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Sound Propagation on Circular Concave Surface Depending on Radius of Boundary.

円形凹境界に沿った音波の伝搬特性の境界半径に対する依存性

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1. Introduction

The phenomenon of “whispering gallery” which observed in the circular hall is that a voice spoken near t a circular concave wall propagate on the wall, and we can clearly hear the voice even if the observer is far from the speaker and the voice is a whisper. In the end of 19th century, J. W. Strutt (Lord Rayleigh) investigated these phenomenon, and elucidated “whispering gallery (WG) modes” which was restrained to the vicinity of the concave surface in the low-order mode[1].

Recent researches of acoustic WG modes were to derive the sound pressure distribution analytically, by math calculation, were to facilitate the physical interpretation of sound pressure distribution, and so on. However, most of the research were to study steady-state response[2-4]. Then, the property of acoustic WG modes in the finite length sound is not well investigated, thus the change of WG modes by sound source positions, frequencies, radius of boundary and signal lengths have not been clear.

In this paper, we analyze the sound propagation on circular concave surface depending on radius of boundary by Transmission-Line Matrix (TLM) method[5]. The TLM method is based on the Huygens’ principle, which gives the time domain solution of the wave field. Circular concave surface is the simplest concave. We investigate the change of sound propagation region corresponding to radius of boundary. The results of this analyzes are expected to be applied to measurement of physical properties on the vicinity of the concave surface.

2. Condition to Simulate

Figure 1 shows the simulated sound field surrounded by circular concave surface. The medium in which sound propagates is air, and concave surface is rigid wall. Sound frequency is 10 kHz, wavelength λ is 0.0337 m. Radius of boundary r_0

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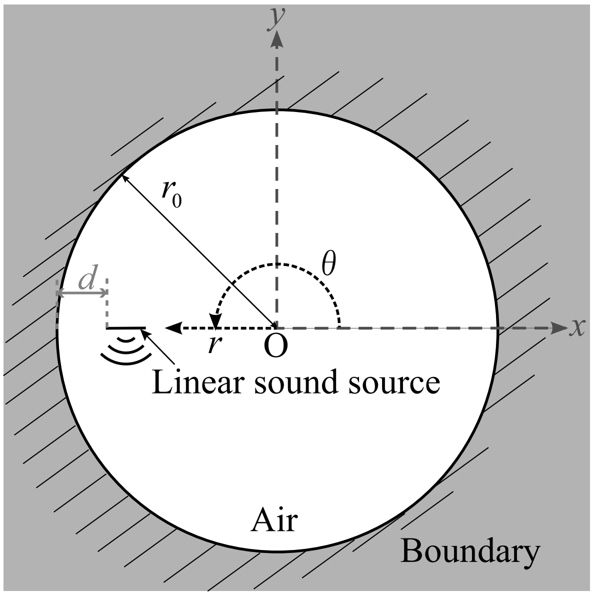

Fig. 1 Simulation sound of surrounded by circular concave surface.

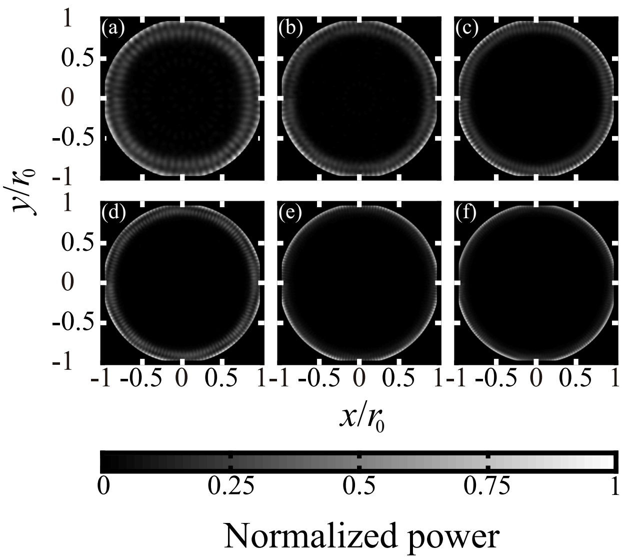

Fig. 2 Distribution of normalized time-averaged power at d = zero and 20 cycle signal; (a) r_0 = 6 λ, (b) 8 λ, (c) 10 λ, (d) 12 λ, (e) 14 λ, (f) 16 λ

and distance of sound source from boundary d are changed from 6 λ to 16 λ, from zero to $r_0-2\lambda$, respectively. Signal length is 20 cycles. The length of line sound source s_L is 0.06 m, and line sound source is located on $r_0-(d+s_L) < r < r_0-d$, θ = 180 deg. Sound waves are outputted the −90 deg

