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Basic analysis and trial of an ultrasonic levitation device using a spherical cavity resonator with a single 40kHz transducer

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1. Introduction

Manipulation techniques for moving and holding small and planar objects objects using a non-contact method have attracted research attention. [1-2] In the field, a number of small ultrasonic emitters, whose original purposes are distance measurement and detection, are used to act on objects in space. [3]

In contrast, we are interested in the trapping performance in a resonant sound field formed by a single ultrasonic emitter transducer. As a first step in the study, the dimensions of the resonator cavity were determined using FEM to obtain antisymmetric modes that could trap an object in the center of the device. The realization of the trap was then confirmed experimentally.

2. Eigen frequencies of antisymmetric modes

A schematic of the prototype device is shown in **Fig. 1**. The spherical reflective wall (diameter D_c) has inlet and outlet holes (diameter D_i) on opposite sides. An optical 3D printer was used to form the inner wall of the spherical reflection, the through-hole for the 9.8 mm diameter transducer (UT1007-Z325), and the fixture for the measurement system.

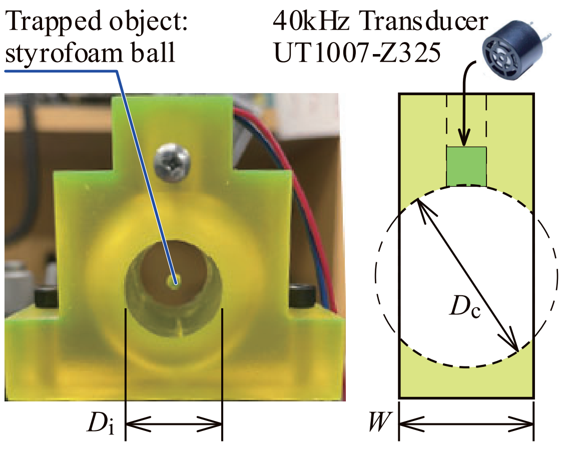
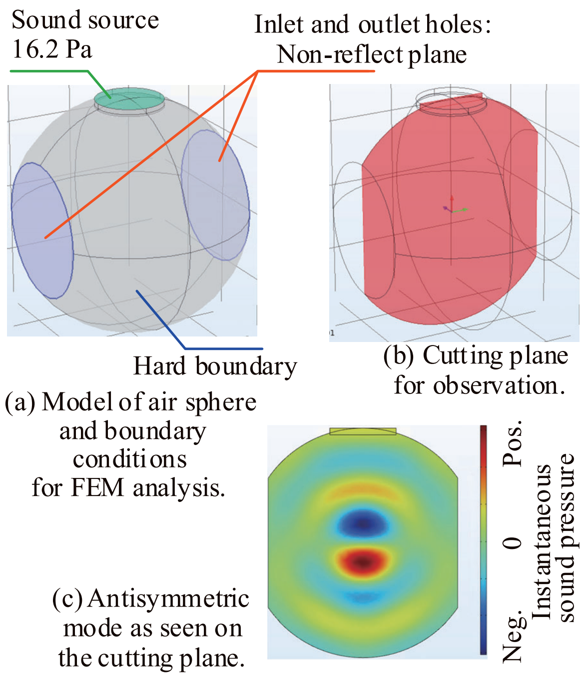


Fig. 1 Spherical cavity resonator with inlet and outlet holes excited by a single transducer.

To determine the diameter of the resonant cavity D_c, an Eigenfrequency analysis was computed using FEM with COMSOL Multiphysics.

The analytical model is shown in **Fig. 2**(a). The outer circumference of the spherical air was defined as the reflecting surface, and the apertures



(a) Model of air sphere and boundary conditions for FEM analysis.

(b) Cutting plane for observation.

(c) Antisymmetric mode as seen on the cutting plane.

Fig. 2 FEM analysis model and a resonant sound pressure profile of antisymmetric mode.

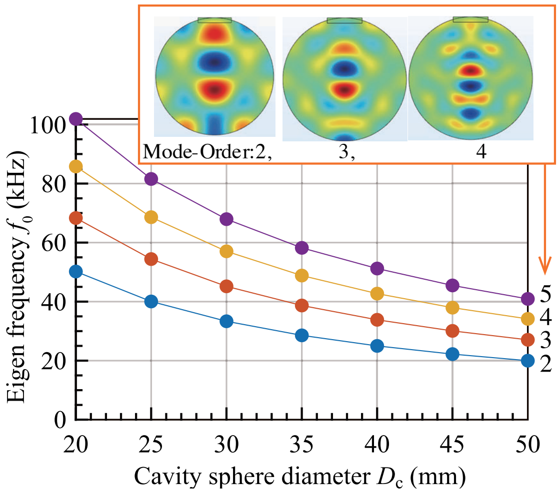


Fig. 3 The Eigenfrequencies of the antisymmetric modes in a spherical cavity with no holes (D_i = 0) as a function of the diameter D_c.

