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Influence of frequency characteristics of ultrasonic transducers on acoustic levitation

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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 ultrasonic sources that are focused in air using a large number of small ultrasonic transducers. Then, they attempted to trap and manipulate small objects in standing wave fields formed by the superposition of ultrasonic waves from multiple sound sources [1–2].

Now, there are individual differences in the characteristics of transducers, and when multiple transducers are used, it is necessary to minimize the influence of variations in the characteristics of the transducers. In this study, 36 transducers are used to construct one sound source. The acoustic radiation forces acting on a small object were examined for the case where the sound source was constructed by randomly selecting the transducers and for the case where the sound source was constructed by selecting the transducers in resonance frequency.

2. Experimental apparatus

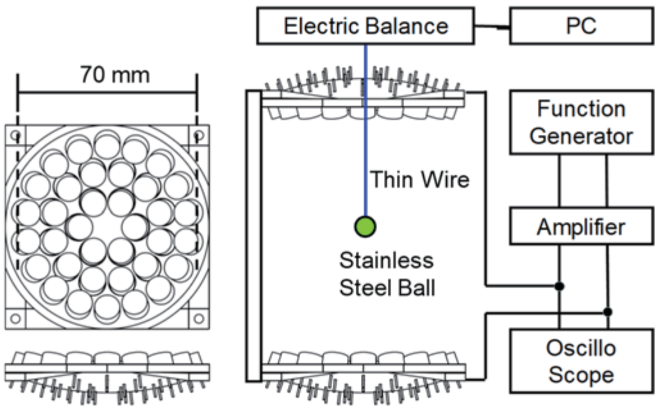
The ultrasonic transducers used in this study were SPL's UT1007-Z325R (frequency 40 ± 1 kHz, cylindrical shape with a diameter of 10 mm × height of 7 mm). A focused ultrasonic source was fabricated by placing 36 of these transducers on a concave base with a 70 mm radius of curvature, which was fabricated using a 3D printer. The two sound sources were placed above and below each other so that their geometric focal points were coincident. **Fig. 1(a)** shows the configuration of one sound source, and **Fig. 1(b)** shows the experimental setup. A hole of 10 mm diameter was drilled in the center of the sound source to pass a thread through which a 3 mm diameter stainless steel ball was suspended. The ball was attached to an electronic balance above, and changes in weight were measured at 0.5 s intervals.

The 40.0 kHz sine wave generated by the function generator (NF, WF1948) is amplified by an audio amplifier (YAMAHA, A-S301), and a voltage of 40.0 Vpp is applied to the transducers. A standing wave field is formed between the sound sources. A ball placed at the center of the standing wave field is subjected to a force from the antinodes of the sound pressure toward the nodes. When the node of the sound pressure is above, the force acts in the direction of lifting the ball, so the weight of the ball measured by the electronic balance becomes lighter. Conversely, if the node of sound pressure is below the ball, the weight is heavier.

It is difficult to adjust the position of the sound pressure node and the position of the ball. Therefore, by adjusting the frequency of the lower source to 0.05 Hz lower than that of the upper source, the distribution of pressure nodes and antinodes in the standing wave field will move continuously in a 20-second period.

The impedance analyzer (IM3570, HIOKI) was used to measure the resonance frequencies of the transducers. **Fig. 2** shows an example of the frequency distribution of 240 transducers at 0.1 kHz intervals from 39.0 kHz to 41.0 kHz, centered at 40.2 kHz. 72 transducers around 40 kHz were selected to fabricate two sound sources.

This study compares the acoustic radiation



(a) Sound source (b) Experimental apparatus

Fig. 1 Experimental apparatus.

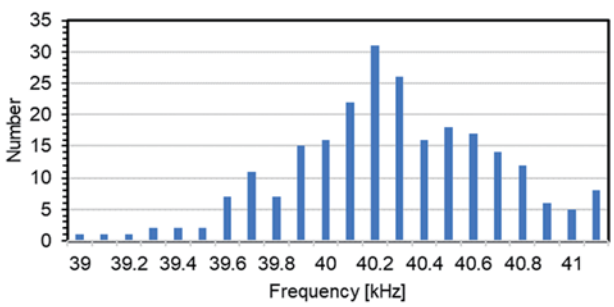


Fig. 2 Histogram of resonance frequencies for transducers.

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force acting on the ball using the sound sources composed of ultrasonic transducers (randomly selected with respect to frequency), which have been used in the past, and the sound sources composed of transducers with a resonance frequency of around 40.0 kHz, which is prepared in the present study.

