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Noncontact transportation in two dimensions using an acoustic standing wave

音響定在波を用いた 2 次元非接触搬送

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1. Introduction

In noncontact ultrasound transportation systems, undesirable external magnetic fields are not generated and the transported objects are not restricted. The ultrasound transportation technique can be applied to the pharmaceutical fields to transport small objects such as capsules and tablets. We have reported ultrasonic noncontact techniques for transportation of small objects [1-3]. In this report, the transportation in two dimensions was investigated.

2. Configuration

Fig. 1 shows the configuration of the noncontact transportation system in two dimensions using ultrasound. The system consists of a rectangular aluminum vibrator (170×170×1 mm^3) and four bolt-clamped Langevin transducers (BLTs 1 to 4) with step horn (transformation ratio of 4). The BLTs were attached to the positions of (x, y) = (12 mm, 12 mm) from the four corners of the vibrator to generate the flexural vibration. A rectangular glass reflector (220×220×2 mm^3) was installed parallel to the vibrator at distance of approximately 8 mm, which corresponds to half wavelength of the acoustic wave in z direction, so that acoustic standing wave is generated between two plates.

The BLTs 1 and 3 are excited with the input voltage of $V=V_0\cos\omega t$, and the BLTs 2 and 4 are excited with $V=V_0\cos(\omega t+\theta)$ where θ is the temporal phase difference. By controlling the phase difference θ, the traveling wave can be generated along the vibrating plate with decrease of the standing wave ratios (SWR). The configuration of the vibrator and the positions where the BLTs were attached were determined by finite element analysis (FEA, ANSYS 11.0, ANSYS Inc.) so that the lattice flexural vibration mode can be generated efficiently.

3. Results

Fig. 2 shows the vibration amplitude and phase distributions of the vibrating plate in z direction measured by a laser Doppler vibrometer (NLV-2500, PI Polytec) with several phase differences θ.

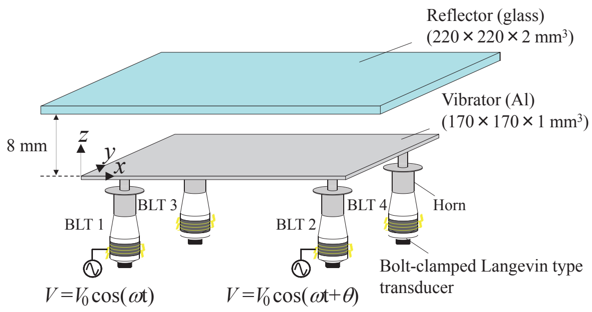

Fig. 1 Configuration of the ultrasonic noncontact transportation system.

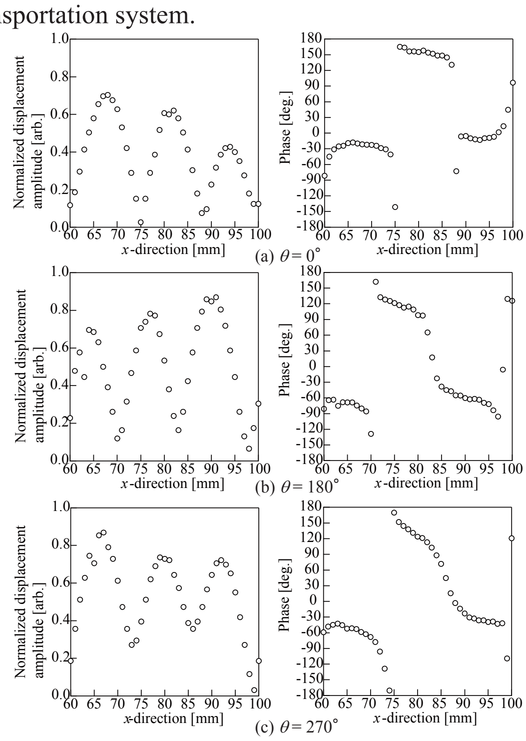

Fig. 2 Vibration distributions of the plate: the vibration amplitudes and phases at the phase differences of (a) 0, (b) 180^o and (c) 270^o.

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The distribution from y = 60 to 100 mm at x = 85 mm was scanned. At the phase difference of 0º (**Fig. 2(a)**), the flexural standing wave with the wavelength of approximately 30 mm was generated. The maximum vibration displacement amplitude in was 0.38 μm when the input voltage was 1 V_{pp}. By changing the phase difference to 180º or 270º (**Fig. 2 (b) and (c)**), the vibration distribution was shifted to the positive x direction. The linear change in the phase distributions implies that traveling wave was generated to the positive x direction with decrease of the SWR.

