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Effect of eigenmode in cavity on acoustic radiation force in near-field acoustic levitation

近距離場浮揚時における空隙内の固有モードが音響放射力に与える影響

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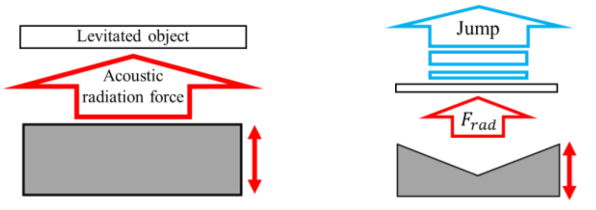
1. Introduction

A plane object near the vibration surface is levitated several hundred μm by the near-field acoustic levitation (NFAL). The bottom surface of the levitated object receives the acoustic radiation force as shown in **Fig.1(a)**. The levitation distance in the NFAL is decided by the balance between the object weight and the acoustic radiation force[1]. However, the object on a non-flat vibrating surface jumped in the vertical direction from the surface when the surface vibrates as shown in **Fig.1(b)**. Such a jumping phenomenon occurs only on the non-flat vibrating surface[2]. It was considered that the cause of the jumping was that the minimum acoustic radiation force became larger than the weight of the object and the levitation distance at the minimum acoustic radiation force was less than the levitation distance at the maximum acoustic radiation force. Therefore, maximum peak distance needs to be known.

The purpose of the present study is to investigate the effect of the eigenmode in the cavity on the maximum peak of the acoustic radiation force.



(a) NFAL (b) Jumping phenomenon

Fig.1 The acoustic levitations.

2. Analysis model

Figure 2 shows the acoustic radiation force analysis model and parameters. The levitated object is acrylic, and the vibration source is aluminum. The analysis was performed using FEA software (COMSOL Multiphysics 5.6). The sound pressure p_1 was calculated using the acoustic structure interaction analysis. The particle velocity $\boldsymbol{u}_1$ was calculated as

$$\boldsymbol{u}_1 = \frac{i}{\omega \rho_0} \boldsymbol{\nabla} p_1. \tag{1}$$

Here, ω is angular frequency, ρ_0 is the density of air. The acoustic radiation pressure p_2 was obtained from p_1 and $\boldsymbol{u}_1$ using

$$p_2 = \frac{\langle p_1^2 \rangle}{2\rho_0 c_0^2} - \frac{\rho_0 \langle \boldsymbol{u}_1^2 \rangle}{2}, \tag{2}$$

where c_0 is the sound velocity of air, and brackets $\langle \cdots \rangle$ indicate a time average. The acoustic radiation force F_{rad} was obtained using

$$F_{rad} = \int_S p_2 dS = 2\pi \int_0^R r p_2 dr. \tag{3}$$

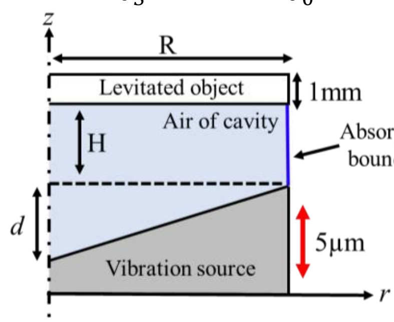


Fig.2 Acoustic radiation force analysis model.

Figure 3 shows the air eigenmode analysis model and parameters. In Fig.3, the air is surrounded by reflection boundary, and air cavity is formed. **Figure 4** shows the calculated eigenmode of the sound pressure analysis model in **Fig.3**. The calculated eigenmode in the cavity has high sound pressure near the center of the object. Additionally, the acoustic radiation force is expected to be the maximum peak for the eigenmode shown in **Fig.4**.

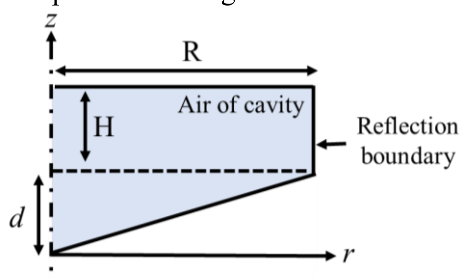


Fig.3 Air eigenmode analysis model.

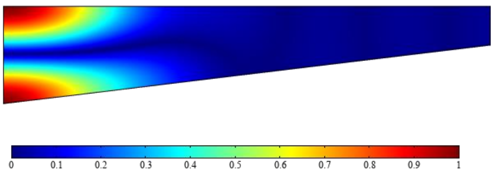


Fig.4 Eigenmode of sound pressure in the cavity.

3. Analysis results

Figure 5 shows the dependence of the acoustic radiation force F_{rad} on the vibration frequency (R = 25 mm, *d* = 3 mm). The frequency was changed 20 to 70 kHz each 100 Hz. In **Fig.5**, the frequency of first peak of F_{rad} is decreased by increasing the levitation distance H.

