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Factor of resonance mode control on a thermoacoustic system – Determination of acoustics by forced oscillation –

熱音響システムにおける共鳴モード制御要因
-強制振動を用いた音響的観点による検討-

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1. INTRODUCTION

The thermoacoustic[1] phenomenon, interconversion between heat energy and sound energy, enables the realization of a cooling system that is powered with heretofore unused energy such as waste heat. A loop-tube type thermoacoustic cooling system (loop-tube) includes two energy-converting components called the prime mover and the heat pump. A stack consisting of numerous narrow channels plays an important role in each component. Sound waves are generated by formation of a steep temperature gradient at both ends of the stack in the prime mover. [2] When sound waves generated in the prime mover pass through the heat pump, one side of the stack in the heat pump cools. Benefits of the system are its low cost and maintenance-free operation, in addition to its waste heat driving source. However, few practical examples exist because of its low energy-conversion efficiency. Previous reports have described that its resonance mode is controlled and that its cooling capacity can be improved by setting a phase adjuster[2] (PA) in the system. First, this report explains how to control the resonance mode by setting a PA. Next, this report describes experiments and the determination of factors of resonance mode control by setting a PA on a thermoacoustic system.

2. RESONANCE MODE CONTROL BY SETTING A PHASE ADJUSTER

A PA is a concentric columnar device. Setting a PA in the system can reduce the cross-section locally. Figure 1 presents examples of the particle velocity distribution and positions for setting PA. The abscissa shows the distance from the electric heater. The ordinate shows the particle velocity. In that figure, panels (A), (B), and (C) present examples of particle velocities distribution of 1–3 wavelengths. Setting PA as (A) forms one wavelength, (B) forms two wavelengths, and (C) forms three wavelengths. In this manner, the resonance mode is controlled by setting PA to a declination gradient of the particle velocity distribution.

Next, results of a comparison between the cooling capacity of a system without PA and with PA are shown. The stainless steel tube has 3300 mm total length, with 42.5 mm inner diameter. The working fluid is air at 1 atm. The prime mover comprises an electric heater, a stack, and a low-temperature heat exchanger to maintain the surrounding temperature. The ceramic stack is 50-mm-long and its channel radius is 0.45 mm. In the heat pump, a low-temperature heat exchanger is set on the stack. The stack channel radius is 0.35 mm. Its material and lengths are the same as those of the stack of the prime mover. The PA is 45-mm-long and has 26 mm inner diameter. Its position is 1125 mm from the electric heater, clockwise. Setting PA to this position can control 1 wavelength. In this condition, each electric heater of the system without PA and with PA is supplied 330 W. When both ends of the stack in the prime mover reach a steady temperature, then the temperature at the cooling point is measured using a K type thermocouple. Results show the temperature as 13.9 °C for the system without PA, and about -4 °C with PA, when cooled from about 20 °C ambient temperature. Resonance mode control by setting PA improves the cooling capacity.

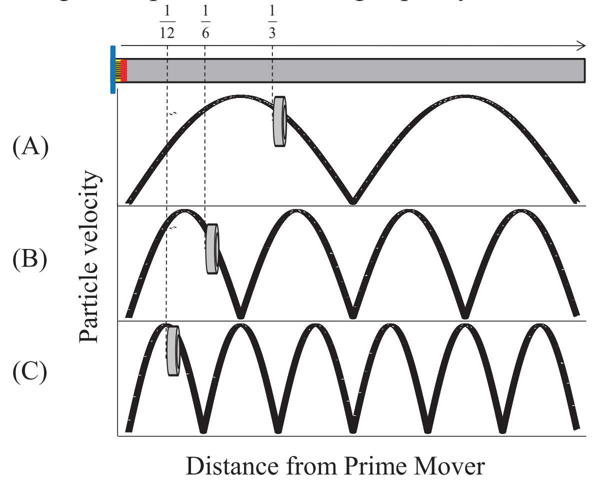

Fig. 1 Schematic particle velocity distribution and position of the phase adjuster.

