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Preliminary Analysis Results of Sound Field Converged by a Convex Acoustic Lens Applying to Ambient Noise Imaging

周囲雑音イメージングに適用する凸型音響レンズによって集束された音場の予備解析結果

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1. Introduction

Buckingham *et al.* developed a revolutionary idea, which views ambient noise as a sound source rather than a hindrance, and which is neither a passive nor an active sonar. [1] This method is often called ambient noise imaging (ANI), and an acoustic lens system would be a suitable choice for realizing ANI. We already designed and made a concave aspherical lens for ANI. The silent targets were successfully imaged under only ocean natural ambient noise, which is mainly generated by snapping shrimps in sea trials. [3-6]

For surveying underwater objects in the vast ocean, it is necessary to mount an ANI system into a movable vessel such as an autonomuos underwater vehicle (AUV). However, the concave lens developed in our previous studies is not suitable to mount it on the bow of AUV. Because the concave lens does not fit to the AUV’s bow shape, its water resistance is large. Our group studied some convex lenses to mount on an AUV's bow. These lenses were composed with solid lenses faced to sea water, and inner liquids placed in the AUV's bow. [7, 8] Recently, we measured the sound velocities and refractive indexes for some materials suitable to the convex lens. [9, 10]

In this report, the preliminary results are described to analyse a sound pressure field converged by a convex lens having optimized surfaces based on the measured refractive indexes, for applying to ANI. Here, the optimized surfaces of the lens are calculated by ray tracing method, and the sound pressure field is roughly calculated by the 2D Finite Difference Time Domain (FDTD) method.

2. Optimized surfaces of convex lens

The conceptual image of the convex lens mounted on the AUV's bow is shown in Fig. 1. The solid lens has two aspherical surfaces, the convex surface S_1 faced to sea water and the concave surface S_2 faced to the inner liquid placed in the AUV's bow. The focal surface, in which receiver array is arranged, is in the inner liquid. Here, the syntactic foam TG-28/4000 was selected as the solid lens, and the Fluorinert FC-72 was selected as the inner liquid from those measured refractive indexes. [10] We are planning to perform a small-scale experiment in a water tank at the scale of 0.24, for evaluating a resolution and a gain of such convex lens. By the ray tracing method, the optimized surfaces S_1 and S_2 of the lens, which will be possibility used for this experiment, were calculated to minimize aberrations as shown in Fig. 2. Here, the aperture diameter is 240 mm, the center thickness T_1 is 10 mm, and the focal length T_2 is 390 mm. The refractive index of TG-28/4000 is 0.585, and that of FC-72 is 2.859.

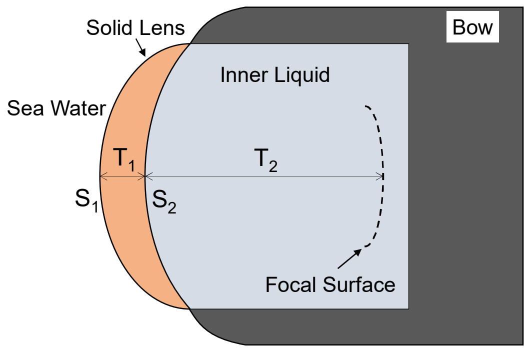

Fig. 1　Conceptual image of convex lens mounted on AUV’s bow

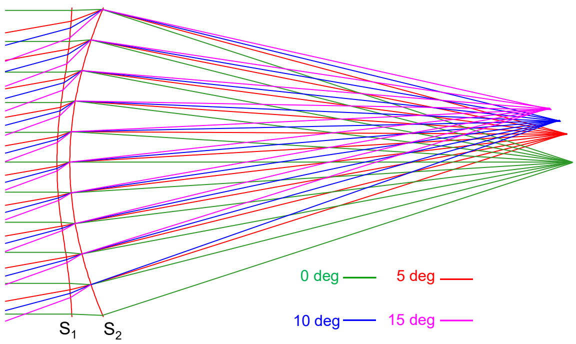

Fig. 2　Optimized surfaces and ray diagram of the convex lens

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3. Preliminary analysis results of sound pressure field converged by the convex lens

