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Fundamental Study on the Acoustic Impedance Relation to Sound Intensity Amplification of a Prime Mover

プライムムーバ内音響インテンシティ増幅量と音響インピーダンスの関係の基礎検討

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1. Introduction

Thermoacoustic phenomenon[1–4] is actually heat transport and energy conversion between heat and sound. Environmentally friendly cooling systems can be realized using this phenomenon. The cooling systems comprise a tube and two energy conversion parts: a Prime Mover (PM) and a Heat Pump. Two stacks, which have narrow flow channels, are set there. For the practical use of such systems, it is necessary to improve the energy conversion efficiency, and to minimize the systems. To improve the energy conversion efficiency, the necessities of satisfying the stack conditions of the acoustic impedance Z by which a progressive phase is used and the increased absolute value of Z have been pointed out by Yazaki *et al*[2]. The proposal is especially considered under the stack condition that $\omega\tau$[2,3], which is the ratio of the thermal relaxation time to the oscillation cycle, is smaller than 2. However, to minimizing the systems, the straight-tube type thermoacoustic systems (straight-tubes) have some advantages. In the straight-tubes, it is pointed out that $\omega\tau$ is about 2 at the stack because the standing wave is dominant[3]. However, few experimental studies of the relation between Z and energy conversion efficiency of the stack under the condition that $\omega\tau$ is about 2 have been reported. Therefore, in this paper, the relation between Z and energy conversion efficiency of the Prime Mover of the straight-tubes under the PM stack condition that $\omega\tau$ is about 2 is investigated.

2. Phase Adjuster

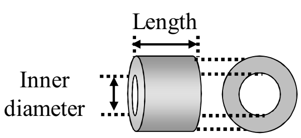

Fig. 1. Schematic of Phase Adjuster.

For this study, a Phase Adjuster (PA)[4] is used to change the energy conversion efficiency. As described in **Fig. 1**, the PA is a device for changing the system inner diameter locally.

3. Relation between Z and ΔI_{PM}

For this study, the straight-tubes without the Heat Pump are closed at both ends for simplicity. Here, an example of the distribution of sound intensity formed in the systems is presented in **Fig. 2(a)**. In the systems, the acoustic energy produced at the PM stack is emitted[2]. An amplification quantity of sound intensity at the PM stack, ΔI_{PM}, is an important parameter because of its dependence on the energy conversion efficiency.

Moreover, Z is shown as an equation (1).

$$Z = |Z| e^{i\Phi} \quad (1),$$

where $|Z|$ is the absolute value of Z and Φ is the phase difference between sound pressure and particle velocity. Here, an example of $|Z|$ and Φ distributions formed in the straight-tubes is presented in **Fig. 2(b)**. The acoustic field formed in this system isn't largely changed by the insertion of PA because the boundary condition at both ends of the system is very strong.

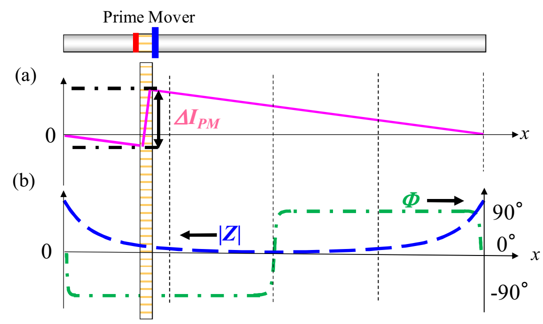

Fig. 2. Image of acoustic field in the straight-tubes (a) the distribution of sound intensity and the ΔI_{PM} definition (b) the distributions of $|Z|$ and Φ.

4. Experimental setup

We studied the relation between the Z and ΔI_{PM} of the straight-tubes by driving the systems in several PA conditions. A schematic of an experimental setup is presented in **Fig. 3**. A

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cylindrical stainless-steel straight tube with 2 m total length and 42 mm inner diameter is closed at both ends. The Prime Mover comprises a spiral-type electric heater, a stack, and circulating water. The electric heater and the circulating water are set at 0.35 m and 0.4 m with their origin at the left end of the system. The 50-mm-long stack has honeycomb ceramic cells (600 cell/inch^2). Electric power of 50 W was supplied to the electric heater. The system was filled with air at atmospheric pressure. Moreover, the 45-mm-long PA is set at 1.0 m. The PA inner diameter was changed from 18 mm to 34 mm in 8 mm increments. Based on the measured pressure using pressure sensors (PCB Inc.), the acoustic impedance and sound intensity distribution in the PM stack was calculated by using the transfer matrix method by Ueda[5].

