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Enhancement of underwater acoustic streaming using a cylinder with a cavity located away from vibrating surface

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1. Introduction

In previous studies, the enhancement effect of underwater acoustic streaming by placing a cylinder with a cavity near the vibrating surface at a resonance frequency of 28.2 kHz under both small and large vibration amplitudes was investigated [1,2]. The sound pressure within the cavity was significantly higher than the gap between the vibrating surface and the top surface of the cylinder, resulting in the initial generation and accumulation of cavitation bubbles inside the cavity. These cavitation bubbles altered the sound pressure distribution, potentially increasing the sound pressure within the gap and triggering the formation of cavitation bubbles in that region. As the vibration amplitude increased, a large amount of cavitation bubbles accumulated in the gap, dispersing the acoustic energy and weakening the enhancement effect of acoustic streaming.

In this study, to mitigate the acoustic cavitation occurring around the vibrating surface at the resonance frequency of 28.2 kHz, the effect of increasing the distance between the cylinder and the vibrating surface on enhancing the acoustic streaming was examined. Particle image velocimetry (PIV) experiments were conducted to observe the actual acoustic streaming distribution and measure the flow velocity. Additionally, finite element analysis (FEA) simulations using acrylic and duralumin cylinders were carried out to obtain the sound pressure distributions.

2. PIV experiments

The vibration source and experiment method were the same as in Ref. 2. Cylinders with the same diameter as the vibrating surface and the optimum size cylinders from the preliminary simulation results were used. The setting parameters are shown in **Table I**. The irradiation area was adjusted manually due to limitations in the width and brightness of the laser sheet. Streaming videos were captured by a high-speed camera at rates of over 8000 fps and analyzed using the PIVlab toolbox in MATLAB.

As shown in **Fig. 1**, without the cylinder, the trajectory of the acoustic streaming exhibited a curved pattern, leading to a large amount of acoustic streaming. In the clear acrylic cylinder, it was observed that a portion of streaming generated by the vibration source traveled along the cylinder surface while the remaining portion flowed through the cavity to become the aggregated streaming.

Table I. Parameters of vibration source and cylinders.

Symbol	Meaning	Value
f (kHz)	Driving frequency	28.2
A (μm)	Vibration amplitude	20
D (mm)	Diameter of cylinder	Duralumin: 10 Acrylic:10, 33
d (mm)	Diameter of cavity	2
H (mm)	Height of cylinder	Duralumin: 25 Acrylic: 13,15
h (mm)	Gap	10 ~ 30
h_t (mm)	Distance from the vibration surface	$H + h$

The relationship between the maximum output streaming velocity v_{max} and the distance h_t from the vibrating surface is shown in **Fig. 2**. At the same position, v_{max} generated by the duralumin cylinder had the largest value, indicating a better enhancement effect. The acrylic cylinders did not significantly affect the streaming velocity. The slope of the decrease in streaming velocity with distance slowed down as the diameter of the cylinder increased.

3. FEA simulation

Sound pressure distribution generated by cylinders with a cavity was simulated using a 2D axisymmetric model in COMSOL Multiphysics 6.2. As shown in **Fig. 3**, it was found that the pressure distribution obtained by eigenfrequency analysis is

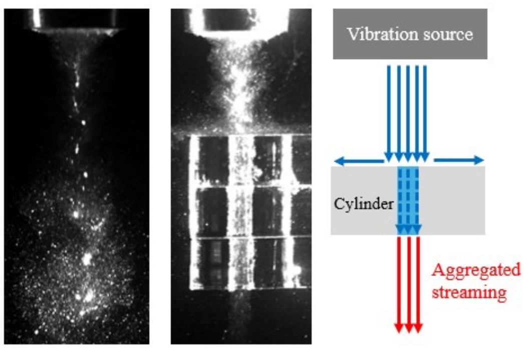

Fig. 1 Photos and schematic of the actual streaming.

