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Non-contact acoustic manipulation in air using several sound sources

複数音源による空中超音波マニピュレーション

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1. Introduction

In micromachining and biotechnology, there is a need for technology to manipulate micro-objects without contact. The authors have shown that it is possible to form a standing wave field by interfering multiple sound waves in water, trap a small object in the sound pressure node, and manipulate it in a noncontact manner by controlling the phase of each sound wave [1].

In the same way, manipulation using standing waves in air was investigated. In order to radiate ultrasonic waves of several tens of kHz into the air, it is effective to use small ultrasonic transducers such as those used in ultrasonic rangefinders. Although an ultrasonic wave radiated from a single transducer is weak, a powerful sound field can be realized by focusing ultrasonic waves radiated from many transducers [2]. One-dimensional manipulation, in which a small object is trapped and moved in the axial direction of the cylinder, has been achieved using a standing wave field formed by arranging ultrasonic transducers on the inner wall of a semicylinder and a reflector on the surface containing the central axis of the semicylinder [3].

In this study, 36 small ultrasonic transducers are arranged on the inner wall of a semicylinder to form an ultrasonic beam. By superimposing these beams from three directions, a two-dimensional standing wave field is formed. When small objects were placed in the standing wave field, it was possible to trap the objects in the nodes of the sound pressure. In addition, by controlling the phases of the three sound sources, we tried to move the trapped objects.

2. Experimental apparatus

The ultrasonic transducers used in this study were UT1007-Z325R (10 mm in diameter × 7 mm in height, cylindrical shape) manufactured by SPL. Thirty-six of these transducers were arranged on the inner wall of a semicylinder of radius 100 mm, approximately 60 mm × 60 mm. **Figure 1** shows (a) a schematic and (b) a photograph of the arrangement.

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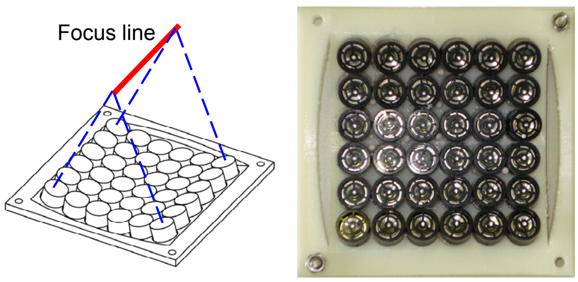
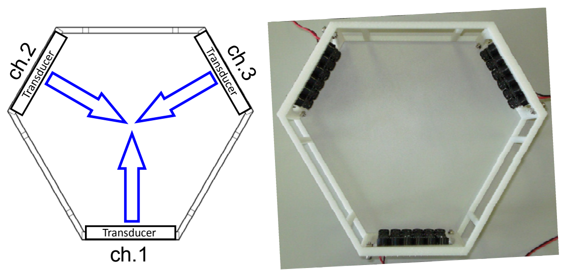
We fabricated three sound source units using these 36 ultrasonic transducers and placed them at the vertices of an equilateral triangle to create a device that radiates sound waves from three directions toward the center of the equilateral triangle. **Figure 2** shows a schematic and a photograph of the actual device. Two function generators (NF, WF1948) with 2 ch outputs were operated synchronously to generate 3 ch 40.0 kHz sinusoidal signals. The signals were amplified to a voltage of 30.0 V_{pp} by two stereo audio amplifiers (DENON, PMA-600NE) and applied to the ultrasonic transducers to radiate ultrasonic waves.



(a) Schematic (b) Photograph

Fig. 1. Array of 36 small ultrasonic transducers for sound beam formation.



(a) Schematic (b) Photograph

Fig. 2. Superimposing device for sound beams crossing from three directions.

3. Experiments and Results

Foamed polystyrene particles with diameters of 0.5 to 1.0 mm were injected into the center of the triangle, and it was confirmed that they were trapped by standing waves and levitated in the air.

