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Resonance control by locally contraction of outer tube in a coaxial thermoacoustic system

同軸型熱音響システムにおける外管の局所的縮小による共鳴モード制御

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1. Introduction

The coaxial-type thermoacousitic system (coaxial-type) consists of two tubes with different diameter arranged coaxially. Due to its straight shape, it is good for downsizing compared with the loop-tube type and considered that the range of practical use can be expanded. In this system, the sound wave propagating in the annular flow path which forms between the inner and outer tubes is reflected at the tube end and propagates to the inner tube, so that a traveling-wave sound field with high energy conversion efficiency can be formed.

In the previous study, In order to suppress the performance deterioration[1], focused on the characteristic of the coaxial-type that an antinode of sound pressure is formed at the end of pipe, resonance control is performed by additional prime mover (PM). As a result, the sound pressure has been increased[2]

As a simpler resonance control method focusing on the characteristic of the coaxial-type, this report propose a method of providing a sound field condition by locally contraction of outer tube. Based on the sound pressure distribution, the installation position where the secondary mode can be suppressed is predicted. The effect on the resonance control and the sound pressure are experimentally investigated.

2. Experimental methods

The experimental system is shown in **Fig. 1**. A stainless steel tube with a 42 mm inner diameter and a 2100 mm total length is used for the outer tube closed at both ends. A coordinate whose origin (x = 0) is set at the left end of the outer tube is defined. Another stainless tube with a 27 mm outer diameter, a 2000 mm total length and a 1 mm thickness is used for the inner tube open at both ends. The inner tube is set in the range 50 mm ≤ x ≤ 2050 mm coaxially with the outer tube. A toroidal stack made from a honeycomb ceramics with a 50 mm length and a 0.65 mm flow-path

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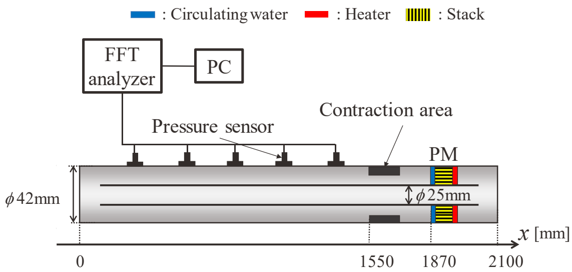

Fig. 1 Experimental setup.

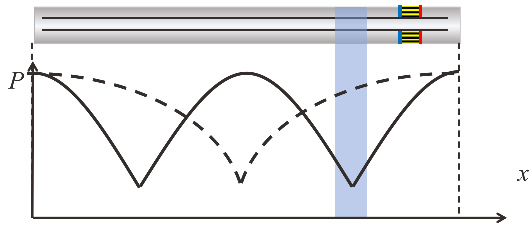

Fig. 2 Schematic of t sound pressure distribution in the annular area.

radius is used for PM. An electric heater is attached to the hot end of PM while 20°C water is circulated around the cold end of PM. The stack is set so that the cold end is at x = 1870 mm where the cooling ability began to drop in the previous report[1]. It is assumed that the acoustic boundary condition that the antinode easily appears can be given by contraction of outer tube becasuse sound pressure tends to increase by reduction of the cross section area of the annular flow path. The sound pressrue distribution by fundamental and secondary mode formed in the annular area is shown in **Fig. 2.** In order to suppress the secondary mode, the width of the outer tube is reduced in the range 1540 mm ≤ x ≤ 1590 mm, which is the position of the secondary mode node. Since this position is the antinode of the fundamental mode sound pressure, it is considered that the fundamental mode excitation is not hindered. The contraction width is changed from 0 mm (without contraction) to 2, 4, 6 mm. At each width, the sound pressure in the annular flow path is measured with pressure sensors (product of PCB Co.) after making sure the temperatures at both ends of PM have been reached at the steady state.

