3P-62

Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 579-580
6-8 December, 2010

An Analysis of Convergence Performance of Acoustic Lens Applied to Ambient Noise Imaging in Actual Ocean Experiment

実海域試験における周囲雑音イメージングに適用する音響レンズの集束特性解析

Kazuyoshi Mori[1†], Hanako Ogasawara[1], Toshiaki Nakamura[1], Takenobu Tsuchiya[2] and Nobuyuki Endoh[2] ([1]National Defense Academy; [2]Kanagawa Univ.)
森　和義 [1†]，小笠原英子 [1]，中村敏明 [1]，土屋健伸 [2]，遠藤信行 [2]（[1] 防衛大学校; [2] 神奈川大）

1. Introduction

The revolutionary idea that views ambient noise as a sound source rather than a hindrance was developed by Buckingham *et al.* This method is called ambient noise imaging (ANI), and is neither passive nor active sonar method.[1] In the 1990's, the Acoustic Daylight Ocean Noise Imaging System (ADONIS), consisting of a 3 m diameter spherical reflector and having an array of 126 hydrophones attached to the focal surface, was built by Epifanio and Buckingham *et al.*[2] In the early 2000's, the Remotely Operated Mobile Ambient Noise Imaging System (ROMANIS), consisting of a 2-D sparse array of 504 hydrophones fully populating a 1.44 m circular aperture, was built by Venugopalan *et al.*[3]

On the other hand, an acoustic lens system would be a powerful choice for realizing ANI, because such a system would not require a large receiver array and a complex signal processing unit for two-dimensional beam forming, which could reduce the size and cost of the system. In our past studies, we analyzed a sound pressure field focused by an acoustic lens system constructed for an ANI system with a single spherical biconcave lens or a single aplanatic lens using the 2-D and 3-D Finite Difference Time Domain (FDTD) method and the small scale trial in water tank. Our aim was the development of a lens with a resolution similar to the beam width of ROMANIS, which is 1° at the frequency of 60 kHz. These results showed that the lens with the aperture diameter of 2.0 m has the sufficient resolution.[4-6]

In this study, an aspherical lens with the aperture diameter of 1.0 m is designed for utilization in an actual ocean experiment of ANI. It is expected that this smaller-sized ANI system realize the directional resolution which is the beam width of 1° at the center frequency of 120 kHz. We analyze the sound pressure distribution focused by the aspherical lens using the 3-D FDTD method. The frequency dependence of –3 dB area is then compared between the center frequency of 120 kHz and the higher or the lower frequency.

† kmori@nda.ac.jp

2. Lens Shape for ANI System

The lens shape is designed by the software "ZEMAX" for optical system design. The refraction index between water and acrylic resin, that is the material of lens, is 0.54 assuming the water temperature of 20 °C at the planned experimental site (Uchiura Bay) in November. The rotationally symmetric polynomial aspheric surfaece by the components of even powers is designated as the lens surfaces as follows:

$$z = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + \alpha_1 r^2 + \alpha_2 r^4 + \cdots ,$$

where r is the radius of the lens, and z is the surface height. The parameters c, k, α_1 and α_2 are optimized by "ZEMAX" assuming that the distance from the object to the lens is 50 m, the distance from the lens to the image is 1.2 m, and the thickness of lens center is 10 mm. The optimized parameters of the object side are as follows:

$c = 1/(-5261)$, k=89.51,

$\alpha_1 = -2.157\times10^{-4}$, $\alpha_2 = 4.482\times10^{-10}$.

Those of the image side are as follows:

$c = 1/(436.0)$, $k = -1.000$,

$\alpha_1 = -5.483\times10^{-4}$, $\alpha_2 = 7.746\times10^{-10}$.

Here, the components over the 6th order are neglected. **Figure 1** shows the lens shape.

