Non-contact transportation system of small objects using Ultrasonic Waveguides

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Non-contact transportation system of small objects using Ultrasonic Waveguides

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Abstract. A transportation system for small object or fluid without contact is investigated being based on ultrasonic levitation. Small objects are suspended against gravity at the nodal points in ultrasonic pressure field due to the sound radiation force generated as the gradient of the energy density of the field. In this study, the trapped object is transported in the horizontal plane by introducing the spatial shift of the standing waves by the switching the lateral modes or travelling waves. The goal of the study is to establish a technology which can provide a total system with the flexibility in composing various transportation paths. Methods for linear/rotary stepping motions and continuous linear transportation are explained in this report. All the transportation tracks are composed of a bending vibrator and a reflector. The design for these acoustic cavity/waveguide is discussed.

1. Introduction
Non contact technology is highly demanded in the next generation process for chemical, pharmacy and food industries as well as production process in microelectronics and precision machinery. Small objects or droplet are to be transported without contact to avoid contamination. Conventional magnetic levitation is not applicable for non-magnetic materials. Suspension technique by air flow is expensive method and easy to induce dust. Authors are focusing on ultrasonic levitation technology, as an alternative method, where small objects or droplet [1] can be trapped at the nodal points of the sound pressure field in air due to acoustic radiation force. To compose a total transportation system in practical use, various kinds of transportation components are required as illustrated in figure 1. The most basic one is linear transportation track. Joint or switch between two transportation tracks are essential for practical use. Elevation of position shall be needed in addition to the horizontal movement. Some of the concepts to realize these variations of the transportation paths using ultrasonic levitation are explained in this report. In order to transport the objects without contact in horizontal direction, the authors have introduced the spatial shift in standing wave field between a vibrating plate and a reflector. The position of the trapped object is moved step by step if the lateral mode pattern is shifted by changing the phase difference between two driving points. The use of travelling wave is also investigated for continuous linear transportation. Design for the travelling wave acoustic waveguide is discussed.

1 Currently, he is at Doshisha University, Kyoto, Japan.
2. Stepping motion using standing waves

2.1. Basic levitation phenomena
Basic levitation setup is composed of a vibrating plate and a reflecting plate as shown in figure 2. The bottom plate is vibrating in the bending mode and standing wave of pressure field is excited between the two plates. Small objects such as a polystyrene ball and a piece of tablet can be suspended at the nodal position due to the radiation force. The radiation force is acting on the object in accordance with the gradient of the energy density of the sound field.

![Figure 2](image2)

Figure 2. Levitation of small objects between the vibrating plate (lower) and the reflector (upper). A small polystyrene ball (left) and a tablet (right) are trapped at the nodal point of the sound pressure field against the gravity.

2.2. Linear transportation with stepping motion
The horizontal position of trapping objects is determined by the sound field distribution. Then, the position is moved if the excitation location of the standing waves is shifted. In the linear transportation system, this can be practically achieved by changing the phase difference between two driving point at the vibrating plate [2] as shown in figure 3. White circles indicate the polystyrene balls levitated in the standing wave field of sound pressure. If the phase difference between the voltages applied to Langevin transducers connected at the left and right ends of the plate is changed from 0 to 60 degrees, the sound pressure pattern is moved rightward by the distance corresponding to the phase shift. As a result, the position of the objects is also shifted.

![Figure 3](image3)

Figure 3. Principle for moving the suspended objects along the horizontal plane being based on the shift in the position of standing waves.
2.3. Rotary transportation with stepping motion
Rotary motion can be achieved by utilizing the same principle. Sound field pattern is rotated by switching the driving position instead of the phase shift. Figure 4 shows an example using a disk vibrator and a disk reflector [3]. Higher order mode of bending vibration is excited using an annular PZT element bonded on the back surface. The electrode on the PZT element is divided into many parts. Angular position of the mode pattern is determined by selecting the electrode to be activated. Small object trapped between the disk vibrator and the reflector is transported along angular direction if the stimulation position is switched one after another.

![Figure 4. Method for rotary motion. Vibration mode pattern is rotated by switching the activated electrode.](image)

3. Continuous linear transportation using travelling waves
In this section we discuss about continuous linear transportation of object at high speed using travelling waves. Let us consider sound pressure field between parallel rigid reflectors using figure 5. Here, the case with two nodal lines is investigated. The spacing between the reflectors $W$ is 11 mm and the frequency is 37 kHz in our experiments. The relationship among the spacing $W$, the free-space wavelength $\lambda_0$ and the angle $\theta$ for propagation is denoted as

$$\theta \lambda_0 = W \sin \theta$$

where $\lambda_0=9.2$ mm. The angle of the incidence was set to 60 degrees in accordance with equation (1) as shown in figure 6, where a commercial airborne ultrasonic radiator (Murata co.) was utilized. In the figure, the sound pressure distribution measured using a probe microphone is overlapped. Red indicates higher pressure, while blue shows zero. Horizontal distribution was not uniform, but since the phase changed almost linearly with the distance as shown in figure 7, travelling wave field was obtained. Along the horizontal nodal lines, polystyrene particle were transported. The distance of transportation was limited under 20-40 mm because of the irregular pressure distribution and the low pressure level. The sound field was attenuated as the distance as can be seen from figure 6.

![Figure 5. Sound pressure field between parallel reflectors.](image)
In order to obtain higher sound pressure, the radiator was replaced by a combination of a bolt-clamped transducer and a vibration plate of 65 mm x 30 mm. The frequency was 25.7 kHz. The moving speed of the transported object is plotted as a function of the distance in figure 8, which is calculated from the trajectory recorded using a video camera. The object was accelerated and reached to the velocity of approximately 0.5 m/s. The transportation distance was successfully extended. The traction force acting on the polystyrene ball of 2 mm in diameter and 0.3 mg in weight is calculated from the acceleration to be 3.5 µN.

**Figure 6.** Measured sound pressure field and the trajectory of small object.

**Figure 7.** Phase distribution along the lines A, B and C in figure 6.  
**Figure 8.** Temporal change in the transportation speed.

4. Conclusions
Non-contact transportation technique was discussed being based on ultrasonic levitation in standing wave field. Stepping motion in horizontal and rotational directions was achieved with the phase shift or switching the excitation position. Continuous linear transportation was realized using travelling sound field, which was obtained by oblique incidence to the waveguide between the parallel reflectors. Using the same setup, droplet can be transported without contact.

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References