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Fundamental Study on Effect of Acoustic Matching Layer on Convex Aspherical Acoustic Lens for Installation in Bow of Small AUV

小型潜水艇搭載用凸型非球面音響レンズにおける音響整合層の効果についての基礎的研究

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1. INTRODUCTION

As the acoustic lens has refractive properties, the underwater sonar system using acoustic lens does not need large-scale array and a dedicated signal processing device for beam foaming. Thus, the acoustic lens is useful for real-time processing, miniaturization, and power saving. From this, it can be expected to be used for underwater imaging sonar of Autonomous Underwater Vehicle (AUV) for obstacle avoidance. Tsukioka et al. produced a spherical lens for AUV mounting and succeeded in actually obtaining images in water [1].

In the previous study, we designed a convex underwater acoustic lens assumed to be mounted on the bow of AUV, and the sound field was calculated by the finite difference time domain method (FDTD method) [2]. Then, the first surface S_1 was considerd as a spherical surface.

In this study, the aspherical surface is used for the surface S_1 of the lens and the aberration is investigated. Additionally, acoustic matching layers of various thicknesses were inserted between two different medium, and the conveged acoustic field was calculated by the FDTD method.

2. LENS SHAPE

1.1 Lens mediums

In this study, the acoustic lens is assumed to be used for underwater imaging sonar for obstacle avoidance of AUV. In this case, we will install a lens on the bow of AUV, as the bow receives the most water resistance, and it is desirable that its effect be as small as possible. In the previous study, the surface facing the water is a convex spherical shape. In this study, not only the surfaces S_2 and S_3 but also the surface S_1 is set to an aspheric to improve the converged sound pressure still further.

Fig. 1 shows a schematic diagram of the lens.The lens surfaces are defined as S_1, S_2 and S_3, and the thickness of layers are defined as T_1 and T_2, respectively.

This lens is arranged on the shell in a medium that has a sound speed higher than that of water (Syntactic foam); internal liquid has a sound speed slower than that of water (Fluorinert). This lens structure was considered to eliminate sound waves from the lens edges, which cause spherical aberration [3].

In order to improve impedance matching, an acoustic matching layer (Silicone rubber) was inserted between Syntactic foam and Fluorinert. The various thicknesses of the acoustic matching layer were surveyed, such as λ/4, λ/8, 3λ/8 and λ/2.

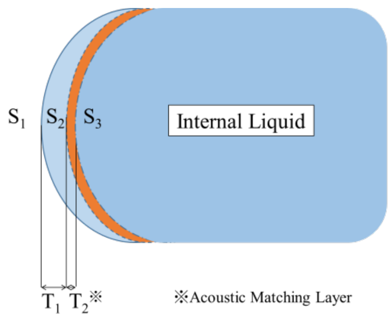

Fig. 1 Definition of lens surface and thickness

1.2 Lens optimization

Blurring and distortion of an image obtained by sound waves passing through a lens is called aberration. Aberration degrades image accuracy [4]. In order to correct this aberration, sound ray tracking was performed using optical design software and aberration was investigated. Also, the optimum lens surface was obtained using the equation of even order aspherical surface to correct aberration (optimization) as follow;

$$z = \frac{rx^2}{1+\sqrt{1-(K+1)r^2x^2}} + Ax^4 + Bx^6 + Cx^8 + Dx^{10} + Ex^{12} + Fx^{14} + Gx^{16} + Hx^{18}$$

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where r is the vertex curvature of the surface (mm^{-1}), K is the Korenich coefficient and A-H are aspheric coefficients. Optimization to minimize aberrations was performed by varying r, K, and A-H in the above equation, and the thicknesses T_1 and T_2. Figure 2 shows the ray tracing results at incidence angles of 0 and 10 degrees. Table 1 shows definition of lens, and Table 2 shows aspherical coefficients of the three surfaces.