Figure 6 shows the dependence of the eigenmode frequency of similar sound pressure in **Fig.4** on the levitation distance H (*d* = 3 mm). The levitation distance H was changed 100 to 2,500 μm each 100 μm. The eigenfrequency was decreased by increasing H and radius R. Focusing on the case of R = 25 mm, *d* = 3 mm, and H = 1,000 μm in **Fig.5** and **Fig.6**, sound pressure modes were compared. **Figure 7** shows the sound pressure of the first peak at H = 1,000 μm in **Fig.5**. **Figure 8** shows the eigenmode of the sound pressure in the cavity of R = 25 mm and H = 1,000 μm in **Fig.6**. Both of these sound pressures are strong at the center of the bottom of the levitated object. Therefore, it is considered that the acoustic radiation force becomes large because the distribution of the sound pressure shown in **Fig.7** is similar to the eigenmode shown in **Fig.8**.

4. Summary

The sound pressure in the cavity formed with the vibrating surface and the bottom of the object was calculated using the acoustic structure interaction analysis and the eigenmode analysis. The appearance of the maximum peak of the acoustic radiation force with respect to the levitation distance was predicted by the eigenfrequency of the cavity.

In our future work, the maximum peak of the acoustic radiation force will be calculated for various vibrating surfaces.

References

1. Y. Hashimoto, Y. Koike and S. Ueha: J. Acoust. Soc. Jpn. **16**, 3 (1995).

2. K. Aono and M. Aoyagi: Proc. of Spring Meet of ASJ, 1-4-2 (2019) 29. [in Japanese]

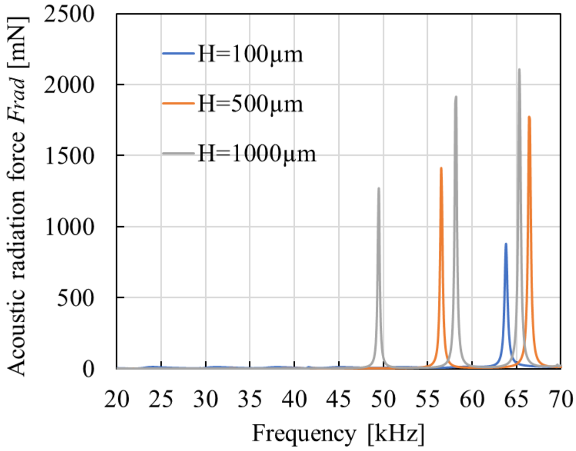


Fig.5 Frequency vs. acoustic radiation force F_{rad}.
(R = 25 mm, *d* = 3 mm)

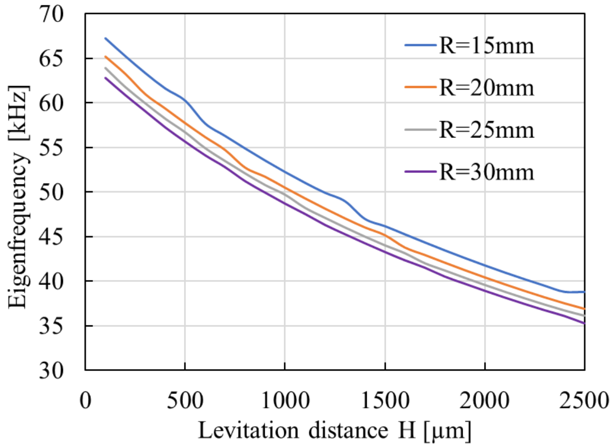


Fig.6 Levitation distance H vs. eigenfrequency.
(*d* = 3 mm)

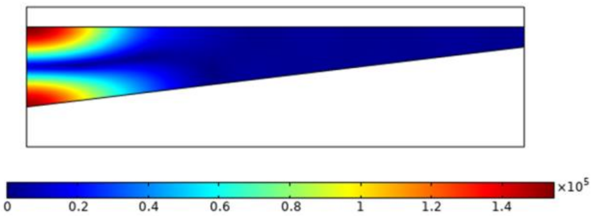


Fig.7 Sound pressure of the first peak selected from Fig.5.
(R = 25 mm, *d* = 3 mm, H = 1,000 μm, 49,500 Hz)

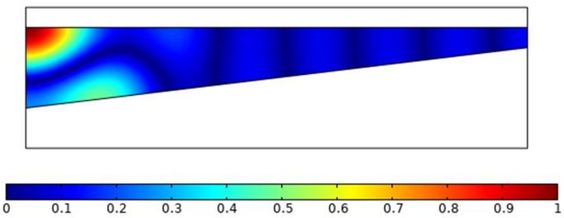


Fig.8 Eigenmode of sound pressure under the conditions selected from Fig.6.
(R = 25 mm, *d* = 3 mm, H = 1,000 μm, 49,845 Hz)

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