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Echo sounder transmitting narrow and broadband signals with a single transmitter using acoustic cavitation

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1. Introduction

Echo sounders using higher-frequency ultrasound have higher distance and azimuth resolution, but their maximum detection range is shorter because of the more significant propagation attenuation. The use of broadband signals and pulse compression processing is effective in improving range resolution and measureing the spectral characteristics of the target[1,2]. Thus, it is desirable to implement a sound source transmitting a high-frequency broadband ultrasound in addition to a low-frequency ultrasound.

In this study, we attempt to utilize shockwaves generated by acoustic cavitation[3,4] as a broadband sound source. The primary ultrasound generating acoustic cavitation is a low-frequency ultrasound of 20 kHz. Thus, low-frequency and broadband transmission of ultrasound can be realized by using primary ultrasound and shockwaves as sound sources, respectively. The principle and results of verification experiments are described below.

2. Experimental setup and principle

Figures 1(a) and 1(b) show the schematic diagram of the experimental system. The range between an echo-detection hydrophone (Panametrics, V309-SU) and tank wall, aluminum plate, or acrylic plate as the targets were measured in the experiment.

The ultrasound from the horn (Branson, 250AA) was used in the ranging with the narrowband signal. Because of the low directivity, the ultrasound directory irradiated the target, not via the mirror. The transmitted ultrasound is a Gaussian-windowed sinusoidal tone burst with ten cycles. The standard deviation of the window was 10 µs. Although the horn resonance frequency was 20 kHz, the center frequency was chosen 140 kHz for a scaled-down experiment in a small tank and to avoid increasing signal duration due to the resonance.

The transmitted ultrasound reaches the echo-detection hydrophone after reflecting by the target. Assuming $a^2 + b^2 << r^2$, the propagation distance, L, can be approximated by

$$L = 2r + d + e\,, \tag{1}$$

where r is the range between the target and the echo-detection hydrophone. The error in this approximation is 0.5 % or lower for $r > 300$ mm. The ultrasonic propagation time is determined by the cross-correlation function,

$$x(\tau) = \int g(t)h(t+\tau)d\tau\,, \tag{2}$$

where g(t), $h(t)$, t, τ are the echo-detection hydrophone output, the replica of transmitted signal, time, and time lag, respectively. The argument of maxima of the cross-correlation function corresponds to the propagation time. The time lag is converted into the range by

$$r = (c_{\mathrm{w}}\tau - d - e)/2, \tag{3}$$

where c_{w} is the sound speed in water.

In the ranging with the broadband signal, spherical shockwaves generated by the acoustic cavitation bubbles clusters near the output surface of the horn were used as a sound source. An off-axis parabolic acoustic mirror shown in Fig. 1(c) shaped the spherical shockwaves into the plane shockwaves. The plane shockwaves propagated along the mirror axis. The echo-detection hydrophone received the echo from the targets. The driving frequency of the horn was 20 kHz. The relationship between the range and the time lag is given by

$$r = (c_{\mathrm{w}}\tau' - e - f)/2, \tag{4}$$

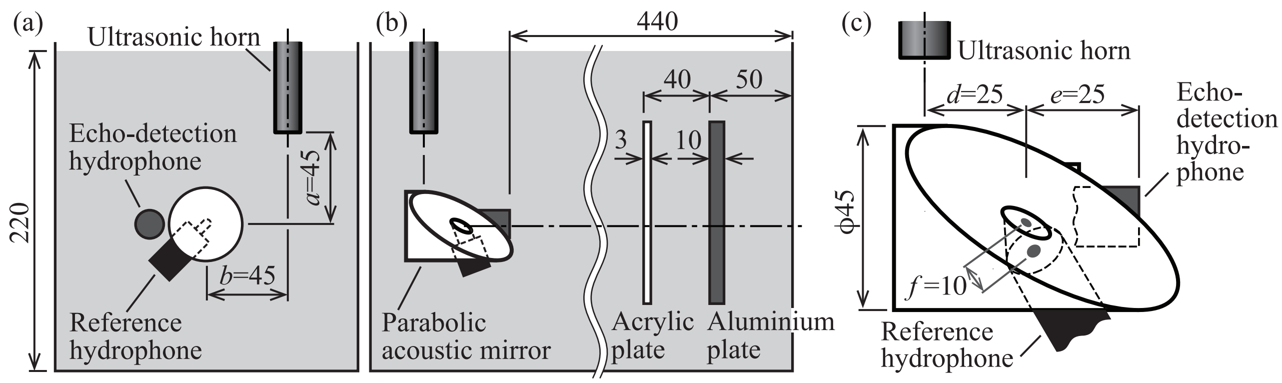

Fig. 1 Schematic diagram of experimental system. (a) and (b) are side and front view of system, respectively. (c)dimensions of acoustic mirror. All dimensions are in mm.

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where f is the distance between the reference hydrophone (Panametrics, V311-SU) and the reflective surface center of the mirror. The cross-correlation function was calculated with the reference hydrophone output instead of the replica. The output signals were acquired by an analog-to-digital converter (Spectrum Instrumentation, M4i. 4451) with sampling frequency of 62.5 MHz. The number of samples is 2^{20}.

