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Acoustic Ranging Using Acoustic Cavitation Noise

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1. Introduction

Acoustic cavitation bubble clouds generated under the ultrasonic horn emit shockwaves at intervals of integer multiples of the period of the incident ultrasound.[1,2] This shockwave is called acoustic cavitation noise. The generated shockwave has a wide bandwidth and a high repetition frequency in the order of 10 kHz. It thus is considered to have distinctive characteristics as a signal for acoustic measurements.[3] This paper evaluates the characteristics of acoustic cavitation noise as a signal for acoustic ranging.

2. Measurement system

Figure 1 shows an experimental system for the evaluation of acoustic ranging. An ultrasonic horn (Branson, Sonifier model 250AA) is inserted into the water at 45° to the water surface. Ultrasonic waves with a fundamental frequency of 19.9 kHz are emitted from the horn tip. Acoustic cavitation bubble clusters are generated near the horn tip, and spherical shock waves centered on the clusters are emitted when the clusters collapse. The driving power of the ultrasonic horn can be adjusted by a dial of the power supply unit from 10% to 100%. In this paper, we call this percentage a driving strength. Experiments are performed at 100% and 50% driving power, which correspond to the 45 and 190 (W), respectively. The water temperature is 26°C, and the sound speed in water is 1499.7 m/s.

In this experiment, a water immersion transducer (Olympus, V311-SU) is scanned with a manual stage, and its displacement is measured using acoustic cavitation noise. V311-SU is directed to the horn tip. A portion of the shock wave generated at the horn tip is reflected by a 6.35 mm diameter steel piece and received by another transducer (Olympus, V309-SU). The displacement of V311-SU is estimated from the cross- correlation function between the received signals of V311-SU and V309-SU. The distance between the horn tip and the reflector is 35 mm, and between the reflector and V309-SU is 50 mm. The distance between the reflector and V311-SU is varied by the stage from 50 mm to 250 at 50 mm intervals. Ten measurements are taken at each point. When the distance between the reflector and V311-SU is 50mm, the sound path lengths from the horn tip and the transducers are the same.

The output signals of V311-SU and V309-SU

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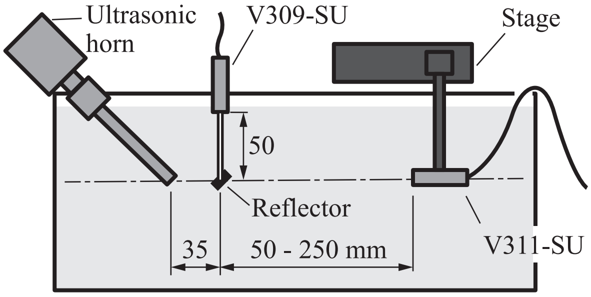

Fig. 1 Schematic diagram of experimental system.

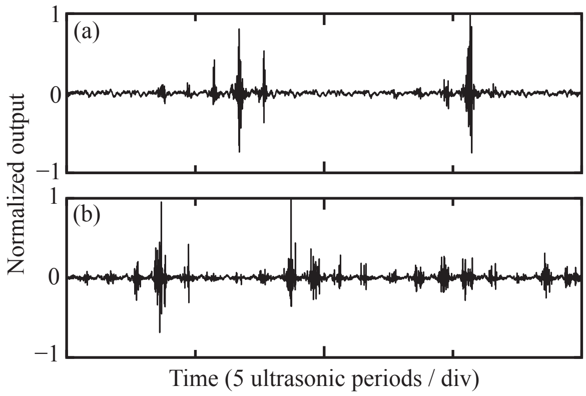

Fig. 2 Waveform of acoustic cavitation noise received by V309-SU at driving strength of (a) 100% and (b) 50%.

are recorded by an oscilloscope (Lecroy, HDO6034). The output signals are band-limited by a low-pass filter with a 20MHz cut-off frequency. The oscilloscope sampling frequency is 50 MHz.

3. Experimental results

Figure 2 shows the waveform of acoustic cavitation noise received by V309-SU. Figures 2(a) and 2(b) correspond to 100% and 50% driving strength, respectively. These waveforms are normalized by their respective maximum values. The pulsed waveforms correspond to the shockwaves produced by the bubble cluster collapse. At 50% driving strength, the pulsed waveforms are seen almost at each ultrasonic period, but at 100%, the pulsed waveforms are sparse. This is due to the fractional harmonic oscillation of the bubble clusters, which collapse once every few periods of the incident ultrasound. As the driving strength increases, the duration of non-shocking activity[1)], during which no pulse is seen, extends.

Figures 3(a) and 3(b) show the cross-correlation function obtained by extracting 100 and 1,000 periods of the recorded signal, respectively.

