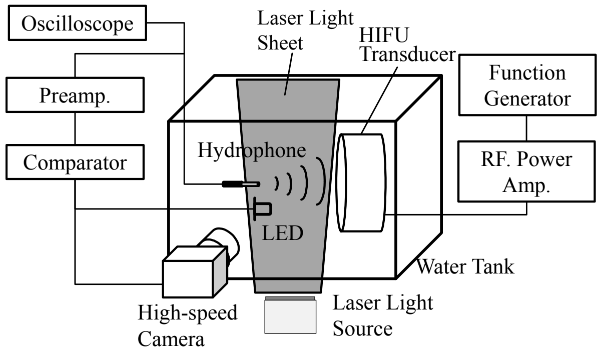

Fig. 1 Block diagram for the simultaneous recording of the acoustic cavitation bubbles movements and the hydrophone signal.

resonant frequency of 1 MHz, diameter of 80 mm, geometoric focal length of 50 mm, and instead of a HIFU transducer. The tough hydrophone tip of 3.5 mm diameter having a flat shape installed at the focal point of the transducer. Ultrasound waveforms received from the transducer was recorded oscilloscope during sonication. The transducer was driven by a function generator and a linear radiofrequency (RF) amplifire. The 1 MHz HIFU transducer was operated in sinusoidal CW with a driving power of up to 95 W.

The behaviour of acoustic bubbles around the tough hydrophone set at the focal point of the transducer was investigated using tap water to ease the generation of acoustic bubbles. The water was irradiated with a laser light sheet located across the focal point from the bottom wall of the water tank (600 × 300 × 360 mm). The movement of the acoustic bubbles in the measurement plane was recorded by using a high-speed digital CMOS camera (K5, Kato Koken, Kanagawa, Japan) with a framerate of 10000 fps. A comparator circuit and a LED light were used to synchronize an instantaneous increasing signal of the output of the hydrophone and the high-speed camera.

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3. Results and discussion

It was noticed in our experiments that some acoustic bubbles were trapped around the tough hydrophone tip due to a standing wave. This standing wave was caused by the flat shape of the tough hydrophone. A specific large acoustic cavitation bubble that was a few 100-hold larger as compared with others was moved from a stable position indicated as an arrow in **Fig. 2 (a)** to a metastable position indicated in **Fig. 2(b)**. After residence of about 100 ms at metastable position, the large acoustic cavitation bubble moved toward the hydrophone tip set at the focal point of the HIFU transducer. Around the hydrophone tip, a series of collision process of acoustic bubble with the hydrophone tip was shown in **Fig. 3(a)** to **Fig. 3(d)** at 1 ms intervals. These figures are increased the contrast due to enhance the bubble images. **Figure 3(b)** shows the moment of triggered signal generated by the comparator, a background image becomes brighter by the LED light at the same time as a triggered signal. **Figure 4** shows output signal of the hydrophone during sonication. The output was overlapped between distorted 1 MHz waveforms and a pulsed signal. The oscilloscope was triggered by the comparator circuit due to the pulsed signal. At this timing, the large acoustic bubble seems to combine with a small acoustic bubble generated on the hydrophone surface shown in **Fig. 3(b)**, after that, the large acoustic bubble collided with the hydrophone tip as shown in **Fig. 3(c)** and **(d)**. Not a few but many examples that the large acoustic bubble was collided with the hydrophone tip with regardless the small acoustic bubble generated on the hydrophone tip were observed. This phenomenon was observed synchronously with the pulsed wave. The pulsed wave was involved with the collision of the large acoustic bubble in almost all cases.

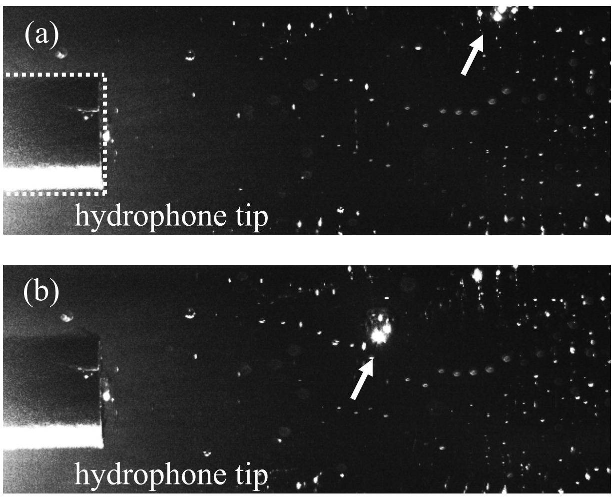

Fig. 2 Observation of the large acoustic bubble at (a) the stable position and (b) the metastable position indicated as the arrow.

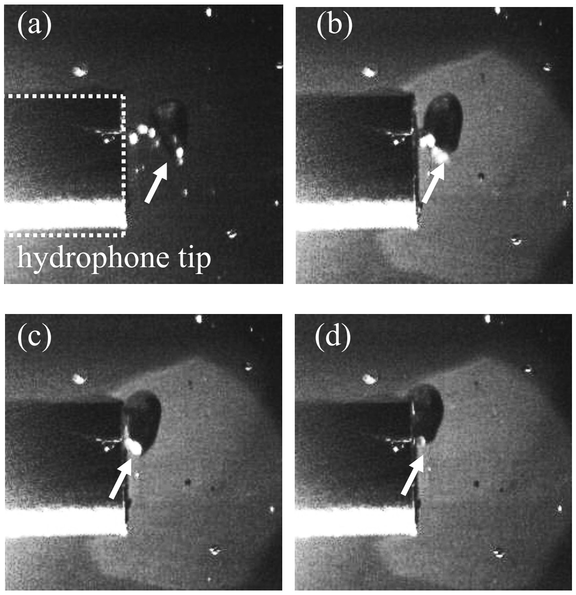

Fig. 3 A series of collision process of acoustic bubble with the hydrophone tip is shown in (a) to (d) at 1 ms intervals. (b) The image triggered by the pulsed wave due to the acoustic bubble collision.

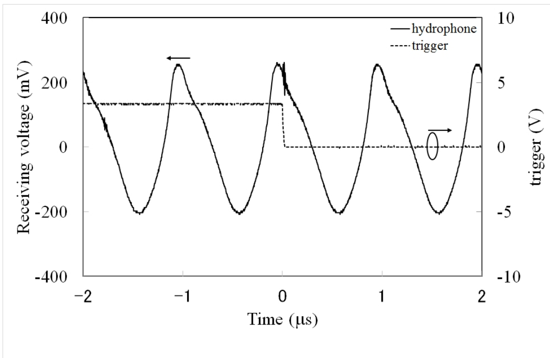

Fig. 4 Output waveforms of the hydrophone and triggered signal generated by the comparator caused by the acoustic bubble collision.

In summary, the relationship between the acoustic cavitation bubbles behavior and the output signal of the hydrophone were observed at the same time. The output signal of the hydrophone was not change in average, even if there was the large acoustic bubble collision. Although the pulsed wave was involved with the collision of the large acoustic bubble, the large acoustic bubble movement was only observed in CW sonication. It should be carried out further experiments in order to evaluate the acoustic field in CW measurements accurately.

References

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