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Effects of trapped particle size on acoustic radiation force in standing wave fields

Teruyuki Kozuka[1†], Taisei Okeda[1], Kyuichi Yasui[2], Masahiro Toyoda[3], and Shin-ichi Hatanaka[4] ([1]Aichi Inst. Tech.; [2]AIST; [3]Honda Electronics; [4]Univ. Electro-Comm.)

1. Introduction

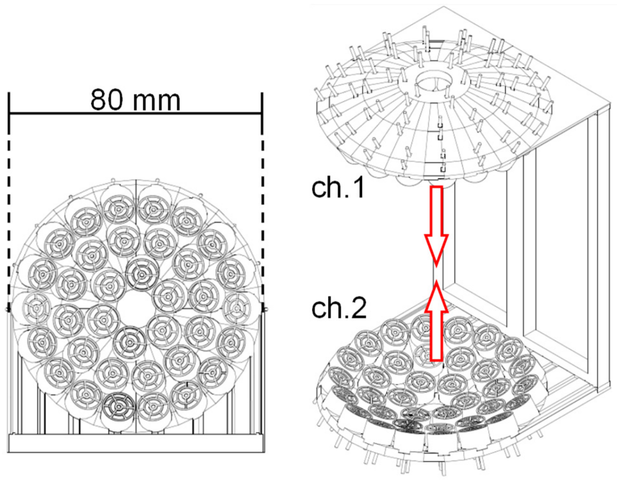
In micromachines and biotechnology, there is a need for technology to manipulate small objects in a non-contact manner. The authors have fabricated a sound source by arranging a number of small ultrasonic transducers, which are used in ultrasonic distance meters and other devices, on a concave base to focus ultrasonic waves toward a geometric focal point. Then, attempts have been made to trap and manipulate small objects at the nodes of sound pressure in the standing wave field formed by superimposing ultrasonic waves from multiple sound sources [1,2].

Two sound sources consisting of 36 ultrasonic transducers were used to superimpose ultrasonic waves from two directions to form a standing wave field. In the standing wave field in the air, a force from the antinode of the sound pressure to the node acts on solid particles that are sufficiently small compared to the wavelength of the ultrasound. Lightweight objects such as foamed polystyrene are capable to be levitated at the nodes of the sound pressure in the standing wave field. In the present study, the acoustic radiation force acting on an object in a standing wave field is evaluated by suspending an iron ball and measuring the load on the iron ball. The effects of different sizes of iron balls are also examined.

2. Experimental Apparatus

Figure 1(a) shows a single sound source array and (b) the arrangement of the two sound sources. The ultrasonic transducers used in this study were UT1007-Z325R manufactured by SPL (frequency 40 kHz, cylindrical shape with a diameter of 10 mm × height of 7 mm). A focused sound source was fabricated by placing 36 of these transducers on a concave base with a 70 mm radius of curvature, which was fabricated using a 3D printer. The sound source was bowl-shaped, with a portion of a sphere with a radius of 70 mm cut out in a circular shape (approx. 80 mm in diameter). These two sound sources were placed top and bottom so that their geometric focal points were coincident. A hole of 10 mm diameter was drilled in the center of the upper sound source to pass a thread through which the iron ball was suspended.

kozuka-t@aitech.ac.jp



(a) Transducer array source (b) Position of two sources
Fig. 1 Sound source composition and arrangement.

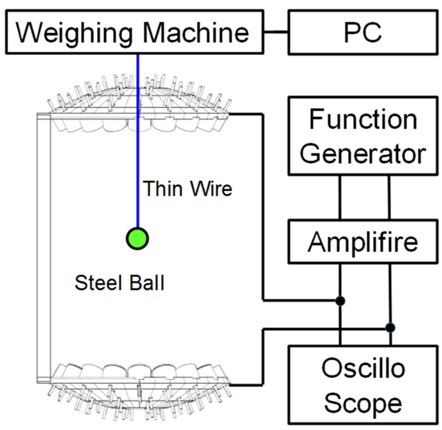


Fig. 2 Schematic view of experimental apparatus.

Figure 2 shows a schematic diagram of the experiment. A 40.0 kHz sinusoidal AC wave generated by a function generator (NF, WF1948) was amplified by an audio amplifier (YAMAHA, A-S301) and a voltage of 40.0 V_{pp} was applied to ultrasonic transducers to radiate ultrasonic waves to form a standing wave field. An iron ball with a string attached was placed near the center of the sound field. The string was attached to a hook at the bottom of an electronic balance (A&D, FX-500i) to measure the load of the iron ball. With the iron ball suspended, a zero reset was performed before the experiment to measure the change in the load of the iron ball due to the acoustic radiation force in the standing wave field. The electronic balance was connected to a PC to automatically measure the load at 0.5 s intervals.

