2Pa6-3

Preliminary 3D FDTD Analysis of Sound Field Converged by Convex Acoustic Lens with Solid-Liquid Compound Structure

固体液体複合凸型音響レンズによって集束される音場の予備的な 3D FDTD 解析

Kazuyoshi Mori[1†], and Hanako Ogasawara[1] ([1]National Defense Academy)
森　和義 [1†]，小笠原英子 [1] ([1]防衛大学校)

1. Introduction

Buckingham *et al.* developed an innovational sonar method, which views ambient noise as a sound source rather than a hindrance[1], and that is often called ambient noise imaging (ANI). An acoustic lens system would be a suitable choice for realizing ANI. We already designed and made a bi-concave aspherical lens for ANI. The silent targets were successfully imaged under only ocean natural ambient noise in sea trials.[3-6]

For surveying underwater objects in a vast expanse of 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 desirable 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 for applying to the convex lens.[9, 10] The optimized surfaces of the lens were already designed by ray tracing method.[11]

In this study, a sound pressure field converged by the designed convex lens are preliminary analyzed by the 3D 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. 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 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. In the 3D analysis, the lens shape is applied

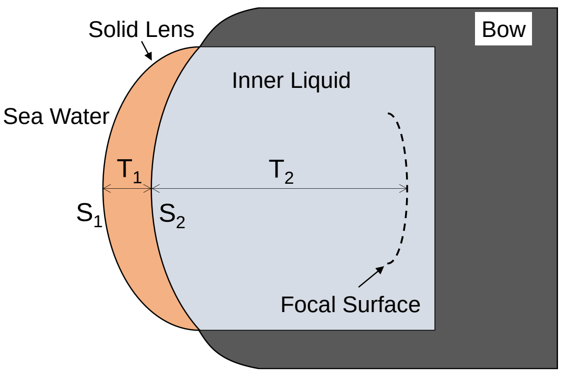


Fig. 1　Conceptual image of convex lens mounted on AUV’s bow

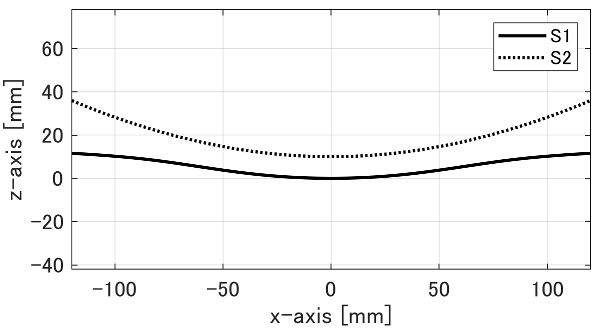


Fig. 2　Optimized surfaces of the designed lens

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

As shown in Fig. 3, the analysis domain for the 3D FDTD method is the area bounded by the absorption layer. Here, the 3D shape of the

† kmori@nda.ac.jp

designed lens is formed as a rotational symmetry centered on x=0, from the 2D shape in Fig. 2. In the x-z plane at y=0 of Fig. 3(a), the plane 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 are 1515.1 m/s and 1030 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 are 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 are 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. As shown in the x-y plane at $z=z_e$ of Fig. 3(b), to reduce the calculation volume, the analysis domain is halved on the y-axis using the symmetric condition with respect to the x–z plane at y=0.

Figure 4 shows the comparison of the beam patterns at the incident angles of 0 degree between 2D and 3D analysis. It is shown that the both main-lobes are agreed well, but the 1st side-lobe of the 3D analysis is about 5 dB lower than that of the 2D analysis.

