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Design for Off-Axis Aplanatic Acoustic Mirror
軸外しアプラナート音響反射鏡の設計

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1. Introduction

Acoustic lenses are useful devices for underwater acoustic imaging. To improve the performance of the lenses, we reported aplanatic acoustic lenses which have two aspherical surfaces to remove spherical and coma aberrations[1)]. These lenses showed better convergence properties than spherical lenses in calculation and experiment[2)]. However, aplanatic lenses have a few problems as the acoustic system. These are sound attenuation in the lens material and impedance mismatch between water and the lens material. To resolve these probrems, we designed Fresnel lenses which has thin shape with silicone rubber whose acoustic impedance is same as water[3,4)]. These lenses have better convergence properties than normal lenses, but these shapes are too complex to produce them. Additionaly, the position of the focal point is changed by the water temperture because the reflaction index depends on the sound speed.

Therefore, we designed the aplanatic acoustic mirror system because the mirror system can make the sound attenuation ibnorable and the position of the focal point is not changed due to the water temperature because the reflection angle is independent from the sound speed[5)]. Using two aspherical mirrors, the system can remove spherical and coma aberrations. We confirmed the temperature characteristics of the aplanatic mirror are better than those of acoustic lens in numerical calculation. However, there are two problems. One of those is the serious side lobes and the other is the narrowness of the field angle.

In this report, we design off-axis aplanatic acoustic mirrors which can resolve two probrems mentioned above and calculate converged sound pressure field to evaluate the mirrors.

2. Design Method

Normal aplanatic acoustic mirrors are designed by the Chrétien's method[6)]. These consist of large and small aspherical mirrors. The projected figures of the normal mirror are shown in **Fig. 1 (a), (b)**. Sound waves radiated at the point source are reflected at a large mirror drawn with black firstly. Next, the waves are reflected at the small mirror drawn with gray. The large mirror has a hole on the center because the sound waves reflected at the small mirror pass through the hole and converge on the focal point. An off-axis mirror is designed by the extraction of the part of the normal mirror and shown in **Fig. 1 (c), (d)**. Two mirrors of the off-axis mirror system are eccentric aspherical mirrors whose projected forms on the *x*-*y* plane are circular. Two aspherical mirrors are placed at off-axis position along *y*-axis direction. Two types of aplanatic mirrors have the same focal length of 300 mm and the same dimension of 150 mm to *y*-axis direction.

3. Theoretical Analysis

Converged sound pressure fields of the two types of the aplanatic mirror are calculated based on the wave theory. It is assumed that a point source exists on (x_0, y_0, z_0). The complex sound pressure distribution on the large mirror P_L is given by following equations;

$$P_L = \exp(-jkl_{0L})/l_{0L}\ , \qquad (1)$$

$$l_{0L} = \sqrt{(x_L - x_0)^2 + (y_L - y_0)^2 + (z_L - z_0)^2}\ , \qquad (2)$$

where, *j* is the imaginary unit, *k* is the wave number, l_{0L} is the distance between the source and a point of the large mirror, and (x_L, y_L, z_L) is the coordinate of the point on the large mirror. Then, the complex sound pressure distribution on the small mirror P_S is given by following equations;

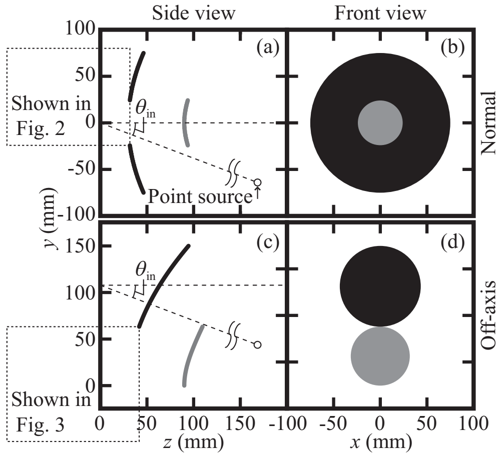

Fig. 1 Projected figures of two types of mirrors: (a), (b) Normal mirror and (c), (d) Off-axis mirror.

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$$P_{\mathrm{S}} = \sum_{x_{\mathrm{L}}}\sum_{y_{\mathrm{L}}} P_{\mathrm{L}} \exp(-jkl_{\mathrm{LS}})/l_{\mathrm{LS}}, \tag{3}$$

$$l_{\mathrm{LS}} = \sqrt{(x_{\mathrm{S}}-x_{\mathrm{L}})^2+(y_{\mathrm{S}}-y_{\mathrm{L}})^2+(z_{\mathrm{S}}-z_{\mathrm{L}})^2}, \tag{4}$$

where, (x_{S}, y_{S}, z_{S}) is the coordinate of a point of the small mirror. Finally, the converged complex sound pressure field P_{F} is given by following;

$$P_{\mathrm{F}} = \sum_{x_{\mathrm{S}}}\sum_{y_{\mathrm{S}}} P_{\mathrm{S}} \exp(-jkl_{\mathrm{SF}})/l_{\mathrm{SF}}, \tag{5}$$

$$l_{\mathrm{SF}} = \sqrt{(x_{\mathrm{F}}-x_{\mathrm{S}})^2+(y_{\mathrm{F}}-y_{\mathrm{S}})^2+(z_{\mathrm{F}}-z_{\mathrm{S}})^2}, \tag{6}$$

where, (x_{F}, y_{F}, z_{F}) is the coordinate of the sound pressure field. It is assumed that the mirrors are surrounded by the water whose sound speed is 1500 m/s. The incidence sound wave is emitted from the point source which is placed on a distance 100 m from the mirror and its frequency is 500 kHz.

