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Convergence Properties of Off-Axis Aplanatic Straubel Acoustic Mirror
軸外しアプラナート・シュトラウベル音響反射鏡の集束特性

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1. Introduction

Underwater acoustic imaging technology is effective for marine resource detection, coastal security, and maintenance of seashore facilities. Underwater acoustic lenses and acoustic mirrors made an effort on reducing sound attenuation, aberration, and having stability for water temperature change[1, 2]. In the past study, we designed an aplanatic Straubel (AS) mirror[3]. The AS mirror is an aplanatic back-surface mirror. The AS mirror could correct spherical and coma aberrations in the result of experiment[4]. However, the AS mirror has a problem. The receiver array is located in front of the mirror, which results in the interruption of incident sound waves, and then we designed an off-axis AS mirror and evaluated the convergence properties by numerical calculations[5].

In this study, we made an off-axis AS mirror with silicone rubber and brass, and measured the convergence properties at different incident angles in a water tank.

2. Design of off-axis AS mirror

The design method for an off-axis AS mirror is almost the same as that for an ordinary AS mirror. The off-axis mirror is the effective area of the ordinary mirror that is not hidden by the receiver array. The design method for the ordinary mirror has been described in our previous report[3].

The off-axis AS mirror can be made by extracting a part with the area from y = 0 to 200 mm of the ordinary AS mirror shown by dashed lines in Fig.1. The gray and black areas are cross-sectional shapes, and regarded as a refractive layer of silicone rubber and a reflective rigid body of brass, respectively. The relative refraction index between water and silicone rubber is 1.5. The focal length and aperture of the original large mirror are both 400 mm. Therefore, the aperture of the off-axis AS mirror is 200 mm. As shown in Fig.1, there are almost no aberrations from incidence angle 0° to 20° in geometrical analysis.

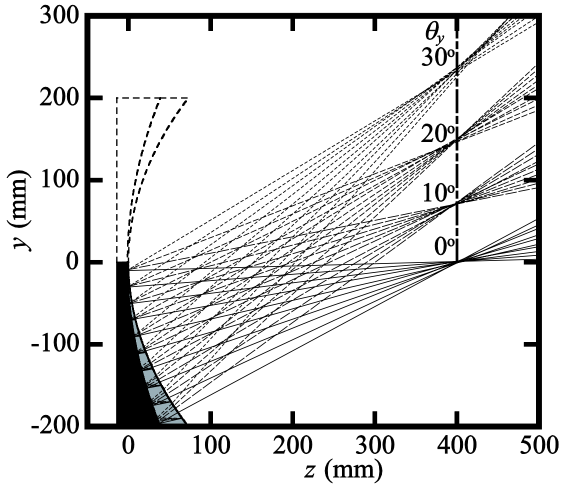

Fig. 1 Cross-sectional shapes and ray trace diagrams of off-axis AS mirror.

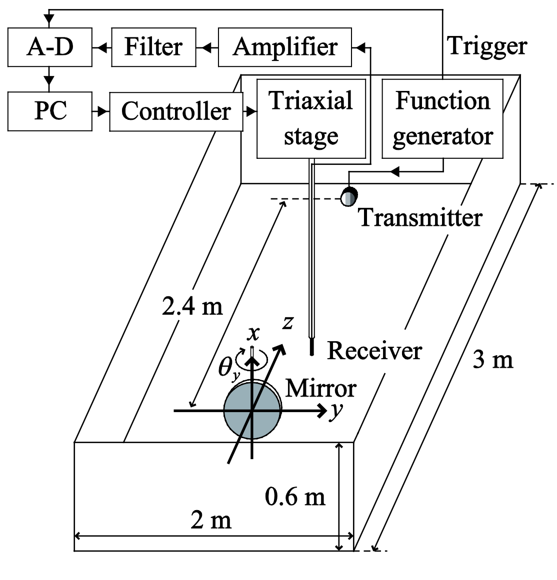

Fig. 2 Schematic view of experimental equipments.

