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Measurement of holding force acting on tabular object in near-field acoustic levitation
近距離場音波浮揚における平板状物体に働く保持力の測定

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1. Introduction

A plane object near the vibration surface is levitated by the near-field acoustic levitation phenomenon. **Figure 1** shows acting forces around the levitated object. The object is levitated about tens or hundreds μm by the acoustic radiation force generated by strong sound pressure in the air layer between the object and vibration surface. In addition, the acoustic streaming also occurs there, and the acoustic viscous force generated by viscosity of air acts on the bottom of the levitated object. The acoustic viscous force is called holding force, because the force prevents the deviation from the vibration surface.[1)] **Figure 2** shows the behavior of the levitated object above vibration surface. The object does a harmonic oscillation above vibration surface by the holding force. The holding force was estimated from the vibration frequency of the harmonic oscillation[2)], or that was measured from the tilt against horizontal of the levitated object dropping out from the vibration surface[3)]. However the holding force was measured only in the case of small variation from the vibration surface.

The purpose of the present study is to measure the holding force when large deviation between the levitated object and the vibration surface by the electromagnetic force (EMF).

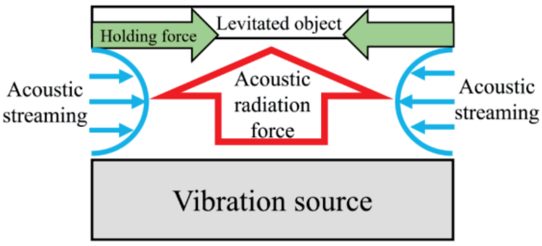


Fig.1 Acting force around the levitated object.

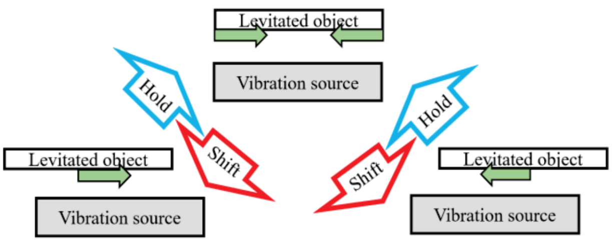


Fig.2 Levitated object's behavior on vibration surface.

2. Measurement device

Figure 3 shows the vibration source consists of a bolt-clamped Langevin type transducer and a vibratory horn with square radiation surface (42×42 mm^2). When the radiation surface vibrates with vertically vibration at 31,750 Hz, the holding force by the vibration source was measured. **Figure 4(a)** shows the measurement apparatus for the holding force. An acrylic rectangular plate-like rotor with a rotating shaft at its center is supported by flanged bearings, as shown in **Fig.4 (b)**, and can be rotated even with a small force. The square parts at both sides of the rotor is 1 mm in thick, and have the same area as the square radiation surface in **Fig.3**. The holding force acts on one square part of the rotor, and the EMF generated by an electromagnet is applied to the other side.

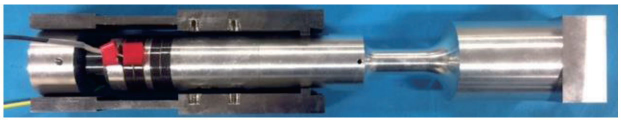
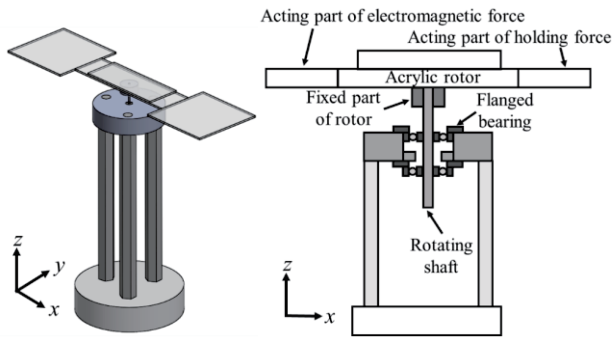


Fig.3 Vibration source with square radiation surface.



(a) 3D view. (b) Configuration.

Fig.4 Measurement apparatus.

3. Measurement method

Figure 5 shows the measurement control system of holding force. A steel sheet and reflective sticker is attached on the side of the square part where the EMF is applied. The position of the rotor is detected by a laser displacement meter (LDM). The holding force side of the rotor was placed above the radiation surface with a deviation distance L from the radiation surface. The electromagnetic force side of the rotor was set between the electromagnet and the LDM, as shown in **Fig.5**.

F_h and F_e in **Fig.5** are the holding force and the EMF, respectively. F_h is estimated from the balanced current I of the electromagnet in the electromagnetic force compensation (EMFC) system. The rotation position detected by LDM was sent to the current control part, and then current I was adjusted by PID control so that the distance between the electromagnet and the rotor was maintained constant at 9 mm. When the distance settles at 9mm, the both forces are balanced. Distance h between rotor bottom and radiation surface was adjusted by a precision jack.