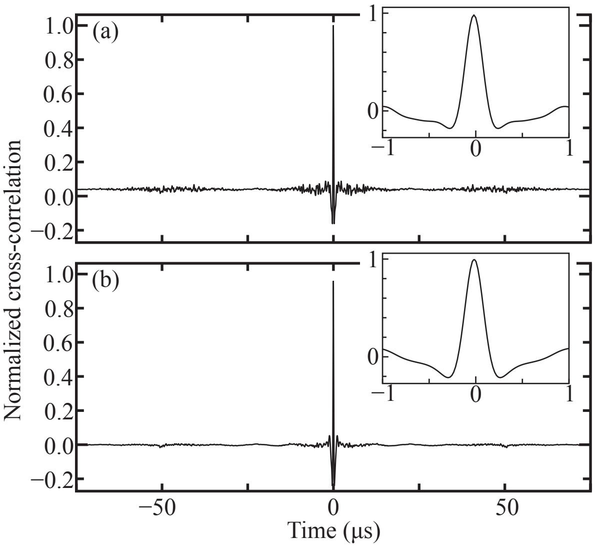

Fig. 3 Cross-correlation function between transducers at driving strength of 100%. (a) and (b) correspond to the signal duration of 100 and 1,000 periods, respectively.

Each cross-correlation function is normalized by its maximum value. The driving strength is 100%. The sound path length between the horn tip and V311-SU, and V309-SU are equal. Thus, a peak is observed at a time difference of 0 s in Figs. 3(a) and 3(b). The fullwidth half maximum of the main lobe is 180 ns. The correlation value is low near a time difference of 50 μs, which corresponds to the period of the ultrasound. It is because of the low periodicity of the pulses.[3] In particular, the peak near the 50 μs time difference is suppressed at a signal duration of 1,000 periods. Therefore, a reasonable estimation of the arrival time difference between transducers is possible from the peak time of the main lobe of the cross-correlation function.

Figure 4(a) shows the displacement estimated from the arrival time difference between transducers calculated from the peak time of the cross-correlation function and the sound speed. The horizontal axis shows actual V311-SU displacement from the position at which the sound path lengths between horn tip and transducers are the same. Figure 4(b) shows the error between the mean estimated displacement of ten measurements and the actual V311-SU displacement, and Figure 4(c) shows the standard deviation of the estimated displacement. The solid and dashed lines are for a signal duration of 100 and 1,000 periods, respectively. In both conditions, the displacement error is less than 200 μm. The standard deviation is smaller when the signal duration is 1,000 periods than when the signal duration is 100 periods. So it is since the signal energy increases with the longer signal duration. The standard deviation is smaller at 50% than at 100% driving strength because, as shown in Fig. 2(a), the pulses become sparce at

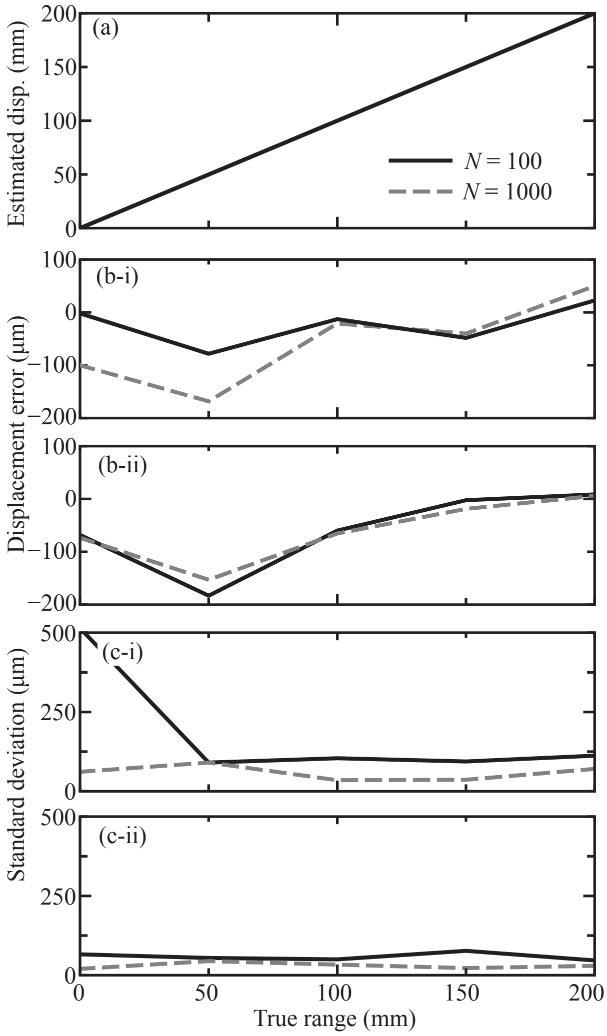

Fig. 4 (a) Estimated displacement. (b) Displacement error. (c) Standard deviation of estimated displacement. (i) and (ii) correspond to driving strength of 100% and 50%, respectively.

100%, and number of pulses in signal is reduced resulting in deterioration of the correlation characteristics.

4. Conclusion

The feasibility of distance measurement using acoustic cavitation noise is verified. Good cross-correlation peaks were obtained, indicating that distance estimation is possible. It was also found that the accuracy of estimated displacement depends not only on the signal duration for calculation of the cross-correlation function but also on the driving conditions of acoustic cavitation.

References

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