The converged sound fields of the normal mirror are shown in **Fig. 2**. These figures are normalized by the maximum sound pressure of each figure. The incidence angles θ_{in} are 0° and 10°. The normal mirror can converge the sound pressure well in θ_{in} = 0°. However, in θ_{in} = 10°, the sound pressure field becomes irregular shape as shown in Fig. 2 (b). A reason of this deformation is that the edge of the large mirror interrupts the converged sound wave reflected by the small mirror. Since, the field angle of the normal aplanatic mirror becomes narrow. The converged sound pressure fields of the off-axis mirror are shown in **Fig. 3**. In Fig. 3 (a), the sound beam is well formed; however it is oblique because the off-axis mirror has unsymmetry shape to y-axis direction. In θ_{in} = 10°, the sound beam is not deformed. We ensured that the off-axis mirror can form the sound beam in the range from θ_{in} = -15° ~ 12°. Therefore, the off-axis mirror can correct the problem of the normal mirror.

Beam patterns on z = 0 mm are shown in **Fig. 4**. These are measured on broken lines drawn in Figs. 2 and 3. These figures are normalized by the sound pressure on the origin of the normal mirror. In θ_{in} = 0°, the beam pattern of the normal mirror shows side lobes. The reason is that the shape of the sound wave becomes cylindrical because the shape of the large mirror is toric. However, the beam of the off-axis mirror does not show the side lobes because the shape of the large mirror is circular. The maximum sound pressure of the normal mirror is larger than that of the off-axis mirror because the normal mirror has the larger mirror. In θ_{in} = 10°, though the beam of the normal mirror is deformed, that of the off-axis mirror is not deformed. The maximum sound pressure of the off-axis mirror decreases about 6 dB comparing with the case of the normal incidence because the small mirror interrupts the incidence sound wave in oblique incidence.

4. Conclusion

We designed the off-axis aplanatic acoustic mirror to resolve the problems which are the side lobes and the narrowness of field angle of the normal aplanatic acoustic mirror. In the theoretical analysis, we showed the convergence property of the off-axis mirror was better than the normal mirror. Future problem is searching the most suitable design parameters of the off-axis mirror.

References

1. Y. Sato, A. Miyazaki, K. Mori, and T. Nakamura: Jpn. J. Appl. Phys. **46** (2007) 4982.
2. Y. Sato, A. Miyazaki, K. Mori, T. Nakamura, and K. Mizutani: J. Marine Acoust. Soc. Jpn. **35** (2008) 157.
3. Y. Sato, K. Mizutani, N. Wakatsuki, and T. Nakamura: Jpn. J. Appl. Phys. **47** (2008) 4354.
4. Y. Sato, K. Mizutani, N. Wakatsuki, and T. Nakamura: Jpn. J. Appl. Phys. **48** (2009).
5. Y. Sato, K. Mizutani, N. Wakatsuki, and T. Nakamura: Proc. of Meeting Marine Acoust. Soc. Jpn. (2009) 63.
6. Per M. Henri Chretien: Revue d' Optique **1**, (1922) 13.

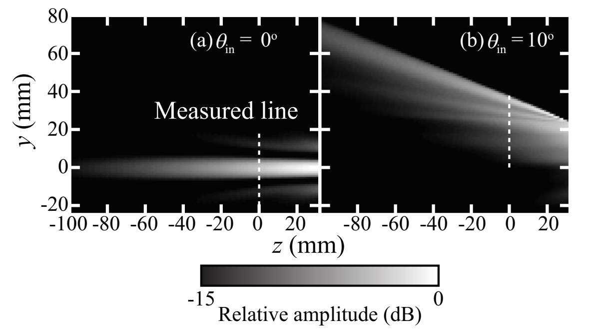

Fig. 2 Converged sound pressure fields of the normal aplanatic mirror.

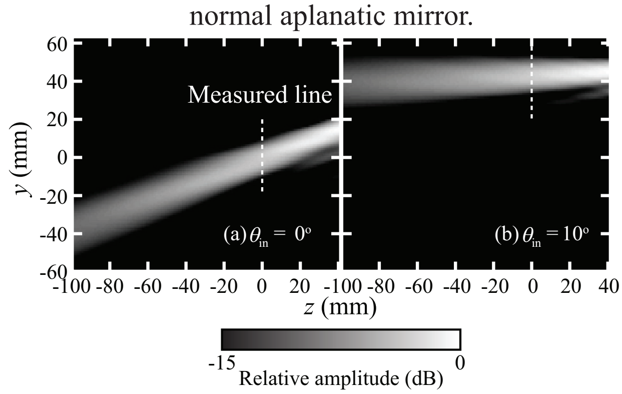

Fig. 3 Converged sound pressure fields of the off-axis aplanatic mirror.

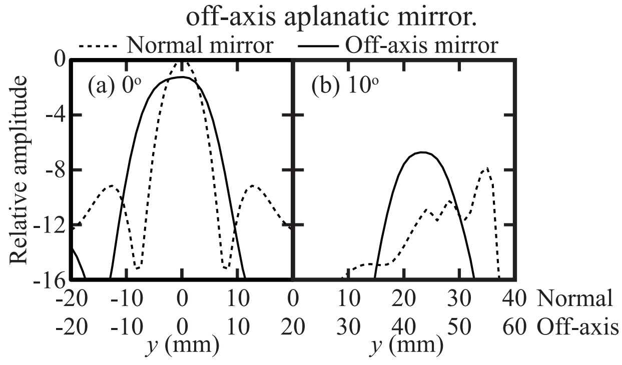

Fig. 4 Beam patterns of two types of mirror.