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Noncontact ultrasonic linear transportation of small objects using traveling waves through a waveguide

導波管中における超音波進行波を用いた微小物体の非接触直線搬送

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1. Introduction

In the field of manufacturing precision machinery component and pharmaceutical biotechnology, a noncontact transportation technique of small particles, such as electronic components and pills, is required. The authors have reported noncontact transportation of small objects in air over long distances[1] and high speed unidirectional non-contact transportation a method of traveling-wave field generated between a bending vibrating plate and a reflector[2]. This report presents a by using traveling-wave field excitation with a sound source located at outside of a waveguide in order to achieve high speed unidirectional noncontact transportation of small objects.

2. Experimental setup

As shown in **Fig. 1**, the experimental setup consists of a bolt-clamped Langevin-type transducer with an exponential horn attached to a bending vibrating plate and two parallel reflectors as a waveguide. An aluminum plate (65×30×0.5 mm^3) was used as a vibrating plate, and the tip of the transducer was attached at 14 mm from the edge of the plate by tightening a screw. The longitudinal vibration of transducer was converted to a bending vibration along the plate. Two aluminum reflectors (220×60 ×3 mm^3) were installed parallel at a distance of 15 mm to generate an standing wave in the vertical direction (z-direction) and a traveling wave in the length direction (x-direction) between the two reflectors by ultrasound waves emitted from the bending vibrating plate. The vibrating plate was installed at one side end of the waveguide with the angle of 30° without contact to the reflectors.

3. Sound field between two reflectors

Figure 2 shows the sound pressure field measured by a probe microphone (Type 5935, Brüel&Kjær) at a frequency of 25.7 kHz. In addition, **Figs. 3** and **4** show the phase distributions of sound pressure on lines A, B and C in x-direction and line D in z-direction illustrated in **Fig. 2**, respectively. The results in **Fig. 3** implies that the traveling wave with the wavelength of 15 mm in the nodal lines A and C and the wavelength of 31 mm in the antinodal line B were generated in the horizontal direction since the phase distribution varied linearly. The difference of wavelength in horizontal line is attributed to the radiated sound field from the vibrating plate and the reflectors' position. In **Fig. 4**, a standing wave in the vertical direction (z-direction) was generated and it assists the levitation of small particles. The traveling wave in the horizontal direction contributes the transportation. **Fig. 5** shows sound pressure distribution in the width direction (y-direction) between two reflectors. At the center of plate in the width direction, the sound pressure was large, and it was decreased at the edge of the plate since the both sides of the waveguide are regarded as open ends.

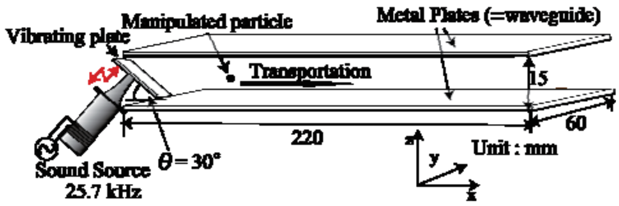

Fig. 1 A bending vibrating plate and two reflectors as a waveguide for noncontact transportation of small particles.

4. Noncontact transportation of a small object

Noncontact transportation of a polystyrene sphere

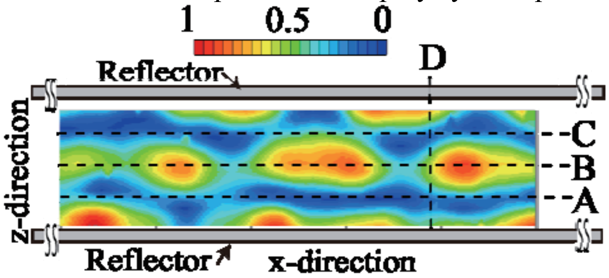

Fig. 2 Sound pressure amplitude distribution in the waveguide.

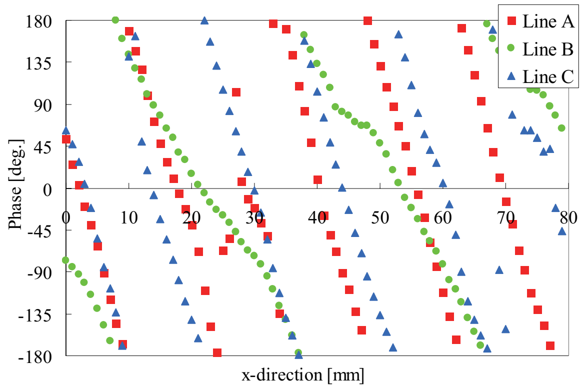

Fig. 3 Phase distributions of the sound pressure in the horizontal direction.

