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Effect of Insertion of an Absorbing Layer on Parametric Ultrasound

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1. Introduction

Ultrasound measurements such as the pulse-echo method utilize high-frequency (HF) signals for improving range resolution. In general, absorption attenuation in a medium limits the penetration depth of HF ultrasound into a target medium. To resolve this problem, we have attempted to use parametric ultrasound at low frequency (LF) generated from the nonlinear propagation of finite-amplitude ultrasound and with improved directivity.

One of the advantages of using an LF signal is the low absorption in a medium [4]. However, with the attenuation of the primary HF ultrasound, there is a concern that the sound pressure of the secondary-generated parametric ultrasound will also decrease. There are several studies on propagation in viscous media and the insertion of absorbing layers for nonlinear sound propagations [5–8]. However, it is not fully understood how much the viscous attenuations, including their position, affect parametric ultrasounds.

This study aims to experimentally investigate the influences of the insertion of an absorbing layer into the parametric ultrasound. In particular, we discuss the effects of the insertion distance of an absorber on sound pressure of parametric ultrasound compared with those of directly-radiated HF and LF ultrasounds.

2. Method

The effect of the absorbing layer's insertion on ultrasound fields was experimentally evaluated in water. A transmitter was a circular-aperture planar ultrasound transducer with an element diameter of 1 inch with a quality factor of 3 at a resonance frequency of 2 MHz. High-frequency ultrasound at several MHz and LF ultrasound at several hundred kHz were received by a needle-type hydrophone of 1 mm in diameter and a cylindrical hydrophone of 4 mm in diameter, respectively.

As an absorbing layer, we use silicone rubber with a thickness of 10 mm, an area of 140×140 mm^2, and an absorption coefficient of 61.3 neper/m at 2 MHz. The silicone rubber was inserted at distances z_a=50, 100, and 200 mm between the transmitter and a hydrophone to be parallel to the transmitter plane.

An HF ultrasound at f_c =2 MHz is emitted directly from the transmitter. To generate parametric ultrasound at frequencies f_d=100, 200, 300, …, and 1000 kHz, the transmitter emitted modulated-primary ultrasounds at $f_\mathrm{c} \pm f_\mathrm{d}/2$. For reference, LF ultrasounds with the same frequencies as parametric ultrasounds were directly radiated from the same transmitter.

3. Results and Discussion

As one of the examples, **Fig. 1** shows measured sound pressures of directly-radiated HF and LF ultrasound at 2 MHz and 600 kHz, respectively, and parametric ultrasound at 600 kHz along the beam axis with and without absorbing layer insertions. Direct radiations of HF and LF ultrasounds do not depend on the distance of the absorbing layer. On the other hand, the parametric ultrasound depends on the distance. The insertion of an absorber closer to the sound source significantly decreases the amplitude. This is because of the reduction of the primary wave before the parametric ultrasound grows sufficiently.

The absorbing layer insertion at a far distance suppresses the attenuation of the parametric ultrasound. However, its sound pressure distribution has the same slope for the beam axis as the directly-radiated LF ultrasound. This is probably because the attenuation of the primary wave stops the growth of the secondary wave, and parametric ultrasound, which has already been generated, propagates almost linearly.

Figure 2 indicates the frequency dependence on the variation of sound pressure level at a distance of 300 mm by the absorbing layer. The reduction of sound pressure for direct radiation increases with the frequency. Although the decrease of parametric ultrasound is more significant than the directly-radiated LF one at the same frequency, the frequency dependence is small except below 300 kHz.

Similar to the pressure distributions, the reduction of direct radiations does not depend on the distance of the absorbing layer. For parametric ultrasound, the insertion of an absorber in the near field increases the reduction, and the value is more significant than that of HF ultrasound, especially at 50 mm. On the other hand, for the insertion at a far distance, the reduction of parametric ultrasound is smaller than that of HF ultrasound.

Positive and significant negative differences in direct radiations below 300 kHz are observed. These are caused by interaction between direct and diffraction waves from a frame to support the rubber.

