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Development of 58 kHz compact ultrasonic sound source using a circular plate with circumferential excitation

円板の周囲を加振した 58 kHz 小型超音波音源の開発

Takuya Asami†, Hikaru Miura (Coll. of Sci. and Tech., Nihon Univ.)
淺見拓哉†，三浦　光（日大・理工）

1. Introduction

A compact ultrasonic sound source about 15 mm in diameter could be used for distance measurement and in creating a powerful sound field with an array of sound sources.[1)] We have developed a method of exciting the circumference of a circular plate using a hollow stepped horn as a sound source for these applications. We previously investigated a 58 kHz compact ultrasonic sound source in which a circular plate is joined to the tip of a hollow stepped horn using an adhesive (AR-R 30, Nichiban).[2)] We found that a maximum sound pressure of about 61 Pa (130 dB) was obtained at a distance of 300 mm when the whole disk vibrated in phase. However, no detailed examination of the sound source has been performed.

In this paper, the combination of the hollow step horn and circular plate was examined to advance the development of a compact ultrasonic sound source. The characteristics of sound sources where the horn and the disk were joined with the adhesive used in the previous study and with a shrink fit joint were measured.

2. Compact ultrasonic sound source

Figure 1 shows a schematic of the sound source. The sound source consists of a 60 kHz bolt-clamped Langevin-type longitudinal ultrasonic transducer (HEC-1560P4B, Honda Electronics), a uniform rod with a flange (material: A2017), and a hollow stepped horn with a circular plate (material: A2017).[2)] The hollow stepped horn has an outer diameter of 15 mm, an inner diameter of the hollow portion of 10 mm, and a length of 39.2 mm (**Fig. 2**).[2)] The tip of the horn is drilled to a depth of 1.0 mm and a diameter of 10.2 mm to join it to the circular plate. The circular plate is 10.2 mm in diameter and 1.0 mm thick and is joined to the tip of the horn with an adhesive (S-6, Devcon) or a shrink fit joint.

The finite element method (Multiphysics 5.4, COMSOL) was used to set the dimensions of the hollow stepped horn with a circular plate to achieve a resonance frequency of about 58 kHz when the circular plate and the hollow stepped horn were joined, and the tip vibrated in phase at the resonance frequency.

Figure 3 shows the conductance versus the driving frequency of the sound source for each joining method. The measurement conditions were

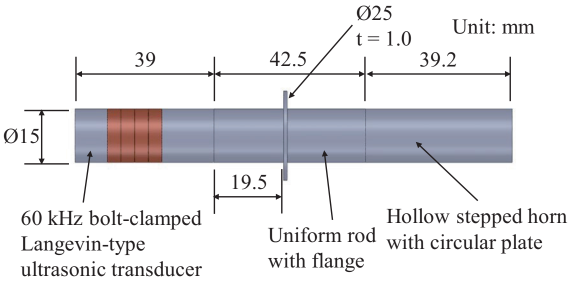

Fig. 1 Ultrasonic sound source.[2)]

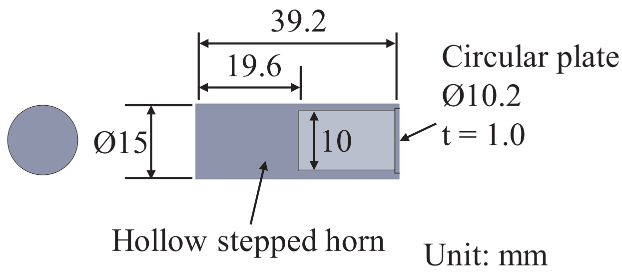

Fig. 2 Hollow stepped horn with a circular plate.[2)]

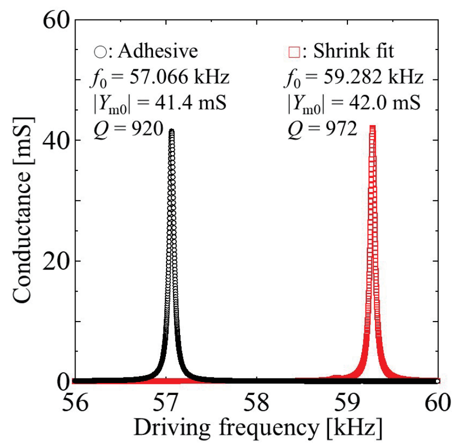

Fig. 3 Conductance versus the driving frequency of the sound source.

asami.takuya@nihon-u.ac.jp

input voltage of 1.0 V_{rms} and driving frequency of 56–60 kHz. The resonance frequencies for the shrink fit and adhesive joints were 57.066 and 59.282 kHz, respectively, and the differences from the values obtained by the finite element method were about 2%. The conductance and Q of the sound source were nearly the same, regardless of the joining method.