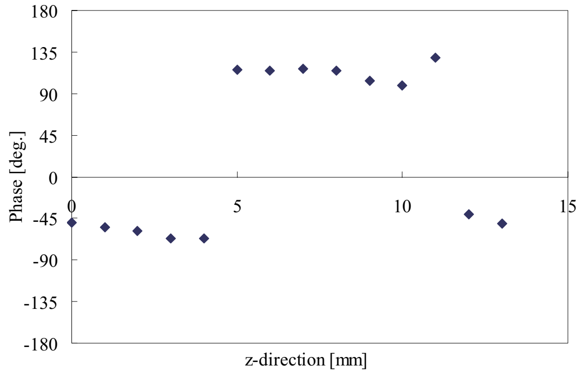

Fig. 4 Phase distribution of the sound pressure in the vertical direction(Line D in Fig.2).

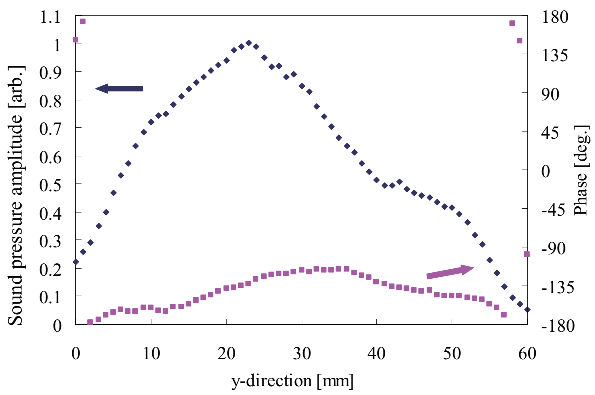

Fig. 5 Sound pressure amplitude and phase distribution of the sound pressure in the width direction.

with diameter of approximately 2 mm was investigated by generating the traveling waves along the waveguide. **Fig. 6** shows the transportation trajectory of a polystyrene particle observed by a high-speed camera and the sound pressure distribution along the waveguide. The photographs taken at each 0.01 s were superimposed. The particle is moved along the horizontal nodal line of sound pressure. In the width direction, the particle was transported in the center line of the waveguide. **Fig. 7** shows the change in the transport speed with respect to time estimated

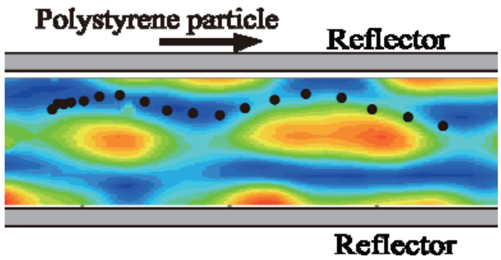

Fig. 6 Transportation trajectory of a polystyrene particle and the sound pressure distribution between the plates.

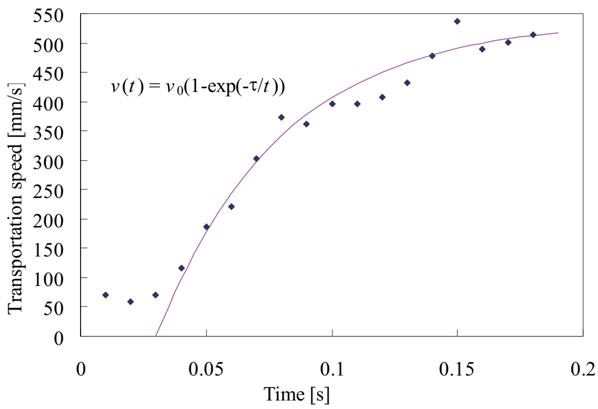

Fig. 7 The change of the transportation speed of the particle with respect to time.

from **Fig. 6**. The particle was affected by the propulsion force by the traveling wave in the positive x-direction and the resistive force due to air viscosity in the negative x-direction. We assumed that the transportation speed of the particle $v(t)$ is expressed as $v(t)= v_0$ (1- exp(-t/ τ)) where v_0 is the terminal speed and τ is the time constant. The solid curve in **Fig. 7** indicates the fitting curve, and in the case of the mass of 0.3 mg, the terminal speed reached 540 m/s at t=0.2 s. Since the acceleration at t=0.04 s was 10.8 m/s^2, the propulsion force can be estimated to be 3.5×10^{-6} N. It is possible that bouncing up and down of the trajectory was caused by the uniformity of the sound field.

5. Conclusions

We discussed noncontact ultrasonic transportation of small object using an acoustic traveling-wave field with the separated sound source from the waveguide. Noncontact transportation of a polystyrene particle with high speed of 540 m/s was succeeded.

Acknowledgment

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References

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2. Y. Ito, D. Koyama and K. Nakamura: to be published in Acoust. Sci. & Tech.