3. Results and Discussions

In each condition, the sound wave whose wavelength is the total flow path length is confirmed to be excited. To confirm the suppression effect of the second mode by contraction of outer tube, executing FFT on the waveform of the sound pressure observed with a pressure sensor set at the position 200 mm distant from the left end of the outer tube, the sound pressure difference between the fundamental mode and the secondary mode is shown in **Fig. 3**. From this figure, it is confirmed that the sound pressure difference increases under all conditions compared to the system without contraction. Also, the sound pressure difference increases as the contraction width increases, it is seen that the locally contraction of the outer is effective for the resonance control in the coaxial-type.

The sound pressure at x = 50 mm (the assumed setting position of heat pump) and the thickness of viscous boundary layer formed at the hot end of the stack in each condition is shown in **Fig. 4.** Comparing to the system without contraction, the enhanced sound pressure is confirmed in the case of 2 mm and 4 mm. However, in the case of 6 mm, the sound pressure turns down. When the contraction width is 6 mm, about 70% of the cross-sectional area of the annular flow path is closed, and it is considered that the sound is hard to be excited. The change in the thickness of the viscous boundary layer is similar to the sound pressure but the change is the opposite. Compared to the system without contraction, the thickness of viscous boundary layer is decreased in the case of 2 mm and 4 mm but is increased in the case of 6 mm. The working fluid in the viscous boundary layer are affected by the viscosity and it is hard to convert heat into sound. It is also confirmed from the viewpoint of the viscous boundary layer that sound wave is difficult to excite in a system with contraction width of 6 mm. It is presumed that the acoustic conditions change due to the increase of the reflection surface by the contraction, which has a influence on the sound field. It is suggested that extreme boundary conditions may inhibit not only the secondary mode but also fundamental mode excitation.

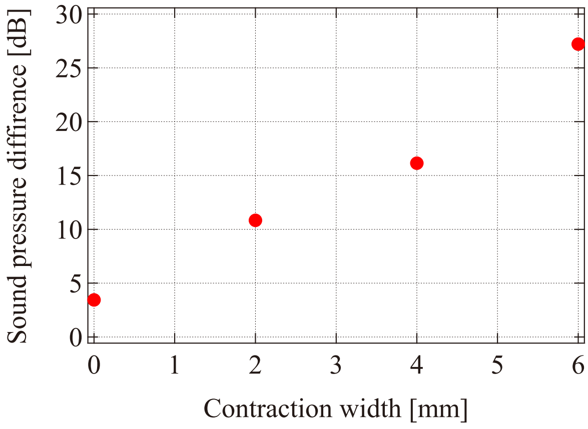

Fig. 3 Sound pressure difference between fundamental and second mode.

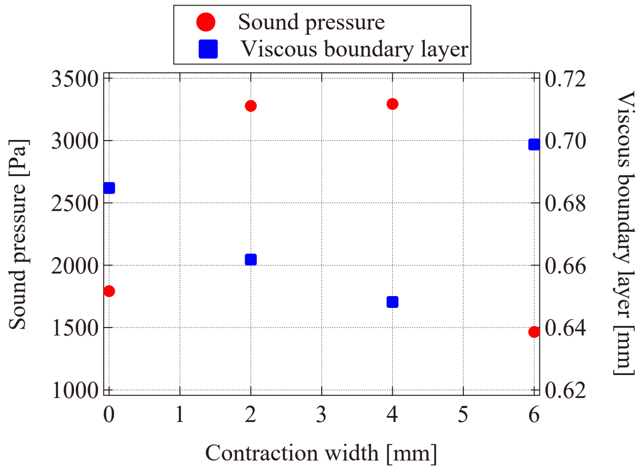

Fig. 4 Sound pressure at HP position and thickness of viscous boundary layer at PM hot end.

4. Conclusion

In this report, to improve the performance of the coaxial-type thermoacoustic system, the control of the resonance mode was investigated by the technique to contract outer tube as a simple method. The resonance control was succeeded with reducing near the node of sound pressure distribution by secondary mode, and the effectiveness of the resonance control based on the sound pressure distribution was suggested. The resonance control effect was enhanced by increasing the contraction but the sound pressure was decreased with extreme contraction. It is also suggested that extreme boundary conditions changed acoustic conditions due to the increase of the reflection surface and hindered fundamental mode sound excitation.

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