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Relationship between the frequency characteristics of receiving sensitivity and received waveform of the anti-acoustic cavitation hydrophone

耐音響キャビテーションハイドロホンの受波感度の周波数特性と受信波形の関係

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1. Introduction

Recently, ultrasound diagnostic methods, such as harmonic imaging and ultrasound elastography for elasticity imaging of organs and soft tissues by using Acoustic Radiation Force Impulse (ARFI), have been used widely. Ultrasound pulses with high intensity are irradiated highly frequently in these diagnostic methods. Furthermore, new ultrasound treatment methods, such as sonoporation for gene transfer, high-intensity focused ultrasound (HIFU) for cancer therapy and sono dynamic therapy (SDT) are developed and used actively. Furthermore, ultrasound cleaners and ultrasonic particle dispersion systems are used in the industrial field. There is a tendency that ultrasound is irradiated at a high frequency. These acoustic field distributions should be measured with a hydrophone.[1-2] However, electrodes or piezoelectric elements of the hydrophones are broken by effect of high sound pressure and acoustic cavitation when acoustic fields of ultrasound apparatus with high intensity ultrasound like ultrasound cleaner or HIFU device were measured by using normal commercial hydrophones. Therefore, it was difficult to measure such high intensity acoustic field by using normal commercial hydrophone. Conventionally, such acoustic fields were measured by using an ultrasound power meter. When an absorbing target of ultrasound power meter was set at focal point, the absorbing target was damaged. Thus, ultrasound power is measured by setting the absorbing target at the position with half length of focal distance from the acoustic radiating surface of ultrasound transducer of the HIFU system, and sound pressure or acoustic intensity at the focal position are estimated by using the previous data at the position with half hength of focal distance. However, such high intensity ultrasound acoustic field is nonlinear acoustic field which cannot be applied to linear acoustic theory. In the ultrasound power meter, the received ultrasound acoustic power with the absorbing target can be measured. It cannot measure the spatial distribution of sound pressure or acoustic intensity.

The novel tough hydrophones were fabricated by deposition of hydrothermally synthesized lead zirconate titanate (PZT) poly-crystalline[3-4] on the reverse side of titanium front plate. These hydrophones were not damaged by measurement of acoustic field formed by HIFU device. Relationship between the frequency characteristics of receiving sensitivity and received waveform of the hydrophone were investigated in this study

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2. Fabrication of Hydrophone

The anti-acoustic cavitation hydrophone for HIFU with a titanium front layer was fabricated. The hydrothermally synthesized lead zirconate titanate (PZT) film with thickness of 15 μm was deposited on the reverse side of titanium front layer with thickness of 50 μm and diameter of 3.5 mm for preparation of the piezoelectric element. The piezoelectric element was bonded to an end tin rod with diameter of 2 mm as backing material and electrical signal line. Tin rod has specific acoustic impedance about 24 MRayl and it is also used as signal line. It was inserted into a brass pipe with inner diameter of 4 mm and with outer diameter of 5 mm. The brass pipe was connected to inner lead wire for signal line of coaxial cable. Furthermore, stainless steel pipe was connected to the outer conductor for GND of coaxial cable. Tin rod and brass pipe were isolated electrically by rubber tube.

3. Measurement and Results

3.1 Frequency characteristics of receiving sensitivity

Receiving sensitivity of the fabricated hydrophone was calibrated in the National Institute of Advanced Industrial Science and Technology. Frequency characteristics of receiving sensitivity of hydrophones are shown in **Fig. 1**.