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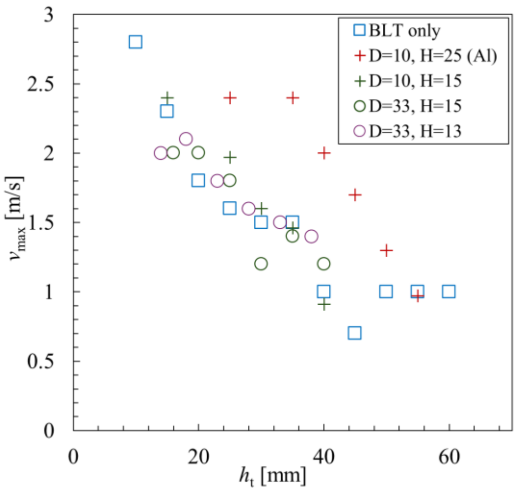

Fig. 2 Maximum output streaming velocity v_{max} vs. distance from the vibrating surface h_t.

similar to that obtained from the frequency domain analysis with the vibration source when the gap and cylinder were regarded as a whole and surrounded by an absorbing boundary. Although the cavity had a large pressure zone, it was less than that around the vibration surface when the gap h=25 mm. The relationship between the maximum sound pressure in the cavity p_{max} and h is shown in **Fig. 4**. It was found that the trend was very similar to that in Fig. 2. The duralumin cylinder exhibited the largest values of both, followed by the acrylic cylinder of the same diameter. The sound pressure and streaming velocity of the two large-diameter acrylic cylinders were similar and both decreased most slowly with increasing distance.

To determine the optimal dimensions of the acrylic cylinder, the height H and diameter D, which affect the distribution and magnitude of sound pressure, were investigated by frequency sweep analysis. The gap length h affected the wave propagation, causing the maximum sound pressure in the cavity p_{max} not to coincide with that near the vibrating surface. This discrepancy was initially overlooked in preliminary simulations, leading to less-than-ideal experimental results. The relationship between p_{max} and D of the modified acrylic cylinder is shown in **Fig. 5**. It was observed that when D=50 mm, H=14 mm, p_{max} could exceed the sound pressure near the vibrating surface.

4. Conclusion

This study investigated the effect of positioning the cylinder with a cavity away from the vibrating surface to enhance acoustic streaming at 28.2 kHz. The reasons for the less-than-optimal results of current PIV experiments were analyzed by FEA simulations, and methods for improvement were proposed. Further experiments with the optimized cylinders will be conducted to validate the feasibility of the study.

Acknowledgment

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References

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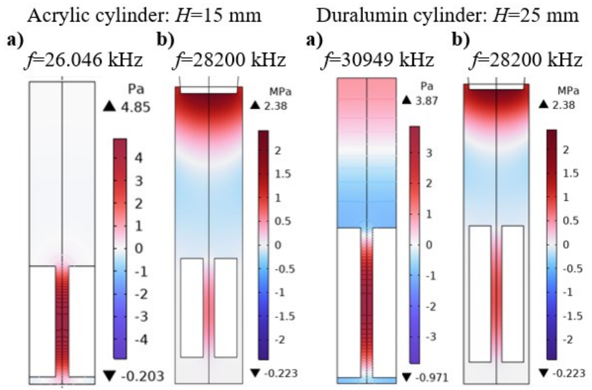

Fig. 3 Sound pressure distributions obtained by a) eigenfrequency analysis and b) frequency domain analysis for D=10 mm, d=2 mm, h=25 mm, and A=20 µm.

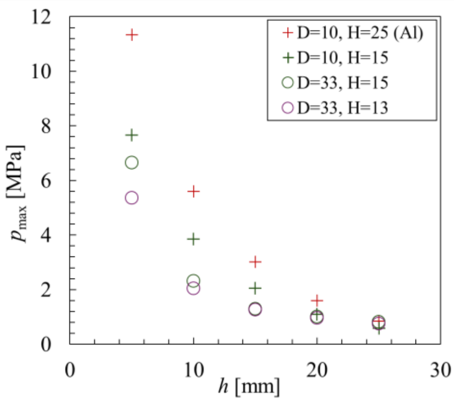

Fig. 4 Maximum sound pressure in the cavity p_{max} (acrylic cylinder) vs. gap h.

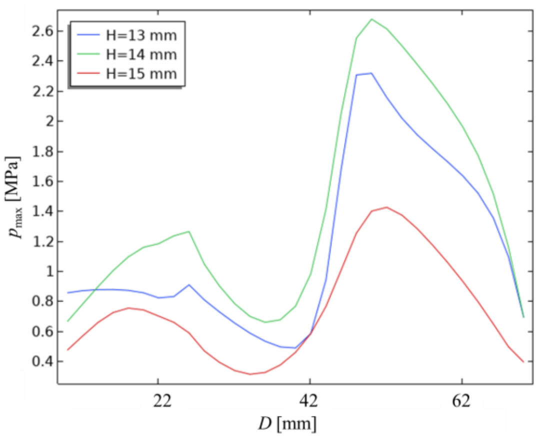

Fig. 5 Maximum sound pressure in the cavity p_{max} vs. Diameter of the acrylic cylinder D (h=25 mm).