3P-66

Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 587-588
6-8 December, 2010

Design Method and Convergence Property of Straubel Acoustic Mirror

シュトラウベル音響反射鏡の設計と集束特性

Yuji Sato[1†], Koichi Mizutani[1], Naoto Wakatsuki[1], and Toshiaki Nakamura[2]
([1]Univ. of Tsukuba; [2]National Defense Academy)
佐藤 裕治 [1†]，水谷 孝一 [1]，若槻 尚斗 [1]，中村 敏明 [2] ([1] 筑波大院 シス情工; [2] 防衛大 地球海洋)

1. Introduction

Underwater acoustic imaging technology is important for detection of marine resources or maintenance for underwater structures. Underwater acoustic lenses or mirrors are useful devises for the imaging because they do not require any beamforming systems. The mirrors have superior temperature stability to the lenses. Recently, an acoustic daylight ocean noise imaging system “ADONIS” using a spherical acoustic mirror has been developed for an ambient noise imaging sonar, for example[1)].

The spherical mirror has several aberrations which worsen acoustic images. Aspherical mirrors are effective to remove the aberrations. We have reported on underwater aplanatic mirror which consists of two aspherical mirrors and can remove spherical and coma aberrations[2)]. However, this mirror has narrow field of view less than 20°.

Therefore, we design new mirrors which can remove aberrations and have wide field of view using reflection and refraction. Straubel mirrors which are constructed by a mirror and a lens attached on the mirror were developed in the former research on optics[3)]. The conventional Straubel mirrors which can remove the spherical aberration showed inferior performance to a parabolic mirror in our pilot study. Thus, we apply the aplanatic system to the Straubel mirror, and describe the designing method and convergence properties of the mirror in this report.

2. Design Method

Figure 1 shows schematic view of the aplanatic Straubel (hereafter, AS) mirror which consists of the mirror and the lens. Thus, the AS mirror has refractive and reflective surfaces. The reflection and refraction points are defined as $P_1(x_1, y_1)$, $P_2(x_2, y_2)$ and $P_3(x_3, y_3)$, respectively. The focal point is defined as $P_f(0, y_f)$. The AS mirror has complicated aspherical surfaces to remove the aberrations, thus, the refractive surface is defined as following 12th order even function to express the shape.

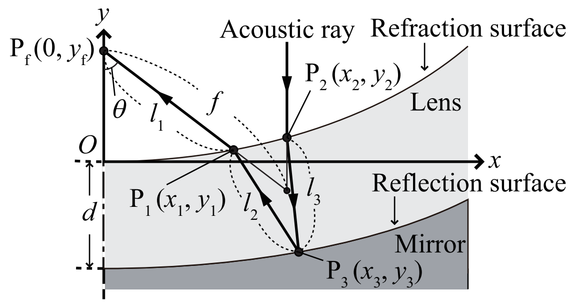

Fig. 1 Schematic view of AS mirror.

$$y = A_{12}x^{12} + A_{10}x^{10} + \cdots + A_2x^2 . \quad (1)$$

Here, A_{12} to A_2 are the coefficients of each order. The principle of equal path length is necessary to remove the spherical aberration, which is described as follow,

$$y_2 + 2nd + y_f = l_1 + n(l_2 + l_3), \quad (2)$$

where, n is the refractive index of lens, d is the thickness of lens, l_1, l_2, and l_3 are length shown in Fig. 1. Abbe’s sine condition is necessary to remove the coma aberration, which is described with convergence angle, θ.

$$f \sin\theta = x_2, \quad (3)$$

where, f is the focal length.The coefficients A_{12} to A_2 are decided firstly. Next, P_1 and P_2 are decided to satisfy eq. (3), and then, the refraction angles are calculated on P_1 and P_2. Then, the intersection point P_3 is derived geometrically. Thus, the shape of reflection surface only depends on the coefficients. Finally, the shapes of refraction and reflection surfaces are discriminated whether the shapes satisfy eq. (2).

The AS mirror should have the thin lens part because the lens attenuates the sound pressure. Thus, the focal length, f, and position of the focal point, y_f, are the same value and is defined as 1 to ease the design. The refractive index, n, is 1.5 because the material of lens is regarded as a room temperature vulcanized silicone rubber. The simulated annealing method is used for the coefficient optimization. 125 points are defined on the refraction surface as P_1 at even intervals. Equation (2) is used for the evaluation function whose tolerance is 0.001. When the