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were assigned as non-reflecting. The upper part of the model has a sound pressure radiating surface corresponding to the emitter transducer. The central cross-section of the model was used as the observation plane shown in Fig. 2(b), and the antisymmetric mode shown in Fig. 2(c) was one of the target modes. Its antisymmetric mode can trap a small object in the center of the resonator cavity.

The Eigenfrequencies of the antisymmetric modes become lower as the cavity diameter D_c increases. The results for some higher order modes are shown in **Fig. 3**.

3. Analytical results for aperture diameter

The frequency response analysis required the sound wave attenuation value in air, which was extrapolated from ref. [4] and applied by estimating the attenuation value at 40 kHz to be 670 dB/km.

Thereafter, a cavity diameter D_c = 34.3 mm and mode-order = 3 are used. These are based on the result that the internal sound pressure is maximum at the aperture diameter D_i = 0 mm (no holes).

The maximum sound pressure P_{max} in the antisymmetric mode obtained by frequency response analysis around the Eigenfrequencies for different aperture diameters D_i is shown in **Fig. 4**. The maximum sound pressure P_{max} at D_i = 0 mm was 78 Pa, and the sound pressure decreased slightly up to D_i = 12.5 mm (D_i / D_c = 36%).

4. Experimental Results

Three prototype levitator devices with aperture diameters D_i of 24 , 17 , and 10 mm were fabricated and evaluated. The admittance frequency responses of resonator/transducer integrated devices are shown in **Fig. 5**. A large peak near 40.8 kHz and several spurious modes at frequencies around the peak are observed.

A styrofoam ball with a diameter of 2.8 mm and a weight of 0.4 mg is used as a floating object, and the trapping state was evaluated with a drive voltage of about 43 V_{p-p}, 14 mA_{rms}.

For aperture diameters D_i of 24 mm, 17 mm, and 10 mm, the strongly trapped driving frequencies were 40.5 kHz, 40.2 kHz, and 40.3 kHz, respectively.

The ball is strongly trapped near the center of the cavity in the initial direction of gravity g shown in **Fig. 6**. When the levitator device is rotated around the θ or ψ axis from the initial holding direction, the holding force decreases and the ball may fall. Under the above conditions, the devices with D_i = 17 mm and 10 mm were able to hold the ball without dropping them even when either the θ axis or the ψ axis was rotated 360°.

Although a qualitative result, the larger the aperture D_i, the easier it is for floating objects to fall when the levitator is rotated and shaken. The holding force will be measured in the future.

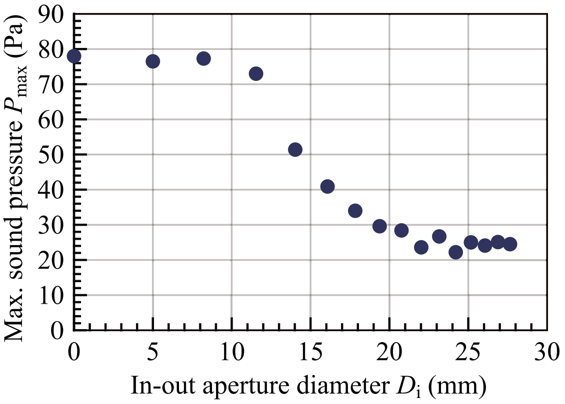

Fig. 4 Variation of maximum sound pressure P_{max} in antisymmetric mode depending on D_c.

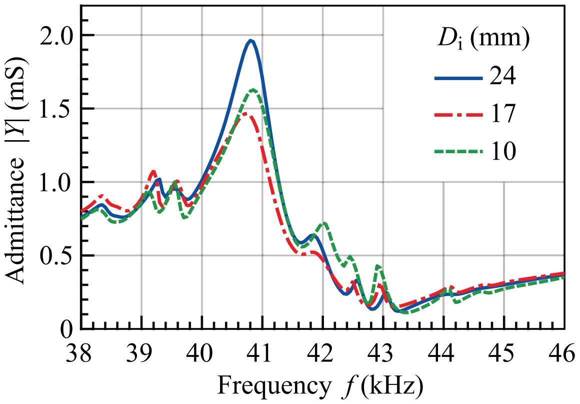

Fig. 5 Admittance frequency responses of resonator/transducer integrated devices.

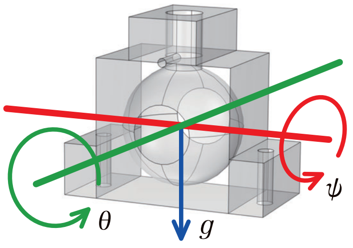

Fig. 6 Initial gravity direction and rotation axis of the levitator device.

References

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