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Aerial ultrasonic source with sharp directivity containing a filleted compact circular transverse vibrating plate

鋭い指向性を持つフィレット入り小型円形たわみ振動板型空中超音波音源

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1. Introduction

In recent years, aerial ultrasonic sensors have been used in many applications, such as driving support systems for automobiles, and the demand for these sensors has been increasing. However, ultrasonic sensors need to be small, which makes it difficult to generate intense sound waves [1,2]. Transverse vibrations have been studied as a source of powerful sound waves that can be emitted into the air, but these devices are large [3,4]. The purpose of this study is to develop a compact but relatively intense ultrasonic source that emits sound waves in the forward direction.

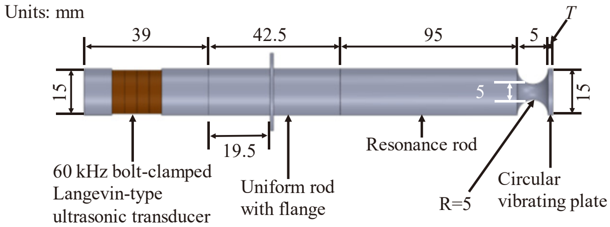
The authors have previously shown that an ultrasonic source with a compact transverse vibrating plate that vibrates in the one direction with a large amplitude can produce sound waves with relatively high sound pressure at a distance, even though the radiating surface is small [5,6].

This study compares the directivity and sound pressure versus input electric power characteristics of the developed aerial ultrasonic source with that of a uniform rod-mounted source.

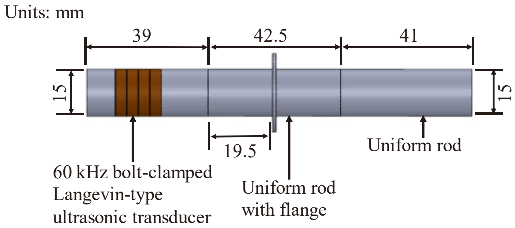
2. Aerial ultrasonic source with filleted compact circular transverse vibrating plate

Figure 1(a) depicts the developed aerial ultrasonic source used in this study. As shown in the figure, a 60-kHz bolt-clamped Langevin-type transducer (HEC-1560P4B, Honda Electronics) and a uniform rod (diameter 15 mm, length 42.5 mm) with a flange (25 mm in diameter and 1.0 mm thick) were connected with screws. A resonance rod (diameter 15 mm, length 95 mm) for adjusting the longitudinal resonant frequency was attached to the end of a uniform rod with a flange, and a circular vibrating plate (diameter 15 mm, thickness 2 mm) was attached to the end of the resonance rod via a small strut (minimum diameter 5 mm, length 1.2 mm). The diameter of the circular vibrating plate was the same as the diameter of the transducer, which was 15 mm. A fillet with R=5 mm was machined on the strut to increase the strength of the vibrating plate area. Henceforth, we refer to this as a compact transverse vibrating plate ultrasonic source.

Figure 1(b) depicts a uniform rod (diameter 15 mm, length 41 mm) attached to the end of another uniform rod with a flange for comparison. Henceforth, we refer to this as a uniform rod ultrasonic source.



(a) Filleted compact circular transverse vibrating plate.



(b) Uniform rod.

Fig. 1. Outline of ultrasonic source types.

3. Simulation analysis of ultrasonic source size

To obtain an intense aerial ultrasonic wave in a direction perpendicular to the vibrating plate surface, the finite element method (COMSOL Multiphysics) was used to examine the size of the vibrating part and the whole surface. The vibrating part had no node of transverse vibration, and the whole surface vibrated only in one direction with a large amplitude.

The simulation model for the ultrasonic source consisted of a transducer, a uniform rod with a flange, a resonance rod, a strut, and a circular vibrating plate, all made of duralumin (A2017). For the analysis, a two-dimensional axisymmetric model was used. For experimental verification, ultrasonic sources with the dimensions shown in Fig. 1(a), which produce relatively high sound pressure, were manufactured.

