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Industrial Ultrasonic Levitation Machine Using Conventional Sound Systems – Theoretical and Simulation Investigation –

通常の音響系による産業用超音波浮揚装置 – 理論とシミュレーションによる検討 –

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1. Introduction

Levitations are interesting phenomena which will become very promising tools to compound new materials in the future. They have been well known in several media, such as magnetic, ultrasonic, electrostatic fields. Meissner effect is the most popular phenomenon to levitate magnets over super conductive materials. However, its application is limited to specific area due to the requirement of extremely low temperature environment. As for ultrasonic levitation, theoretical calculation was conducted about 50 years ago. During recent 20 years, many papers about levitations were published. However most papers have focused on physical issues. Industrial applications in the field have not been discussed so lively. The notable application was for Space Lab. In material experiments in Space Shuttle, the ultrasonic levitation was used to keep the materials in a chamber. There are a lot of demands to use such phenomena in industrial fields, especially in chemical, pharmaceutical areas, etc. However, today's levitation instruments limit their applications to very specialized requirements. Because Langevin-type transducers, whose sizes are a bit large, are used to excite high power ultrasonic waves of 130-150 dB. The peripheral devices to drive and control the transducers are also rather bulky.

We have studied the possibility of industrial levitation machines using conventional sound technologies such as magnetic-coil loud speaker, etc. In this paper, we investigate the already published levitation instruments consisting of Langevin-type transducers first. By using COMSOL simulator, sound pressure distributions within Fabry-Perot resonator, i.e. between transducer and reflector, are obtained. Based on the simulation results and theoretical examination, we make clear the required sound pressure and amplitude of vibrating plate. Radiation resistances from vibrating circular plate are also calculated, which will be very important to design the industrial machines.

2. Ultrasonic levitation using Langevin-type transducer

There have been many papers about ultrasonic levitations. A typical levitation instrument using Langevin-type transducer is shown in Fig. 1(a). Experimental results at 19.9 kHz cited from the paper of M. A. B. Andrade, et al [1] are shown in Fig. 1(b) to (d). Styrofoam spheres are levitated in air at positions determined by the distances between the transducer and reflector as shown in the photos. But three points should be considered to achieve industrial machines; (1) levitation area is small, (2) Langevin-type transducer is large, (3) external driver must provide very high voltages.

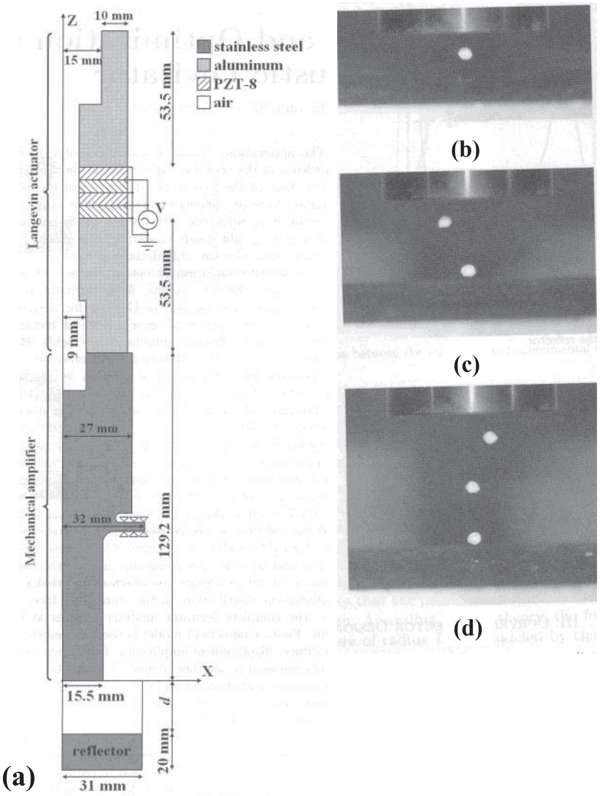

Fig. 1 Example of levitation instrument and experimental results (form M. A. B. Andrade, et al. [1]). (a) Langevin-type transducer at 19.9 kHz; (b) d = 9 mm; (c) 18 mm; (d) 26.5 mm.

