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Design of small ultrasonic sound source with square radiation surface

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1. Introduction

Small ultrasonic sound sources with a diameter of about 15 mm are used for non-contacting non-destructive testing and ultrasonic levitation.[1,2] Ultrasonic sensors are typical examples.[3] However, the sound pressure obtained from this ultrasonic sensor alone is low. Therefore, to obtain a large sound pressure, an array structure with a large number of sensors is essential.

Miura et al. previously developed a small ultrasonic source capable of generating high sound pressure.[4-6] However, the directivity of the radiation sound waves from this ultrasonic vibration source produced sidelobes, which are problematic. As a result, this source is not suitable for non-destructive testing.

Asami et al. proposed a small ultrasonic sound source that radiation sound waves by vibrating the surroundings of the radiation part.[7, 8] However, the radiation part was connected to the vibrating part by using an adhesive with insufficient mechanical strength, which led to difficulties in producing high sound pressure.

In the present study, the authors propose an ultrasonic sound source that integrates the sound wave radiation part and the vibrating part into a single structure in order to increase mechanical strength and prevent side lobes in the radiation sound wave. This paper describes the geometry of the proposed ultrasonic sound source and presents the analytical results.

2. Structure of the proposed sound source

A diagram of the proposed sound source is shown in **Fig. 1**. The sound source is composed of a bolt-clamp Langevin-type longitudinal ultrasonic transducer rated at 60 kHz (HEC-1560P4B; Honda Electronics), a uniform rod with a flange (material: A2017) for fine-tuning the resonance frequency, and a square bar (material: A2017), that has a square radiation surface and a slotted hole in the tip. The length of each section is equal to about 0.5 wavelengths of the propagating longitudinal vibration, for a total length of around 1.5 wavelengths. The square bar measures 15 mm on each side and has a slotted hole in the tip. The right side of this hole acts as the sound wave radiation part. In Figure 1, the red dashed line in the sound wave radiation part indicates the line from which the vibration displacement distribution is extracted, as described below.

Figure 2 shows a close-up view of the tip of the square bar and provides sample dimensions. Figure 2 also shows the analytical model used in this paper. As the figure shows, the thickness of the sound wave radiation part is 2.7 mm, and the design is such that sound waves are produced by the vibrations at both ends of the radiation part. The vibrating part and the radiation part form a single integral structure through the slot holes, which are 1.4 mm in height and have a sufficient width to form the vibrating section. The corners of the slot hole were enlarged to the extent as possible in order to prevent the concentration of vibration stress.

3. Analysis of sound wave radiation part

The vibration modes of the sound wave radiation part were analyzed with COMSOL ver. 6.0, using a 3D model, based on Fig. 2. The analysis was

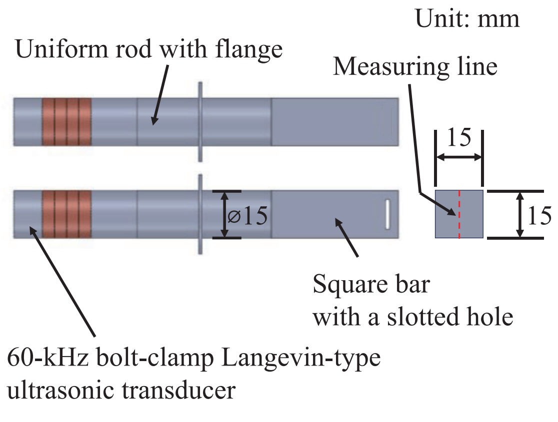

Fig. 1 Diagram of the proposed ultrasonic sound source.

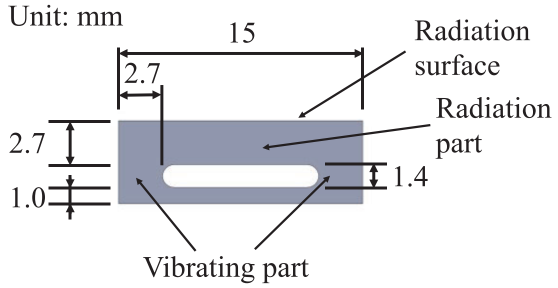

Fig. 2 View of the tip of the square bar.