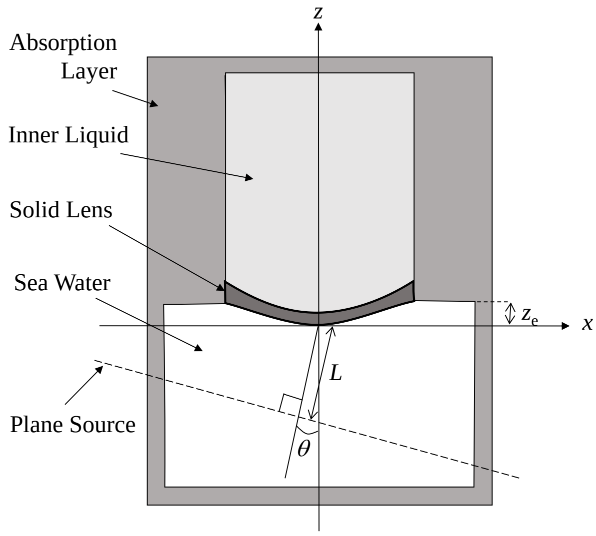
In the near future, the lens performances such as resolution and gain will be evaluated by a series of the numerical analysis of the 3D FDTD method and the small-scale experiments in a water tank, in more detail.

Acknowledgment

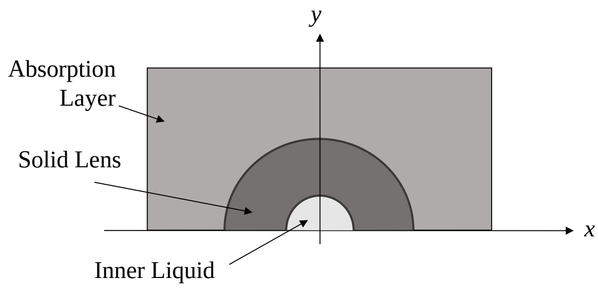
This work was supported by JSPS KAKENHI Grant Number JP18K04597.

References

1. M. J. Buckingham, B. V. Verkhout and S. A. L. Glegg: Nature, **356** (1992) 327.
2. K. Mori, H. Ogasawara, T. Nakamura, T. Tsuchiya, N. Endoh: Jpn. J. Appl. Phys., **50** (2011) 07HG09.
3. K. Mori, H. Ogasawara, T. Nakamura, T. Tsuchiya, N. Endoh: Jpn. J. Appl. Phys., **51** (2012) 07GG10.
4. K. Mori, H. Ogasawara, T. Nakamura, T. Tsuchiya, N. Endoh: Jpn. J. Appl. Phys., **52** (2013) 07HG02.
5. K. Mori, H. Ogasawara, T. Tsuchiya, N. Endoh: J. Appl. Phys., **55** (2016) 07KG07.
6. K. Mori, H. Kawahara, H. Ogasawara, T. Tsuchiya: J. Appl. Phys., **57** (2018) 07LG05.
7. H. Kawahara, H. Ogasawara, K. Mori: Proc. UACE2017 (2017) 975.
8. H. Kawahara, H. Ogasawara, K. Mori: Proc. USE2017 (2017) 3P6-2-1.
9. K. Mori, H. Ogasawara: Proc. USE2019 (2019) 1P6-1-1.
10. K. Mori, H. Ogasawara: J. Marine Acoust. Soc. Jpn., **47** (2020). [in Japanese]
11. K. Mori, H. Ogasawara: Proc. USE2020 (2020) 2Pa6-1.



(a) x-z plane at y=0



(b) x-y plane at $z=z_e$

Fig. 3 Arrangement of 3D FDTD method.

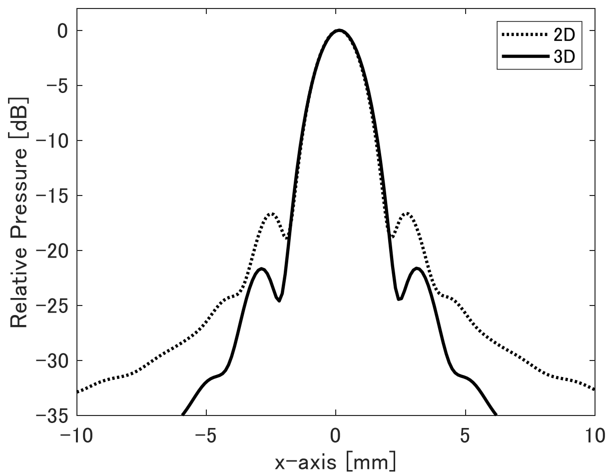


Fig. 4 Comparison of beam patterns between 2D and 3D analysis.