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Positioning of an object in near-field acoustic levitation and its application

近距離場音波浮揚を用いた浮揚物体の位置決めとその応用

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1. Introduction

An object having a flat surface can be levitated by acoustic radiation pressure above a vibration plate. This phenomenon called near-field acoustic levitation (NFAL) was reported as applications into non-contact transportation and non-contact ultrasonic motor (USM).[1,2] **Figure 1** shows forces around an object which is levitated by NFAL. An acoustic streaming occurs between the vibration plate and the levitated object as shown in Fig. 1. [2] The object is levitated by acoustic radiation pressure and acoustic viscous force is generated horizontally by the acoustic streaming. Acoustic viscous force acts as a holding force for levitated object. We focus a holding force generated horizontally at the edge of a vibration plate. The holding force yields at the edge of vibration plate and the node of a bending vibration mode. The holding force is in proportion to vibration amplitude of the vibration plate. [3] When the vibration plate vibrates with a standing wave, the potential of vibration energy is large around loops and it is small near nodes. The acoustic streaming occurs from loops toward nodes. Hence, the holding force occurs from loops toward nodes and it depends on vibration modes. [4]

The purpose of this study is to determine positioning of a flat object levitating above stator vibrators by utilizing the holding force. This technology can be applied into the development of a non-contact-stepping ultrasonic motor (NCS-USM). As one of the positioning method of a levitated object, we considered making a difference among vibration amplitudes of some stator vibrators aligned in line or circle. As an experimental result, it is possible to move a levitated object to the next stator vibrator one by one and to hold it.

2. Operating principle of NCS-USM

Figure 2 shows an example of the schematic figure of the NCS-USM. The positioning of a levitated object is applied to develop NCS-USM. An operating principle is described below.

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(1) A flat object is levitated above the vibration plate (stator vibrator).
(2) When increasing the vibration amplitude of the next stator vibrator, the object is shifted to the next stator, and is held there.

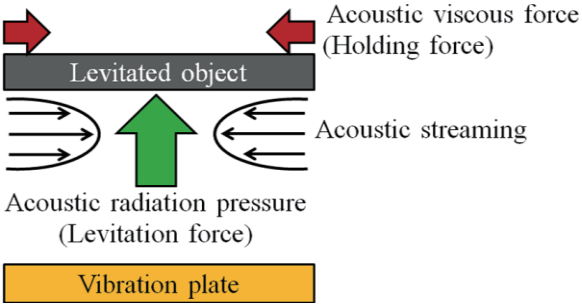

Fig. 1 Forces around levitated object.

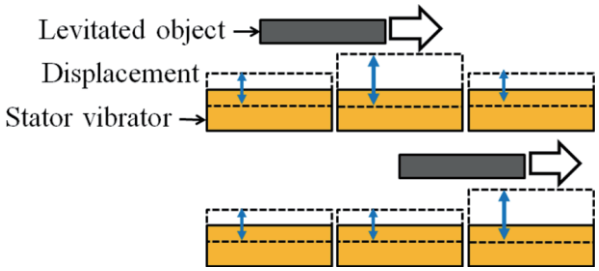

Fig. 2 An operating principle of positioning and NCS-USM.

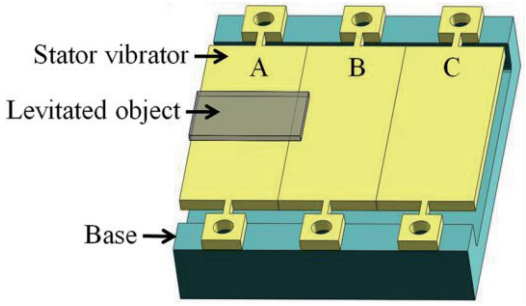

Fig. 3 Experimental setup.

3. Experimental method

Figure 3 shows the configuration of the experimental setup. Three stator vibrators are aligned on the base. The clearance between each stator vibrator is approximately 60 μm. An acryl plate 10.7 mm wide, 17.5 mm long, 1.0 mm thick and 210 mg in weight was used as a levitated object. **Figure 4** shows the dimension of the stator vibrator made of stainless steel and piezoceramics. Three stator vibrators, A, B, C were provided. The

resonance frequency of Stator A was 22.52 kHz, Stator B, 22.61 kHz and Stator C, 22.64 kHz. **Figure 5** shows the vibration mode of the stator vibrator. The object was levitated and held in the area between transverse nodal lines on the stator vibrator.

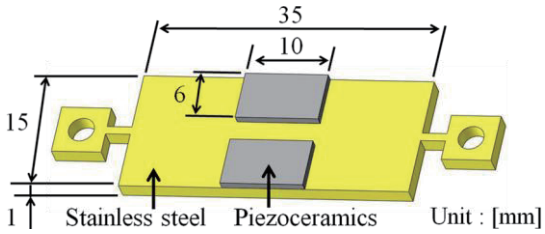

Fig. 4 Dimension of a stator vibrator.

