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Effect of superimposed external sound wave on loop-tube type thermoacoustic system

外部音波の重畳がループ管型熱音響システムに与える影響

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1. Introduction

To practically use a thermoacoustic system, the improvement of conversion efficency necessary. As the solution to this problem, the method of superimposing external sound waves has been reported [1]. In previous paper, intending the enhancement of the energy conversion efficiency by superposing acoustic vibrations on the oscillating sound field in the working fluid of straight tube thermoacoustic system, the promotion of the thermoacoustic conversion phenomenon has been confirmed[1]. However, the application of this method to loop-tube thermoacoustic system has not been reported yet.

In this study, the application of the external sound wave superposition method to loop-tube thermoacoustic system, in which traveling waves are dominant, was investigated.

First, we examined the change of the self-excited oscillation frequency with the change of the position of the external sound wave input. Next, the heat exchange mechanism during the superposition of external sound waves was investigated in detail, focusing on the change in heat exchange area and heat flow during oscillation and superposition.

2. Experiments

The schematic of the experimental system is shown in Fig. 1. A stainless tube with a 3300 mm total length and a 42 mm inner diameter filled with the working fluid of atmospheric air is used. A honeycomb ceramics with flow path radius of 0.55 mm and length of 50 mm is used for the stack. A high-temperature heat exchanger (an electric heater) and an ordinary temperature heat exchanger (circulating water) are set at the ends of the stack and the temperature difference is given between both ends of the stack. The input to the heater is kept at 330 W and the cool end is kept at 20°C by circulating water. The loudspeaker (SP) (TOA TU-750) is installed at x = 250, 500, 900, 1200, 1700, and 2200 mm, with the hot end of the stack at x = 0 mm. The SP is driven by the continuous sinusoidal wave whose input frequency is the resonance frequency of the self-excited oscillation, and the sound pressure in the tube is input to be 500 Pa. At each SP location, we compare the self-excited vibration without SP drive and the self-excited vibration with SP drive

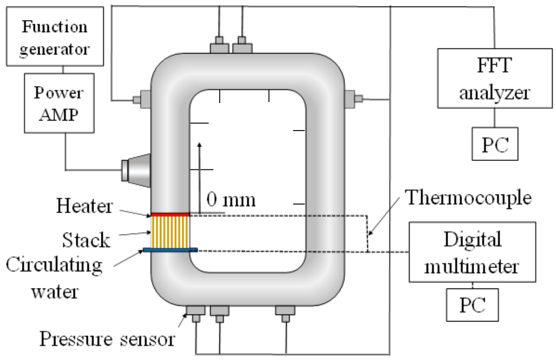

Fig. 1 Experimental setup.

and superimposed sound waves. The temperatures at both ends and the center of the stack are measured with K-type thermocouples to calculate the amount of heat exchange in the stack. In addition, the sound pressure in the system is measured with the crystal-type pressure sensor (PCB Co., 112A21).

Work flow I [W/m^2] at each condition is evaluated by the following equation.[2]

$$I = \frac{1}{2}|p||u|\cos\phi, \quad (1)$$

where p is the sound pressure, u is the particle velocity, and ϕ is the phase difference between the sound pressure and the particle velocity. In the present study, the difference ΔI of the work flow between hot and cold end of the stack is defined as the amplification of the work flow in the stack.

3. Results and discussions

The variations of ΔI at both ends of the stack for various SP input positions are shown in Fig. 2 and the oscillation frequency at the self-excited oscillation is listed in Table 1. ΔI and resonance frequency are difference depending on the location of SP. It is clearly confirmed that ΔI for each SP position is increased when superimposing the external sound on the self-excited sound. The amount of increase is different for each installation position.

The difference in oscillation frequency and ΔI with self-excitation are supposed to be due to the change in the sound wave in the tube caused by SP installation position. The system of SP installation position at x=900 mm shows a stable self-exited vibration at the resonance frequency with 2 wavelengths of full tube length. In previous studies, it has been confirmed that the resonance mode can be controlled by installing phase adjuster (PA) in the system[3]. In this report, the system of SP installation position at x=250, 550, 1700, and 2200 mm install at the upward slope in 1 wavelength resonance of the particle velocity distributions and at x=900 mm install at the downward slope in 1 wavelength resonance and the upward slope in 2 wavelength resonance. It is assumed that this determines the resonance mode.

