Multi degree-of-freedom noncontact transportation using near-filed acoustic levitation

近距離場音波浮揚による多自由度非接触搬送

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1. Introduction

A tabular object can be levitated with tens or hundreds micrometers gap by the ultrasonic acoustic radiation pressure generated by a vibration source, as shown in **Fig. 1**. This phenomenon is called near-filed acoustic levitation(NFAL). When the acoustic radiation pressure differs between two adjacent vibration sources due to different vibration amplitudes, the acoustic streaming let a tabular object transport, as shown in **Fig. 2(a)**.[1-3]

The purpose of this study is to investigate the possibility of multi degree-of-freedom(MDOF) noncontact transportation using NFAL. Four vibration sources allow the object to be transported not only in one degree of freedom but also diagonally, as shown in **Fig.2(b)**. As one of MDOF transportation, this paper reports the mechanism how the rotation of the object occurs while it is two-dimensionally transported in plane by plural vibration sources.

2. Finite element analysis

The rotational force of the levitated object was calculated by acoustic-structure interaction analysis and fluid-structure interaction analysis by using the commercial finite element analysis software (COMSOL Multiphysics5.4), which allows the user to incorporate arbitrary differential equations.[4] **Figure 3** shows the model of the analysis. Two vibration sources(41 x 41 x 1.5 mm3, A2017) are placed at 0.3 mm intervals, and a levitated object (42 x 42 x 0.94 mm3, acrylic) is arranged on the surface of the sources with the air gap of 0.1 mm. In addition, the levitated object was placed on the sources with shift distance, as shown in **Fig.4**. The analysis range of the position of the object was set from 0 mm to 45 mm in the transportation direction. [5]

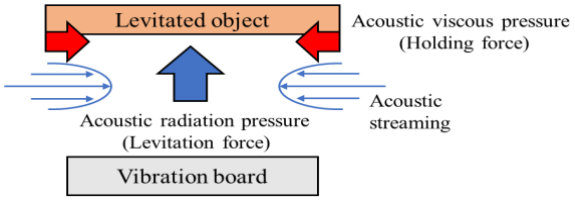

Fig.1 State of near-field acoustic levitation.

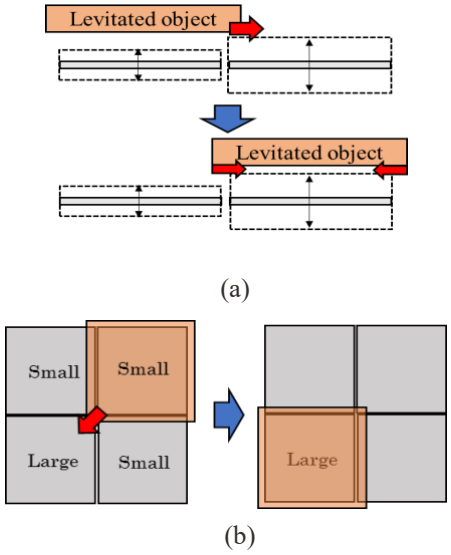

Fig.2 Principle of noncontact transportation.

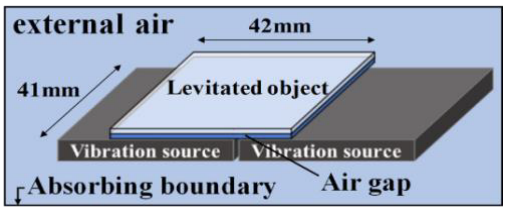

Fig.3 Model of finite element analysis.

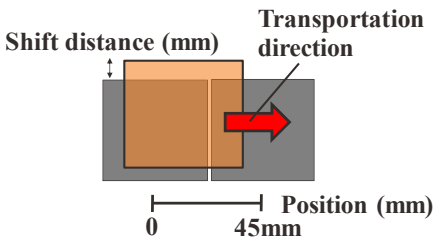

Fig.4 Definitions of analysis range and shift distance.

3. Experimental and analysis results

Figure 5 shows normalized values of measured acceleration and simulated transportation force when the levitated object was transported without shift-distance. The changes in both were almost the same, which means that the validity of the analysis results was obtained.