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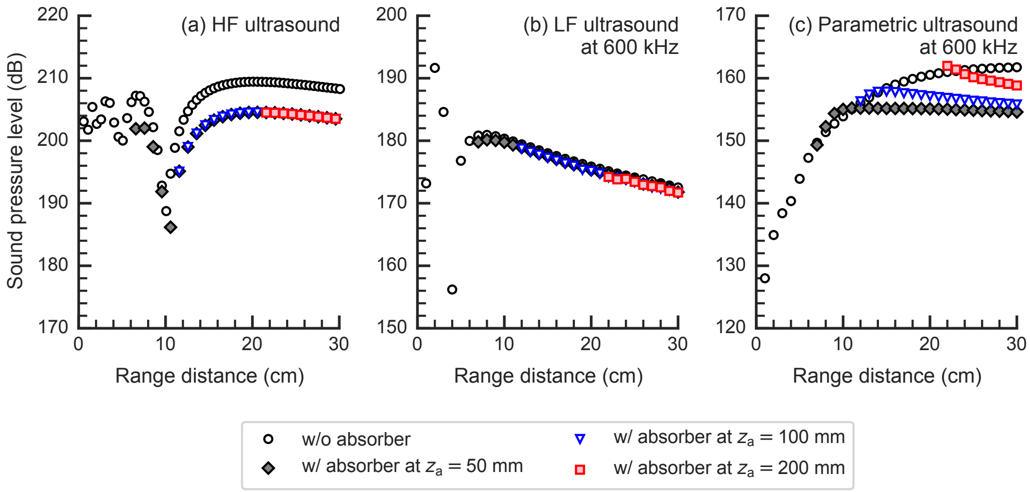

Fig. 1 Sound pressure distribution of directly-radiated at high-frequency (HF) and low-frequency (LF) ultrasounds and parametric ultrasound with an absorbing layer.

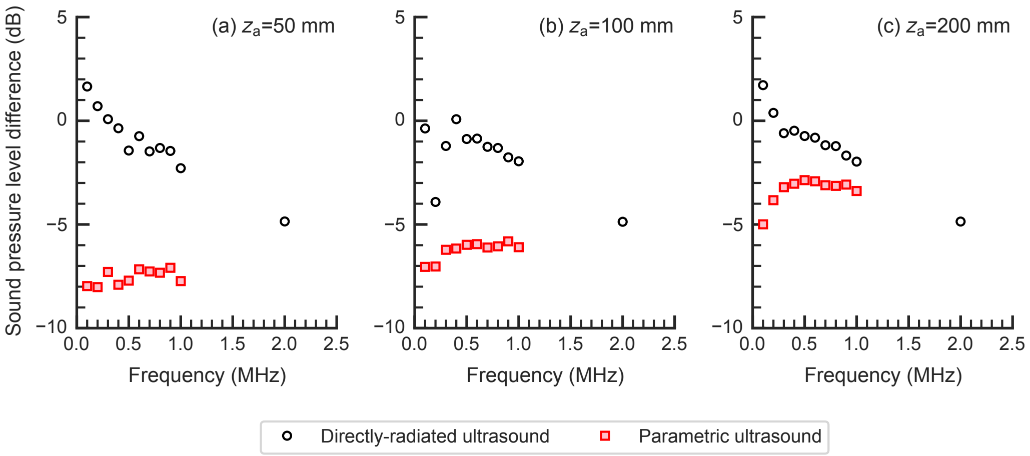

Fig. 2 Variation of sound pressure level at 300 mm by insertion of an absorbing layer.

4. Conclusion

We experimentally evaluated the effects of the insertion of an absorbing layer on parametric ultrasounds. The results indicate that the reduction of parametric ultrasound is mainly caused by the absorption attenuation of the primary wave. The decrease in secondary waves due to the insertion of the absorbing layer in a far field is suppressed compared to the absorption of the direct wave at several MHz. Although absorption in a near field reduces parametric ultrasound, the amplitude change along the distance is smaller than that of the linear propagation.

In actual ultrasonic measurements, pulsed waves are often used. In addition, the ultrasound propagation in the silicone rubber enhances the generation of the secondary wave by the nonlinearity of the medium with the absorption of the sound energy [5]. We will conduct theoretical and experimental studies that include these points.

Acknowledgment

This work was financially supported by TOITU CO., LTD.

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