2P2-17

Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 261-262
3-5 December, 2014

Introduction of Linear Array with Small Number of Elements in Reflection Point Search by Rectangular Sound Source
矩形音源による反射点探索における少数要素線形アレイの導入

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1. Introduction

Rectangular transducers are widely used in measuring devices or imaging equipment by ultrasonic waves, as elements of the sound source. Spatial impulse response of a rectangular sound source changes in proportion to the position of the observation point[1)]. And, the waveform acquired by a rectangular sound source complicatedly 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[3-6)].

In this study, the linear array sound source with small number of elements is introduced as the sound source. The overall dimension of the linear array sound source with three elements used in this study is equal to the dimension of the single rectangular sound source used in conventional method[2)]. 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)], using the sound source that has concise and common structure than the conventional methods[3-6)]. 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 is $2a' \times 2b$. 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 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[7)]

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

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.

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 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.

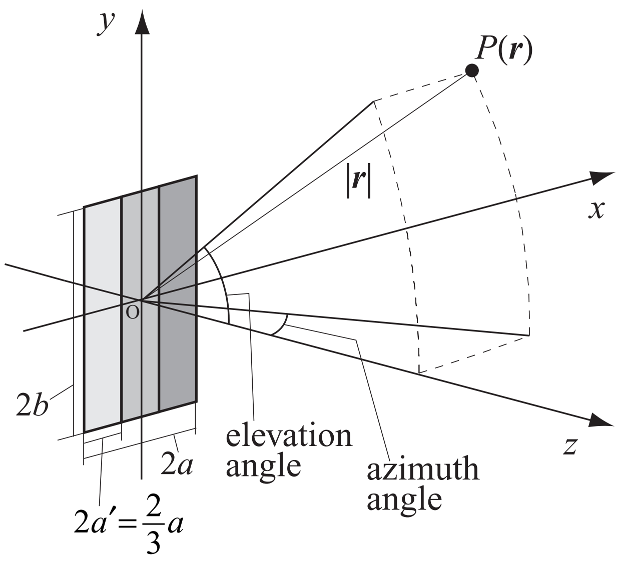

Fig. 1 Configuration of a sound source with rectangular elements and a reflection point P.

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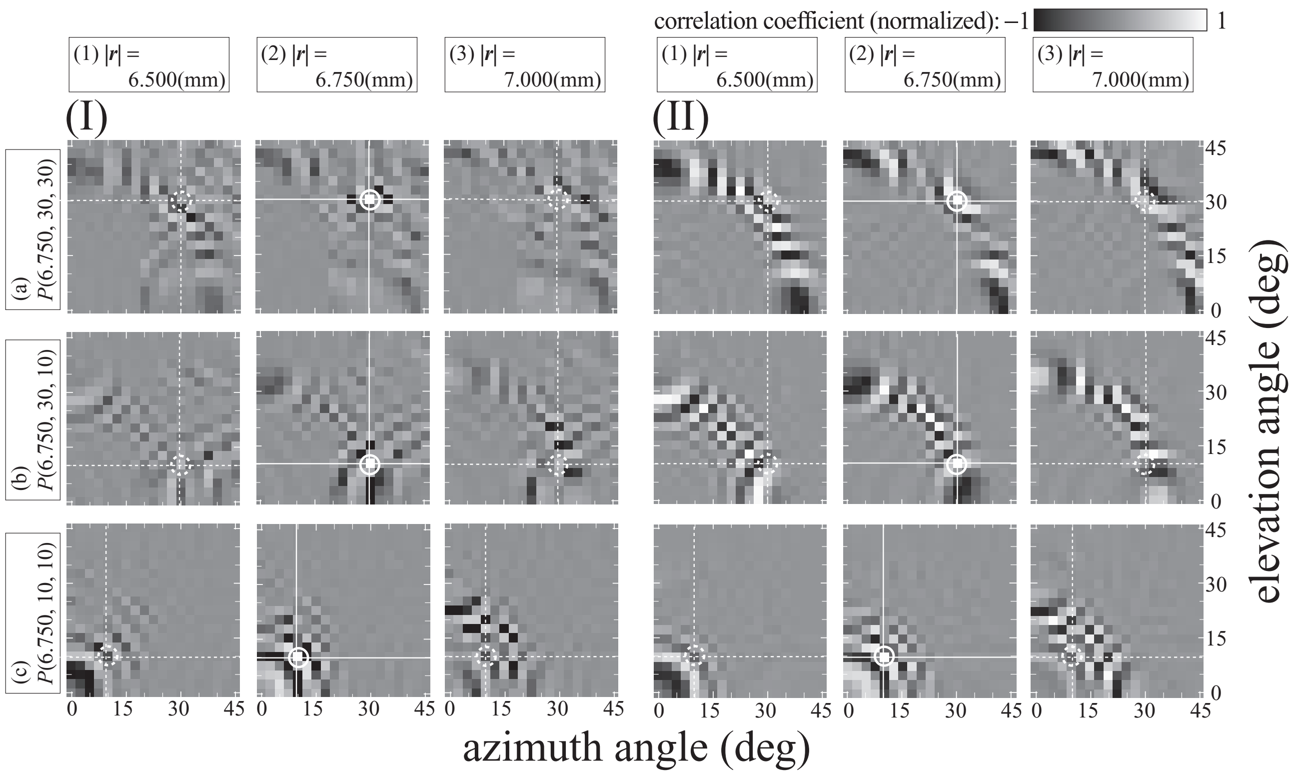

Fig. 2 Calculation results of cross-correlation coefficients at three reflection points: (I) using linear array sound source with three elements; (II) using single rectangular sound source.

3. Numerical Calculations

The results of numerical calculations by the linear array sound source with three 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 $2a = 12.90$ mm, and $2b = 20.10$ mm, and the width of each array element $2a'$ is set to 4.30 mm. The convolution integral and the correlation coefficient are calculated in each sound source element separately, 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 Fig. 2(I)(a) and 2(I)(b), a noticeable fluctuation of the correlation coefficient is suppressed, in comparison with the result using a single rectangular sound source (In Fig. 2(II)(a) and 2(II)(b)). These results indicate that the influence of the reflected waveform due to the direct wave, that is found when using a single rectangular sound source, is suppressed. Additionally, it is considered that the proposed sound source has some efficacy on the improvement of the search results. However, in Fig. 2(I)(c), the significant improvement is not observed in comparison with the result of the conventional method shown in Fig. 2(II)(c).

4. Summary

In the reflection point search by rectangular sound sources, the linear array sound source with small number of elements was introduced. In this study, the linear array sound source with three elements was used, and the overall dimension of the linear array sound source was equal to the dimension of the conventional single rectangular sound source. Calculation results of the correlation coefficient showed that a conspicuous fluctuation was suppressed at some set reflection points, and some improved search results were obtained by the proposed sound source. However, in the case where the reflection point is located near the sound source, there was no noticeable improvement in search results.

References

1. J. L. San Emeterio and L. G. Ullate: J. Acoust. Soc. Am. **92** (1992) 651.
2. H. Masuyama and K. Mizutani: Jpn. J. Appl. Phys. **46** (2007) 7793.
3. H. Masuyama and K. Mizutani: Jpn. J. Appl. Phys. **48** (2009) 07GC05.
4. H. Masuyama: Proc. Symp. USE **30** (2009) 45.
5. H. Masuyama: Proc. Symp. USE **31** (2010) 65.
6. H. Masuyama: Proc. Symp. USE **34** (2013) 51.
7. J. P. Weight and A. J. Hayman: J. Acoust. Soc. Am. **63** (1978) 396.