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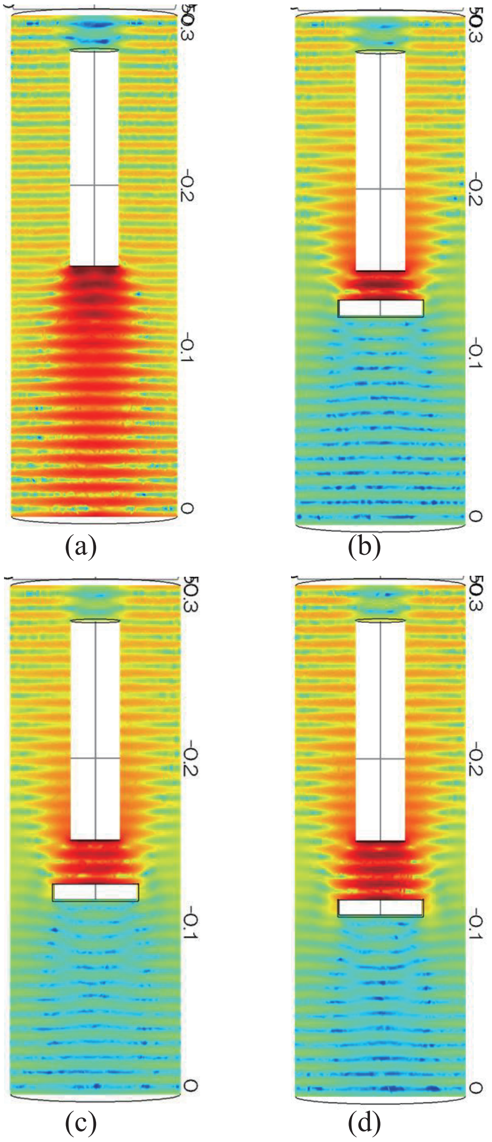

(a) (b)

(c) (d)

Fig. 2 Sound pressure distributions at 20 kHz by COMSOL simulator (corresponding to M. A. B. Andrade's experiment). (a) Radiation pressure distribution without reflector; (b) Two pressure standing waves between transducer and reflector; (c) Three standing waves; (d) Four standing waves.

3. Simulation of ultrasonic pressure field exited by Langevin transducer

Sound pressure distributions simulated by COMSOL simulator are shown in Figs. 2, whose physical parameters are almost same as M. A. B. Andrade's experiment. Fig. 2(a) is the simple radiation pressure distributions, while Fig. 2(b), (c) and (d) are cases of 2, 3 and 4 standing waves respectively. Sound pressure increase due to energy trapping within Fabry-Perot resonator is 10-15 dB (not shown in the figure).

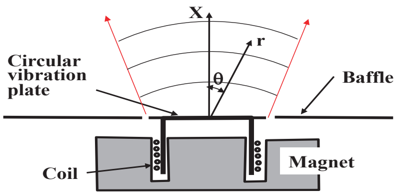

Fig. 3 Cross-sectional view of baffle magnet-coil speaker.

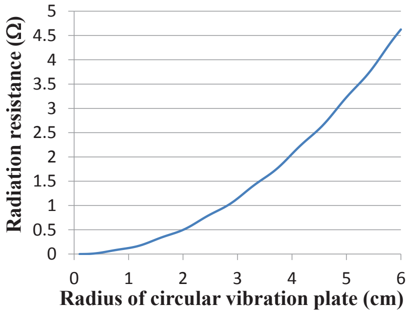

Fig. 4 Fig. 3's radiation resistance.

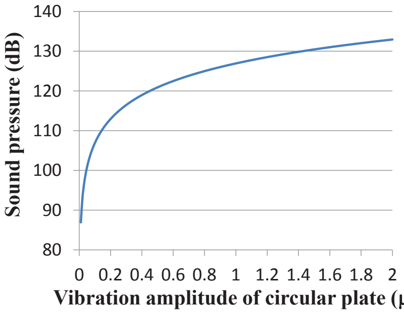

Fig. 5 Fig. 3's sound pressure at 3.4 cm height vs vibration amplitude with r=1.5 cm.

4. Theoretical investigation of replacement by conventional sound devices

Assuming Fig. 3's baffle magnet-coil flat speaker, we theoretically calculated radiation resistance (Fig. 4) to achieve impedance matching. We also calculated sound pressure at 3.4 cm height in case of r=1.5 cm same as Langevin transducer (Fig. 5). The pressure increases by 10-15 dB from simulation, which requires 125 dB pressure and 0.8 μm amplitude.

5. Conclusion

We have studied industrial levitation machines. COMSOL simulation and theoretical investigation results were presented.

References

1. M. A. B. Andrade, et al, IEEE Trans. on UFFC, Vol. 57, No. 2, pp.460-479, 2010.
2. T. Ando and M. Hikita, in Proc. of Symp. on Ultrason. Electron. Vol. 34, pp.431-432, 2013.