----

yuji@aclab.esys.tsukuba.ac.jp

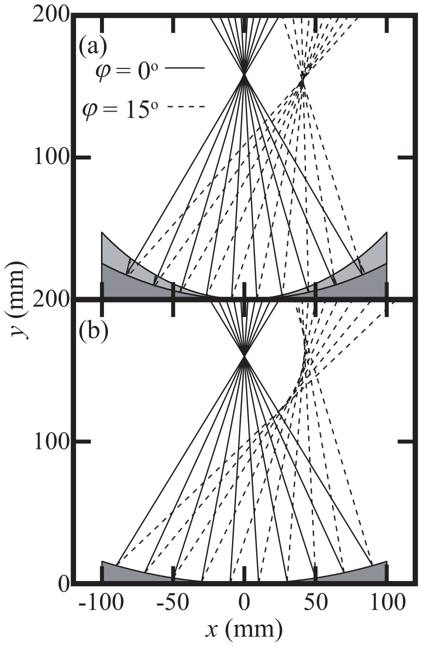

Fig. 2 Shapes and ray trace diagrams:
(a) AS mirror, (b) Parabolic mirror.

evaluation function is satisfied on the 95 % of discrete points, the optimization is finished. As a result, A_{12} to A_2 are -0.0371, -0.0270, 0.3579, -0.1664, 0.1872, and 0.6883, respectively. The shape of designed mirror and ray trace diagrams are shown in **Fig. 2(a)**. The incidence angle φ is 0° and 15°. The acoustic rays cross on the almost single point in each incidence angles, respectively. The diagrams of a parabolic mirror which has the same aperture and focal length are shown in **Fig. 2(b)** for comparison. When the incidence angle φ is 0°, the rays are converged without the spherical aberration, however, the rays are not converged under φ = 15° due to the coma aberration.

3. Convergence Property

Converged sound pressure fields of the mirrors are calculated and convergence properties of the designed AS mirror is evaluated using two dimensional finite difference time domain (2-D FDTD) method. Calculated power distributions of sound fields under φ = 0° to 15° are shown in **Fig. 3**. Crosses are focal points in each incidence angle. Gray areas are showing half power to each focal point. The half power areas show almost the same shape in Fig. 3(a) because the coma aberration is removed. On the other hand, the gray areas are deformed in Fig. 3(b). Thus, it is considered that the AS mirror has superior convergence property to the parabolic mirror.

Beam patterns on focal planes are shown in **Fig. 4**. The focal planes are defined as 2nd order curves passing thorough the each focal point shown in Fig. 3. The beam patterns are normalized by the maximum sound power of the AS mirror under φ = 0°. The beam patterns of the AS mirror have almost the same beam width and maximum power in each incidence angle as shown in Fig. 4(a). Side lobes and maximum powers of the parabolic mirror become worse, the incidence angle becomes large as shown in Fig. 4(b), on the contrary. The maximum sound pressures of the parabolic mirror are larger than those of the AS mirror in each incidence angle because the lens of AS mirror attenuates the sound pressure.

4. Conclusion

We designed the AS mirror which can remove the aberrations using the coefficients optimization. Then, we calculated the converged sound pressure field to evaluate the property of the proposal mirror. The AS mirror could almost remove the spherical and coma aberrations geometrically and wave-theoretically. Therefore, the AS mirror showed better properties than the parabolic mirror which could only remove the spherical aberration.

References

1. C. L. Epifanio, J. R. Potter, G. B. Deane, M. L. Readhead, and M. J. Buckingham: J. Acoust. Soc. Am. **106** (1999) 3211.
2. Y. Sato, K. Mizutani, N. Wakatsuki, and T. Nakamura: Jpn. J. Appl. Phys. **49** (2010) 07HG03.
3. S. Yoshida: *Optical Science Machinery and Tools* (Seibundo Shinkosha, Tokyo, 2000) p. 213 [In Japanese].

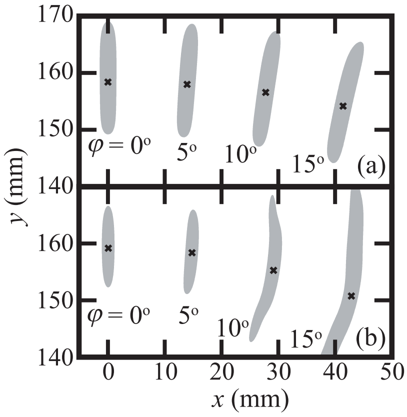

Fig. 3 Sound power distributions under changing incidence angle: (a) AS mirror, (b) Parabolic mirror.

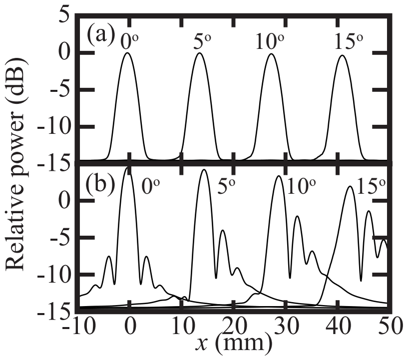

Fig. 4 Beam patterns of mirrors:
(a) AS mirror, (b) Parabolic mirror.