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Investigation on Effect of Driving Signal Length in Reflection Point Search Using Rectangular Sound Source

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1. Introduction

Rectangular ultrasonic transducers have four vertices and four sides, and a spatial impulse response of them changes complicatedly depending on the order in which edge waves from these vertices and sides and direct waves from the sound source surface arrive at the observation point[1)]. In addition, the waveform acquired by a rectangular sound source changes depending on the position of the observation point. A method to apply this complicated change to the reflection point search using a single rectangular sound source[2-5)] or a rectangular array sound source with a small number of elements[6-8)] has been proposed.

In this study, the length of the driving signal of the sound source is considered. In the reflection point search in this study, the cross-correlation between the acquired and calculated reflection signals is used. Therefore, the search results can be expected to be improved by using the driving signals of the sound source in which the cross-correlation coefficients appear sharply. In this study, a chirp signal is used as the driving signal for the sound source. The effect of different signal lengths (signal durations required for frequency change) on search results in chirp signals with relatively small frequency changes will be investigated. The validity of the investigation result is confirmed by performing numerical calculations.

2. Method of Reflection Point Search

The configuration of a rectangular sound source and a reflection point P is shown in **Fig. 1**. 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 origin of the coordinates ($|\boldsymbol{r}|$), the azimuth angle, and the elevation angle.

When the sound source is driven with uniform 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[9)]

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

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, c is the velocity of sound, $h(\cdot)$ is the spatial impulse response of the sound source, and $*$ denotes the convolution integral.

The procedure diagram for searching for reflection points and obtaining search results is also shown in Fig. 1. Since the rise time of the reflected wave is measurable, the value of $|\boldsymbol{r}|$ can be determined in the range expressed as

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

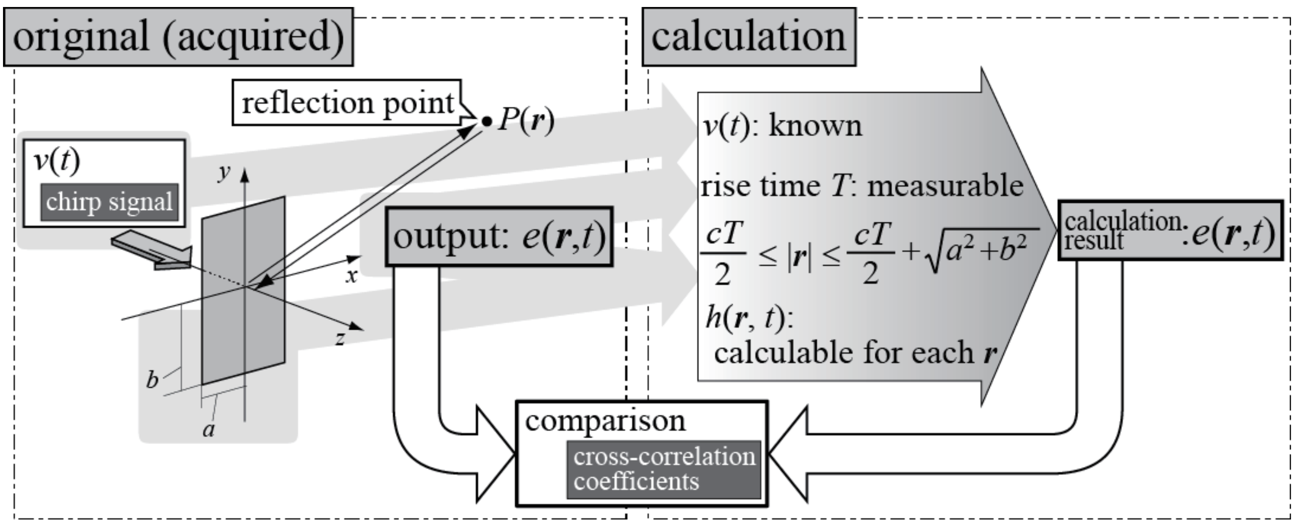

Fig. 1 Configuration of a sound source with a rectangular element and a reflection point P, and the procedure diagram for searching reflection points and obtaining search results.

