1P4-1

Attempt to levitate and transport a flat plate between horizontally opposed bending vibrating plates

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1. Introduction

A standing wave sound field is formed between the vibrating surface and the reflector, and a light object, such as a styrofoam sphere, can be levitated at the position of the sound pressure nodes.[1-3] However, when attempting to levitate a planar object in a standing wave sound field, the planar object acts as a reflector and significantly disturbs the standing wave sound field, resulting in insufficient levitation and holding force and stable levitation of the planar object is not easy. On the other hand, when a standing wave sound field is formed between the plate and the vibrating surface, a large acoustic radiation force acts on the plate, and the plate can be levitated at a high distance.[4] Although near-field acoustic levitation is desirable for levitating and transporting planar objects because of its stable levitation and holding force, the levitation distance is very small, making it difficult to handle. Therefore, we would like to challenge the non-contact transport of a planar object in a standing wave sound field by applying levitation and holding forces to planar objects by two plate transducers.

The purpose of this study is to explore the potential of forming standing and traveling wave sound fields, which are less affected by the levitated and transported planar object, using two planar vibrating surfaces that apply acoustic radiation force to a levitated object.

2. Design of Vibrating plate

In this study, two aluminum plate vibrators are placed facing each other, as shown in **Fig.1.1**, and the vertical acoustic radiation force of the standing wave sound field formed in the space is used to levitate the planar object. It is expected that the planar object is less likely to disturb the standing wave sound field. To efficiently generate levitation force, it is necessary to match the resonance frequencies of the vibrating plates and the air between them. To match the resonance frequency of the air and the plate vibrators around 28 kHz, the size and spacing of the two plate vibrators were designed using finite element analysis software (COMSOL Multiphysics 6.2). Based on the analysis, **Fig. 1.2** and **Fig.1.3** show the vibration modes of the diaphragm and air tuned to 28073 Hz.

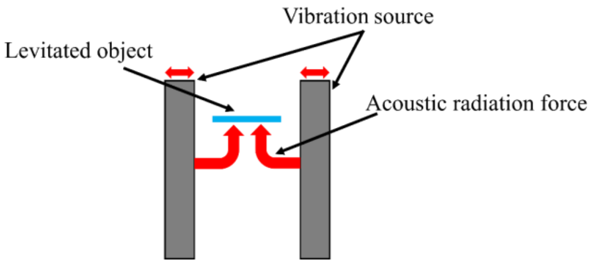

Fig1.1 Acoustic levitation model.

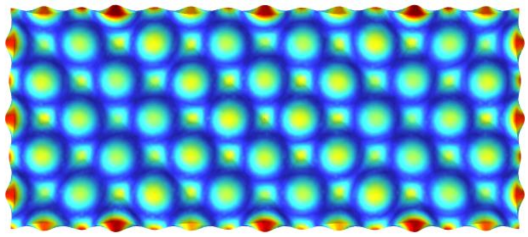

Fig1.2 Vibration mode of the plate.

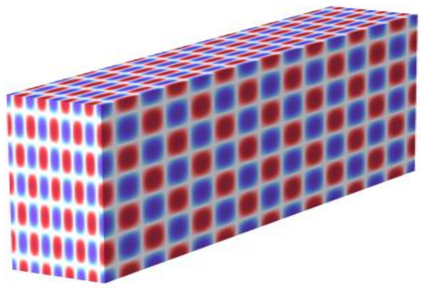

Fig1.3 Vibration mode of air.

3. Analysis model

A finite element analysis of the sound pressure field between the vibrating surface and the plate object was performed. The analytical model is shown in **Fig. 2**. The structure consists of a planar object sandwiched between left and right vibrators. A levitated object (40 x 40 x 0.5 mm^3) and a vibrating plate (302 x 3 x 128 mm^3) were used. The acoustic radiation force acting on the upper surface of the planar object is Fz^+, the acoustic radiation force acting on the lower surface is Fz^-, and the forces acting on the sides are Fx^+ and Fx^- for the x-axis, respectively, to analyze the levitation, holding, and carrying forces acting on the planar object when the planar object is moved.

