1P4-5

Examination of near-field acoustic levitation of plate-like object between opposite vibration sources

対向する振動子間に配置された板状物体の近距離場音波浮揚

Kouhei Aono[1†], Manabu Aoyagi[1], Hidekazu Kaziwara[1], Hideki Tamura[2] and Takehiro Takano[2] ([1]Muroran Institute of Technology, [2]Tohoku Institute of Technology)
青野浩平 [1†]，青柳学 [1]，梶原秀一 [1]，田村英樹 [2]，高野剛浩 [2] ([1] 室蘭工大, [2] 東北工大)

1. Introduction

A plane object was levitated by the near-field acoustic levitation phenomenon (NFAL) when the object faces to vertical or flexural vibration sources. **Figure 1** shows acting forces around the levitated object. The object is levitated in tens or hundreds of micrometers by levitation force. Strong sound pressure field and acoustic streaming are generated in air gap between the object and the vibration surface. Acoustic viscous force generated by the acoustic streaming acts to the levitated object as a holding force which prevents the fall of the object from the vibration surface.[1, 2)] The stepping transportation of the object can be realized by the control of the holding force.[2)] However, the holding force is desired to increase, because it is too small to use in practice. As the method of increasing the holding force, to insert the levitated object between a pair of ultrasonic transducers was tried, and changes in holding force and levitation distance by the phase difference of vibration sources have been confirmed experimentally.[3, 4)]

In this study, the possibility of the increase of the holding force is examined with finite element analysis (FEA) under the condition that the levitated object is put between two vertical vibration sources.

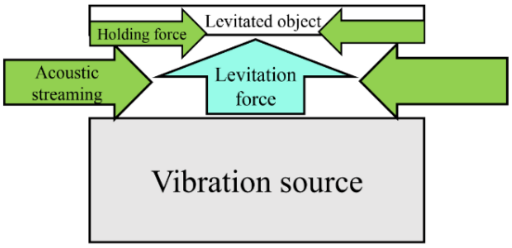


Fig.1 Acting forces around levitated object.

2. Effect by opposite vibration sources

Figure 2 shows the model of the acoustic levitation between opposite vibration sources. The levitation distances, h_1 and h_2 are steady positions which balance forces acting around the object. In this figure, T and d ($= h_1+h_2+\mathrm{T}$) denote the thickness of the levitated object ($42\times42\times\mathrm{T}$ mm^3) and distance between opposite vibration sources, respectively. It is guessable that the holding force increases with increasing the levitation force, F_1, while preventing the increase of the levitation distance, h_1, by the levitation force, F_2.

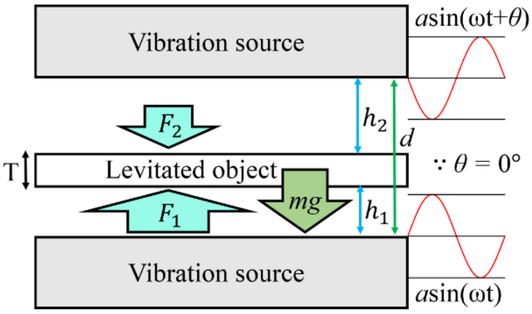


Fig.2 Definition of parameters about acoustic levitation between opposite vibration sources.

3. Holding force analysis

Figure 3 shows an analysis model. Two vibration sources ($42\times42\times5$ mm^3) vibrate vertically at the frequency of 32 kHz. The analysis model is symmetrical about xz plane to decrease calculation load. The levitated object is made of acrylic plastic, and vibration sources is aluminum. Absorb boundary is set to the outside surface of air block. The holding force was calculated for the variation distance, L_x, of the levitated object. Following analyses were carried out by the commercial FEA software (COMSOL Multiphysics 5.3).

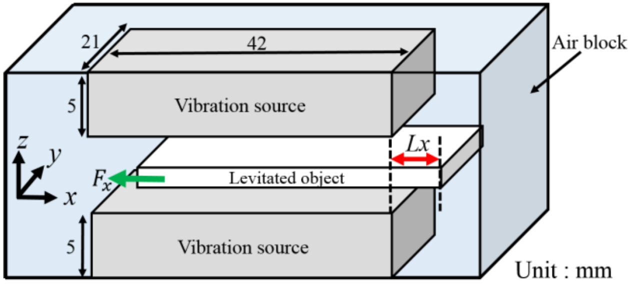


Fig.3 Analysis model for FEA.

First of all, the body force was calculated by acoustic-structure interaction analysis. An acoustic streaming was calculated by solving incompressible fluid equations using the body force. Then, the force, $\boldsymbol{F} = [\ F_x, F_y, F_z\ ]$, acting around the levitated object was calculated by fluid-structure interaction analysis. Only holding force, F_x, was

examined, because F_y was canceled due to the symmetrical structure of the model. When $F_x < 0$ N, the holding force acts to bring back the object onto the original position above the vibration source.
The viscosity of air gap was taken into account in the region within narrow space of the analysis model shown by dotted-line squares in **Fig. 4**.

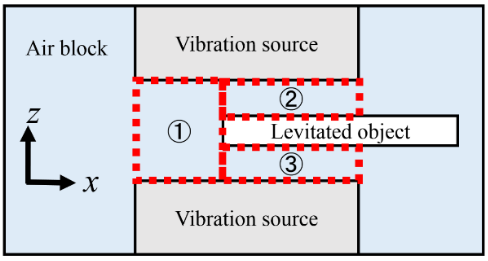


Fig.4 Consideration of viscosity area.

