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# Investigation on Transmitting and Receiving Elements Applied in Reflection Point Search by Rectangular Sound Source
# 矩形音源による反射点探索において適用される送受信要素に関する検討

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## 1. Introduction

In measuring devices or imaging equipment by ultrasonic waves, rectangular transducers are widely used as elements of the sound source. Spatial impulse response of a rectangular sound source complicatedly changes in proportion to the position of the observation point[1)]. And, the waveform acquired by a rectangular sound source changes depending on the position of the observation point, subject to the spatial impulse response. 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[3-7)].

Here, a sound source with two elements is used, as the sound source for the reflection point search. Each sound source element is used as for transmission and reception of ultrasonic waves, respectively. By made different the propagation paths of ultrasonic waves in the transmission and reception, 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 method using single rectangular sound source[2)].

## 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, for transmitting and receiving ultrasonic waves, 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 for transmission is driven with uniform velocity $v(t)$, and when the wave radiated from the sound source is reflected at

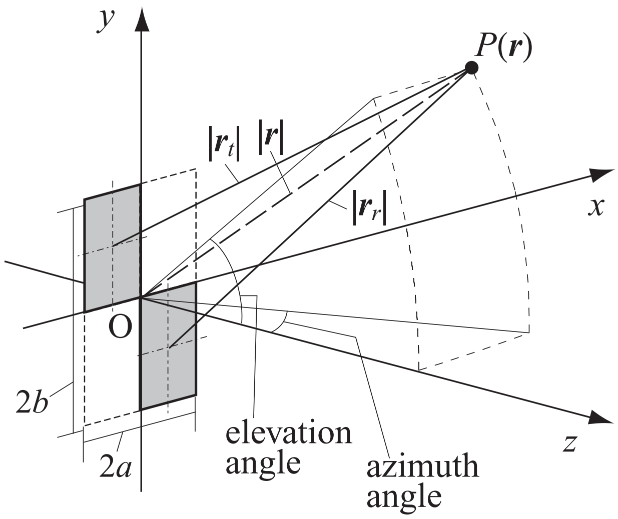


Fig. 1 Configuration of a sound source with rectangular elements and a reflection point $P$.

$P$, the output $e(\boldsymbol{r}, t)$ in terms of the reflected wave received at the sound source for reception is expressed as[8)]

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

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, $c$ is the velocity of sound, $h(\cdot)$ is the spatial impulse response of the sound source, and $*$ denotes the convolution integral. And, $\boldsymbol{r}_t$ and $\boldsymbol{r}_r$ represent the position of the reflection point from the center of the transmitting and receiving sound sources, respectively.

The rise time of the reflected wave is measurable. Therefore, 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 responses $h(\boldsymbol{r}_t, t)$ and $h(\boldsymbol{r}_r, t)$ corresponding to each $\boldsymbol{r}_t$ and $\boldsymbol{r}_r$ 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

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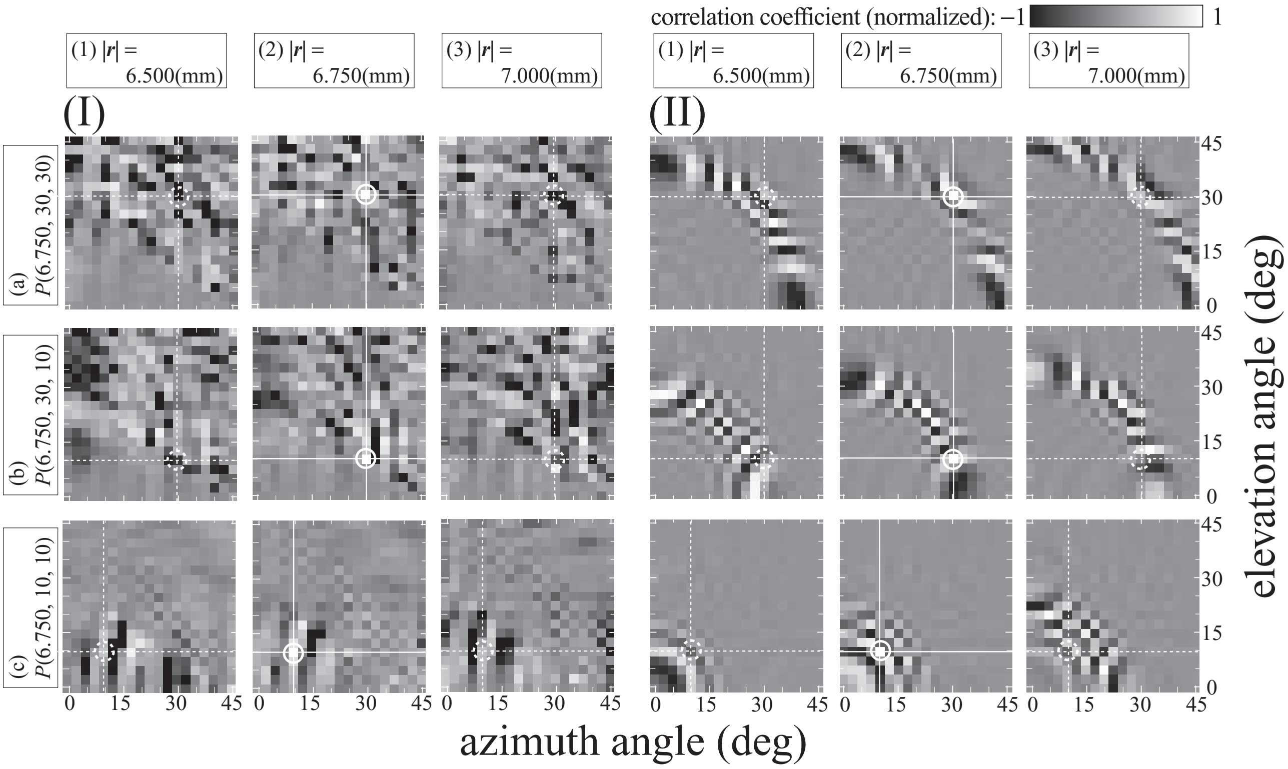


Fig. 2 Calculation results of cross-correlation coefficients at three reflection points: (I) using sound source with two elements for transmission and reception; (II) using single rectangular sound source.

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*.

## 3. Numerical Calculations

The results of numerical calculations by the sound source with transmitting and receiving 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. 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 Fig. 2(I), fluctuations of the correlation coefficient that appear noticeably in Fig. 2(II) are suppressed, especially in Fig. 2(I)(c), in the case of the distance from the sound source to the reflection point is close. It is considered that the proposed method has some efficacy on the improvement of the search results under certain conditions. However, in Fig. 2(I), the region in the calculation space that the fluctuation of the correlation coefficient is found is expanded, in comparison with Fig. 2(II).

## 4. Summary

In the reflection point search by rectangular sound sources, the sound source with two elements was used. Each sound source element was used as for transmission and reception of ultrasonic waves. Propagation paths of ultrasonic waves were made different between the case of the transmission and the case of the reception. Calculation results of the correlation coefficient showed that noticeable fluctuations were suppressed in certain conditions, and some slightly improved search results in comparison with the conventional method were obtained by the proposed method. However, in the whole calculation space, the region where the fluctuation of the correlation coefficient occurred was expanded.

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