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Basic Study of Low-frequency Airborne Ultrasonic Emitter with an Annular Piezoelectric Element

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1. Introduction

Recent years have seen studies of high-speed nondestructive testing methods based on elastic-wave source scanning technique using an airborne ultrasound phased array (AUPA) [1,2,3]. However, when an AUPA is used for nondestructive inspection, grating lobes are generated in the radiated sound wave depending on the relationship between the wavelength of the sound wave from the ultrasonic emitter and the distance between the emitter arrays. The grating lobes are a source of artifacts. In this report, we investigated a low-frequency airborne ultrasonic emitter that combines an annulus piezoelectric ceramic and a metal film to aim at a smaller size.

2. Structure and materials of ultrasonic emitter

2.1 Structure

Previous studies have reported ultrasonic emitters based on annular piezoelectric ceramics [4,5]. We aimed at realizing a smaller ultrasonic emitter with the same structure. **Figure 1** shows a schematic of the structure of the ultrasonic emitter under investigation, which comprises an annulus-shaped piezoelectric ceramic with a thin metal film attached to it.

The resonance frequency of the emitter was set to approximately 40 kHz. Considering the emitter array pitch, the piezoelectric element (C-203; Fuji Ceramics) was made as an annulus with an outer diameter of 4 mm, an inner diameter of 2 mm, and a thickness of about 0.2 mm. The piezoelectric element was polarized in the thickness direction, and its electrodes were folded electrodes to which silver wires were soldered for power supply. To form the ultrasonic emitter, a 4-mm-diameter stainless-steel film was bonded to the surface of the piezoelectric element using epoxy resin.

2.2 Thickness of vibrating film

To investigate the thickness of the stainless-steel film to be applied to the piezoelectric element, an eigenmode analysis was performed using the finite-element method (FEM). **Figure 2** shows the results of the eigenmode analysis for the frequency range of 35 - 45 kHz in steps of 2 Hz. The figure shows the relationship between frequency and the vibration velocity at the center of the ultrasonic emitter's vibrating film when the film is vibrating in-phase. The result shows that with increasing thickness of the vibrating film, the resonance frequency increases and the vibration velocity decreases. When the thickness is 17 μm, the resonance frequency is 40.9 kHz, which is the same as that of commercial emitters, and so the emitter can be driven at the desired frequency.

Figure 3 shows the vibration velocity distribution of the stainless-steel film. The result shows that the film vibrates in a centered mode with the maximum vibration velocity at the center of the film. Based on the results of this analysis, a prototype was constructed.

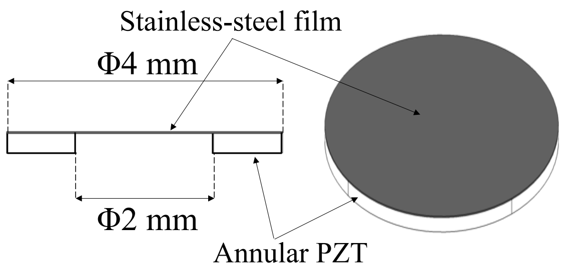

Fig. 1. Configuration of ultrasonic emitter under investigation.

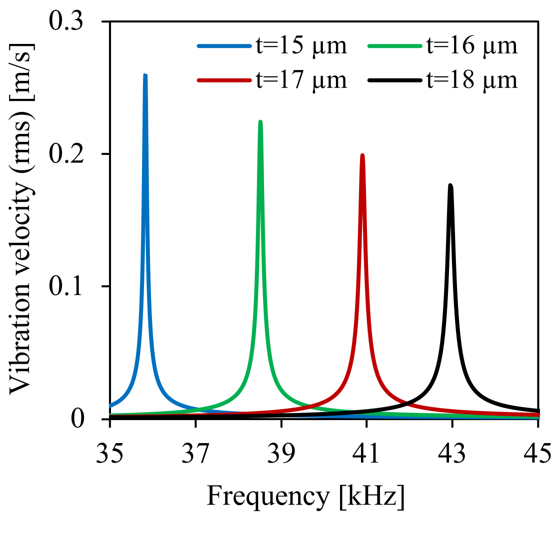

Fig. 2. Vibration velocity–frequency response determined by FEM with differing thickness of stainless-steel film.