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performed by applying a 60-kHz frequency and a 1-μm upward displacement to the bottom surface of the 3D model.

The results of the analysis are shown in **Fig. 3**, which indicates the magnitude of the vibration displacement amplitude using a heatmap. As the figure shows, the sound radiation part has a significant vibration displacement near its center. Additionally, the vibration phase of the radiation surface stays in phase across its entire surface. Moreover, the vibration phase at the bottom surface was in phase with the vibration phase of the sound radiation surface. According to these results, the vibration applied to the bottom surface was transformed into transverse vibration at the sound radiation part, resulting in considerable displacement. The transverse vibration and sound waves on the radiation surface were synchronized, reducing the likelihood of generating side lobes. The maximum stress during this vibration mode was less than 100 MPa. Thus, it is considered unlikely that damage would occur after a short driving period.

The vibration-mode analysis results are shown in **Fig. 4**. The vibration distribution was obtained from the red dashed line on the sound radiation surface shown in Fig. 1. In Fig. 4, the horizontal axis indicates the distance up to ±7.5 mm from the center position marked as 0 mm, and the vertical axis indicates the vibration displacement amplitude at each position. The distribution is in phase, with the minimum values at the ends and the maximum value in the center, and the distribution can be inferred from the vibration mode results. This distribution is similar to the vibration mode of a beam with fixed ends. The minimum-to-maximum ratio was approximately 20. The 1 μm-to-maximum ratio during the analysis was approximately 6.

The vibration mode and distribution results suggest that the sound wave radiation part produces sound waves in phase from its surface and its directivity is less likely to produce side lobes.

4. Conclusion

In this paper, we proposed a structure with a square bar and slotted holes as an ultrasonic sound source that realizes increased mechanical strength by integrating the sound wave radiation part and the vibrating part, thereby preventing side lobes in the radiation sound wave. We used COMSOL to investigate the vibration modes of the sound wave radiation part. The analysis results revealed that the sound wave radiation part of the proposed structure vibrates in phase with the sound wave radiation surface, and thus the radiation sound wave is also assumed to be in phase, thereby reducing the likelihood that side lobes will be generated in the radiation sound wave. In the future, we plan to refine the design of the sound wave radiation part and analyze the characteristics of the actual ultrasonic source.

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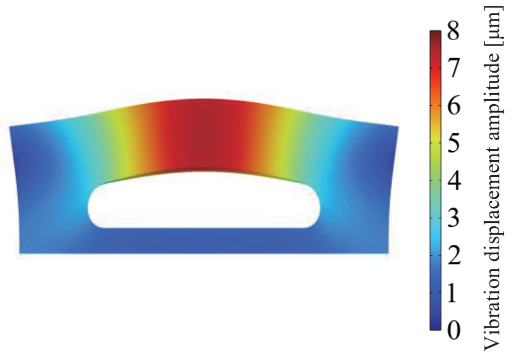

Fig. 3 Vibration-mode of the tip of the square bar.

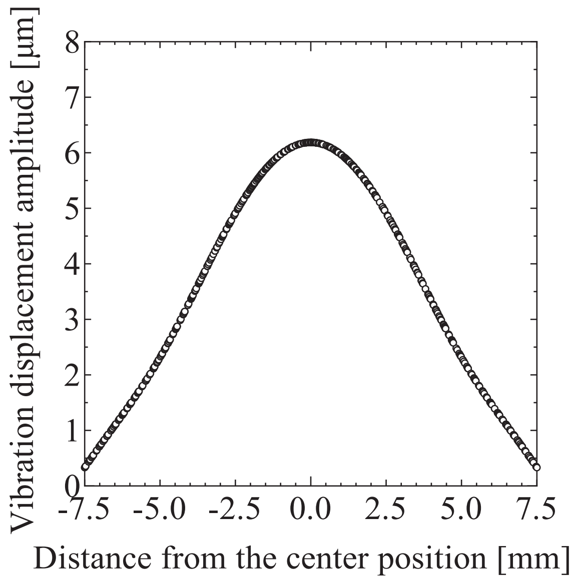

Fig. 4 Vibration displacement amplitude distribution of the sound wave radiation surface.