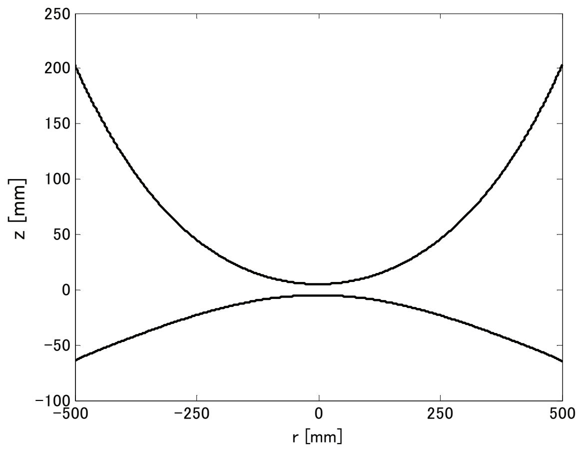


Fig. 1　Lens shape

3. Analysis Results

Using the 3-D FDTD method, the sound pressure distribution focused by the designed lens was calculated at every 1° of the incidence angle, when the range between the point source and the lens is 25 m. The –3 dB area, whose pressure is 3 dB lower than the maximum pressure at the image point, is used for evaluating the directional resolution of the lens, the same as 3 dB beam width. The –3 dB areas are shown in **Fig. 2**. In Fig. 2(a) at the center frequency of 120 kHz, we can see that each –3 dB area has a width of about 0.016 m. In Fig. 2(b) at 160 kHz, each –3 dB area is smaller than that at 120 kHz, and its width is about 0.012 m. Whenever the incidence angle increases by 1°, the image point shifts to the right by about 0.021 m. The –3 dB areas do not overlap each other in Figs. 2(a) and 2(b). These results suggest that the designed lens has fine resolution over the center frequency of 120 kHz. However, in Fig. 2(c) at 80 kHz, each –3 dB area is larger than that at 120 kHz, and its width is about 0.024 m. The sufficient resolution cannot be realized under 120 kHz, because the –3 dB areas overlap each other in Fig. 2(c) at 80 kHz.

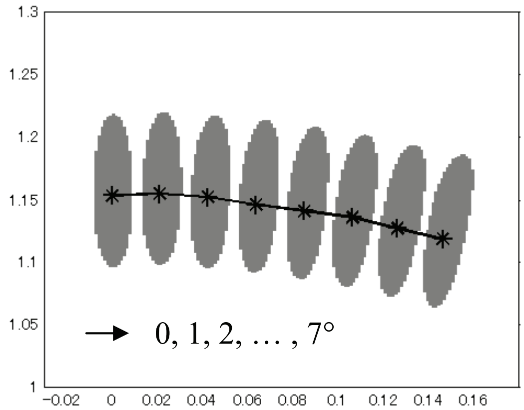
4. Summery

In this study, the aspherical lens with the aperture diameter of 1.0 m was designed for the actual ocean experiment of ANI. The analysis results using the 3-D FDTD method suggested that the designed lens has fine directional resolution over the center frequency of 120 kHz.

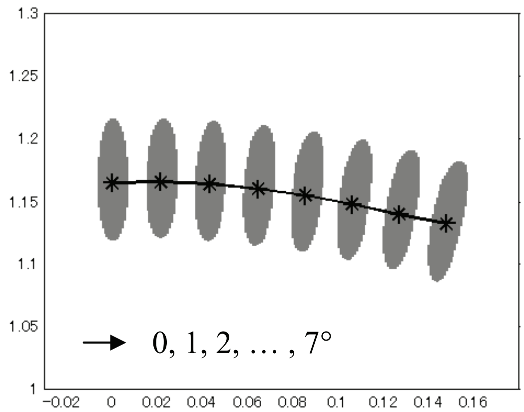
We have a plan to measure the directionality of the designed lens on an actual ocean experiment in Uchiura Bay on November of 2010. It will be verified that the ANI system with this lens realizes the directional resolution which is the beam width of 1° over 120 kHz. We also have another plan to conduct the experiment of target imaging under snapping shrimp dominant noises using this lens system.

Acknowledgment
This work was partially supported by a Grant-in-Aid for Scientific Research (B) from the Japan Society for the Promotion of Science (No. 21360440).

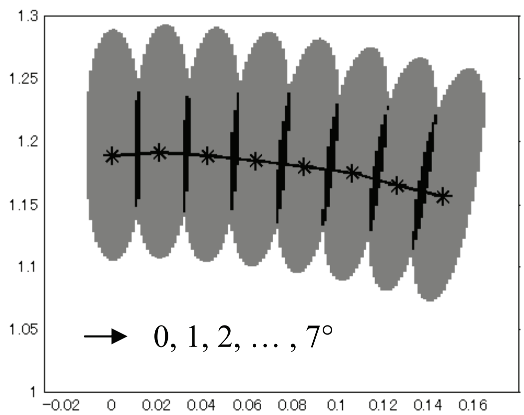
References
1. M. J. Buckingham, B. V. Verkhout and S. A. L. Glegg: Nature, **356** (1992) 327.
2. C. L. Epifanio, J. R. Potter, G. B. Deane, M. L. Readhead and M. J. Buckingham: J. Acoust. Soc. Am., **106** (1999) 3211.
3. P. Venugopalan, M. A. Chitre, E. T. Tan, J. Potter, K. T. Beng, S. B. Ruiz and S. P. Tan: Proc. Oceans 2003 Marine Technology and Ocean Science Conf. (2003) CD-ROM.
4. K. Mori, A. Miyazaki, H. Ogasawara, T. Yokoyama and T. Nakamura: Jpn. J. Appl. Phys., **45** (2006) 4834.
5. K. Mori, H. Ogasawara, and T. Nakamura: Jpn. J. Appl. Phys., **47** (2008) 4344.
6. K. Mori, H. Ogasawara, T. Nakamura, T. Tsuchiya, N. Endoh: Jpn. J. Appl. Phys., **48** (2009) 07GL05.



(a) 120 kHz (the center frequency).



(b) 160 kHz.



(c) 80 kHz

Fig. 2 Frequency dependence of –3 dB area ('*': image point, gray zone: –3 dB area). The horizontal axis is the radial distance (m) and the vertical axis is the axial distance (m).