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Non-contact manipulation of particles using ultrasonic speakers

超音波スピーカを用いた非接触微粒子操作

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1. Introduction

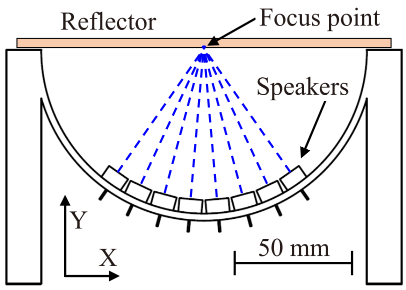
In recent years, there is a demand for non-contact manipulation of small objects in the fields of micromachines and biotechnology. The acoustic radiation pressure of ultrasound can be used to capture and manipulate small objects without contact. Traditionally, research has been performed using Langevin-type transducers to emit powerful ultrasonic waves. In recent years, many studies have been carried out to capture objects in a sound field formed by arranging a number of small ultrasonic speakers used for ultrasonic sensors [1,2].

In many of these studies, the focal point of the sound field is moved by changing phase differences between the signals given to the ultrasonic speakers. Although it is a very interesting technique, the electrical control is considered to be complicated and inefficient.

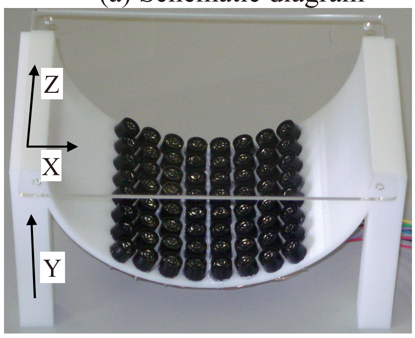
In this paper, ultrasonic speakers were arranged on a semi-cylindrical base and the sound waves were focused on the central axis of the cylinder. Then, a standing wave field were formed by placing a reflector on the surface containing the central axis and trapping an object at the pressure node. By switching the driving ultrasonic speakers, we tried to move the object trapped at the pressure node.

2. Experimental apparatus

Fig. 1 shows the experimental apparatus. Figs. 1(a) and 1 (b) show a schematic diagram and a photograph, respectively. Ultrasonic speakers were arranged on the inner wall of the semi-cylinder to focus the ultrasonic waves on the central axis of the cylinder [3]. The semi-cylindrical base was made by a 3D printer. The ultrasonic speaker was an SPL UT1007-Z325R. The radius of curvature of the inner surface was about 70 mm, there was a dent of 2 mm at the place where the speaker was placed, and the radius of curvature of the speaker surface was 65 mm. The central angle of the cylinder between the adjacent speakers was about 10 degrees. The central angle of the range of 64 ultrasonic speakers arranged on the cylinder was 80°. The wiring was configured such that 8 speakers in the circumferential direction were connected in parallel as one group, and a position to apply a voltage can be selected by a switch for each of the eight turns.



(a) Schematic diagram



(b) Photograph

Fig. 1. Experimental apparatus.

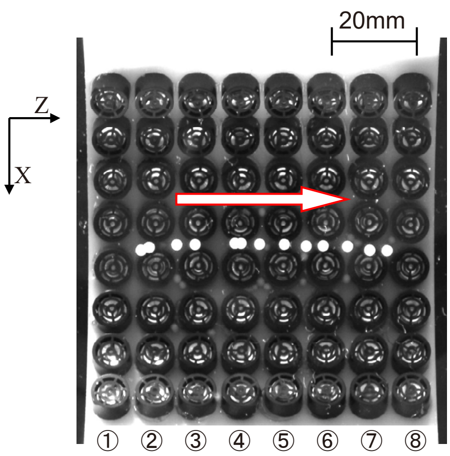


Fig. 2. Manipulation of a particle.

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3. Experiment and Results

Ultrasonic waves were radiated by applying a 20 V_{pp} sinusoidal signal at 40 kHz to the ultrasonic speakers of multiple consecutive circumferences. When a foamed polystyrene particle was placed above the driven ultrasonic speakers and near the acrylic plate, it levitated without contact.