3. Experimental results

Fig. 3 shows the change in weight during 60 s when the sound sources were driven at 40 kHz and 40 Vpp. Fig. 3(a) shows the conventional sound sources (without frequency selection), and Fig. 3(b) shows the newly prepared sound sources (selected with a resonant frequency of around 40.0 kHz). Since the difference in frequency (ch.1: 40 kHz, ch.2: 39999.95 Hz) is 0.05 Hz, the sound pressure distribution shifts downward in a 20-second period, and the weight of the ball changes in the same period. In the case of the sound sources with frequency-selected transducers (Fig. 3(b)), the weight changes significantly.

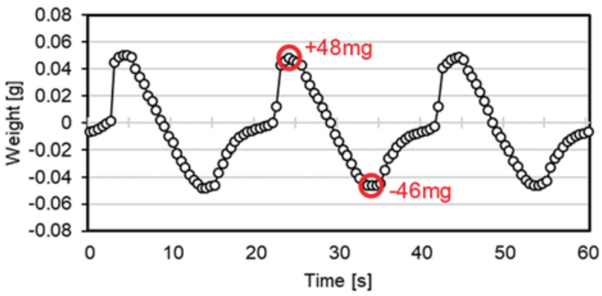
Next, the frequency was varied from 39.0 kHz to 41.0 kHz in 0.1 kHz increments, and the same experiment was conducted. After the 60 s experiment, an interval of at least 60 s was allowed before the next experiment. The maximum and minimum values for one cycle from 20 s to 40 s in each experiment are summarized in **Fig. 4**. The change in weight for the frequency-selected sound sources is particularly large from 40.0 kHz to 40.4 kHz. In contrast, the conventional sound sources without frequency selection do not show such a great change.

4. Discussion

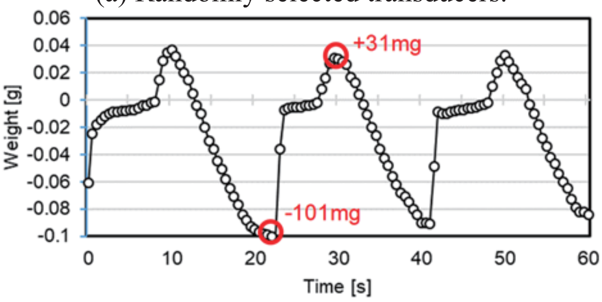
In this experiment, weight changes were observed for three cycles (60 s), and the data for the central 20 s were used to produce the results shown in Fig. 4. However, the data may differ slightly from cycle to cycle. Therefore, we conducted a continuous driving experiment for 5 minutes (300 s, 15 cycles), and observed that the range of weight change became smaller as the cycles were repeated. This is probably due to the change in resonance frequency caused by the rise in temperature by continuous driving.

5. Conclusion

To investigate the influence of the frequency characteristics of ultrasonic transducers on the acoustic radiation force, we evaluated the force applied to a stainless steel ball using sound sources composed of transducers selected at the same resonant frequency and those of randomly selected transducers. It was found that selecting transducers with the same resonance frequency resulted in a powerful force. In addition, the force weakened with time in the continuous drive, probably because of the effect of heat generation.

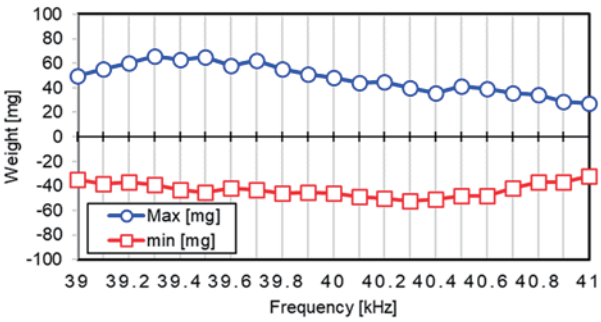


(a) Randomly selected transducers.

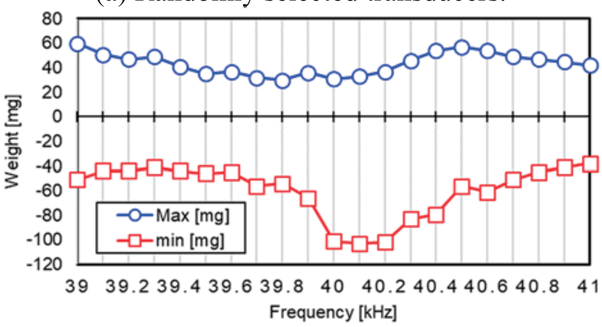


(b) Selected transducers around 40.0 kHz.

Fig. 3 Weight changes for 60 s at 40 kHz and 40 Vpp with and without transducer selection.



(a) Randomly selected transducers.



(b) Selected transducers around 40.0 kHz.

Fig. 4 Maximum and minimum values for weight change per cycle as a function of frequency.

References

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