3. Results and discussion

Figure 2(a-i) shows the cross-correlation function of the narrowband signal without the plate targets. The function has a local maximum at the range of 440 mm, and that indicates that the tank wall is detected correctly. However, the peak position of the function envelope is unclear because of the gentle autocorrelation gradient of the tone burst. Strong reverberation was observed in a range over 450 mm.

Figure 2(b-i) shows the cross-correlation function of the broadband signal without plate targets. The function has a clear peak due to the steep autocorrelation characteristics of the shockwaves[3] at the range of the tank wall. A multiple reflection component within the tank wall's glass plate is seen after the peak, but there is no significant reverberation. This is because the shockwave is highly directional, and the reverberation waves do not enter the hydrophone.

Figures 2(a-ii) and 2(b-ii) are the cross-correlation functions for the narrowband and broadband signals with the aluminum plate, respectively. Since the aluminum plate was placed 40 mm from the tank wall, the range peak positions for both signals were shortened by 40 mm. Due to the high reflectivity of the aluminum plate, echoes from the tank wall are not detected.

Figures 2(a-iii) and 2(b-iii) are the cross-correlation functions with the acrylic and aluminum plate, respectively. For both signals, the functions have peaks in the ranges of the acrylic and aluminum plates. Because the acrylic plate transmits a portion of the ultrasound, the echoes of the aluminum plate are detected. However, in the case of the narrowband signal, the peaks are unclear due to the interference of the signals caused by both plates. On the other hand, in the case of the broadband signal, both peaks are well distinguished.

4. Conclusion

The echo sounder transmitting narrowband and broadband signals was realized with a single transmitter by using acoustic cavitation. Ranging with the low-frequency narrowband ultrasound from the transmitter was demonstrated. It was also shown that the ranging resolution can be improved by using the shockwaves caused by acoustic cavitation.

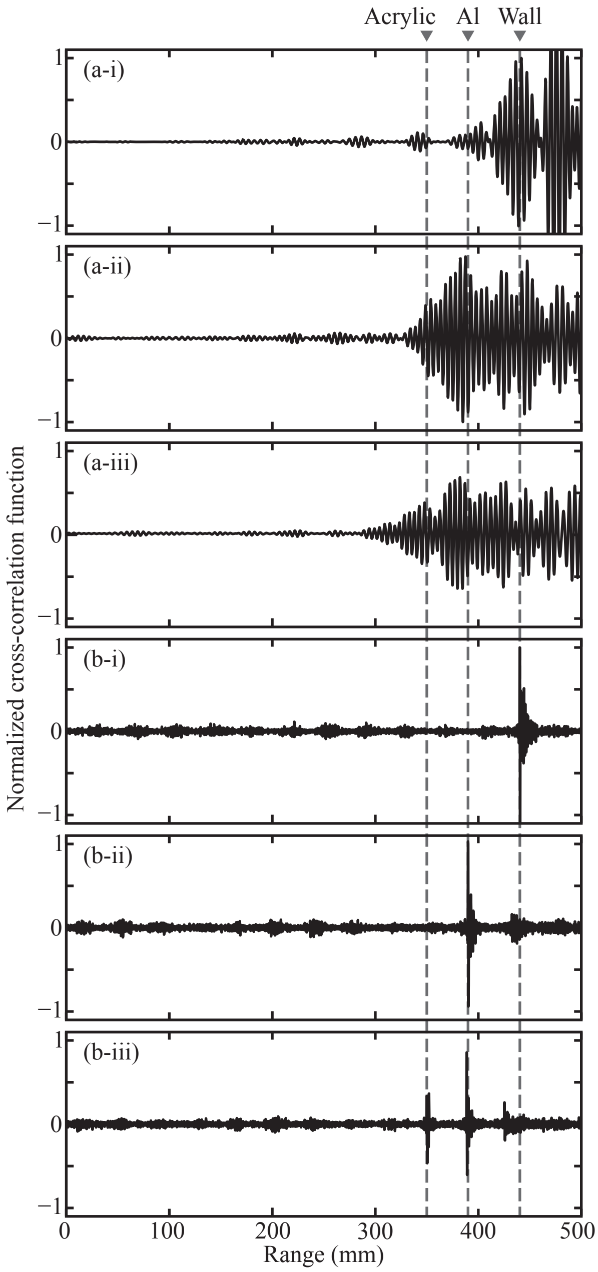

Fig. 2 Cross-correlation function. (a) and (b) are for narrowband and broadband setups, respectively. (i) to (iii) correspond to without reflection plate, with aluminum (Al) plate, and with acrylic and aluminum plate, respectively. Arrowheads and dashed lines indicate true range of wall and plates.

Acknowledgment

This work was partially supported by JSPS KAKENHI Grant No. 22K04941.

References

1) A.C. Levery *et al*., ICES J. Marine Sci. **74**, 2262 (2017).
2) K. Amakasu *et al*., Polar Sci. **12**, 70 (2017).
3) T. Kuroyama *et al*., Jpn. J. Appl. Phys. **62**, SJ1032 (2023).
4) T. Kuroyama *et al*., Proc. Marine Acoust. Soc. Jpn., 23-12 (2023) [in Japanese].