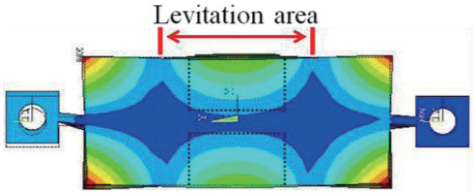

Fig. 5 Analyzed vibration mode.

4. Experimental results

Figure 6 shows measured displacements of three stator vibrators, A, B, C and levitation distances, when the levitated object can be moved to the next stator vibrator. From experimental results, conditions to move the object to the next stator vibrator were found as follows.

(1) To increase the displacement of a stator next to the object more than that of stator levitating the object.
(2) To make over 1.5 times differences between displacements of two adjacent stator vibrators.

As the levitated object reached the next stator vibrator with large displacement, the levitated object oscillated above the stator vibrator and stopped after a few seconds. The oscillation has to be reduced for an accurate positioning of a levitated object.

5. Summary

The method of positioning of a levitated object above many aligned stator vibrators was proposed. From an experiment, an object moved to the next stator vibrator under the condition that the displacement of the next stator was over 1.5 times larger than that of the stator levitating the object. Hereafter, it is necessary to analyze the mechanism that the levitated object moves toward the next stator vibrator which has large displacement. Moreover, the reduction of an oscillation of the levitated object has to be considered for an accurate positioning.

A rotary type NCS-USM shown in **Fig. 7** can be proposed. Its operating principle is the same as NCS-USM. This motor has a possibility of high torque compared with ordinal non-contact USM using traveling wave.

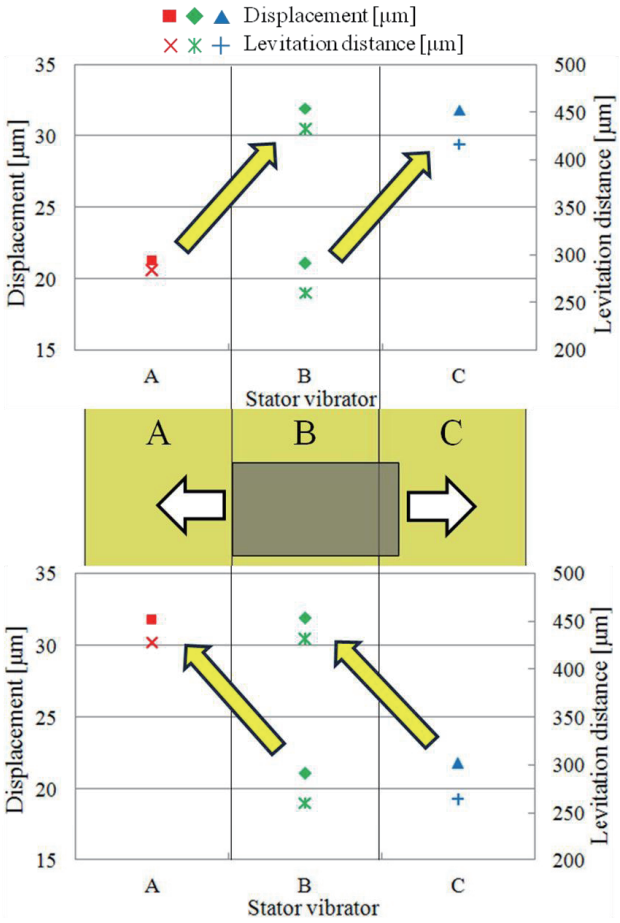

Fig. 6 Displacements of each stator vibrator and levitation distance on them.

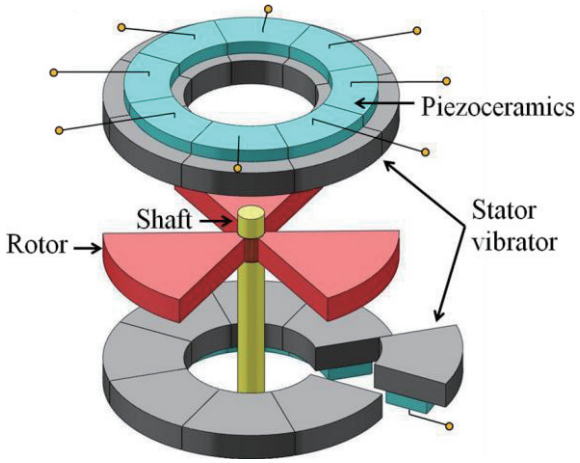

Fig. 7 An example of Rotary type NCS-USM .

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