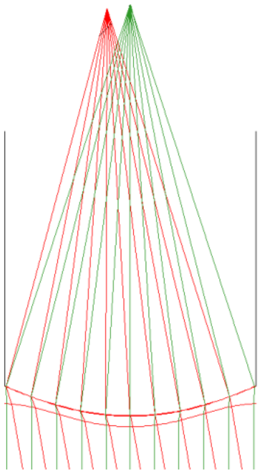

Fig. 2 Ray tracing results at the incidence angles of 0 and 10 degrees

Table 1 Definition of lens

Surface	S_1		S_2		S_3
Radius (m)	0.181		0.242		0.244
Thickness (m)		0.01		0.000555	∞
Material	W	SF		SR	FL
Korenich coefficient	-0.31		-0.76		-0.89

W: Water, SF: Syntactic foam,

SR: Silicone rubber, FL: Fluorinert

Table 2 Aspherical coefficients

	S_1	S_2	S_3
A	0.87×10^{-8}	0.12×10^{-7}	0.48×10^{-8}
B	-0.19×10^{-11}	-0.18×10^{-12}	-0.21×10^{-11}
C	0.99×10^{-15}	0.20×10^{-16}	0.11×10^{-15}
D	-0.81×10^{-20}	0.10×10^{-20}	-0.57×10^{-20}
E	-0.85×10^{-24}	0.32×10^{-25}	0.38×10^{-24}
F	0.25×10^{-28}	-0.27×10^{-30}	0.24×10^{-28}
G	0.69×10^{-33}	-0.15×10^{-33}	-0.33×10^{-32}
H	0.44×10^{-37}	-0.17×10^{-37}	-1.00×10^{-37}

3. RESULTS

A simulation using the FDTD method was performed on the proposed lens, and the converged field was analyzed. For various thicknesses of acoustic matching layers, the beam patterns and on-axis characteristics at the focal point are compared in Figs. 3 and 4. When the thickness is 3λ/8 or λ/2, the converged sound pressure was largest. In this case, the pressure was 0.13 dB larger than that without the acoustic matching layer. The side lobes are similar except the thickness of λ/8.

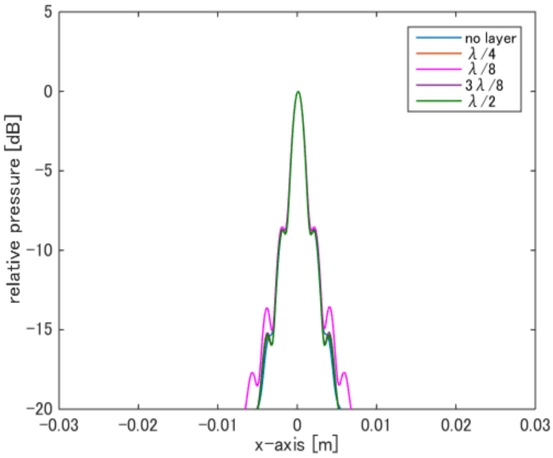

Fig. 3 Simulation results for beam patterns on horizontal plane at the focal point (normalized by each peak)

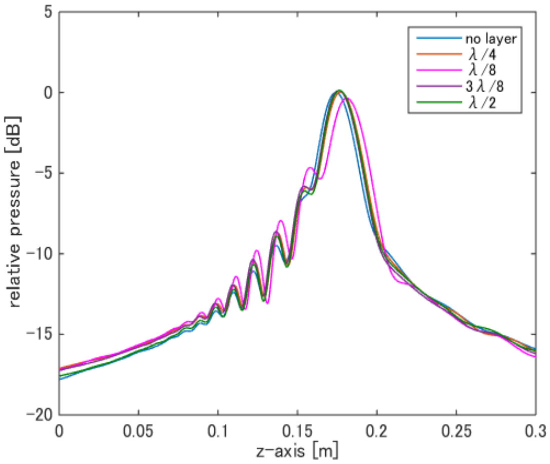

Fig. 4 Simulation results for on-axis characteristics of the lens (normalized by the maximum sound pressure at the focal point without acoustic matching layer)

Acknowledgment

This work was supported in part by a Grant-in-Aid for Scientific Research (C: 15K06633) from the Japan Society for the Promotion of Science.

References

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