3. DETERMINATION OF THE FACTOR OF RESONANCE MODE CONTROL

1. Experimental method

Factors of resonance mode controlled by setting PA on a loop-tube type thermoacoustic system are assessed. Especially as described in chapter 2, the characteristics for changing the PA position in a sound field formed by forced oscillation are verified to ascertain the relation of the position of the PA to the gradient of the particle velocity distribution. Figure 2 portrays the experimental system. The stainless steel tube has 3000 mm total length with 42.5 mm inner diameter. This loop-tube has neither PM nor HP. The working fluid is air at 1 atm. A loudspeaker (TU-750; TOA) was set on the loop-tube and a sound field was formed as one wavelength. A 50 mm straight tube was set with the loop-tube to connect a loudspeaker. Input to the loudspeaker was 10 V. Then the PA setting point was changed to 500 mm, 550 mm, 950 mm, and 1000 mm. Under each condition, the pressure in the tube was measured using a berg crystal type pressure sensor made of PCB. The work flow in the system was computed using Rott's equation. For this experiment, clockwise is positive because the center of the loudspeaker is the origin.

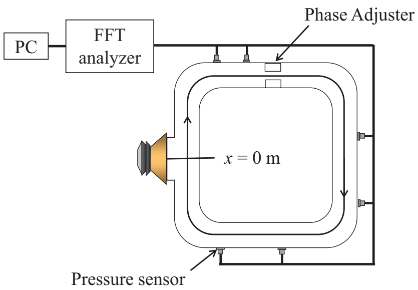

Fig. 2 Experimental setup of the loop-tube with a loudspeaker.

2. Experimental Results and Discussion

Figure 3 presents particle velocity distribution in the system without PA. And this shows that x=500 and 550 are the rise positions, and x=950 and 1000 are declination positions. Figure 4 presents the computed work flow. The horizontal axis shows the distance from the center of loudspeaker. The vertical axis is the work flow in the tube. The direction of positive work flow is the same as that to the x-axis. The direction of negative work flow is the other direction. In the system without PA, x=2.0 shows that the workflow is 0 because the phase difference between the pressure oscillation and particle velocity oscillation is 90 deg. Therefore, it is verified that in the system without PA, a standing wave is formed. However, it was verified that in the system with PA, a traveling wave was formed because the work flow was not 0. With the positions of PA as x=950 and 1000, the work flow direction was the same as the x-axis. With the positions of PA as x=500 and 550, the work flow direction was the other direction. These results demonstrate that the PA position determines the work flow direction. Therefore, it is considered that the resonance mode controlled as the direction of work flow decided by the position of PA is the same as the direction of work flow in a loop-tube type thermoacoustic system.

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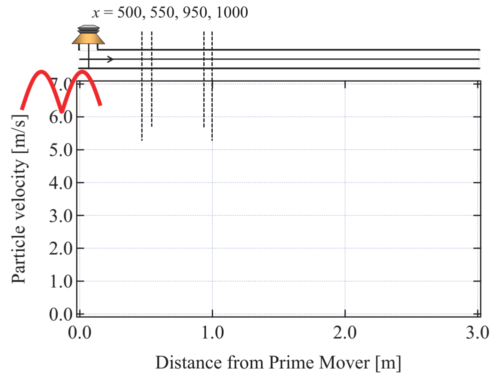

Fig. 3 Particle velocity distribution in the system without PA and setting positions of PA.

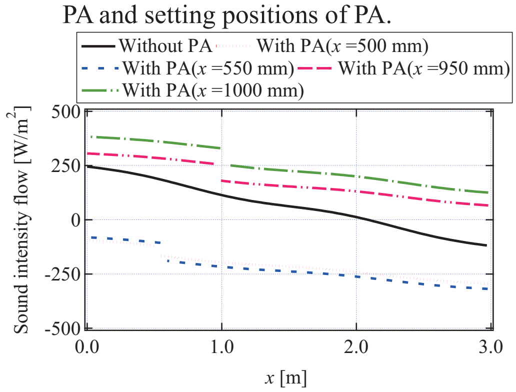

Fig. 4 Sound intensity flow in the loop-tube with a loudspeaker.

Acknowledgments

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