The actual ultrasonic transportation was investigated by using a polystyrene particle with the diameter of 2 mm and weight of 0.3 mg. **Fig. 3** shows the motion of the particle transported in two dimensions and observed by a high-speed camera. The acoustic standing wave was generated in air between two plates and the particle could be trapped at the nodal points of the standing wave. By changing the phase difference θ, the nodal points of the standing wave were shifted and the trapped particle was transported without contact to x direction. The transportation direction can be controlled by controlling the driving conditions of four BLTs; when BLTs 1 and 2 were excited with the $V=V_0\cos\omega t$ and the BLTs 3 and 4 were excited with $V=V_0\cos(\omega t+\theta)$, the particle could be transported to y direction. It should be noted that the particle was transported along zig-zag trajectories. This is because the vibration mode of the plate changed to the reversed mode as the phase difference changed to 180º and the nodal points of the standing wave in air were shifted to 45º direction from x direction. **Figure 4** shows the relationship between the phase difference and the moving distance of the particle to the x direction. When the phase difference was changed from 0º to 720º, the moving distance was approximately 28.0 mm, which corresponds with half the wavelength of the lattice flexural vibration on the plate. When BLT 1, BLTs 2 and 3, and BLT 4 were excited with $V=V_0\cos\omega t$, $V=V_0\cos(\omega t+\theta/2)$, and $V=V_0\cos(\omega t+\theta)$, respectively, the particle could be transported to 45º direction from x direction as shown in **Fig. 5**.

4. Conclusion

Noncontact ultrasonic transportation of a small particle in two dimensions was discussed. The configuration of aluminum plate, resonant frequency and position of the four transducers with step horn were determined by FEA. By controlling the phase difference of two pairs of transducers, the nodal lines of the flexural vibration of the plate and the acoustic standing wave in air could be shifted, which enabled the manipulation of the small particles for two-dimensional direction.

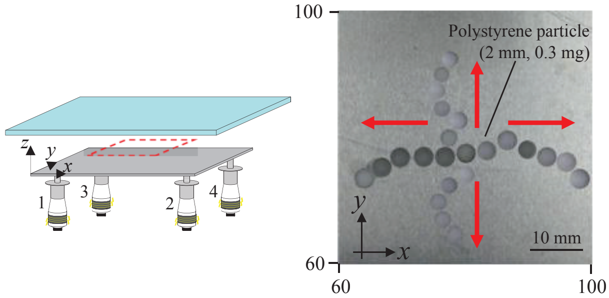

Fig. 3 Photograph of the polystyrene particle transported in two dimensions without contact. The photographs taken every 60º were superimposed.

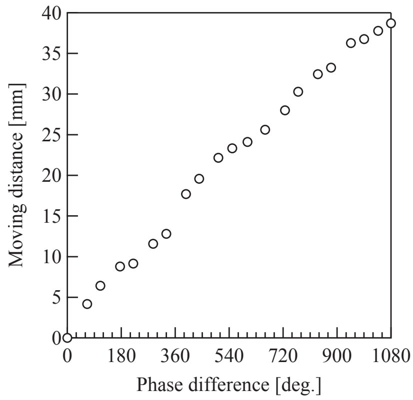

Fig. 4 Relationship between the driving phase difference of the transducers and the moving distance of the particle in x direction.

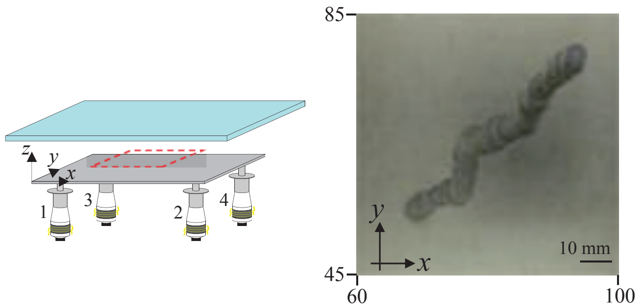

Fig. 5 Photograph of the polystyrene particle transported to 45º directions without contact. The photographs taken every 10º were superimposed.

References

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2. D. Koyama *et al*: IEEE UFFC, **57** (2010) 1434.
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