ELUCIDATION OF THE RETENTION MECHANISM IN NEAR–FIELD ACOUSTIC LEVITATION

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Abstract

In near-field acoustic levitation, the lateral position of the levitated object is automatically maintained by a 'holding force' [1][2][3], which acts on the object so as to minimize the lateral displacement. The authors discuss in this report on the simulation of the holding force under the assumption that the force is generated by the acoustic streaming induced in the gap between the vibrator and the levitated object. First, the acoustic streaming is observed by a video camera to confirm the relationship between the streaming and the holding force. The acoustic streaming is caused by the sound pressure distribution in the plane between the vibrator and the levitated object. Therefore, next, we measured the sound pressure distribution with a probe microphone. The holding force can be calculated from the sound pressure distribution by the Nyborg's equation.

Introduction

For the production process of silicon wafers or glass plates for Liquid Crystal displays, we have proposed a new non-contact transportation system based on near-field acoustic levitation (NFAL). In NFAL, a plate object is levitated very near to the flat radiation surface by radiation pressure, and the lateral position of the levitated object is automatically maintained by "holding force". Based on the assumption that the retention is generated by the acoustic streaming in the gap between the vibrator and the levitated object, in this report, the mechanism of holding force is studied both experimentally and numerically.

Configuration of the system to be studied

As a vibrator, we used the top surface of a straight horn (52 mm x 52 mm x 130 mm, 19.15 kHz) driven by a Langevin transducer. The vibrator is almost uniform over the surface. A bakelite plate (52 mm x 52 mm x 0.5 mm) is placed on the vibrator as a levitated object as shown in Figure 1.

Visualization of acoustic streaming

We assume that the holding force is caused by the acoustic streaming. To confirm this assumption, we observed the acoustic streaming by a video camera where fine particles are introduced as "tracer"between the vibrator surface and the levitated plate.

A transparent plate (acrylic) is used in order to observe the movement of the particles, as it is shifted laterally and held in position. Some frames from the video are shown in Fig.2.

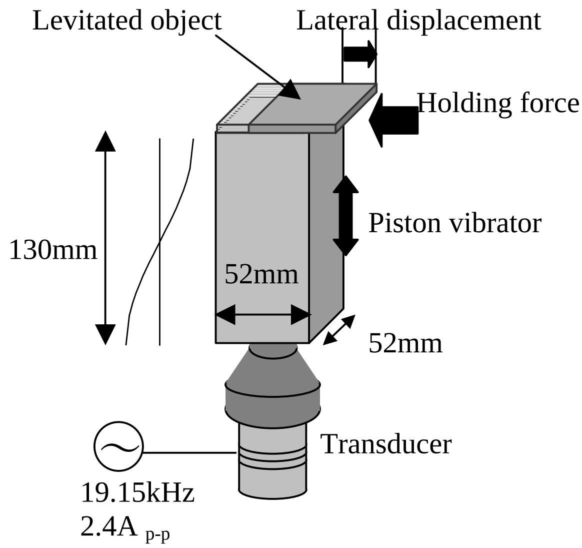


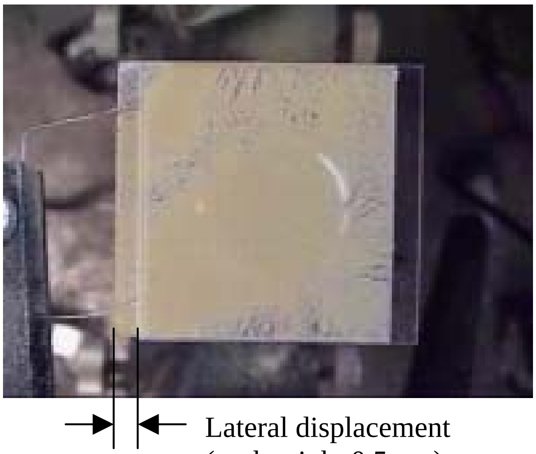
Figure 1 : Measurement object.

Figure 2 shows that the particles move in a direction opposite the lateral displacement of the levitated object. This means that the acoustic streaming is generated in a direction opposite the lateral displacement. From this observation, we concluded the acoustic streaming is the origin of holding force.

Measurement of the sound pressure distribution

By a slope in z direction of the acoustic streaming U, the Stokes' viscous force is generated. (As shown in Figure 3.)

To calculate the holding force, we need the sound pressure distribution in the gap between the vibrator surface and the levitated plate. From the sound pressure distribution we can calculate the particle velocity. And we obtain the acoustic streaming and the Stokes' viscous force by Nyborg's equation. By integrating the Stokes' viscous force over the levitated plate, we obtain the holding force. In this process, we need the real and imaginary values of the sound pressure distribution. In another words, we need the absolute value and phase of the sound pressure distribution.