Since the driving signals of the three sound sources are independent, it is possible to change the phase of any ultrasonic wave. When the phase was changed, the trapped position moved in the direction of the sound axis. In other words, it was possible to move the object trapped at the sound pressure node in two dimensions without contact.

Continuously changing the phase is equivalent to having a difference in frequency. **Figure 3** shows an example of the result when the frequency of ch. 2 is set to 39.999 kHz (ch. 1 and ch. 3 both remain at 40.000 kHz). The 5-second behavior was captured on video, and still images at 0.2-second intervals were extracted from the video and superimposed. The phase changed by 5 cycles in 5 s with the difference of 1 Hz in frequency. Since the sound field were formed over a wide area, multiple particles were trapped in the sound field. In Fig. 3, six particles were trapped. We can see that the particles are moving in the direction of ch. 2 (upper left). The speed of movement was constant and was about 5.8 mm/s.

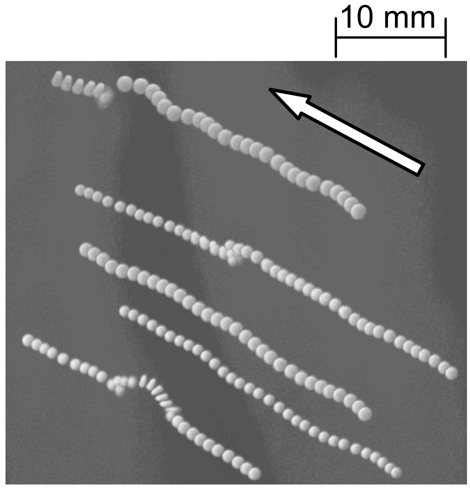


Fig. 3. Superimposed photograph of successive frames of a video showing the movement of six trapped particles.

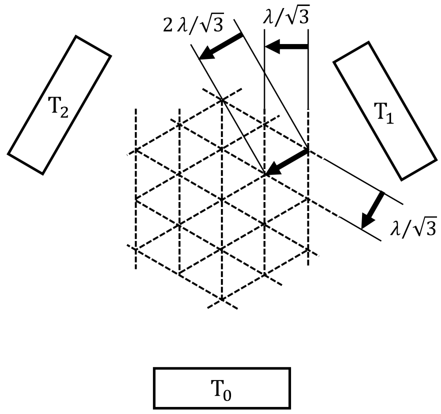


Fig. 4. Schematic of formed standing wave field by crossing three sound beams.

4. Discussion

An airborne ultrasonic wave of 40 kHz has a wavelength of 8.5 mm, assuming a sound velocity of 340 m/s in air. In the case of opposing sound waves, the nodes of sound pressure exist at half-wavelength intervals, but in this case, the sound waves from the three directions intersect at an angle of 120 degrees to form a standing wave field. **Figure 4** shows the nodal lines of the sound pressure. It can be seen that the nodes of the sound pressure move two-thirds of a wavelength when the sound wave changes by one cycle. **Figure 5** shows the numerical results of the sound pressure distribution caused by crossing three sound beams, showing that the hexagonal honeycomb-shaped sound pressure distribution in two dimensions.

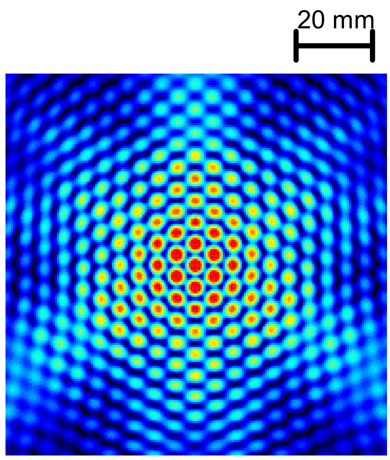


Fig. 5. Calculated sound pressure distribution at the intersection of three sound beams.

5. Conclusion

By irradiating airborne ultrasonic waves from three directions, small objects were trapped at the pressure nodes in the formed standing wave field, and by controlling the phase of the sound waves, it was possible to move the pressure nodes and the trapped object in the direction of each sound axis.

References

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