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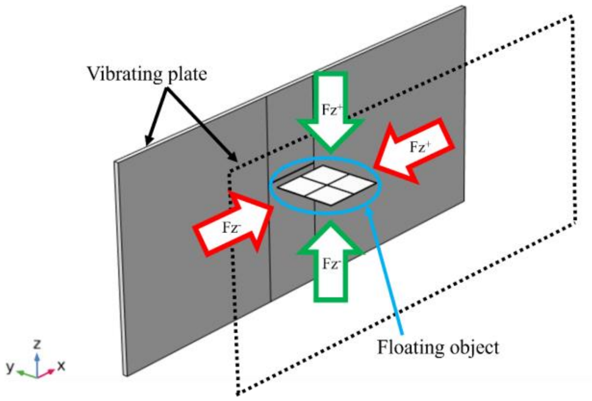

Fig.2 Analytical model.

4. Analysis results

4.1 Levitation force analysis

Fig. 3 shows the analytical results of the levitation force (Fz^--Fz^+) when the position of the planar object is x=140mm and is varied in the z-axis direction from z=72mm to z=77mm by 0.5mm. The analysis results show that at x=140mm, positive levitation force is generated on the planar object from z=73mm to z=75mm.

4.2 Transport Force Analysis

When one of the plate vibrators is shifted in the x-axis direction by 1/4 wavelength of the wave generated on the vibrator, a traveling wave is generated in the air between the plate vibrators.[5] **Figs .4.1** and **4.2** show the analytical results when a traveling wave is generated by shifting the plate vibrator in the x-axis direction using this phenomenon. From the above results, the levitation force was maximum at z=79mm, and the transport force was 0.0322mN.

5. Conclusion

The analysis confirmed that placing a planar object in the sound field between two horizontally opposed plate vibrators applied the force in the direction against gravity. In addition, when the plate vibrators were shifted by a quarter wavelength, the traveling waves in the air were confirmed, and the generation of the transport force was also confirmed at the position where the levitation force was generated. In the future, experiments will be necessary to determine the holding force of the posture of the planar object and to experiment with the actual levitation of the object.

Acknowledgment
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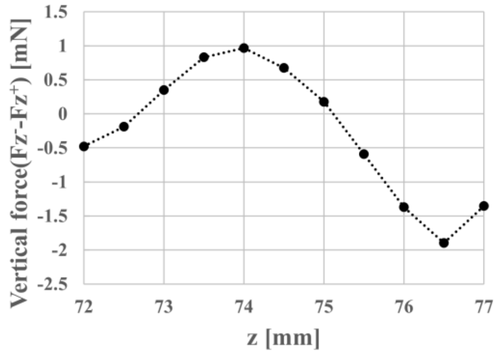

Fig.3 Change in vertical force (Fz^--Fz^+) with position in z direction.

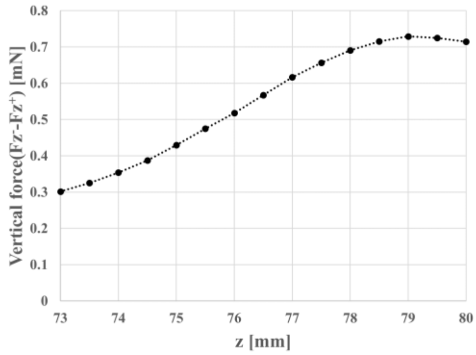

Fig.4.1 Change in vertical force (Fz^--Fz^+) with position in z direction.

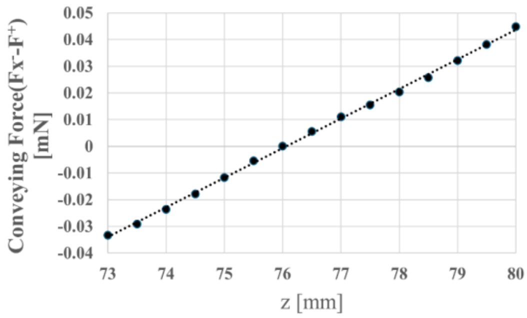

Fig.4.2 Transport Force (Fx^--Fx^+) with position in z direction.

References

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