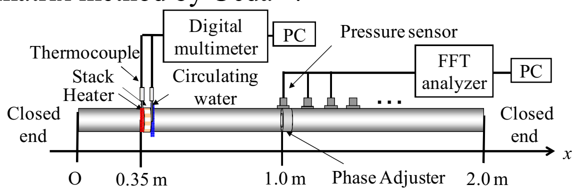

Fig. 3. Experimental setup of the straight-tubes when the PA is set at 1.0 m from the left end.

5. Results and Considerations

The calculated ΔI_{PM} with each PA is portrayed in **Fig. 4**. The ΔI_{PM} maximum is confirmed with the PA (ID 34 mm). Moreover, **Fig. 5** and **Fig. 6** show that the calculated distributions of $|Z|$ and Φ in the PM stack with each PA, respectively. These figures represent that $|Z|$ is larger and Φ is closer to 0° at the PM stack when the inner diameter of the PA is smaller. Thus, it is expected that there are optimal |Z| and Φ values for realizing the ΔI_{PM} maximum. Moreover, in this experiment, it is confirmed that the sound wave of half wavelength was excited in the systems. Thinking about the resonant phenomenon, the acoustic energy in the tube is most likely to amplify when the PA, which is the acoustic load, isn't set in the systems. However, ΔI_{PM} takes the maximum value with the PA (ID 34 mm). The result is probably because the amplification of the sound wave caused by the thermoacoustic phenomenon is effectively realized because a traveling wave component, which is essentially more effective for the heat exchange than a standing wave component[3], is used by Φ approaching to 0° in the PM stack.

6. Summary

In this study, the relation between Z in the PM stack and ΔI_{PM} of the straight-tubes was investigated. From the results, it is expected that there are $|Z|$ and Φ optimal values in the PM stack for realizing the ΔI_{PM} maximum.

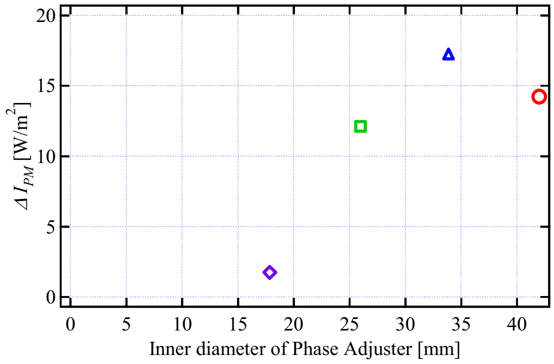

Fig. 4. Relation between the inner diameter of PA set at the straight-tubes and calculated ΔI_{PM}.

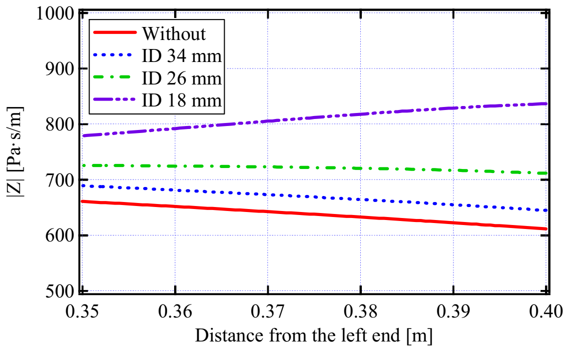

Fig. 5. Calculated distribution of |Z| in the PM stack.

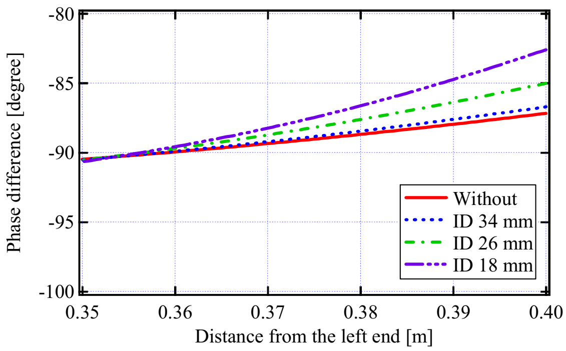

Fig. 6. Calculated distribution of Φ in the PM stack.

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