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Evaluation of the Rotation Speed of a Small Object Levitated by Ultrasound

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1. Introduction

Small objects can be trapped without contact using high-intensity ultrasound [1,2]. The ultrasonic noncontact manipulation can be applied to measurement techniques in the industrial field such as measurements of physical properties of high-temperature material over 2000 °C. Gravity-free environment can be realized by rotating the sound field, which allows convectionless crystal growth within a rotating droplet [3].

In this report, non-contact rotation of a small object using ultrasound standing wave in the air between a vibrator and a reflector was examined. The effects of the sound field between them on the rotation characteristics were investigated.

2. Methods

The vibration system consists of an aluminum vibrating disc (thickness: 3 mm; diameter: 210 mm), four bolt-clamped Langevin-type transducers (BLTs) with step horns attached to the disc, and two half-circular reflectors (reflector 1 and 2; diameter: 210 mm) arranged above the vibrating disc (**Fig. 1**). A continuous in-phase sinusoidal electric signal at the resonant frequency of 31.7 kHz was input to each BLT to excite the longitudinal vibration on the BLTs and the resonance flexural vibration on the disc. The distance between the vibrator and reflectors was approximately 30 mm so that an acoustic standing wave could be generated in the air between them. Polystyrene spheres (diameter of approximately 4 mm) were used as objects to be levitated and rotated. The tilt angles of the two reflectors to the vibrating disc was varied to induce the non-contact rotation of the object by changing four distance parameter 1 to 4 related to the distance between the vibrator and reflector (see **Fig. 1**). The rotation speed of the object and the sound pressure distribution between the discs were measured using a high-speed camera and a probe microphone, respectively.

3.Results and Discussion

An acoustic standing wave was generated in the vertical direction (z direction), and a small object was levitated around the center of the discs (**Fig. 2**). **Fig. 3** shows the normalized sound pressure amplitude and phase distributions between

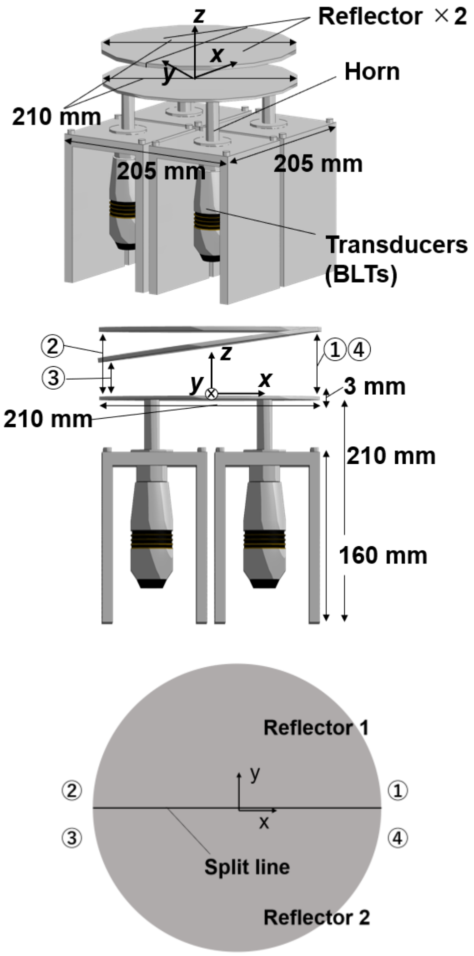

Fig. 1. (a) Configuration of the ultrasound vibrator and the reflectors and (b) (c) distance parameter 1, 2, 3, and 4.

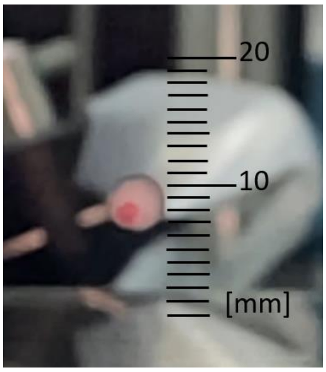

Fig. 2. Photograph of a polystyrene particle rotating in the ultrasound field.

