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Experimental evaluation of Bessel-like ultrasound beam with a single drive system

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1. Introduction

One of the properties of physical waves is diffraction. Diffraction makes it difficult to transmit sound energy and information without spreading around the beam region. To resolve the spreading, for example, focused sound sources are used to radiate sound waves in a restricted area on the beam axis. This achieves sound converging in the vicinity of the focal point but causes spreading in front of and behind it.

Bessel beams are non-diffractive beams whose lateral profile are given by Bessel function.[1)] While an infinitely large source is required to generate an ideal non-diffractive beam, finite aperture sources also can Bessel-like beams of finite length in the propagation direction.[2)] Conventional Bessel-like beams[3,4)] used phased arrays of discrete small ultrasonic transducers controlled electronically with phase and amplitude. However, implementing this type emitter is relatively complex and expensive because the transducers are controlled by multiple drive systems with a signal generator and amplifier. Therefore, a simpler method is needed to apply Bessel beams to practical uses.

Our study aims to realize a Bessel-like beam by multiple small ultrasonic transducers driving a single system. In this study, we first proposed a method to arrange multiple transducers driving a single signal to generate a Bessel-like beam.[5)] Then, we constructed a proto-type emitter and investigated the sound field by comparing theoretical predictions.

2. Construction of emitters

A Bessel-type emitter to form a Bessel-like beam was designed by adjusting transducer placement.[5)] The number of transducers (driving area weighting function $W(r)$) on a ring of radius r from the source center is adjusted to coincide with the value of the Bessel function $J_0(\alpha r)$, where $J_0(\cdot)$ is the 0th order of the first kind of Bessel function, and $W(r)$ is the ratio of the area of active elements to the area $2\pi r \Delta r$ of the ring at r with the width Δr. This originates from that the sound field at some point is a superposition of multiple sound waves from multiple transducers, and the superposition value on the beam axis is controlled by adjusting the number of transducers with the same amplitude. However, the application of this idea is limited to the area around the beam axis, and the difference between realized and theoretical sound fields increases in the region away from the beam axis.

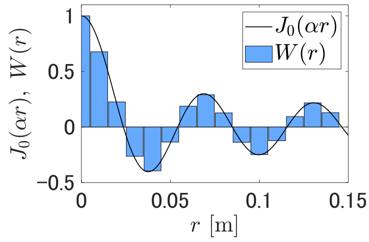

Fig. 1 Weighting of Bessel-type emitter for $\alpha = 102\ \mathrm{m}^{-1}$ and $\Delta r = 10$ mm.

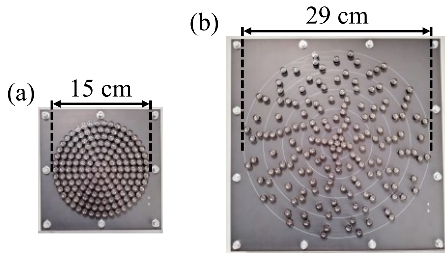

Fig. 2 Top view of (a) uniform-type emitter and (b) Bessel-type emitter.

In this study, to realize the Bessel-like beam of a width of 20 mm and beam length of 1 m, we determined the emitter diameter of 290 mm and $\alpha = 102\ \mathrm{m}^{-1}$ for $\Delta r = 10$ mm (see **Fig. 1**). Transducers on the negative weighting are driven by a reverse phase signal. We used transducers of 9.5 mm in diameter with a resonance frequency of around 40 kHz (UT1007-Z325R, SPL) to build emitters. For comparison, a uniformly vibrating emitter (uniform-type emitter) composed of almost same number of transducers was also designed. **Figure 2** shows the top views of uniform-type emitter with 169 transducers and Bessel-type emitter with 171 transducers arranged according to the weighting shown in Fig. 1.

