Acoustic Standing Wave Field for Manipulation in Air. 気体中超音波マニピュレーションのための定在波音場の検討

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1. Introduction

Using a standing wave field generated between a transducer and a reflector, it is possible to trap particles at nodes of the sound pressure field. In the previous paper[1], a standing wave field was formed by crossing two sound beams generated by two transducers in air. It was possible to realize manipulation of particles by controlling the sound field.

In order to trap and manipulate a particle stably, the force should be strong enough and focused at a small region. It is necessary to optimize a sound field varing the parameters such as frequency, sound source size, reflector form, their position and so on. This paper describles an evalution method of a sound field both by experimental measurement and numerical calculation. A sound field was generated under several configurations of sound sources and reflectors. The sound pressure distribution was measured by microphone and calculated numericaly by computer.

2. Evaluation method of sound field

The sound pressure distribution was measured by scanning the microphone three dimensionally. The microphone used in the experiment was the smallest one available whose diameter is 1/8 inches in order to minimize the influence of the microphone on the sound field.

With regard to the numerical simulation, the sound pressure is calculated by the Rayleigh's formula.

$$p = j \frac{\rho c V}{\lambda} \exp(j \omega t) \iint_{F} \frac{\exp(-jkr)}{r} dF$$

Where V_0 is velocity of a vibrating plate at the sound source, ρ is density of the medium, *c* is sound speed, λ is wave length, ω is angular frequency, *k* is ω/c and *r* is the distance between an arbitary point on the transducer and the observation point. When there are several sound sources, the sound pressure was calculated to by adding the sound pressure by each sound source.

When there are reflector in the sound field, the reflected waves should be calculated. If the

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reflector has a flat surface and an enough large area, the reflected sound pressure is calculated by the imaginary sound source that is set in the mirror position by the reflector from the original sound source. If the reflector has a curved surface or a small area, the reflected sound pressure is calculted by the integral from the reflector surface. Moreover, when there are several reflectors, the sound pressure is calculated by adding several reflected waves.

3. Experiment and result

In the first experiment, a sound field discribed in the previous paper[1] was studied. The sound field is a standing wave field that was generated by two sound beam axes crossing each other without using a reflector in **Fig. 1**(a). Figure 1(b) shows measured sound pressure distribution by the microphone, and Fig. 1(c) shows the calculated sound pressure distribution. In the calculated result the single reflection of each sound wave has been take into account. Each results show the standing wave field, because the nodes and the antinodes of the sound pressure are seen as dark and bright lines, respectively.



Fig.1 Standing wave field generated by two sound sources. (a) Experimental apparatus. (b) Measured sound pressure distribution. (c) Calculated sound pressure distribution.



Fig.2 Measured sound pressure distribution. (a) l=41.32mm. (b) l=40.40mm

In the next experiment, a reflector was set in front of the sound source. The transducer is cylindrical bolted Langevin type transducer of 33 mm in diameter, the frequency is 38.2 kHz. The reflector is circular glass plate of 47 mm in diameter. The sound pressure measured by the microphone was shown in Fig. 2 for the (a)resonant and the (b)anti-resonant distances. The sound pressure amplitude is quite different from each other. Figure **3** is the calculated sound pressure distribution under the similar condition with the experiment of Fig. 2. Figure 4 shows the sum of the four sound waves for two different distance between the transducer and the reflector. Figure 4(a) is for resonance and 4(b) is for anti-resonance. The calculated result agrees well with the experimental data. It has been concluded that a standing wave field could be calculated by Rayleigh's formula if multiple reflection is taken into account.

In the final experiment, the reflector was optical lens of a concave glass plate. The curvature radius of the reflector is 51.9 mm, the distance between the sound source and the reflector was 50.0 mm. **Figure 5** shows the measured and calculated sound pressure distribution. The sound pressure in the case of a concave reflector in Fig. 5 is higher and the region for high sound pressure is smaller.

4. Conclusion

The standing wave field was evaluated both experimental measurement and numerical by calculation. The sound field was studied under three configurations of sound sources and reflectors. The experimental sound pressure was measured by a small microphone. The numerical calculations of an acoustic field have been performed using Rayleigh's formula taking into account the multiple reflection of ultrasonic wave. The calculated result agrees well with the experimental data. Although the Rayleigh's formula is usually used to calculate direct sound pressure from the sound source, it is possible to calculate the sound pressure of the standing wave field by adding multiply reflected waves.



Fig.3 Calculated sound pressure distribution.(a) Traveling wave. (b) First reflected wave. (c)Second reflected wave. (d) Third reflected wave.



Fig.4 Calculated sound pressure distribution taking into account multiple reflection.(a) *l*=44.00mm. (b) *l*=46.17mm.





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References

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