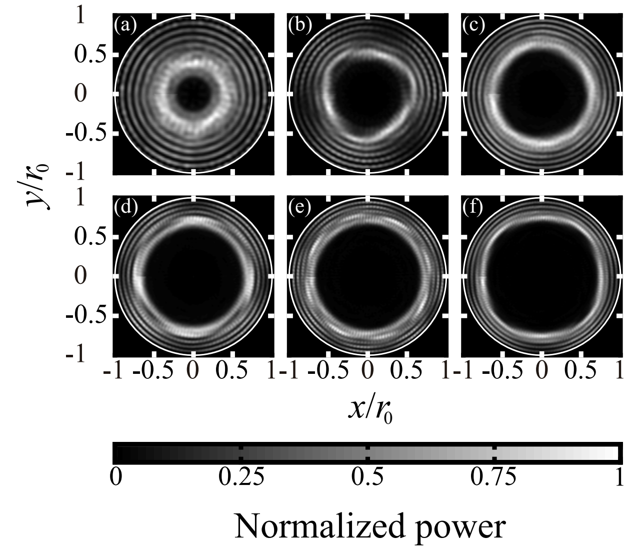

Fig. 3 Distribution of normalized time-averaged power at d = 3 λ and 20 cycles signal; (a) r_0 = 6 λ, (b) 8 λ, (c) 10 λ, (d) 12 λ, (e) 14 λ, (f) 16 λ

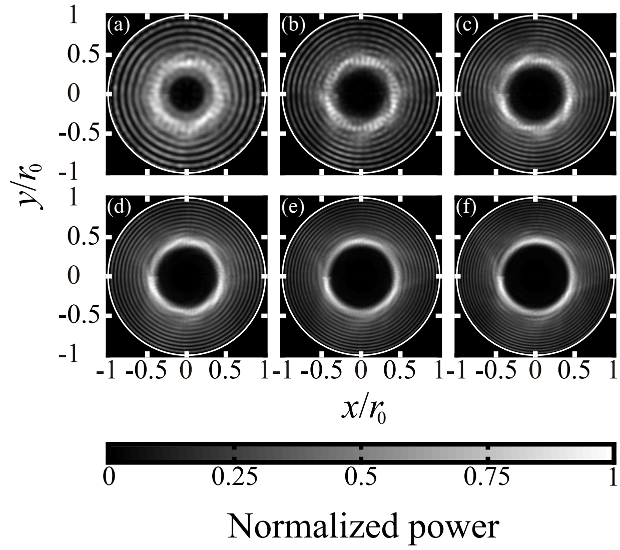

Fig. 4 Distribution of normalized time-averaged power at 20 cycle signal and d = 0.5 r_0; (a) r_0 = 6 λ, (b) 8 λ, (c) 10 λ, (d) 12 λ, (e) 14 λ, (f) 16 λ

direction from x-axis. Calculation time t_c is set the time required to propagate the sound on the surface about 5 laps.

3. Results and Discussion

Figure 2 shows the distributions of normalized time-averaged power at d = 0 and 20 cycles signal, r_0 are changed from 6 λ to 16 λ. Time-averaged power $P(r,\theta)$ define as follows,

$$P(r,\theta) = \frac{1}{t_c} \sum_{t=0}^{t_c} \left(R(r,\theta,t)\right)^2 , \qquad (1)$$

where $R(r,\theta,t)$ is received sound at position (r,θ) and time t. In all cases of Fig. 2, sound propagates on circular concave surface and the distributions are almost identical. $P(r,\theta)$ is distributed within the range of $r_0 - \lambda \leq r \leq r_0$ and exhibits a maximum at the surface, regardless of r_0. Furthermore, $P(r,\theta)$ fluctuates in the radial direction periodically. It is thought that this result is a kind of WG modes.

Distributions of normalized time-averaged power at d = 3 λ and 20 cycles signal are shown in **Fig. 3**; r_0 are changed from 6 λ to 16 λ. At r_0 = 8 λ and 16 λ, the distributions on $r_0-(d+s_L) < r < r_0-d$ are shaped like a triangle and square, respectively. These distributions occur due to reflection sounds a regular polygon path. $P(r,\theta)$ exhibits a maximum at $r_0-d-\lambda < r < r_0-d$, independently of r_0.

In Fig. 2 and 3, $P(r,\theta)$ is large within the range ($r_0-d-\lambda < r < r_0-d$) and exhibits a maximum there, independently of r_0 and d. Therefore, it is supposed that similar distribution can be reproduced when the length of sound source is about wavelength.

Figure 4 shows distribution of normalized time-averaged power at 20 cycles and d = 0.5 r_0, and r_0 are changed from 6 λ to 16 λ. At 10 $\lambda \leq r_0 \leq$ 16 λ, normalized time-averaged power distributions do not change. On the other hand, at r_0 = 6 λ and 8 λ, these distributions change. However, this change is due to the length of the sound source. Thus, the ratio between r_0 and d is closely related to the region of sound propagation.

4. Conclusion

We analyzed sound propagation on circular concave surface depending on radius of boundary using the sound propagation simulation by TLM method. As the results, time-averaged power $P(r,\theta)$ shows the periodic radially fluctuation at d = 0: thus, it is supposed the formation of WG modes. $P(r,\theta)$ is large within the range ($r_0-d-\lambda < r < r_0-d$) and takes a peak there, regardless of r_0 and d. Consequently, it is thought that similar distribution can be reproduced if the length of sound source is about wavelength. Furthermore, the ratio r_0 and d is more important than the value of both r_0 and d.

In the future, the investigation of received sound is planned. It contains important information about the formation of WG modes to received sounds. Experimental verification is also planned. We need to verify the simulation results and confirm the actual sound pressure distribution.

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