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Transmission Characteristics of Wedge-shaped Medium with Evanescent Field

エバネッセント波が生ずる楔の音波透過特性

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1. Introduction

Acoustic lens has widely been used in underwater applications. As well as optical lens, the acoustic lens is made of a material for which the speed of sound differs from that in the surrounding medium (e.g. water), and the curved surface makes the wavefront bend results in focusing of acoustic signal. However, the performance of the acoustic lens has been evaluated only in small angle of incidence regime (e.g. 15 deg.)[1)].

In geometrical optics, perfect reflection occurs at an incidence angle greater than the critical angle, results in no transmission. However, it is well known that an evanescent field is generated near the incidence plane even under such conditions. Since the wavelength is large relative to the thickness of the acoustic lens, we have clarified that the incident waves with large incident angle transmit the lens[2)]. However, the transmission characteristics of acoustic lens, such as refractive angle and transmission coefficient, have not well been investigated yet.

In this paper, we evaluate transmission characteristics of wedge-shaped medium (the lens components) with evanescent field by simulation using finite-difference time-domain (FDTD) method. Section 2 describes simulation environment. Section 3 discusses simulation results. Section 4 concludes this work.

2. Simulation environment

We evaluate the acoustic wave that is transmitted through a wedge-shaped medium by changing the angle of the incident wave. Note that the acoustic wave refracts at boundaries of a wedge-shaped medium so that we are focusing on a specific part of the lens. **Figure 1** shows a simulation environment. The calculation field is a size of 200 × 200 (mm^2). We use 2D FDTD method where the discretization steps were set as Δt = 0.1μs in time and Δs = 1.0mm in space. We set a wedge-shaped medium with angle of ϕ and a line sound source. The

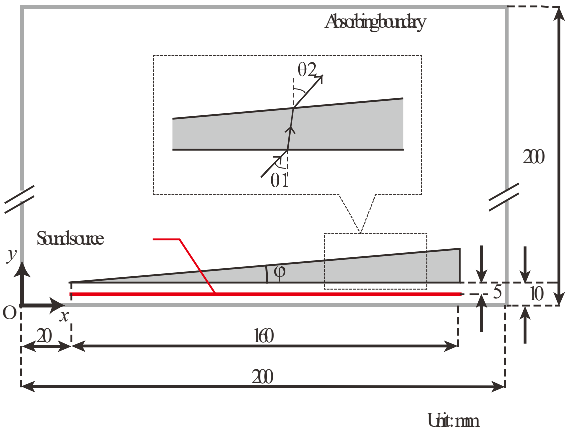

Fig. 1: Simulation environment.

Table I: Parameters used in simulation.

	Sound velocity (m/s)	Density (kg/m^3)	Refractive index (to water)
Medium 1	2,683	1,200	0.56
Medium 2	2,080	980	0.72
Water	1,500	1,000	1

sound velocity, density, and refractive index of the medium are shown in **Table I.**

In simulation, the sound source emits a continuous sinusoidal wave of frequency 100 kHz by changing incident angle θ_1 from -60 to 60 (deg.). Note that the amplitude of the emit signal is weighted with a Hamming window in space. The refraction angle θ_2 is calculated by observing the field of size 16 × 16 (mm^2) whose center locates at (x,y) = (100, 27) and (100, 35) when ϕ is 5 and 10 (deg.), respectively. The amplitude distribution of the refracted signal is also calculated by measuring the signal by a line microphone that locates $20 \leqq x \leqq 180$ and y = 40.

3. Simulation results and discussions

Figures 2 and **3** show simulation results. In detail, Fig. 2 shows relationship between θ_1 and amplitude distribution of the refracted signal, where the amplitude of the received signal without the

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wedge-shaped medium is 57.58 Pa. As shown in the figure, we found that the amplitude of the refracted signal gradually decreases as $|\theta_1|$ increases. However, there exists no significant change at the critical angle ±34.05 and ±46.05 (deg.) in medium 1 and 2, respectively. One of the reasons considered is the existence of the evanescent wave – when the acoustic signal enters the wedge at an incidence angle greater than the critical angle, an evanescent field is generated near the incidence plane even under such conditions. Because the wavelength (15 mm) is larger than the thickness of the wedge, the evanescent wave connects both surface of the wedge with small attenuation, and the incident waves transmit the wedge.

