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Investigation on Arrangement of Sound Source Element in Reflection Point Search by Rectangular Sound Source
矩形音源による反射点探索における音源要素の配置に関する検討

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1. Introduction

In the field of measurement or imaging using ultrasonic waves, rectangular transducers are widely used as elements of the sound source. Since the spatial impluse response of the rectangular sound source changes in proportion to the position of the observation point[1)], the waveform acquired by a rectangular sound source complicatedly changes depending on the position of the observation point. An application of this complicated change to the reflection point search is proposed using a single rectangular sound source[2)] or a rectangular array sound source with small number of elements[3-5)].

In this study, an improvement from conventional methods is carried out on the arrangement of sound source elements. In the sound source used in this study, the dimension of each sound source element is set smaller than the single rectangular sound source[2)] and each sound source element is arranged the center of the element to deviate from the origin of the coordinates. Thereby, it aims at the reduction of the failure of the search occurred in the case where the reflection point is located in the position where the direct wave from the sound source arrived in the conventional methods. And, it is intended that the improvement on the search result of the position of the reflection point.

2. Method of Reflection Point Search

The configuration of a sound source with rectangular elements and a reflection point P is shown in **Fig. 1**. The sound source is assigned to a plane that is perpendicular to the z-axis so that the center of the whole sound source is the origin of the coordinates. The dimension of the whole sound source is $2a \times 2b$, and the dimension of each sound source element E_1 and E_2 is $a \times b$. The position of the reflection point is indicated by $P(\boldsymbol{r})$. In the calculation result showing in the following section, $\boldsymbol{r}$ is expressed using the distance from the center of the sound source ($|\boldsymbol{r}|$), the azimuth angle, and the elevation angle.

When the sound source is driven with uni-

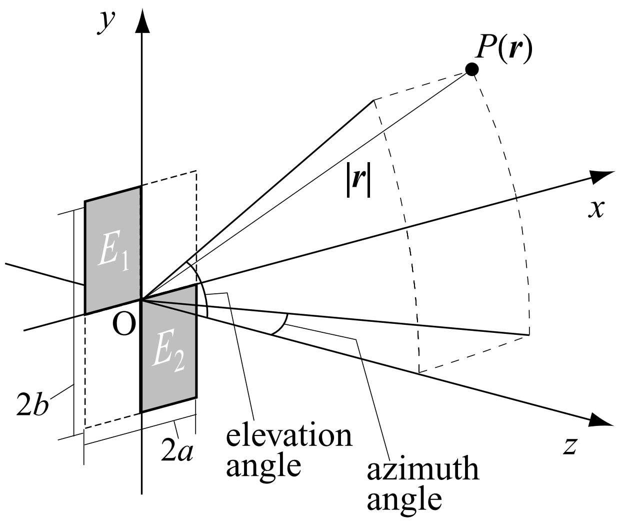

Fig. 1 Configuration of a sound source with rectangular elements and a reflection point P.

form velocity $v(t)$, and when the wave radiated from the sound source is reflected at P, the output $e(\boldsymbol{r}, t)$ in terms of the reflected wave received at the sound source is expressed as[6)]

$$e(\boldsymbol{r},t) = -\frac{k\rho A}{2c} v(t) * \frac{\partial}{\partial t} h(\boldsymbol{r},t) * \frac{\partial}{\partial t} h(\boldsymbol{r},t), \quad (1)$$

where k is the proportionality constant, ρ is the density of the propagation medium of the sound wave, A is the area of the region in which the reflection point contributes to the reflection, $h(\boldsymbol{r}, t)$ is the spatial impulse response of the sound source, and $*$ denotes the convolution integral.

Since the rise time of the reflected wave is measurable, the value of $|\boldsymbol{r}|$ can be determined in the range expressed as

$$\frac{cT}{2} \le |\boldsymbol{r}| \le \frac{cT}{2} + \sqrt{a^2 + b^2}, \quad (2)$$

where T is the rise time of the reflected wave, and c is velocity of sound. When the value of $\boldsymbol{r}$ is set at an appropriate interval in the range of $|\boldsymbol{r}|$, the spatial impulse response $h(\boldsymbol{r}, t)$ corresponding to each $\boldsymbol{r}$ can be obtained. Since $v(t)$ is known, the output waveform $e(\boldsymbol{r}, t)$ in eq. (1) at each $\boldsymbol{r}$ can be calculated. By deducing the cross-correlation coefficient between the waveform obtained by the calculation and the original (acquired) reflected wave in the sequential order, it becomes possible to estimate the position of the reflection point P.