3. Experiment

3.1 Method

We measured sound fields of two emitters. Signals at frequency of 40.7 kHz driving emitters were generated by a synthesizer (WF1966, NF) and amplified by a power amplifier (PS-A2002, Victor). The sound fields formed by the uniform- and Bessel-type emitters were measured by a 1/4-inch condenser

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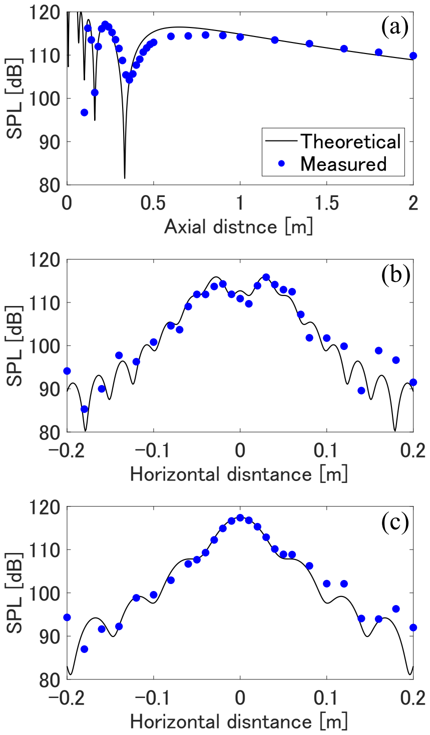

Fig. 3 Sound field of uniform-type emitter. (a) Axial direction and (b) and (c) horizontal directions at distances of 0.4 and 0.8 m along the beam axis from the emitter, respectively.

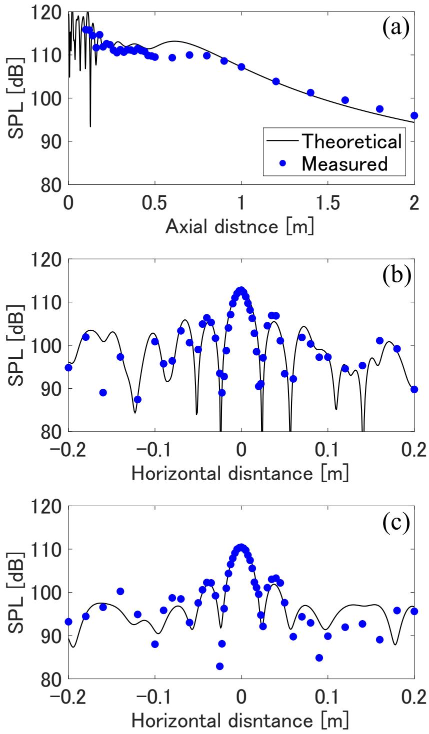

Fig. 4 Sound field of Bessel-type emitter. (a) Axial direction and (b) and (c) horizontal directions at distances of 0.4 and 0.8 m along the beam axis from the emitter, respectively.

microphone (4939, B&K) and a 1/8-inch condenser microphone (40DP, GRAS), respectively.

3.2 Results and Discussion

Figure 3 shows the measured sound field of uniform-type emitter with theoretical predictions calculated by Rayleigh integral. The measured values for the uniform-type emitter are generally similar to the theoretical values. Some pressure peaks and dips were observed within 0.6 m on the beam axis. The beam patterns in horizontal sound field show that the beam width varies with distance.

Figure 4 shows the sound field of Bessel-type emitter. The measurement results also show a trend similar to the theoretical values. The sound pressure was almost constant up to 0.8 m on the beam axis, although several peaks and dips are observed in the same range of the uniform-type emitter. However, the measured values are relatively lower than theoretical predictions in the range from 0.5 to 0.8 m.

In the horizontal sound field of a Bessel-type emitter, the beam at the center is close to the theoretical values. The 3-dB widths at 0.4 and 0.8 m from the emitter were maintained at about 20 mm. There are discrepancies between measured and theoretical values of beam patterns 0.1 m away from the beam axis. This is because the emitter was designed to match the Bessel beam only near the central axis.

The sound pressure along the beam axis at far distance was lower than that of the uniform-type emitter. This seems to result from the fact that some transducers of the Bessel-type emitter are driven in opposite phases according to the sign of the weighting function, so some of the sound waves cancel each other out.

4. Conclusion

In this study, we attempted to realize a Bessel-like ultrasound beam with a single drive system by adjusting the placements of transducers with the same amplitude. As the results of sound field measurements, we found that the proposed Bessel-type emitter generate a Bessel-like beam within a certain range along the sound axis. However, compared to the uniform-type emitter using a similar number of transducers, the sound pressure in far distance tended to be lower.

References

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