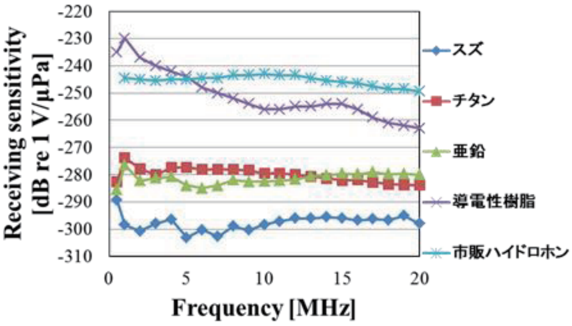

Fig. 1 Frequency characteristics of receiving sensitivity of our fabricated tough anti-cavitation hydrophones and commercial hydrophone for high intensity ultrasound

The frequency characteristics of the receiving sensitivity were not flat characteristics at the vicinity of 1 MHz. It is considered to be the resonance of surface waves generated on the acoustic receiving surface of the hydrophone.

Moreover, receiving sensitivity became a low level as compared with the commercial hydrophone (ONDA : HNR-1000). We think there is no problem because it is the measurement of high-intensity ultrasound acoustic field.

3.2 Comparison of the output waveform of each hydrophone

Received ultrasound pulse was measured with our fabricated tough hydrophone at acoustic far-field of 3.5 MHz ultrasound probe. The output signal (frequency: 3.5 MHz; number of cycles in burst: 5 cycles; voltage amplitude: 500 mV) from a function generator was amplified with a power amplifier with a gain of 50 dB. The amplified signal was applied to an ultrasound probe. The output signals from the hydrophone were amplified by preamplifier with gain of 20 dB and observed with a digital oscilloscope. Output signal from commercial hydrophone is shown in **Fig. 2**. Output signal from our anti-acoustic cavitation hydrophone is shown in **Fig. 3**.

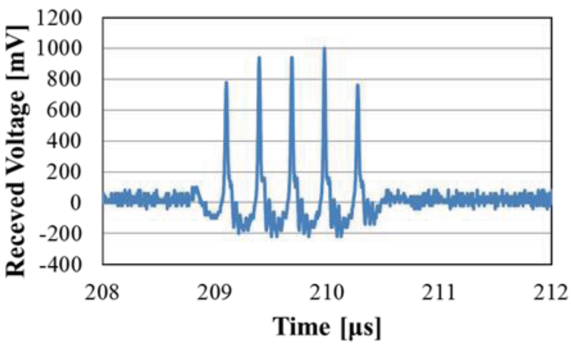

Fig. 2 Output signal from commercial hydrophone at 3.5 MHz ultrasound probe

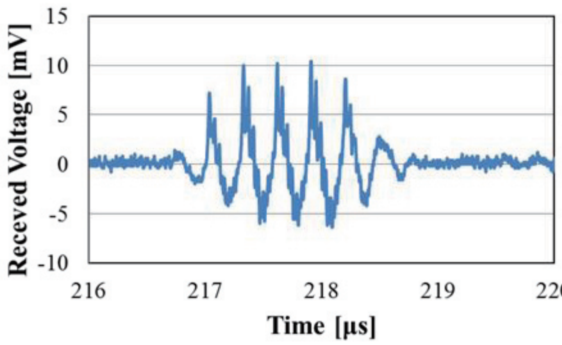

Fig. 3 Output signal from our tough hydrophone with tin backing material at 3.5 MHz ultrasound probe

An output waveform from our fabricated tough anti-acoustic cavitation hydrophone did not agree with that from the commercial hydrophone for high intensity ultrasound. However, it was confirmed that distortion of the output waveform was increased by increasing the applied voltage to the transmitting ultrasound probes.

4. Future Works

The authors have succeeded in development of a tough anti-cavitation hydrophone with hydrothermally synthesized lead zirconate titanate (PZT) polycrystalline film deposited on the reverse side of titanium front layer which was not broken even after measurement of high intensity acoustic field like HIFU.

In the future, it is scheduled that the resonance of the surface wave generated on the acoustic receiving surface of the hydrophone should be suppressed, and a structural hydrophone that the improvement of the receiving wave sensitivity can be furthermore hoped for is developed in the future.

Moreover, it is necessary to confirm the change in the output waveform by the change in driving frequency.

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