Direction-Variable Beam by Decentered Annular Array
Sound Source with Rounded Width of Elements

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1. Introduction

In the field of measurement, imaging, and communication, applying acoustic probe is widely studied. In order to obtain an output with high accuracy, it is desirable that ultrasonic beam with a small width is used.

A sound source using equiamplitude-driven annular transducer array has a simple structure, and it can become one of the useful means for obtaining such beam. And, by the decentering operation for the array element, it becomes possible that the radiation direction of the beam changes and trims, and that the beam is scanned.

In the production of the sound source, it is necessary to ensure the sufficient accuracy in forming the narrow beam. Meanwhile, in actual production, it is desirable that the process is simplified, insofar as the problem does not occur in the use.

In this paper, the rounding is applied to the width of each element of a decentered annular array, as one of the simplification technique in the production process. Then, the effect on the shape of the radiated direction-variable beam by the rounding operation is examined using numerical calculations.

2. Design of Sound Source

Figure 1 shows the design method of a sound source. The location and the width of each element of the array are determined by the zeroth-order Bessel function of the first kind, \( J_0 \), shown in Fig. 1(a). The central disk element is located at \( r = 0 \), which yields the main extreme value of the \( J_0 \) function, and the central radius of the \( n \)th ring element from the innermost disk element is located at \( r_n \), the \( n \)th extreme value of the scaled \( J_0 \) function, \( J_0(\alpha r) \).

Initially, the width of each element is relatively determined using the area \( S_n \) shown in Fig. 1(a). When the maximum radius of the central disk element is \( D \), the actual radius of the disk element \( d \) is given by \( d = KD (0 < K \leq 1) \), where \( K \) is the coefficient that determines the absolute width of each element. The widths of other ring elements are also relatively determined for \( d \), and a concentric annular array is formulated. By driving this array with an antiphase from its neighboring elements and with an equiamplitude, the beam with sharp profile is radiated.

The decentering procedure of the array element as the radiation direction of the beam changes is shown in Fig. 1(b). The separations existing in the neighboring array elements are expressed by the inner radii \( a_n \) and the outer radii \( b_n \) of the array elements, and the width of the separation between the \( (n-1) \)th element and the \( n \)th element becomes \( (a_n-b_{n-1}) \). This is the maximum possible value of decentering for the \( n \)th ring element. The actual decentering amount \( e_n \) of the \( n \)th element is given by \( e_n = L_n(a_n-b_{n-1}) (n > 2) \), where \( L_n \) is the coefficient that is determined arbitrarily from the range of \( 0 \leq L_n \leq 1. \)

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Fig. 1 (a) Formulation procedure of concentric annular array, and (b) decentering procedure of array element.
Firstly, the innermost separation, \( a_2 - b_1 \), is considered, and all elements except for the center disk are decentered at \( e_2 \). Next, the subsequent separation, \( a_3 - b_2 \), is considered, and array elements that are located more outside than the separation are decentered at \( e_3 \). By repeating the above operation for the case of the outermost separation, a decentered annular array transducer is constructed.

3. Numerical Calculations

Calculation results of the radiated pressure distributions, when the decentered annular array sound sources are driven by a single-frequency continuous wave are shown. The driving frequency of the sound source is 1 MHz, and the sound velocity \( c \) is 1500 m/s. The number of array elements is 10, the central radius of the outermost element \( R \) is 15 mm \((10\ \lambda)\), and \( K \) is 0.6. The directions of decentering are identical, and \( L_n \), the “decentering ratio” of each element, is set at the identical value in all elements of each array, and (a) 0.0, (b) 0.2, (c) 0.4. Here, the results obtained by the seven kinds of arrays that have the different rounding of the width of each element \( w \) [mm] are shown.

In Fig. 2, the profiles of the beam, as the plot of the maximum value of the amplitude of the radiated pressure distribution in each calculation point \( z \), are shown. In the result of the cases of (vi) and (vii) in each subfigure, the very considerable turbulence appears in the shape of formed beam. The reason why the turbulence appears is considered that the situation that cannot exist as a ring element causes since the inner radius agrees with outer radius by the rounding operation of the width of the element. In the other case, although slight differences appear in the fluctuation of the beam shape, the beams with the shape that is similar to the case of (i), in which the rounding operation of the element width is not applied, are obtained.

Table I shows the root mean square of the difference with the result of the case of (i) on each calculation result shown in Fig. 2. From Table I, there is an aspect in which the value remarkably rises at the cases of (iv) and (vii).

4. Conclusion

On the decentered annular array sound source, the rounding operation was applied at the width of the each array element, and the effect on the shape of the direction-variable beam by this operation was examined. When the number of element and center radius of the outermost element of the desire was satisfied, there was an aspect in which the beam of stable shape without considerable turbulence was formed, even if the rounding operation was applied to the widths of the elements.

Acknowledgment

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References


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<th>Decentering ratio ( L )</th>
<th>(ii) ( w=0.01 )</th>
<th>(iii) ( w=0.025 )</th>
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<th>(v) ( w=0.1 )</th>
<th>(vi) ( w=0.25 )</th>
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