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Aerial ultrasonic source with integrated horns and vibrating plates

Hikaru Miura (Nihon University)

1. Introduction

We have developed a sound source that radiates intense ultrasonic waves into the air using a transverse vibrating plate.[1] The sound source was large and had a transverse vibrating plate attached to the tip of a 1.5-wavelength longitudinal vibration generator consisting of a longitudinal transducer, a horn, and a resonance rod. A reflector was used to form a standing wave sound field, further increasing the size.[2] We have also reported a method of arranging two transverse vibrating plates in parallel to form a standing wave sound field between the vibrating plates, but it required a longitudinal vibration 1.5 wavelengths long.[3]

To reduce the sound source size, I developed an ultrasonic source consisting of a longitudinal transducer and an ultrasonic radiator with two horns and two transverse vibrating plates integrated into a half-wavelength, and a standing wave sound field was formed by the two vibrating plates. Therefore, the ultrasonic source was a full length of one wavelength.

This paper describes the structure and characteristics of the ultrasonic radiator for this ultrasonic source, developed for a frequency of 28 kHz.

2. Structure of the aerial ultrasonic source

Figure 1 is a schematic of the ultrasonic radiator developed for the ultrasonic source. The ultrasonic radiator consisted of a part for mounting on the transducer, two conical horns that expanded the longitudinal vibration amplitude to generate transverse vibration, and two vibrating plates that performed the transverse vibration. Each of the measurements was determined by using a numerical simulation (COMSOL Multiphysics 5.6) with the finite element method (FEM). The ultrasonic source was designed for driving at a resonance frequency of 28 kHz. The total length of the ultrasonic radiator was 89 mm, which was half the wavelength of the longitudinal vibration.

The transducer mounting part (40 × 40 × 20 mm) held the connecting bolt for attachment to the 28 kHz bolt-clamped Langevin longitudinal transducer (D2428PC, NGK SPARK PLUG CO., LTD.). The diameter of the transducer was also 40 mm. The length of the two conical horns was set to 30 mm based on the ratio to the total length. The two transverse vibrating plates, in which the transverse vibration nodes were formed in the long dimension direction and no nodes were formed in the orthogonal directions, had dimensions of 39 × 20 × 4 mm.

The distance between the vibrating plates was set to 24.6 mm, which was the length of two wavelengths of 12.3 mm (frequency 28 kHz) of sound waves in air. The ultrasonic radiator (A2017-T4 alloy) with these dimensions was manufactured with an integral structure. For the following explanation, the orthogonal coordinates of x, y, and z are defined as shown in Fig. 1.

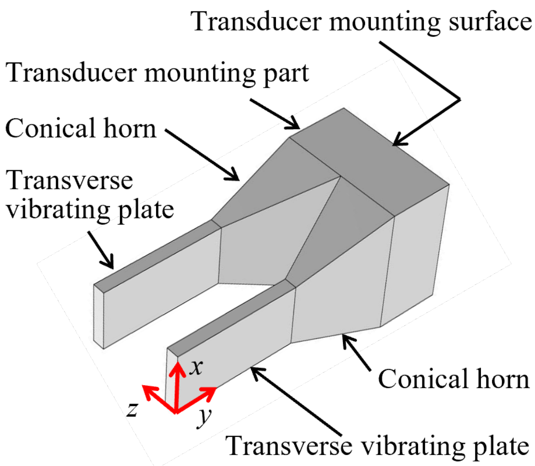

Fig. 1. Schematic of ultrasonic radiator.

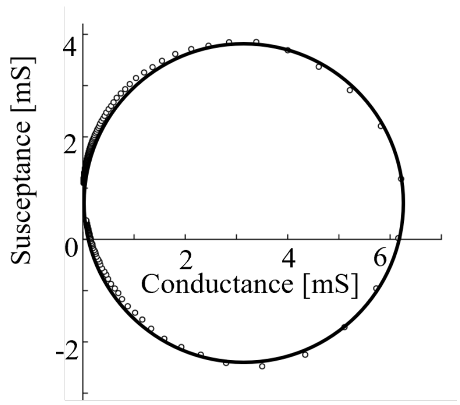

Fig. 2. Admittance characteristics of the ultrasonic source.