As shown in Fig. 3, the analysis domain for the 2D FDTD method was the area bounded by the absorption layer. The line source arranged in the sea water radiates the plane wave of the burst pulse with 5 waves at 500 kHz. The sound velocities and the densities were 1515.1 m/s and 1000 kg/m^3 in sea water, 2592.1 m/s and 448 kg/m^3 in the solid lens, and 530.0 m/s and 1680 kg/m^3 in the inner liquid, respectively. The attenuation constants were 0 dB/λ in sea water and the inner liquid, 0.1 dB/λ in the solid lens, and 5 dB/λ in the absorption layer, respectively. Mur's first-order absorbing boundaries were applied to the exteriors in order to eliminate the reflection wave from the outer boundary of the analysis domain. The origin is set to the center of the 1st surface S_1.

Figure 4 shows the sound pressure field calculated by the 2D FDTD method at the incident angle of 0 deg. It can be seen that the sound wave radiated from the line source was refracted by two surfaces of the solid lens, and converges toward the focal point in the inner liquid. There is a prominent peak at x=0 mm and z=400 mm. The maximum point of the z-axis is formed at the sum of T_1 and T_2 described above. The beam patterns at the incident angles of 0, 1, and 2 deg are compared in Fig. 5. It is clear that the directional resolution of this lens is less than 1 deg because the main-lobes of these beams at the -3 dB line are not overlap each other.

In the near future, the lens performances such as resolution and gain will be evaluated by the numerical analysis of the 3D FDTD method and the small-scale experiments in a water tank, in more detail.

Acknowledgment

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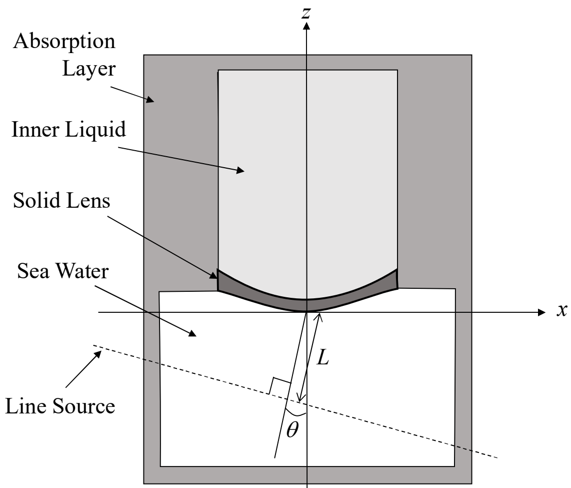

Fig. 3 Arrangement of 2D FDTD method.

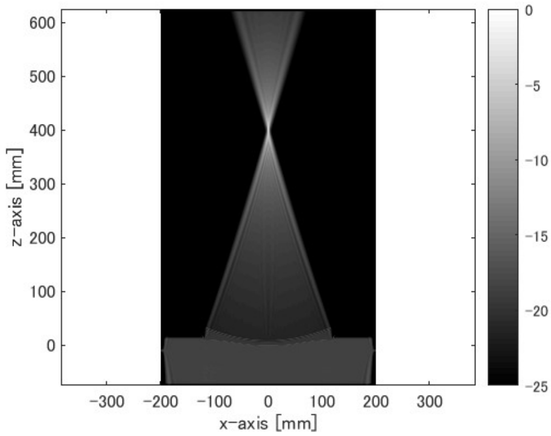

Fig. 4 Sound pressure field calculated by the 2D FDTD method at the incident angle of 0 deg.

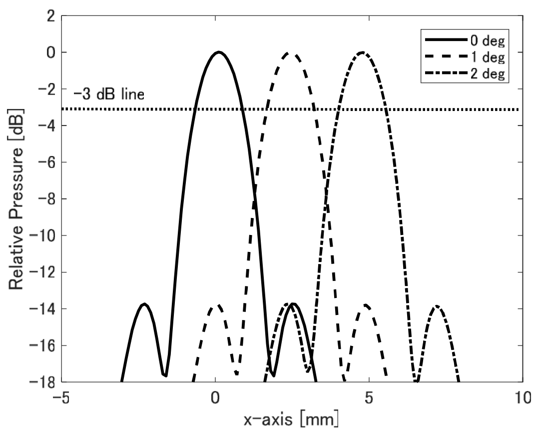

Fig. 5 Comparison of beam patterns at the incident angles of 0, 1, and 2 deg.