Next, in order to clarify this amplification effect when external sound waves are superimposed, the heat exchange area and heat flow are focused on. It is supposed that heat flow in the stack changes by superimposing external sound waves. Furthermore, as the heat flow changes, the temperature distribution in the stack changes, and thus the heat exchange area is also expected to change. In this study, the product of heat flow and heat exchange area $Q \cdot S$ was used as the index of heat exchange. Here, the heat exchange area S that can contribute to the heat exchange in the cross section of the stack is calculated using the thicknesses of the viscous boundary layer and the heat boundary layer as a representative value [4]. $Q \cdot S$ distribution inside stack at x=250 mm is shown in Fig. 3. It is found that the amount of energy passing through the region contributing to heat exchange per unit time throughout the stack increases by superimposing external sound waves. It is considered that the application of the external sound waves superposition method into loop-tube type thermoacoustic system promote thermoacoustic phenomena as well as straight-tube type.

4. Conclusion

In this report, to improve the energy conversion efficiency of thermoacoustic system, the external sound wave superposition method was applied to loop-tube type system. We attempted to improve the energy conversion efficiency by superimposing sound waves on the self-excited system using an external loudspeaker. As a result, it was confirmed that the external sound wave superposition method could expand the heat exchangeable area in the stack and promote the thermoacoustic phenomenon in loop-tube type thermoacoustic system.

Acknowledgment

This work was supported by a JSPS Grant-in-Aid for Young Scientists (A) [grant number 22686090]; JSPS Grant-in-Aid for Challenging Exploratory Research [grant number 23651072]; Grant-in-Aid for Scientific Research (C) [grant number 17K06234]; the Program for Fostering Regional Innovation; and the JST Super Cluster Program.

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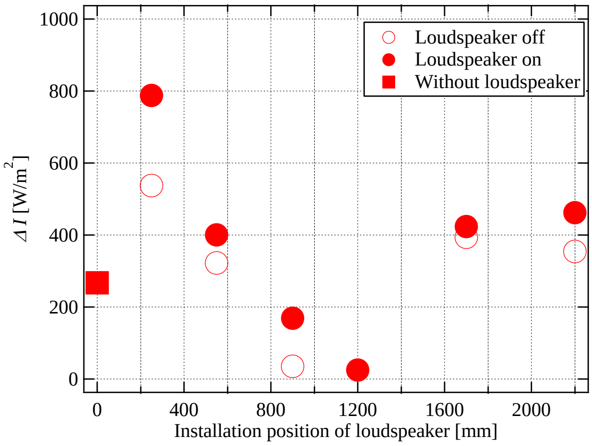

Fig. 2 Relationship between work flow and installation position of loudspeaker.

Table 1 Resonance frequency with self-excited oscillation.

Installation position of the loudspeaker [mm]	Resonance frequency [Hz]
0	105
250	103.75
550	105
900	206.25
1200	No oscillation
1700	102.5
2200	105

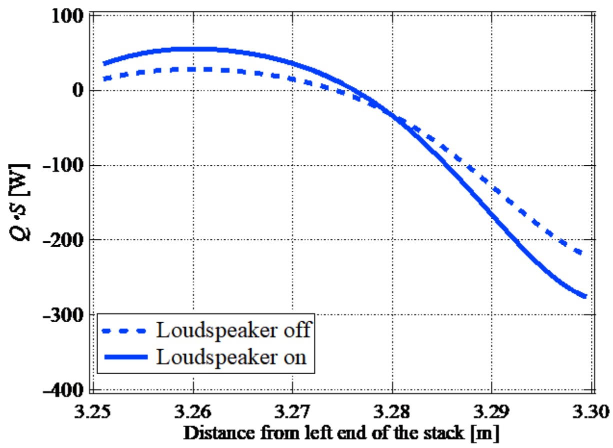

Fig. 3 $Q \cdot S$ distribution inside stack. (x=250 mm)

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