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4. Comparison of directivity

The directivities of the sound waves emitted from the two ultrasonic sources described in section 2 were measured using a 1/8-in. condenser microphone (ACO, Type 7118). The measurements were made at a distance of 300 mm between the ultrasonic source and the measurement point, at 0° along the center axis of the vibrating plate, and at intervals of 1° within the range ±90°. The driving conditions of the ultrasonic sources were that the input current to the transducer was kept constant at 50 mA, and the driving frequency of the ultrasonic sources was set at the resonance frequency (around 58 kHz).

Figure 2 depicts the results. The horizontal axis is the angle with respect to the ultrasonic source axis and the vertical axis is the sound pressure (RMS value). In the figure, black circles indicate the compact transverse vibrating plate source and red circles indicate the uniform rod source. The results show that the sound pressure of both the compact transverse vibrating plate source and uniform rod source were significantly higher in the forward direction normal to the vibrating plate (0°). The maximum sound pressure of the compact transverse vibrating plate source was about 25 Pa, which is about 3.6 times higher than that of the uniform rod-type ultrasonic source (~7 Pa).

5. Comparison of sound pressure versus input electric power characteristics

The sound pressures on the central axis of the sound waves emitted from the ultrasonic sources were measured at various input electric power levels for the two ultrasonic sources described in section 2. The measurement method was the same as that described in section 4. The input electric power was gradually increased from 0 W to about 10 W.

Figure 3 depicts the results. The horizontal axis is the input electric power and the vertical axis is the sound pressure (RMS value). In the figure, black circles indicate the compact transverse vibrating plate source and red circles indicate the uniform rod source. The results show that the sound pressure level of both the compact transverse vibrating plate source and uniform rod source increased as the input electric power increased. The maximum sound pressure of the compact transverse vibrating plate source was about 242 Pa (~141 dB), which was about 3.7 times higher than the maximum sound pressure of the uniform rod source (~65 Pa).

6. Conclusion

This paper compares the directivities and the sound pressure versus input electric power characteristics of a compact transverse vibrating plate ultrasonic source with those of the uniform rod ultrasonic source. The results showed that the compact transverse vibrating plate source was able to achieve about 242 Pa (~141 dB), which is about 3.7 times higher than that achieved by the uniform rod source.

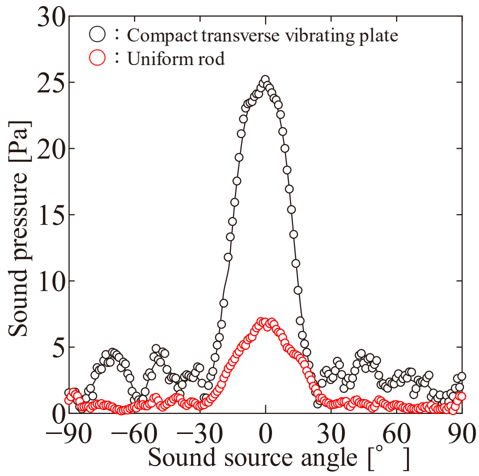

Fig. 2. Relationship between sound pressure and ultrasonic source angle.

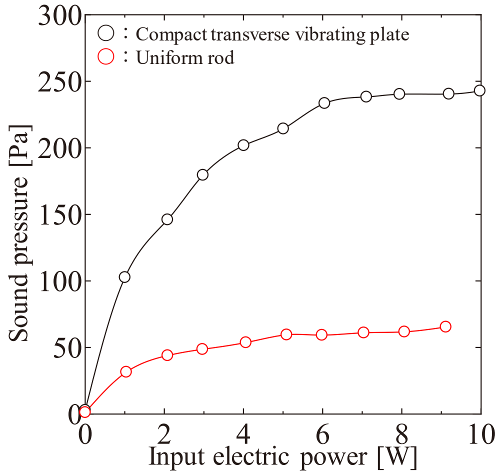

Fig. 3. Relationship between sound pressure and input electric power.

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