Lateral displacement
(to the right 0.5mm)

t = 0.0 (s) Beginning of the excitation

t = 0.1 (s)

t = 0.2 (s)

t = 0.3 (s)

t = 0.4 (s)

t = 0.7 (s)

t = 1.0 (s)

t = 1.3 (s)

Figure 2 : Observed flow between the output surface of the vibrator and the levitated plate.

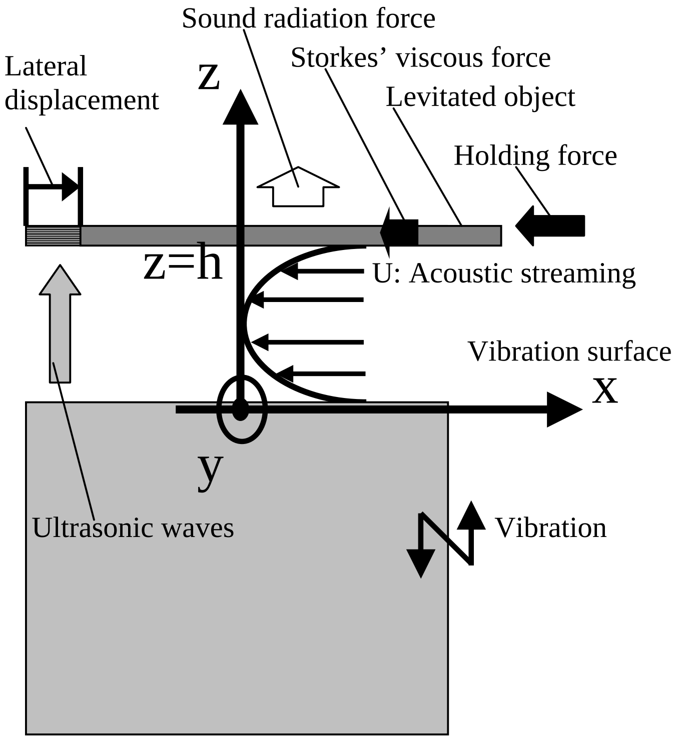


Figure 3. Model for the analysis.

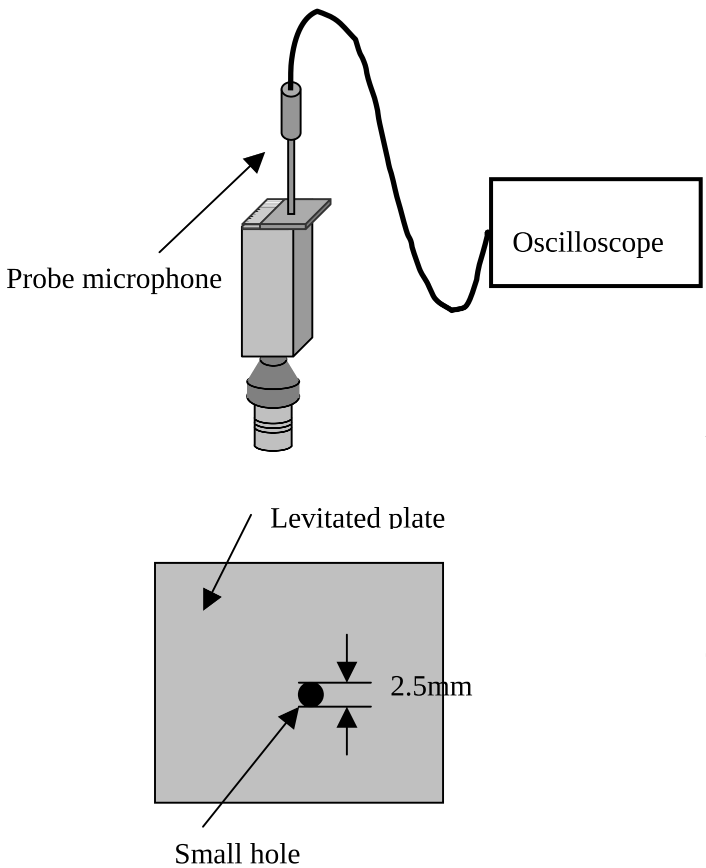


Figure 4 : Experimental setup.

We measured the sound pressure distribution in the gap between the vibrator and the levitated plate with a probe microphone. The plate with a small hole (2.5mm in diameter) is used. This small hole does not affect the sound pressure distribution. The experimental setup is shown in Fig.4.

For one measurement point, we prepare one plate that has one hole. We measured the sound pressure distribution, absolute value (Pa) and phase (radians), for these cases:

1. lateral displacement is 0mm
2. lateral displacement is 2.5mm
3. lateral displacement is 5mm
4. lateral displacement is 10mm

The obtained results (absolute value, real value, imaginary value) are shown in Fig.5.

Holding force

When the lateral displacement of the levitated plate changes, the sound pressure distribution changes. Therefore, when the lateral displacement changes, the holding force also changes. The holding force versus displacement is as shown in Figure 6.