Fig. 3 shows a relationship between θ_1 and θ_2, and solid and dotted lines show simulation and theoretical results, respectively. Note that the theoretical result considers the existence of the evanescent wave as shown in **Figure 4** and Eq. (1),

$$\theta_2 = \arcsin(\cos\phi \sin\theta_1) - \phi. \quad (1)$$

As shown in the figure, we found that the simulation and theoretical results well agree in $-30 \leqq \theta_1 \leqq 60$ regime. This supports the idea that the incident waves transmit the wedge due to the existence of the evanescent wave. However, there exists a difference between the simulation and theoretical results when $-60 \leqq \theta_1 \leqq -30$. One of the reasons considered is the evanescent wave occurs in the thin end of the wedge, as shown in Figs. 2(b) and 2(d). In such environment, the evanescent wave is affected by a interaction between the first and second layer, so the wavefront of the evanescent wave may not be normal to the lower boundary.

Consequently, we have found that the incident waves with large incident angle transmit the wedge with enough amplitude, and the relationship between incident and refraction angles well agrees to the theoretical value.

4. Conclusion

We evaluated the effect of the evanescent wave on transmission characteristics of wedge-shaped medium using simulation. The refractive angle and transmission coefficient of the acoustic wave that was emitted to of the the wedge were investigated. As results, the incident waves with large incident angle transmit the wedge with enough amplitude, and the relationship between incident and refraction angles well agrees to the theoretical value. Design of the acoustic lens that utilizes the effect of the evanescent wave is one of our future work.

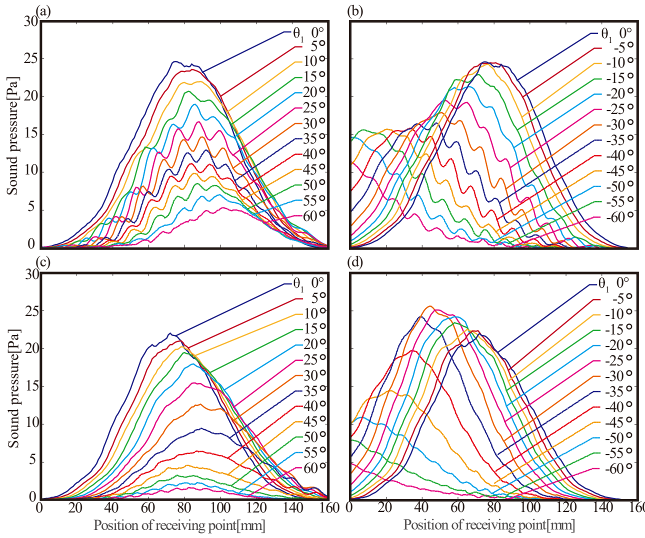

Fig. 2: Relationship between θ_1 and amplitude distribution of the refracted signal; (a) $0 \leqq \theta_1 \leqq 60$ and (b) $-60 \leqq \theta_1 \leqq 0$ in medium 1 and (c) $0 \leqq \theta_1 \leqq 60$ and (d) $-60 \leqq \theta_1 \leqq 0$ in medium 2.

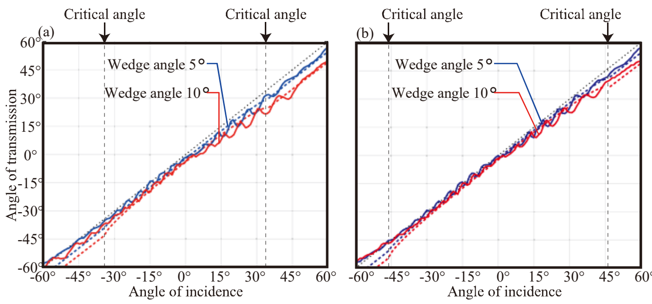

Fig. 3: Relationship between θ_1 and θ_2 obtained from simulation; (a) medium 1 and (b) medium 2.

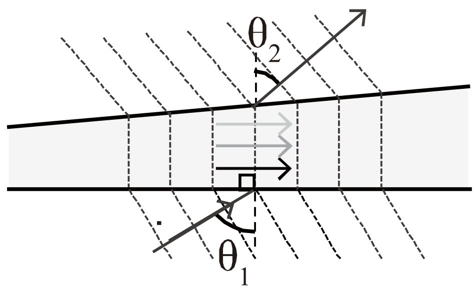

Fig. 4: Relationship between incident and refracted wave with exsistence of evanescent wave.

References

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