4. Analysis result

Figure 5 shows the calculated holding force to L_x when the levitation position of $h_1 = h_2 = 100$ μm and the vibration amplitude of 2 μm. The broken line denote the folding force when the acoustic levitation by a single vibration source. The holding force, F_x was expressed by the same plots when phase differences of 90° and 270°, because the relationship between each vibration source and sound pressure field of areas ② and ③ are the same. The levitated objects of thickness 0.5 mm and 1.0 mm received the maximum holding forces when the phase difference of 180°, and the forces were larger than those of a single vibration source.

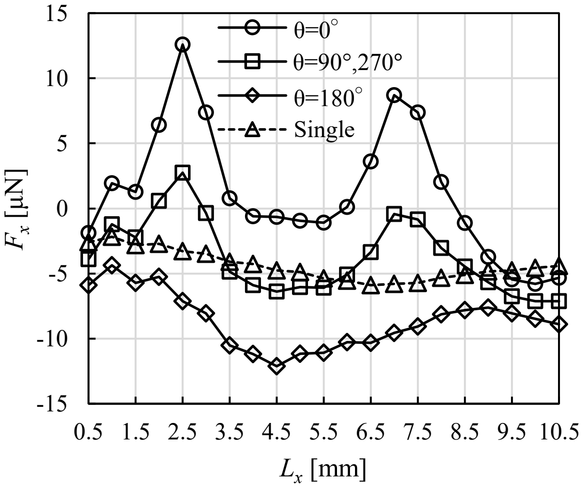
Figure 6 shows the holding force to L_x when T = 1.0 mm and the levitation position of $h_1 = h_2 = 50$ μm. The holding force at phase difference of 180° was larger than that at the phase difference of 180° in **Fig.5 (b)**. It is guessable that the holding force increase by increasing sound pressure with the decrease of the levitation distances, h_1 and h_2.

5. Summary

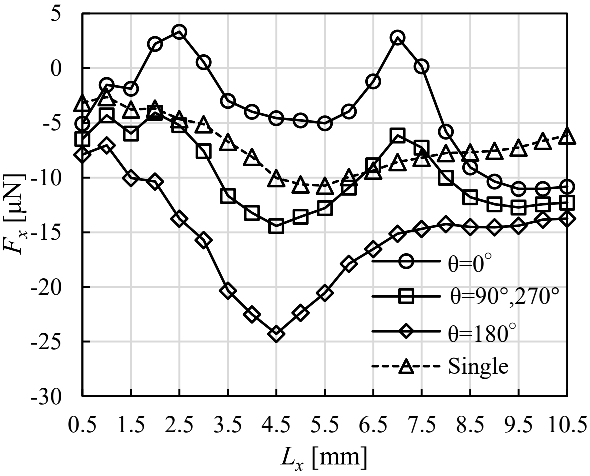
The holding force in acoustic levitation between opposite vibration sources was calculated by FEA. As analysis results, when phase difference of 180°, the holding force became larger than that of single vibration source. Furthermore, the holding force was increased when air gap (d, h_1 and h_2) decreased. In future work, the calculated holding force need to be confirmed in a measurement.

References

1. Y. Hashimoto, Y. Koike and S. Ueha: Jpn. J. Appl. Phys. 36 (1997) 3140.
2. R. Yano, M. Aoyagi, H. Tamura and T. Takano: Jpn. J. Appl. Phys. **50** (2011) 07HE29.
3. M. Aoyagi, Y. Ohmura, H. Kajiwara, H. Tamura and T. Takano: Proc. of Autumn Meet of ASJ. 3-P-24 (2014) 1407. [in Japanese]
4. K. Aono, M. Aoyagi, H. Kajiwara, H. Tamura and T. Takano: Proc. of Spring Meet of ASJ. 3-10-7 (2018) 1017. [in Japanese]



(a) T = 0.5 mm, d = 0.7 mm.



(b) T = 1.0 mm, d =1.2 mm.
Fig.5 L_x vs. F_x ($h_1 = h_2 = 100$ μm).

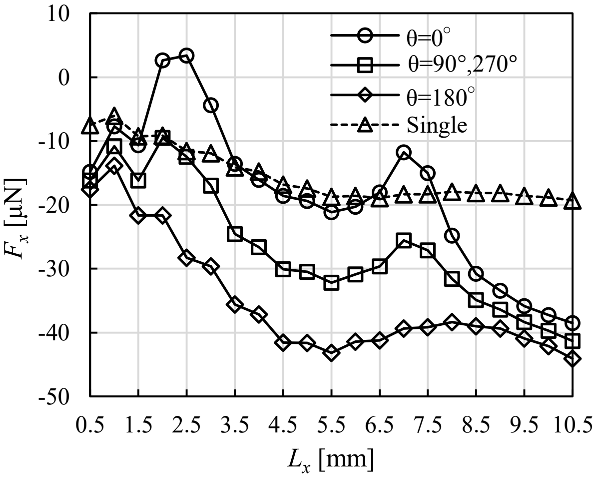


Fig.6 L_x vs. F_x
(T = 1.0 mm, d = 1.1 mm, $h_1 = h_2 = 50$ μm).

E-mail address: maoyagi@mmm.muroran-it.ac.jp