3. Measurement of vibration distribution at the tip

To clarify the vibration mode of the sound source tip, the vibration distribution of the tip was measured at each position in the radial direction passing through the center of the tip. The input power was 0.1 W and the tip was driven at the resonant frequency determined in Fig. 3. The vibration displacement was measured with a laser Doppler vibrometer (LV-1610, Onosokki).

Figure 4 shows the vibration distribution of the tip. The horizontal and vertical axes represent the radial position of the tip and the effective value of the vibration displacement amplitude, respectively. For the adhesive joint, the sound source tip was in phase and the center showed the largest vibration displacement. Thus, the adhesive joint allowed the horn and circular plate to function as an almost integral structure. In contrast, for the shrink fit joint, the vibration displacement of the tip was about 2.5 μm at the center, but the phase of the vibration displacement was reversed about ±5.0 mm from the center position. This reversal may have been caused by machining of the shrink fit joint, and the horn and plate did not function as an integral structure because the circular plate side surface and the horn were not in close contact around the whole circumference. These results showed that an adhesive joint should be used to obtain a large sound pressure in front of the sound source.

4. Sound pressure versus input electric power characteristics

The sound pressure versus the input for an adhesive joint was measured by setting a 1/8-in. condenser microphone (7118, ACO) in front of the sound source at a distance of 300 mm and varying the input power. **Figure 5** shows that the sound pressure increased in proportion to about the square root of the input electric power. A sound pressure of 91 Pa (133 dB) was obtained at an input electric power of 4.1 W. The impedance of the sound source increased rapidly when the input power was 4.1 W or more. Therefore, the sound pressure was measured up to an input electric power of 4.1 W.

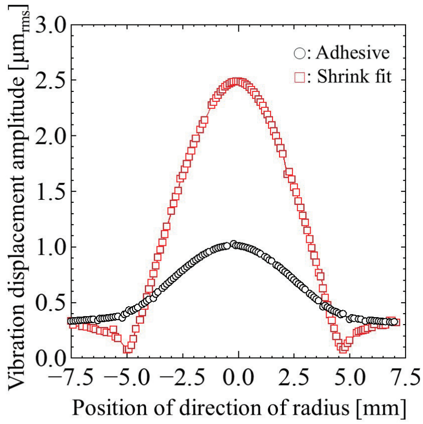

Fig. 4 Vibration distribution of the tip.

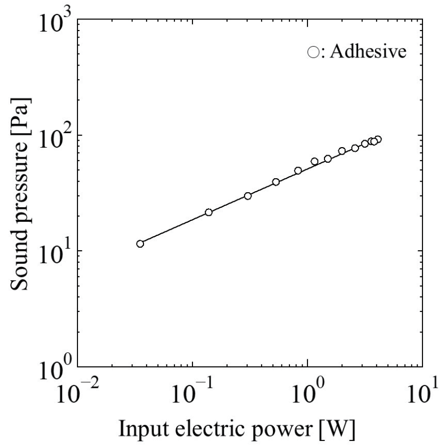

Fig. 5 Sound pressure versus input electric power characteristics in the case of adhesive.

The circular plate did not separate from the hollow stepped horn at an input power of 4.1 W.

5. Conclusions

In this paper, adhesive and shrink fit joints between a hollow stepped horn and a circular plate were compared. The adhesive joint allowed the stepped horn and circular plate to function as a nearly integral structure. The sound source using the adhesive achieved a sound pressure of 91 Pa (133 dB) at a distance of 300 mm. However, the shrink fit joint did not allow the plate and horn to function as an integral structure due to problems with the machining.

In future work, we intend to reconsider the shrink fit machining conditions and examine a structure that can provide a sound pressure that exceeds that obtained using an adhesive joint.

References

1. Ayumu Osumi, et al., Jpn. J. Appl. Phys. **58** (2019), SGGB14.
2. Takuya Asami, et al., Proc. Autumn Meet. Acoust. Soci. of Jpn. (2017), pp. 1117-1118 (in Japanese).