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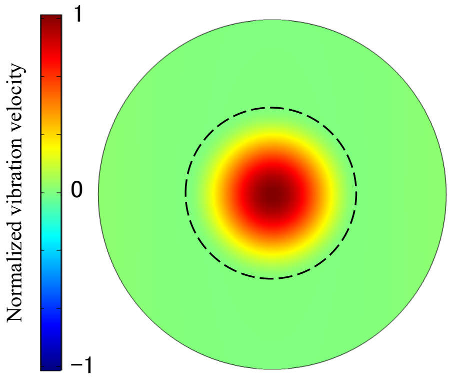

Fig.3. Vibration Velocity distribution on surface of prototype emitter (FEM).

3. Experiment

3.1. Vibration velocity distribution of vibrating plate of the prototype emitter

Experiments were conducted to measure the vibration velocity distribution of the vibrating film of the prototype ultrasonic emitter. A laser Doppler vibrometer (OFV-5000, Polytec) and a synthesizer (WF1974, NF) were used in the experiments. The emitter was driven with a frequency of 42.8 kHz (the resonance frequency of the emitter), an applied voltage of 4 Vp-p, and 20 cycles, and the measurement interval was 0.1 mm.

Figure 4 shows the measured vibration velocity distribution at a certain time. The result is normalized to the maximum value and color mapped. It shows that the prototype emitter could be driven in an in-phase vibration mode, with the maximum vibration close to the center of the vibration film. Figure 4 agrees well with the FEM equivalent in Fig. 3.

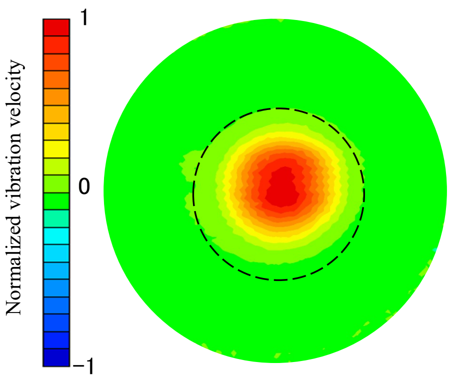

Fig.4. Vibration Velocity distribution on surface of prototype emitter (experiment).

3.2. Characteristics of radiated sound waves

The characteristics of the sound waves radiated by the prototype ultrasonic emitter were investigated. In the experiment, a 1/8-inch condenser microphone (40DP, GRAS) was scanned in 1-mm steps to 100 mm from the front of the emitter and ±50 mm from its center to measure the sound pressure distribution of the radiated sound waves.

Figure 5 shows the sound pressure distribution at a certain time when a voltage of 50 Vp-p was applied to the emitter. The result is normalized to the maximum sound pressure at that time and color mapped. It shows that at 10 mm in front of the emitter, the radiated sound waves had a relatively broad directivity of about 80° at half-maximum, and a relatively high sound pressure of about 11 Pa was radiated at 10 mm from the emitter.

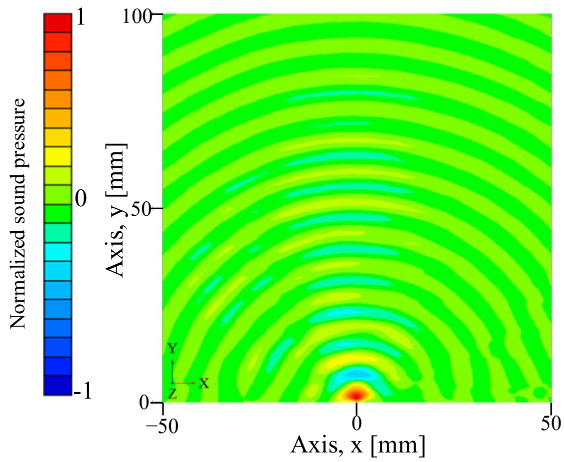

Fig.5. Sound pressure distribution from prototype emitter.

4. Conclusion

Aimed at realizing a small emitter of low-frequency airborne ultrasonic for use in an AUPA, we designed an emitter by means of FEM and then fabricated a prototype emitter based on the design. Consequently, we succeeded in developing a prototype of a small emitter that can emit sound waves with a resonance frequency that is almost the same as that of conventional emitters.

Acknowledgment

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