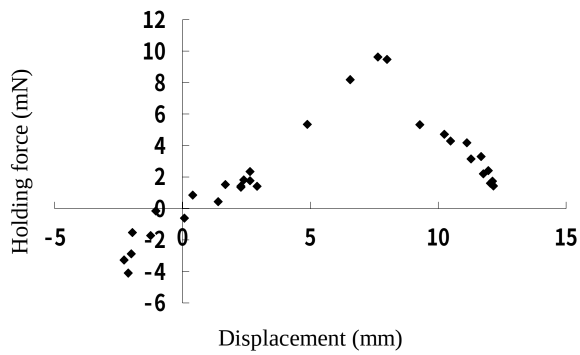


Figure 6 : Holding force vs. displacement.

Reference

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[3] C. Yamazaki et al: Proc. Spring Meet. Acoust. Soc. Jpn, pp. 977-978, 2002 (in Japanese).

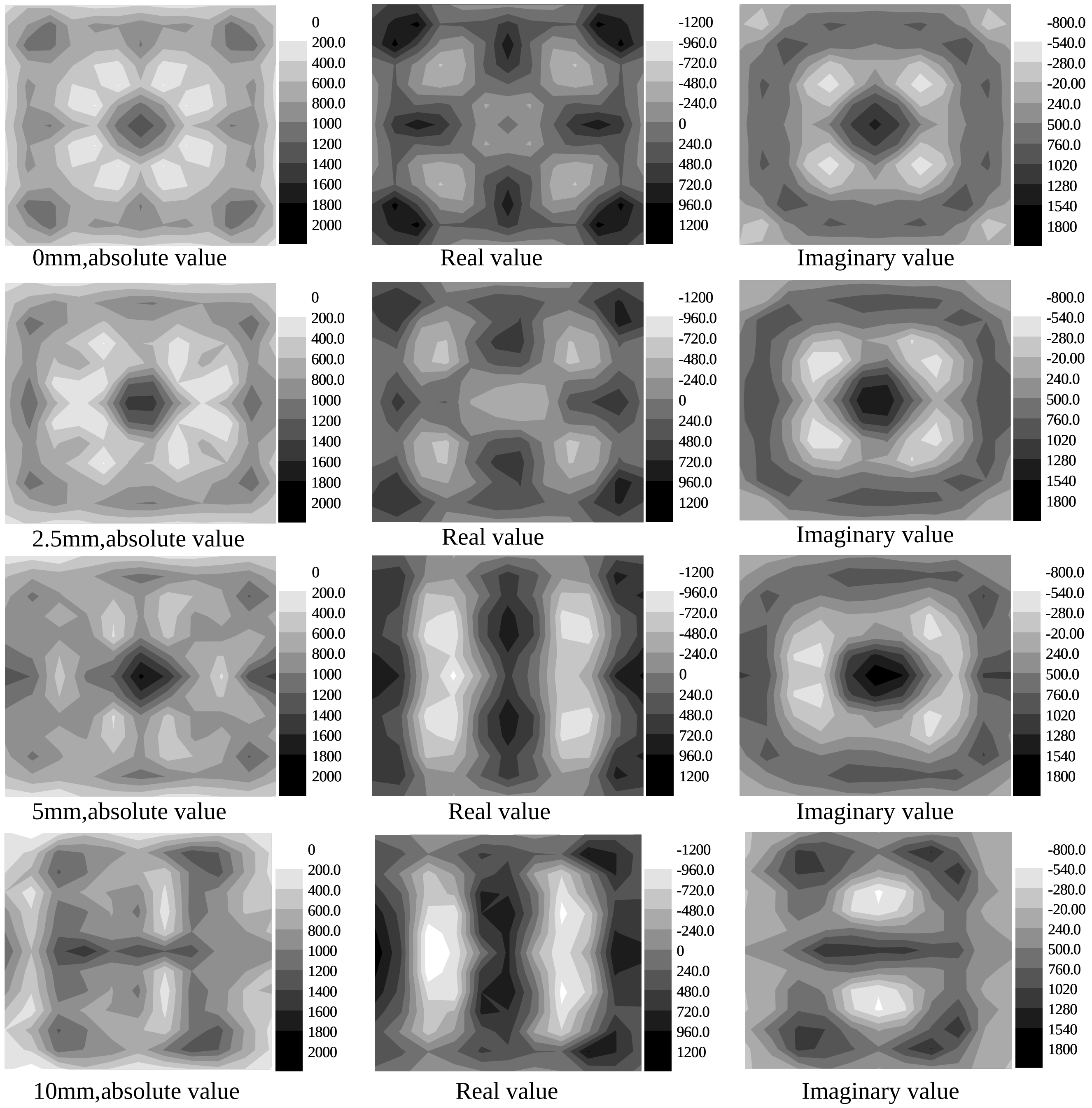

Figure 5 : Measured sound pressure distributions.