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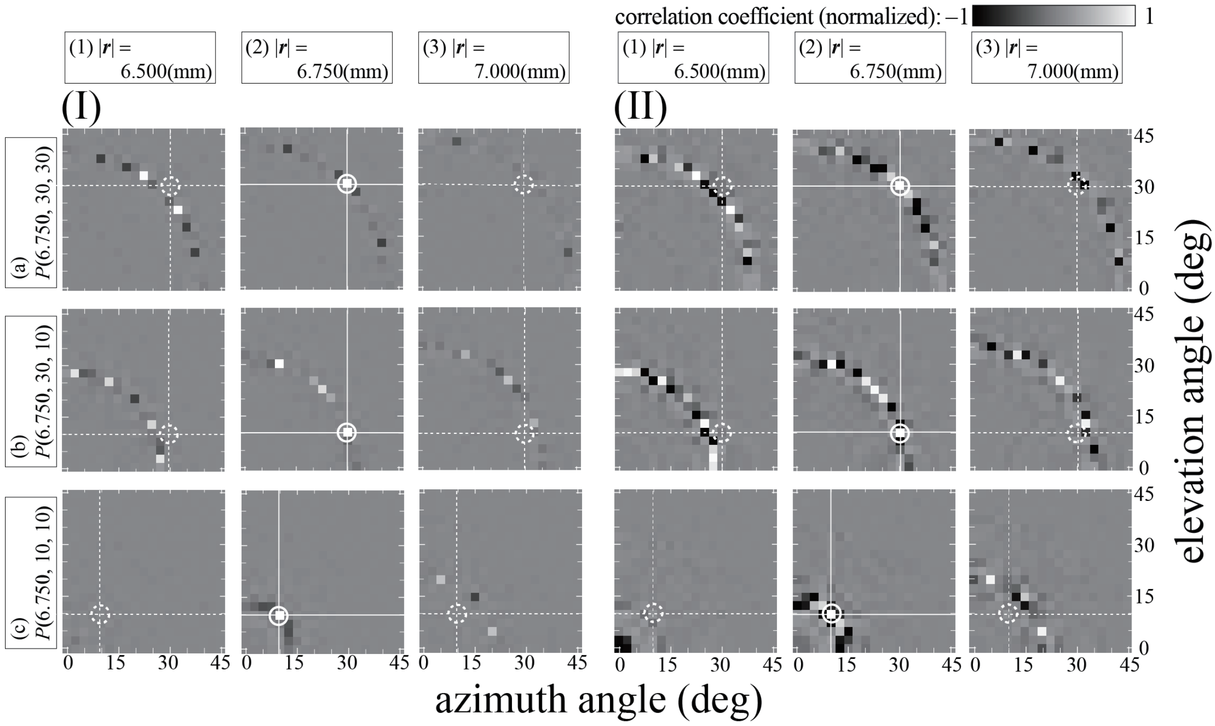

Fig. 2 Calculation results of cross-correlation coefficients using single rectangular sound source at three reflection points: (I) using up-chirp signal with 20 cycles duration for driving sound source; (II) using up-chirp signal with 5 cycles duration for driving sound source.

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.

3. Numerical Calculations

The results of numerical calculations by the sound source with a rectangular element are shown in **Fig. 2**. 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 $a = 6.450$ mm, and $b = 10.050$ mm. As the driving signal of the sound source $v(t)$, an up-chirp signal in which the frequency is increased from 2.5 MHz to 3.5 MHz is used.

In Fig. 2(I), calculation results of the cross-correlation coefficients for each set reflection point P using the up-chirp signal within a duration of 20 cycles are shown. In addition, in Fig. 2(II), calculation results when the up-chirp signal within a duration of 5 cycles is used are shown.

In Fig. 2(I), the relatively good search results without conspicuous fluctuations in the cross-correlation values are obtained, even for driving signals with relatively small frequency changes. Fig. 2(II) also shows that strong positive cross-correlation coefficients are obtained at the correct reflection point positions. However, in Fig. 2(II), a sharp fluctuation of cross-correlation values is noticeable compared to Fig. 2(I).

4. Summary

In order to improve the results of the search for reflection points using a rectangular sound source, a chirp signal was considered as the driving signal of the sound source. The effect of changing the length of the driving signal of the sound source on the search results was considered. Numerical calculations showed improved search results for reflection points, but the effect of improvement was not significant when the driving signal length was relatively short. Further study on the optimal duration of the driving signal of the sound source is needed to improve the search results.

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