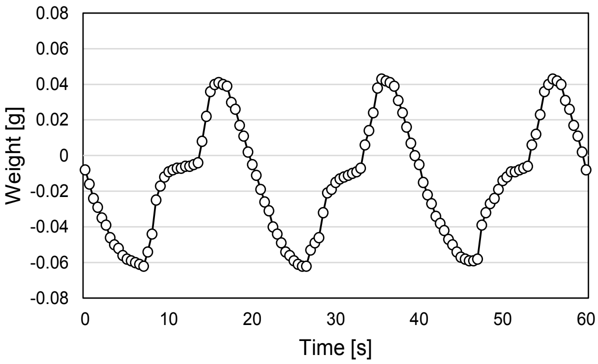
3. Results and Discussion

A voltage of 40 kHz and 40 V_{pp} was applied to the sound sources to form a standing wave field. An iron ball was placed between the upper and lower sound sources. If the node of sound pressure near the iron ball is above the iron ball, the force acts in the direction of lifting the iron ball, and the load on the iron ball becomes lighter. Since the distance between pressure nodes at 40 kHz ultrasound is 4.25 mm at half-wavelength, it is difficult to precisely adjust the relative positions of the iron ball and the pressure nodes. Therefore, we attempted to make the pressure nodes move up and down continuously by applying a slight difference in ultrasonic source frequencies. A difference of 0.05 Hz in the frequencies of the two sources would cause the distribution of pressure nodes and antinodes in the standing wave field to move continuously at a rate of one cycle every 20 s. **Figure 3** shows the variation of the load for approximately one minute when the upper source frequency was fixed at 40 kHz and the lower source frequencies were (a) 40.00005 kHz and (b) 39.99995 kHz. In Fig. 3(a), the iron ball is observed to lighten gradually from +0.04 g to –0.06 g as the sound field moves from the bottom to the top. Eventually, when the iron ball reaches the position of the sound pressure antinode (the sound pressure nodes are equidistant above and below), the ultrasonic force ceases to act and the load becomes 0 g. Then, it is pulled by the next node of sound pressure approaching from below, and the load becomes +0.04 g, the maximum load, and then gradually lightens again, which is repeated in a 20-second cycle. In Fig. 3(b), the opposite change is observed.

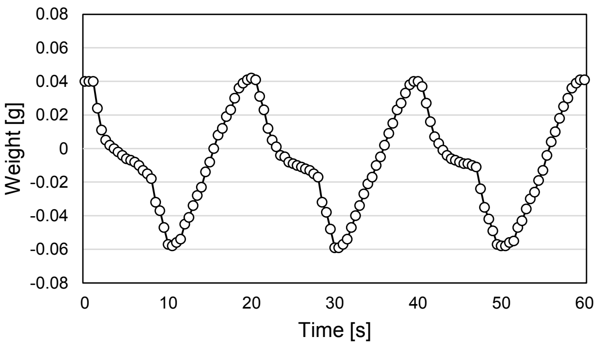
Next, we conducted an experiment by changing the size of the iron ball. **Figure 4** shows the results of the same experiment using two different sizes of iron balls, (a) φ2.5 mm and (b) φ3.5 mm. The frequency of the lower sound source was 40.00005 Hz. It can be seen that the larger the iron ball, the greater the load acting on it.

4. Conclusions

In an ultrasonic standing wave field, an object sufficiently small compared to its wavelength is trapped in a node of sound pressure. To evaluate the force acting on a sphere, the load applied to an iron ball suspended in a standing wave field was measured. Experiments were conducted varying the size of the iron ball, and it was confirmed how the force acts on the iron ball smaller than half a wavelength, and that the larger the ball, the greater the force acting on it.

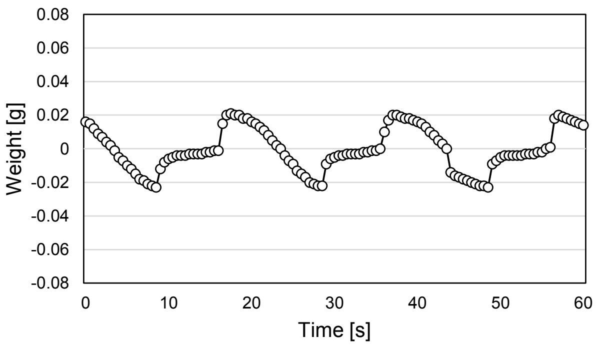


(a) 40.00005 kHz

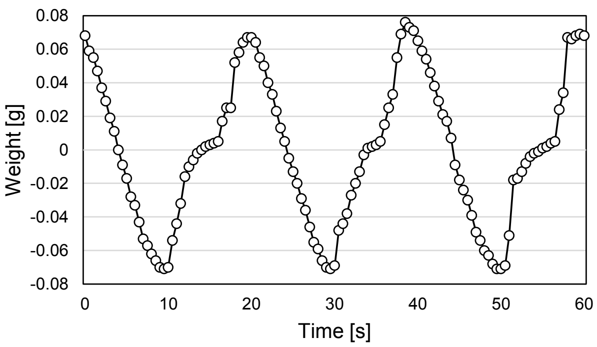


(b) 39.99995 kHz

Fig. 3 Influence of different frequencies on load changes acting on the iron ball of φ3 mm.



(a) φ2.5 mm



(b) φ3.5 mm

Fig. 4 Influence of different iron ball sizes on load changes acting on the iron ball.

References

1. T. Kozuka et. al.:Jpn. J. Appl. Phys. 60 (2021) SDDD18.
2. T. Kozuka et. al.:Jpn. J. Appl. Phys. 61 (2022) SG1063.