An experiment was performed to move the captured particle by switching the driving ultrasonic speakers. **Fig. 2** shows an example of the results. First, ultrasonic waves were radiated from the two rows of the speakers at the left end (①,②) to capture a foamed polystyrene particle at the left end. Next, when the ultrasonic speakers in the third row (③) were driven, the particle moved to the right by a half width of the speaker. Then, when the ultrasonic speakers in the first row (①) were turned off, the particle moved to the right by a further half width of the speaker. By repeating this operation, the particle can be moved from left to right. Note that Fig. 2 is an image in which a moving state of the particle was captured by video, and the images of the particle at respective positions were superimposed on the image of Fig. 2.

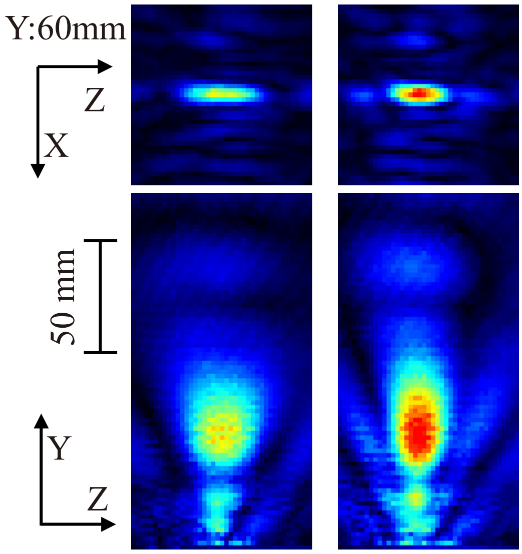
4. Discussion

In order to find out how the sound waves were focused, we removed the acrylic plate, inserted the microphone from above, and moved it every 2 mm to measure the two-dimensional distribution of sound pressure. **Fig. 3** shows sound pressure distributions when two adjacent rows of the speakers were driven (a) and when three adjacent rows of speakers were driven (b). A vertical plane of 80 mm × 160 mm and a horizontal plane near the position of the captured particle were measured. It can be seen that the sound pressure distributions in the second row and the third row differ in the magnitude of the sound pressure due to the difference in the applied power, but the shapes of the sound pressure distributions are almost the same. It can be seen that the sound pressure is extremely high near the focal point. From the sound pressure distribution on the horizontal plane, it can be seen that the sound waves are concentrated in a particularly narrow range in the circumferential direction.

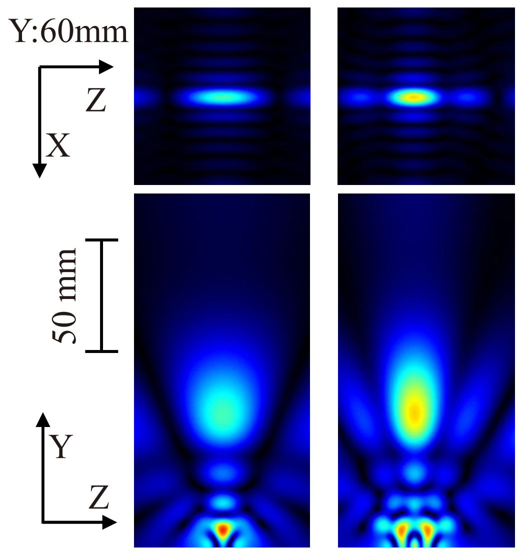
Fig. 4 shows the result of the sound pressure calculation by the Rayleigh equation. The sound source was a circular plate with a diameter of 7 mm. The sound pressure distributions agree well with the measurement ones of Fig. 3.

5. Conclusion

A large number of ultrasonic speakers were arranged on a part of the cylinder, and a reflector was placed on the focal line to form a standing wave field. A high sound pressure was formed near the focal line, and it is possible to capture a small object in the sound pressure node of the standing wave field. By switching the driving ultrasonic speakers, the pressure node in the standing wave field can be moved and the captured object can be manipulated without contact.



(a) 2 rows driven. (b) 3 rows driven.
Fig. 3. Measurement sound pressure distribution.



(a) 2 rows driven. (b) 3 rows driven.
Fig. 4. Calculated sound pressure distribution.

References

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