the discs in the *x*-*y* plane at *z* = 4.7 mm around the center of the discs (an area of 30×30 mm^2 was scanned. *z* = 0 mm corresponds to the surface of the vibrator). In **Fig. 3(a)**, distance parameter 1, 2, 3, and 4 were 30.0, 25.3, 25.3, and 30.0, respectively, meaning both half-circular reflectors were inclined at 1.2° against the vibrator (we term these positions *both slopes*). When distance parameter 1 to 4 were 29.2, 29.2, 22.0, and 29.2, respectively, only one reflector was inclined (*one-side slope*, **Fig. 3(b)**). Dotted lines and Points P represent the split lines of reflector 1 and 2 and the antinodal position of the sound pressure around the center of the discs where the object was levitaited, respectively. The maximum sound pressure amplitudes in *both slopes* and *one-side slope* were 0.36 and 0.38 kPa, respectively, when the input voltage was 120 V_{pp}. The phase distributions in the two cases changed gradually in the *x* direction in *both slopes* although it changed diagonally in *one-side slope*. These results mean that the acoustic traveling wave propated in the positive *x* direction (left to right) due to the asymmetric arrangement of the reflectors.

In both modes, the small object was rotated without contact. **Fig. 4** shows the the change in the rotation speed of the object with respect to time in the both modes when the input voltage was 120 V_{pp}. The rotation speeds in *both slopes* and *one-side slope* were 1.54±0.31 and 2.99±0.16 rps, respectively. The rotation speed in *one-side slope* is higher and more stable than those in *both slopes*. This is because, in *both slopes*, the rotation torque in both rotation direction acted to the object since the distance parameter 1 to 4 were axisymmetric to the *x* axis. In fact, the rotation direction of the object was sometimes switched. On the other hand, in *one-side slope*, only reflector 2 was inclined to the vibrator (reflector 1 was parallel), resulting in that the traveling in the horizontal direction (positive *y* direction) was generated under only reflector 2 and the rotation torque in one direction acted to the object so that higher rotation speed could be obtained.

4. Conclusion

Noncontact rotation of a small object using ultrasound was discussed. The vibrating system consists of an ultrasonic vibrator and two hailf-circular reflectors. By controlling the positions of two reflectors, the asymmetric travelling-wave field was generated, which allowed high-speed and stable noncontact rotation.

References

1. D. Koyama and K. Nakamura. IEEE Trans. Ultrason. Ferroelect. Freq. Contr. **57** (2010) 1152.
2. D. Koyama and K. Nakamura. IEEE Trans. Ultrason. Ferroelec. Freq. Contr. **57** (2010) 1434.
3. Trinh EH. Experimental Phys. Fluids. **11** (1994) 3567.

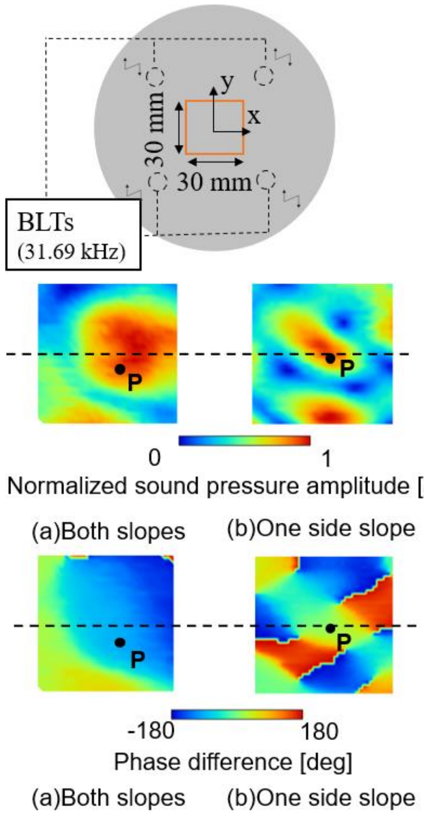

Fig. 3. Sound pressure amplitude and phase distributions at 31.7 kHz between the vibrator and reflectors in the *x*-*y* plane in (a) *both slopes* and (b) *one-side slope*.

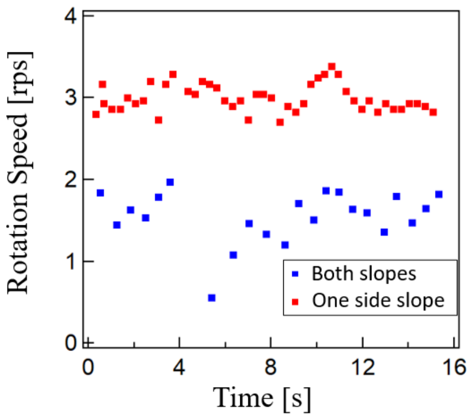

Fig. 4. Changes in the rotation speed of the small object with respect to time in *both slopes* and *one-side slope*.