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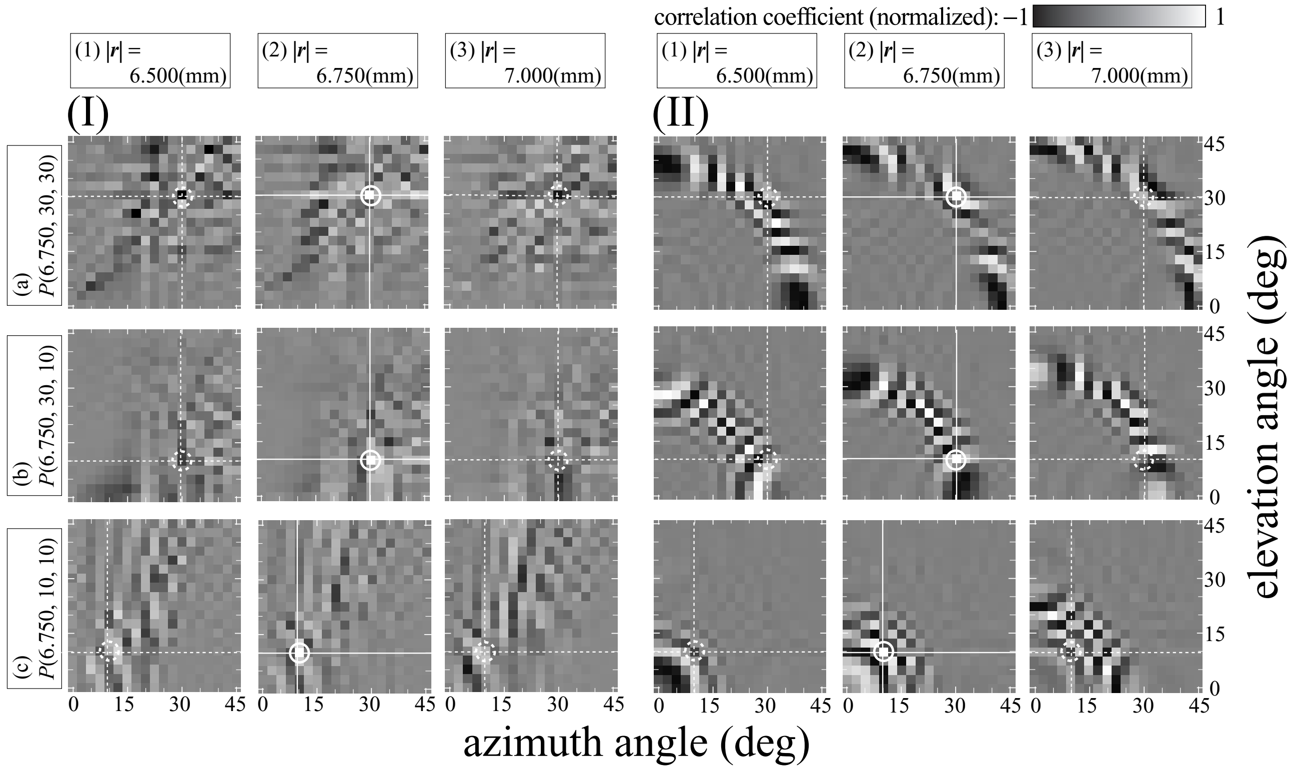

Fig. 2 Calculation results of cross-correlation coefficients at three reflection points: (I) using sound source with two rectangular sound source elements; (II) using single rectangular sound source.

3. Numerical Calculations

The results of numerical calculations by the sound source with two smaller sound source elements are shown in **Fig. 2**(I). The results are obtained by calculating convolution integral in eq. (1) and the cross-correlation coefficient at time zero with the calculation result for the points around the reflection points sequentially. The dimensions of the sound source used in the calculation are a = 6.45 mm, and b = 10.05 mm. The convolution integral and the correlation coefficient are calculated in each sound source element E_1 and E_2, and the average is taken. For the comparison, the calculation results by a single rectangular sound source which has the dimension of $2a \times 2b$[2)] are also shown in Fig. 2(II).

In comparison with the result using a single rectangular sound source, a conspicuous fluctuation of the correlation coefficient is suppressed. Therefore, it is considered that the influence of the reflected waveform due to the direct wave that appears when using a single rectangular sound source and is suppressed, and that using proposed sound source brings a certain positive effect for the improvement on the search result. However, the images of the calculation results shown in Fig. 2(I) are blurred as a whole, and are not necessarily shown the position of the reflection point clearly.

4. Summary

In the reflection point search by rectangular sound sources, the arrangement of the sound source element was investigaed. In the sound source used in this study, smaller sound source elements were used, and each element was arranged the center of the element to deviate from the origin of the coordinates. Calculation results of the correlation coefficient showed that a noticeable fluctuation was supressed, and the improved search results were obtained by the proposed sound source. However, the images of the search results obtained by calculation were not clearly, and it is considered that the further examinations about the arrangement of sound source elements are necessary.

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