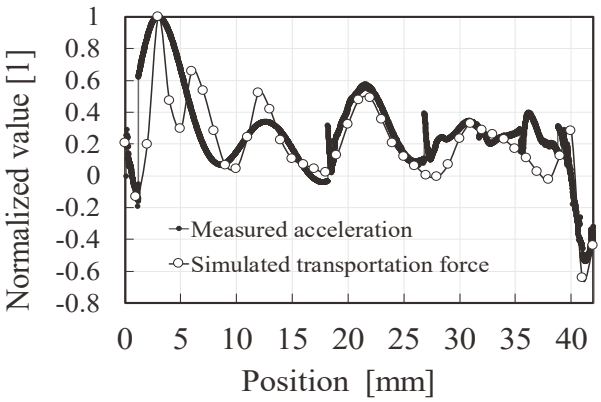

Fig.5 Normalized measured acceleration and simulated transportation force.

4. Rotation of levitated object

Figure 6 shows the difference between holding forces generated on the right side and left side of the levitated object, and the rotational torque of the levitated object. From these results, it was considered that the rotation of the levitated object was caused by the difference in the holding forces generated on both sides of the object. During actual transportation, the levitation object shifted from the center position for some reason, resulted in rotation. The rotational force increases most when the position of the levitated object was between the two 21 mm square vibration sources, but decreased near the source(0 mm) and destination(45 mm). This was because the difference in holding forces on both sides of the object changes.

Figure 7 shows the simulated holding force and average torque with respect to the shift distance when the position of the levitated object was 0 mm. This result indicated that the rotational torque changed depends on the shift distance of the levitated object. When the shift distance was 3 mm, the holding force generated on the levitated object was smaller than when the shift distance was 1 mm. The decrease in holding force was considered to be because the end of the levitated object was located at the vibrating node of the flexural vibration mode of the vibration source when the shift distance was 3 mm. From the above, it was found that the rotational torque of the levitated object depends on the magnitude of the holding force.

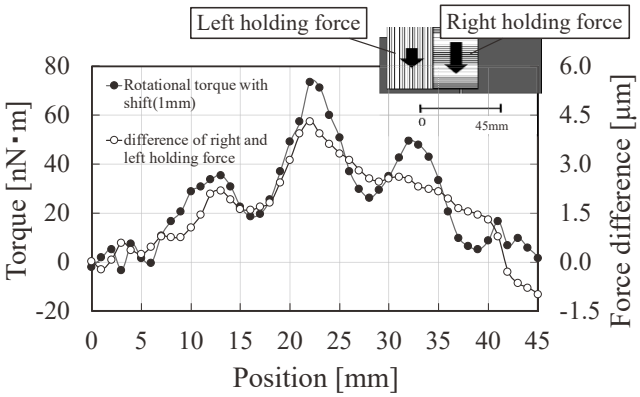

Fig.6 Simulated rotational torque of levitated object with shift distance of 1 mm, and difference between right and left holding forces.

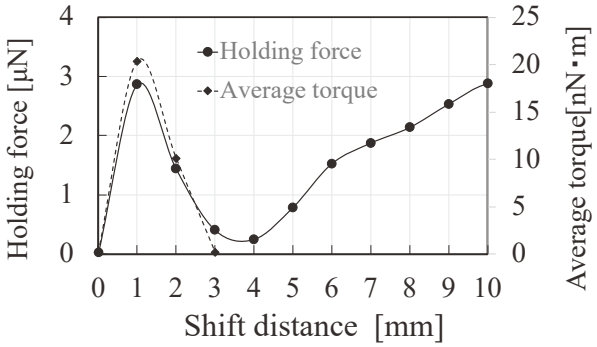

Fig.7 Holding force and average torque with respect to shift distance at the position of 0 mm.

5. Summary

It was clarified that the rotation of the levitated object during transportation was caused by the holding force generated when the levitated object was shifted from the center position. In this state, if there was a difference in amplitude between the stators, the levitated object would rotate due to the difference in holding force. Therefore, by arranging the vibration source in a two-dimensional direction and intentionally shifting the position of the levitated object, the levitated object can be rotated in any direction, and there is a possibility of x-y-θ transportation.

References

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