1P4-2

Analysis of vortex caused by multiple acoustic streaming

複数の音響流による渦流の解析

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1. Introduction

The acoustic streaming caused by nonlinear phenomena of sound waves generates a direct current component in the fluid medium. Ultrasonic beams of high intensity radiated from multiple transducers can generate vortices in the fluid medium and it could be applied to the various fields. In this study, as a basic step to design the vortex formation, we analyze the synthesized component of the acoustic streaming generated by two ultrasonic transducers using a simplified theoretical model. To verify the effectiveness of the model, the analytical results are compared with the numerical results obtained by a simulation program with the finite element method (FEM).

2. Theory

The acoustic streaming, the direct current component of the particle velocity, is produced by the nonlinear phenomena along the acoustic axis when the ultrasound is radiated from a piston source of radius a with high intensity, as shown in Fig. 1[1]. The velocity distribution of the acoustic streaming is given by Nowicki[2] as follows:

$$v_D(z) = \frac{\alpha I_0 a^2}{\mu c}\int_0^\infty e^{-2\alpha a s} \times \left[\begin{array}{c} \sqrt{1+\left(\frac{z}{a}-s\right)^2} - \sqrt{1+\left(\frac{z}{a}+s\right)^2} \\ +\left(\frac{z}{a}+s\right) - \left|\frac{z}{a}-s\right| \end{array} \right] ds \quad . \tag{1}$$

Here c is the sound speed of acoustic medium, I_0 the acoustic intensity of the source, μ the viscosity coefficient, and the variable s is given by

$$s = \frac{z}{a}. \tag{2}$$

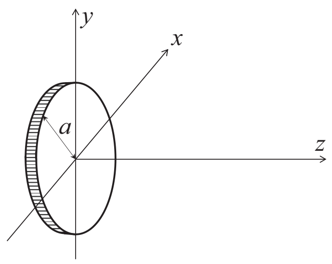

Fig. 1 Theoretical coordinate of acoustic source.

Figure 2 shows the two sound sources of diameter d arranged at an angle. Calculation of acoustic streaming by sound waves radiated from these two sound sources is not easy, and the numerical calculations are also enormous. Here, we suggest an approximation calculation method for the practical applications. The vortex caused by the acoustic streaming is most affected by the sound intensity in acoustic axis direction. Therefore, if the acoustic intensity on the acoustic axis of the arrayed transducers is $I(z, \theta)$ and applied to Eq. (1), the velocity distribution of the acoustic streaming can be evaluated.

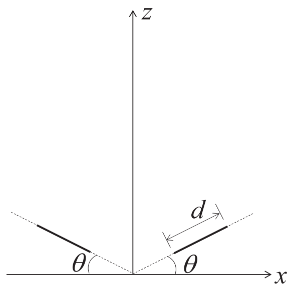

Fig. 2 Coordinate for arrayed two transducers.

3. Results

The velocity distribution of acoustic streaming of the single acoustic source is shown in Fig. 3. In this calculation, the driving frequency and the radius of the transducer were 1.7 MHz and 8 mm, respectively. The attenuation coefficient, the viscosity coefficient, and the sound speed of the water, were $25.3\times10^{-15}f^2$ m^{-1}, 8.5×10^{-4} kgm/s, and 1502 m/s, respectively. The red dot line in the figure shows the result by the finite element method. In this figure, the result calculated by eq. (1) shows the validity in the given range. As shown in Fig. 2, when two identical transducers are arrayed at an angle θ=10°, the acoustic field from the transducers is shown in Fig. 4. In the results of Fig. 4, the acoustic field distribution on the acoustic axis is shown in Fig. 5. This result shows that the acoustic pressure can be approximated as a function that increases linearly with distance from the sound source.

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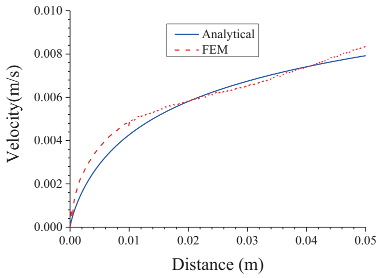

Fig. 3 Velocity distribution of acoustic streaming caused by a transducer.

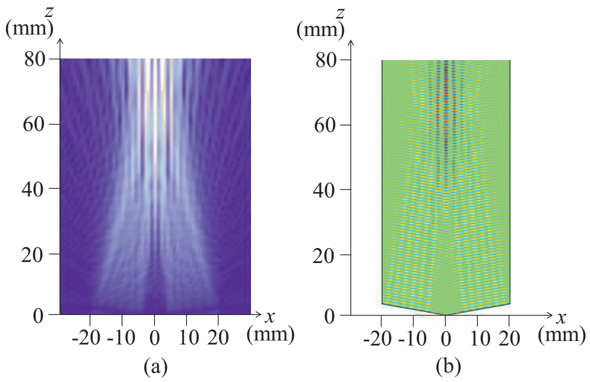

Fig. 4 Acoustic fields caused by two arrayed transducers calculated by (a) the analytical method and (b) the finite element method.

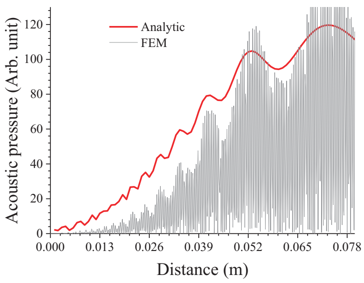

Fig. 5 Acoustic pressure distribution on the acoustic axis.

Figure 6 shows the distribution of acoustic streaming calculated using the FEM program. This result shows that although the sound waves radiated from the two sound sources cross each other in a certain region, the distribution of sound waves generated from the acoustic field shows a linear distribution. From these results, the velocity profile on the acoustic axis is taken and is shown in Fig. 7 together with the analytical results. In the case of analytical calculation, the function of acoustic intensity is determined as follows:

$$I=\kappa(2000z)^2/\rho c. \tag{3}$$

Here, ρ is the density of acoustic medium. The calibration constant κ is taken as 120. This constant is determined by the angle and distance between the transducers, and this is required further consideration. In Fig. 7, the tendency of increasing in both velocities is similar in the range of 40 mm < z < 80 mm. Because the vortex will be produced most remarkably in this range, it can be confirmed that the suggested method is effective in practical terms.

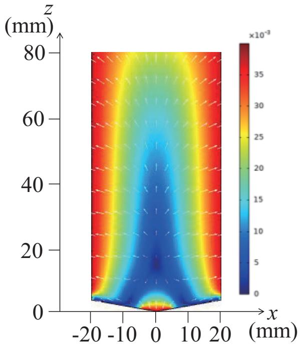

Fig. 6 Velocity distribution of acoustic streaming caused by two arrayed transducers.

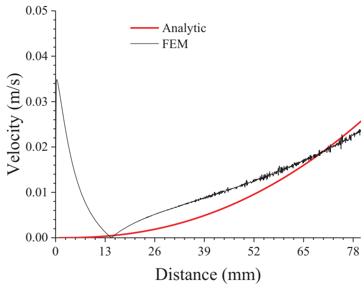

Fig. 7 Velocity distribution of acoustic streaming

4. Summary

As a basic step for the analysis of vortices generated by multiple sound sources, the acoustic fields radiated from two sound sources arrayed at an angle are analyzed. A practical approximation was proposed to calculate the acoustic axis distribution of acoustic streaming generated from the acoustic field. The acoustic streaming distributions calculated with suggested method were compared with the results calculated by the FEM program. As a result, we confirmed that the tendency of increasing velocity is similar in the vicinity of the intersection of the acoustic field where the vortices are generated.

Acknowledgment

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References

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