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Observation of acoustic streaming ejected from a small hole in a disk levitated by near-field acoustic levitation
近距離場浮揚時の小径穴付き円板から噴出する音響流の観察

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1. Introduction

A plane object near the vibration surface is levitated up to several hundred micrometers by the near-field acoustic levitation (NFAL) phenomenon. The levitation distance by NFAL is determined by the balance between the weight of the object and the acoustic radiation force[1]. In addition, the acoustic streaming is generated in a narrow air layer between the bottom of the object and the vibration surface[2]. When the object with a small hole was levitated by NFAL, the acoustic streaming was ejected from the hole. **Figure 1** illustrates the acoustic streaming ejecting from a small hole in a levitated object. The acoustic streaming observed at NFAL flowed from the side of the narrow air layer into the small hole.

The purpose of this study is to measure characteristics of the acoustic streaming from a small hole in a levitated disk.

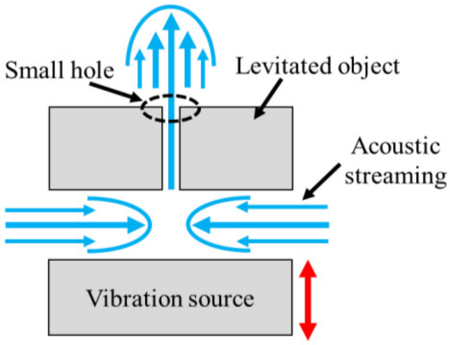
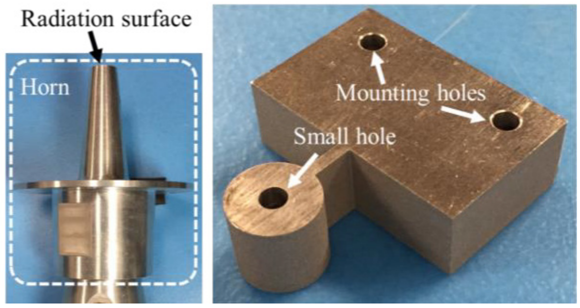


Fig.1 Acoustic streaming from small hole in levitated object.

2. Measurement apparatuses and method

Figure 2(a) shows the vibration source consists of a bolt-clamped Langevin type transducer and a vibratory horn with a 10mm diameter circular radiation surface at the tip. The end surface of the vibration source in **Fig.2(a)** vibrates vertically at a resonance frequency of approximately 28 kHz. **Figure 2(b)** shows the generation device of the acoustic streaming from the small hole. The disk part has a small hole for the generation of the acoustic streaming. In additional, the rectangular part has two mounting holes. The acoustic streaming is generated in the small hole when the disk part is put with small gap on the vibrating surface. **Figure 3** shows the measurement method and setting parameters. To prevent the influence by the ejector effect, the acrylic pipe (inner diameter: 7 mm, thickness: 2 mm, length: 8.8 mm) was attached on the disk part when measuring the velocity of the acoustic streaming from the small hole. The parameters of the disk part are thickness T and hole diameter D. In addition, other parameters are vibration amplitude A of the vibration source and air gap *h* between the disk part and the vibration surface. The flow velocity of the acoustic streaming was measured with a hot-wire anemometer (KANOMAX, 6501 series, sensor probe diameter: 2.5 mm) installed at the outlet of the acrylic pipe.



(a) Vibration source. (b) Generation device of acoustic streaming from the small hole.

Fig.2 Acoustic streaming generation apparatuses.

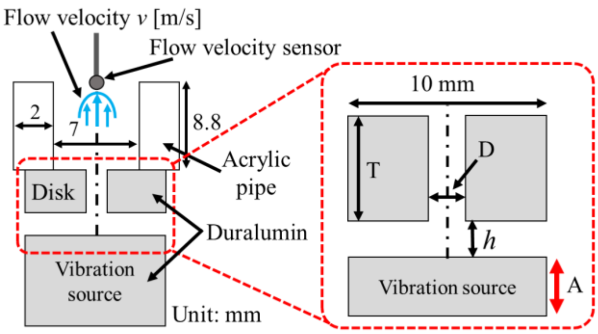


Fig.3 Measurement method and parameters.

3. Measurement results

Figure 4 shows the distribution of the flow velocity *v* measured radially from the center of the acrylic pipe for the disk with T = 3 mm and D = 1mm with air gap of *h* = 150 µm. The flow velocity *v* was almost constant with respect to the radius. The acoustic streaming in the acrylic pipe was considered to be turbulent flow because the central velocity was not maximum but almost constant. Therefore, the

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flow velocity was measured only at the center.

Figure 5 shows flow velocity v with respect to air gap h when using the disk with T = 5 mm and D = 1 mm. The flow velocity v decreased with the increase of h. The maximum flow velocity for each vibration amplitude A was obtained at about h = 150 μm. Furthermore, when A > 7.5 μm, the flow velocity v was stable near 1 m/s in h > 750 μm, but it rapidly decreased to 0.17 m/s when h was further increased. The cause of the rapid decrease in flow velocity is unknown.