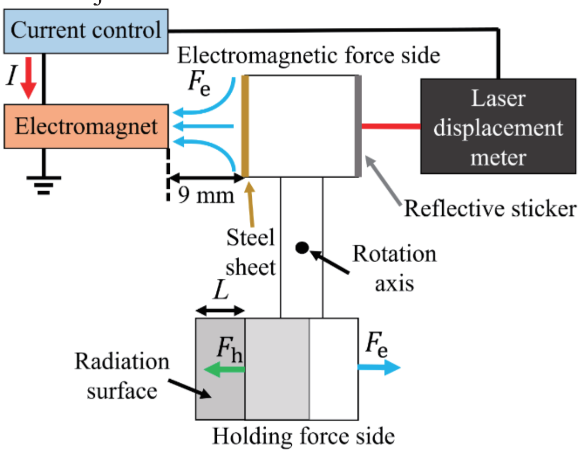


Fig.5 Measurement control system of holding force.

4. Measurement result

Figure 6 shows the balanced current I against the deviation L from radiation surface when h = 320 μm and the vibration amplitude of 5 μm. The current was measured three times by changing L from 0.5 to 4.5 mm every 0.5 mm. Plot points indicates average of the values measured three times. The balanced current I was almost constant for L = 0.5 to 3 mm, but it increased for L > 3 mm; the holding force increased even if acting area decreased.

Figure 7 shows the current I against the vibration amplitude at L = 4 mm and h = 450 μm. The current I increased with increasing the vibration amplitude; increasing the vibration amplitude made the holding force large. **Figure 8** shows the current I against h at L = 4 mm and the vibration amplitude of 5 μm. The holding force decreased with increasing distance h, because sound pressure between rotor and radiation surface decreased.

5. Summary

The holding force was estimated by the EMFC system. In particular, the holding force was measured successfully when there was the deviation between radiation surface and levitated object. The holding force was increased with increasing vibration amplitude or decreasing the distance between the rotor and radiation surface, as well-known.

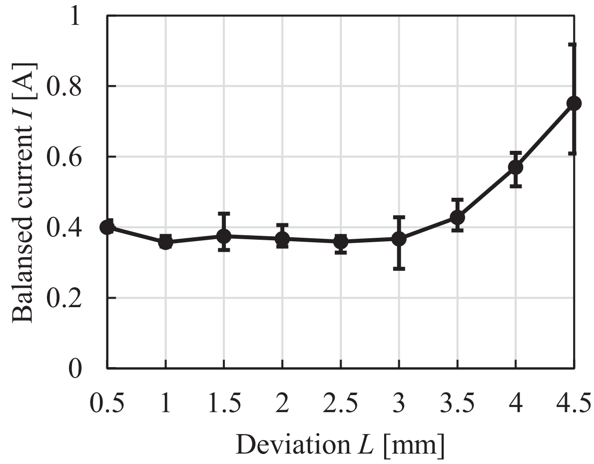


Fig.6 L vs. I (h = 320 μm, vibration amplitude 5 μm).

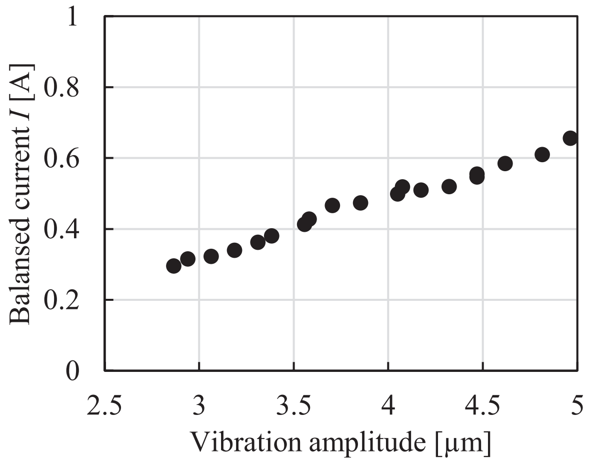


Fig.7 Vibration amplitude vs. I (L = 4 mm, h = 450 μm).

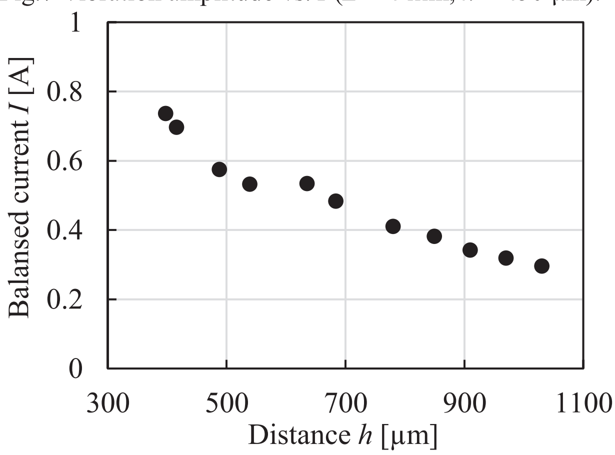


Fig.8 h vs. I (L = 4 mm, vibration amplitude 5 μm).

References
1. Y. Hashimoto, Y. Koike and S. Ueha: Jpn. J. Appl. Phys. 36 (1997) 3140.
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