E-mail: miura.hikaru@nihon-u.ac.jp

3. Admittance characteristics of the source

The admittance characteristics of the ultrasonic source with the transducer attached were measured. The measurement was performed using an impedance analyzer (ZGA5920, NF Corporation) with the drive voltage (effective value) constant at 1.0 V. **Figure 2** shows the results, where the horizontal axis is conductance and the vertical axis is susceptance. The resonance frequency was 28.34 kHz, the conductance was 6.2 mS (impedance about 160 Ω), and the sharpness (*Q*) was about 2800.

4. Vibration displacement of the vibrating plate

Transverse vibration displacement was measured to clarify the vibration distribution of the vibrating plate. The measurements were in the *x*-*y* plane where *z* remained at 0 mm, *x* was 0 to 40 mm, and *y* was 0 to 20 mm. The measurement was performed with an input power of 0.10 W (voltage 4.6 V, current 24 mA) and a constant frequency of 28.34 kHz.

Figure 3 shows the results, where the horizontal axis of the figure is the distance in the *y*-axis direction, the vertical axis is the distance in the *x*-axis direction, and the color bar shows the vibration displacement amplitude. The vibration displacement amplitude was almost uniform in the *x*-axis direction, there were vibration nodes (blue) around 5 and 21 mm in the *y*-axis direction, and there was a large vibration antinode (red) around 30 mm.

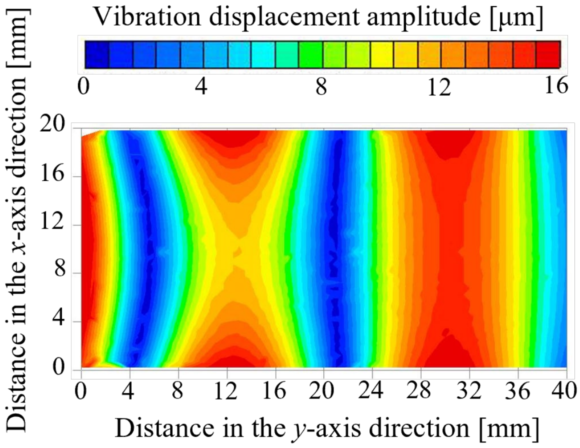

Fig. 3. Vibration displacement distribution of the vibrating plate.

5. Sound pressure between the vibrating plates

The sound pressure between the two vibrating plates was measured with a microphone with a probe (1 mm in diameter). The measurements were in the *y*-*z* plane, where *x* remained at 10 mm, *y* was 0 to 40 mm, and *z* was 5 to 23 mm. The measurement was performed with an input power of 0.10 W and a constant frequency of 28.33 kHz.

Figure 4 shows the results, where the horizontal axis of the figure is the distance in the *y*-axis direction, the vertical axis is the distance in the *z*-axis direction, and the color bar shows the sound pressure normalized by the maximum value. There were six sound pressure antinodes in the measured range. The three large antinodes were at 28 to 38 mm along the *y*-axis, and the three small antinodes were at 12 to 16 mm along the *y*-axis. Both groups of antinodes were arranged almost linearly in the *z*-axis direction, and the distance between antinodes in this direction was about 6 mm, which was similar to the half wavelength in air at a frequency of 28 kHz.

In addition, compared with the vibration displacement amplitude in Fig. 3, the positions where the sound pressure and the vibration displacement amplitude were large were both around 30 mm in the *y*-axis direction.

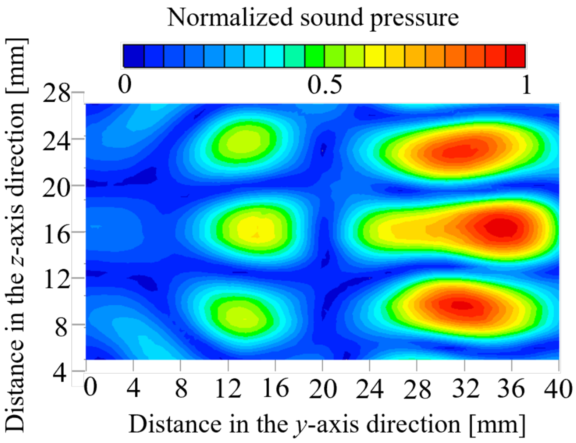

Fig. 4. Sound pressure distribution between the transverse vibrating plates.

6. Conclusions

A method of forming a standing wave ultrasonic field by integrating the horn, resonance rod, and transverse vibrating plate was investigated. A standing wave ultrasonic field was formed in the air when the total length was half the wavelength of the longitudinal vibration.

Acknowledgment

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References

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2. R. Sato, T. Asami, and H. Miura: Jpn. J. Appl. Phys. **56** (2017) 07JE05.
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