1P6-1

Preliminary Results of Refractive Index Measurements for Some Materials of 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材の屈折率測定の予備的結果

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 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 with an aperture diameter of 1.0 m for ANI. It was verified that this acoustic lens realizes directional resolution, which is a beam width of 1 degree at the center frequency of 120 kHz over the field of view (FOV) from -7 to +7 degrees. [2] In the 1st and 2nd sea trials, the silent targets were successfully imaged under only ocean natural ambient noise, which is mainly generated by snapping shrimps. [3-5] In the 3rd sea trial, the frequency-dependent targets were effectively imaged by RGB additive color mixing. [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]

We have measured the refractive indexes for some solid materials suitable to the convex lens for an ANI system to mount an AUV’s bow. The optimized surfaces of lenses were also calculated with the measured refractive indexes. In this report, these preliminary results are described.

2. Measurement of refractive indexes of solid lenses

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 the inner liquid placed in the AUV's bow. The focal surface, in which receiver array is arranged, is in the inner liquid. In our previous studies, it was supposed that the inner liquid has a higher density and a lower sound speed than those of sea water. The Fluorinert FC-72 was selected, because the sound speed was known. [9] It was also supposed that the materials of solid lenses were syntactic foams, which have lower densities and higher sound speeds than those of sea water. In this study, three syntactic foams, TG-26/3000, TG-28/4000, and TG-39/11500 were selected. [10] Table 1 shows the sound speeds measured by the sing-around method [11], and refractive indexes referenced by that of sea water. Here, the water temperature in the measurement tank was kept at about 24.6 degrees Celsius, using the heating/cooling system. The sea water’s sound speed of 1530.07 m/s was calculated by the Mackenzie's equation at the water temperature of 24.6 degrees Celsius, the salinity of 32 ppt, and the water depth of 0 m. Table 1 shows that the measured values of sound speeds of solid lenses are greater than that of sea water.

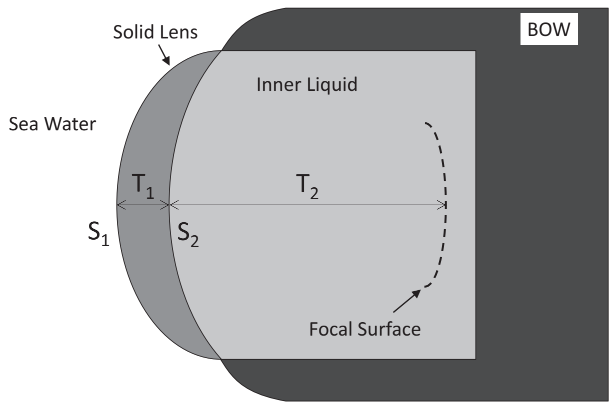


Fig. 1 Conceptual image of convex lens mounted on AUV’s bow

---

† kmori@nda.ac.jp

Table 1 Preliminary results of sound speeds and refractive indexes for materials of solid lenses

Materials	Sound speed (m/s)	Refractive index
TG-26/3000	2507.91	0.6101
TG-28/4000	2605.58	0.5872
TG-39/11500	2799.73	0.5465

3. Calculations of ray diagrams

We are planning to perform a small-scale experiment in a water tank at the scale between about 1/4 and 1/2.5, 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 lenses, which will be possibility used for this experiment, were tentatively calculated to minimize aberrations. 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 sound speed of the inner liquid FC-72 is 512 m/s, and its refractive index is 2.9884 referenced by that of sea water. The ray diagrams of three materials of solid lenses are shown in Fig. 2, at the angles of incidences of 0, 5, 10, and 15 degrees. It can be seen that the rays are concentrated to the individual image point at each incident angle although the thickness of lens edge is larger with the refractive index.