Figure 6 shows flow velocity v with respect to the vibration amplitude A when using the disk with D = 1 mm at h = 150 μm. The flow velocity v was proportional to A when A < 15 μm. However, v and A had a nonlinear relationship when A > 15 μm. Maximum flow velocity for each thicknesses T was measured when A = 15 ~ 20 μm. The flow velocity v when the thickness T = 8 mm was larger than other thicknesses. In contrast, flow velocity v when T = 6 mm was very small. Besides, the thickness of the disk affected the flow velocity for some reason.

Figure 7(a) shows the flow velocity v with respect to thickness T when A = 15 μm at h = 150 μm. Maximum and minimum flow velocities were obtained for each diameter D when T = 8 mm and T = 6 mm, respectively. In addition, flow velocity increased with the decrease of diameter D, as shown in **Fig.7(b)**. It was inferred that the change in flow velocity with thicknesses T depends on the relationship between the thickness T and the wavelength of the sound wave in the small hole.

4. Summary

The acoustic streaming ejected from the small hole occurred by NFAL phenomenon. The flow velocity of the acoustic streaming increased as the air gap and the hole diameter decreased and the vibration amplitude increased up to about 20 μm. The flow velocity changed nonlinearly when the vibration amplitude exceeded about 20 μm. Furthermore, the flow velocity increased when the thickness of the disk was 8 mm, but it decreased when the thickness was 6 mm. However, the detailed mechanism of these characteristics is currently unknown. In future work, the mechanism of the acoustic streaming through the small hole will be made clear in air and underwater.

References

1. Y. Hashimoto, Y. Koike and S. Ueha: J. Acoust. Soc. Jpn. **16**, 3 (1995).
2. H. Takei, D. Koyama, K. Nakamura and S. Ueha: Jpn. J. Appl. Phys. **47**. 5 (2008) 4276.

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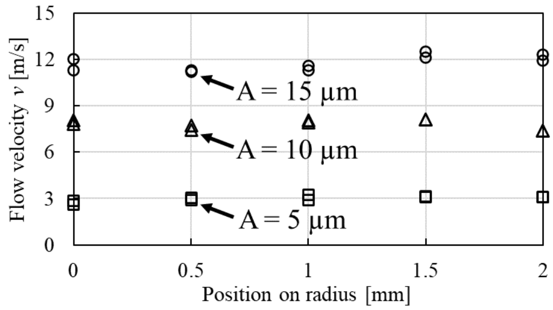


Fig.4 Position on radius vs. flow velocity v.
(T = 3 mm, D = 1 mm, h = 150 μm)

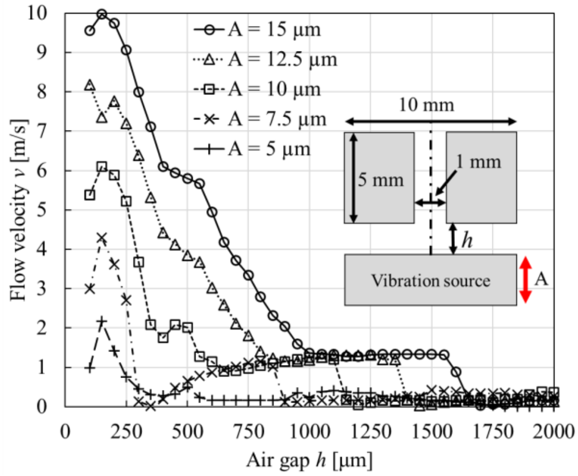


Fig.5 Air gap h vs. flow velocity v.
(T = 5 mm, D = 1 mm)

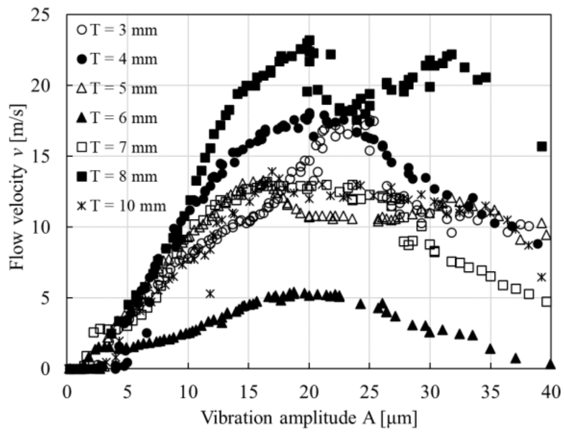
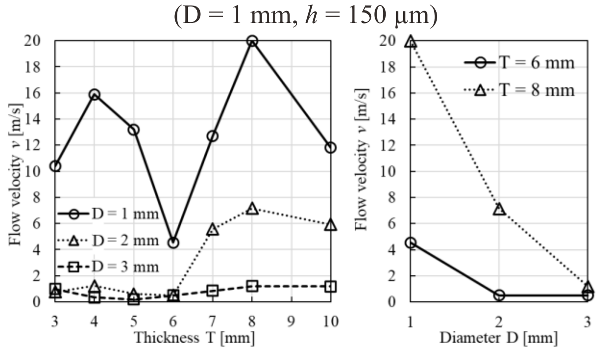


Fig.6 Vibration amplitude A vs. flow velocity v.
(D = 1 mm, h = 150 μm)



(a) To thickness T. (b) To diameter D.

Fig.7 Characteristics of v to thickness T and diameter D.
(A = 15 μm, h = 150 μm)