3. Experiment in water tank

Schematic view of the experimental equipments is shown in Fig. 2. In the experiment, we used a water tank which has 2 meters wide (y-axis), 3 meters long (z-axis), and 0.6 meters depth (x-axis). A transmitter (RESON TC3029) was

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put in the center of the mirror and was parallel to the z-axis direction. A receiver (RESON TC4035) was put in a movable arm.

We measured sound field distribution around the focus from incidence angle 0° to 10° at 5° step. We input the sinusoidal burst wave whose pulse length was 5 cycles from a function generator (AGILENT 33120A) to the transmitter. The frequency was 500 kHz. The reflected sound pressure was received by a hydrophone, and passed through an amplifier (NF 5307), a band-pass filter (NF 3628), and an A/D converter (ELMEC EC-6904). We defined the mean square at each point as a measured value. The mirror could be rotated in order to change the incident angle, θ.

The measured sound fields of the off-axis AS mirror are shown in Fig. 3. We could not measure at larger incidence than 10° due to the restriction of our experimental apparatus. Gray area and broken line in Fig. 3 show -3 dB areas around focus, and the azimuth angle from the z-axis, respectively. At large incident angles, -3 dB areas move close to the mirrors. This deformation seems to be caused by field curvature.

Figure 4 shows the beam patterns along the spherical imaginary array shown in Fig. 3. Each beam pattern is normalized by maximum value at $\theta = 0°$. The peak value at $\theta = 10°$ is about 2 dB lower than the value at $\theta = 0°$, but the beam widths of the off-axis mirror are almost the same width at all incident angles. From these results shown in Figs. 3 and 4, it is confirmed that spherical and coma aberrations are corrected. The side-lobe levels at oblique incidence are below -20 dB and lower than the value at normal incidence.

4. Conclusion

An incident sound wave coming into an ordinary AS mirror is interrupted by a receiver array. Thus, an off-axis AS mirror was proposed to solve this problem. We evaluated the convergence properties of the off-axis mirror in water tank experiments

From the results of the experiment, the off-axis AS mirror showed aplanatic convergence properties within the incident angle of 10°, and the beam patterns showed almost the same width within 10° incidence.

In this report, the convergence properties of the off-axis AS mirror were measured at $\theta = 0°$, 5° and 10° incidence. We need measure the properties at wider incident angle than 10°, and compare with those of an ordinary AS mirror in near future. And we will measure the 3-dimensional convergence properties of the off-axis AS mirror by rotating the mirror in future.

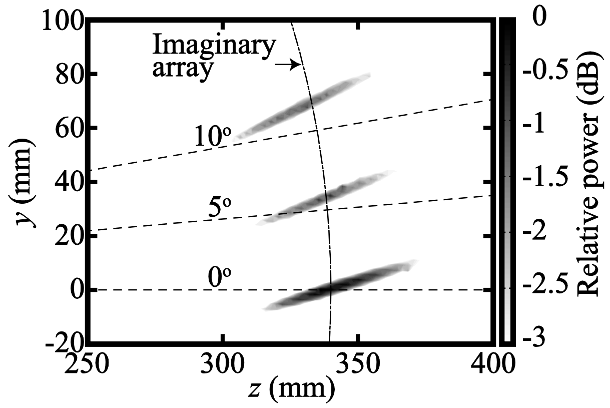

Fig. 3 Sound power distributions of off-axis AS mirror under changing incidence angle.

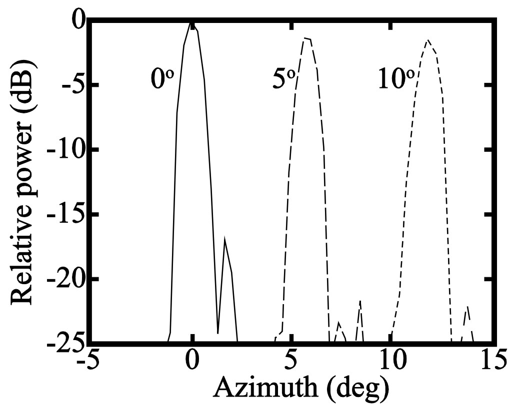

Fig. 4 Beam patterns of off-axis AS mirror along the imaginary array shown in Fig.3.

Acknowledgment

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