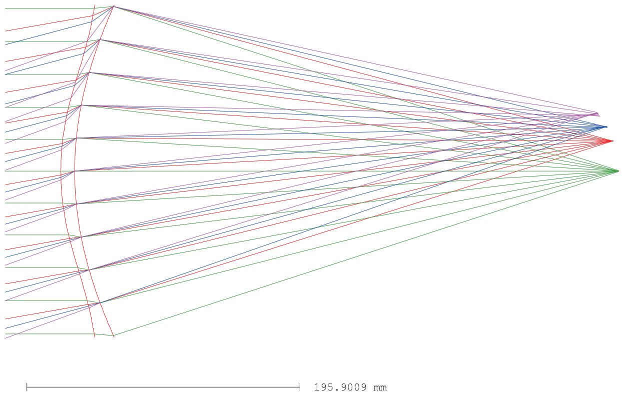
In the near future, we will measure the temperature dependence of the refractive indexes of these three materials for the solid lenses. Then, the lens performances such as resolution and gain will be evaluated by the numerical analyses of the finite difference time domain method and the small-scale experiments in the water tank.

Acknowledgment

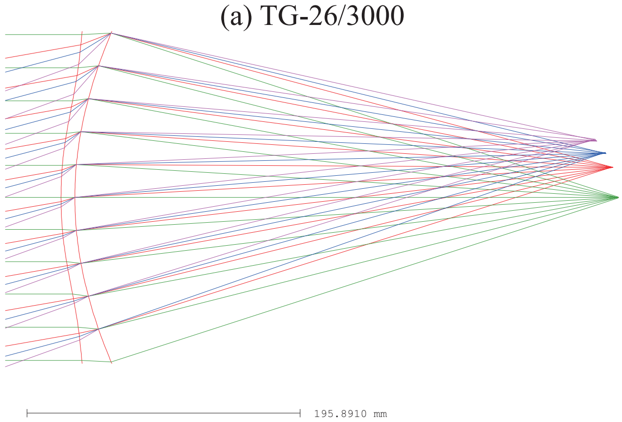
This work was supported by JSPS KAKENHI Grant Number JP18K04597.

References

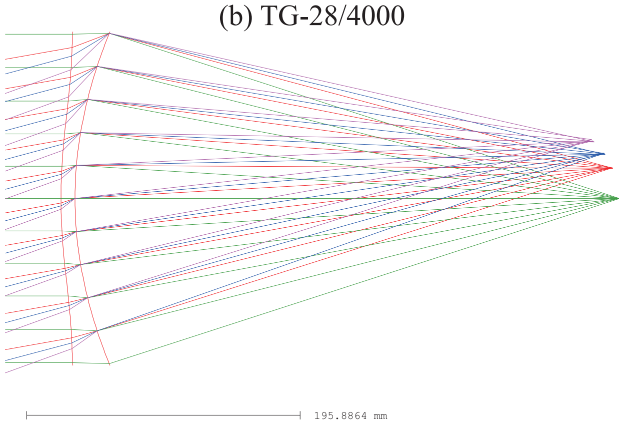
1. M. J. Buckingham, B. V. Verkhout and S. A. L. Glegg: Nature, **356** (1992) 327.
2. K. Mori, H. Ogasawara, T. Nakamura, T. Tsuchiya, N. Endoh: Jpn. J. Appl. Phys., **50** (2011) 07HG09.
3. K. Mori, H. Ogasawara, T. Nakamura, T. Tsuchiya, N. Endoh: Jpn. J. Appl. Phys., **51** (2012) 07GG10.
4. K. Mori, 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. Onda Corp.: Tables of Acoustic Properties of Materials, http://www.ondacorp.com/tecref_acoustictable.shtml
10. Trelleborg Offshore: Eccofloat, https://www.trelleborg.com/en/offshore/products/rov--auv--hov--buoyancy--systems/eccofloat
11. T. Tsuchiya, N. Endoh, S. Matsumoto, K. Mori: J. Marine Acoust. Soc. Jpn., 38 (2011) 195. [in Japanese]



(a) TG-26/3000



(b) TG-28/4000



(c) TG-39/11500

Fig. 2 Examples of ray diagrams of lenses calculated by the measured refractive indexes. (a) TG-26/3000; (b) TG-28/4000; (c) TG-39/11500.