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Effects of generation for work flow on the standing-wave thermoacoustic-system -Relationship between the installation position and the temperature gradient of stack-

定在波熱音響システムにおける仕事流生成に与える影響 -スタック位置と温度勾配の関係-

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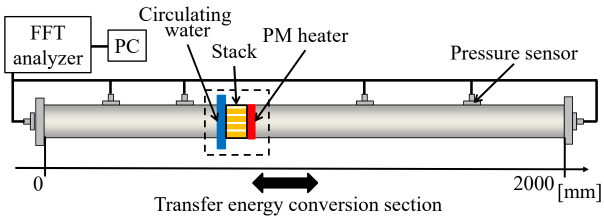
1. Introduction

A thermoacoustic system can generate the work flow from industrial waste heat without using any moving parts. The standing-wave system realizes the mutual energy conversion between the heat flow Q and work flow I via the irreversible thermodynamical process[1]. The energy conversion takes place in the device called a stack that consists of many narrow tubes. When a temperature difference is provided between both ends of the stack, a thermoacoustic phenomenon is induced where the self-oscillation of the sound occurs[2]. In the previous experiments of the thermoacoustic systems[3,4], the ratio T_H/T_C of surface temperatures at both ends of the stack was observed so far but the temperature distribution within the stack was scarcely examined.

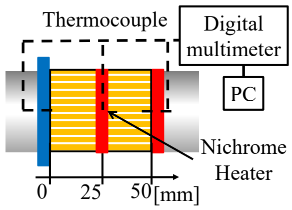
In this report, the generation of the work flow is measured at the controlled temperature-gradients varied under the identical T_H/T_C. The influence of the setting position of the stack and the temperature gradient in the stack on the standing-wave thermoacoustic system is also discussed.

2. Experimental method

The measurement system is illustrated in **Fig. 1(a)**. Closing at both ends, a straight tube with a 2000 mm total length and a 42 mm inner diameter is used. The working fluid is atmospheric air. The energy conversion section is a 50 mm long honeycomb ceramic stack with 0.45 mm radius channels. The stack is set at 700, 900, 1400, or 1700 mm from the left end. The resonant frequencies of the system are 170 Hz in the case of 700 or 900 mm, and 80 Hz in the case of 1400 or 1700 mm. A schematic view of the energy conversion section is shown in **Fig. 1(b)**. A temperature difference is obtained between the circulating water at 0 mm and the PM heater at 50 mm. Furthermore, a nichrome heater is installed at the middle of the stack (25 mm). While the temperature in the stack is varied by changing the



(a) Straight-tube thermoacoustic system



(b) Energy conversion section

Fig.1 Schematics of experimental system.

input voltage to the heater, NH_{input}, of 0-23 V, the temperature ratio at both ends of the stack is conserved by holding the input voltage to the PM heater constant. The temperatures at the hot end of the stack, T_H, at the cold end of the stack, T_C, and at the middle of the stack, T_N, are measured with K-type thermocouples. In addition, the sound pressures in the tube are measured with pressure sensors (PCB Inc.). The distribution of work flow I was calculated from the measured pressures using the transfer matrix method[5].

3. Experimental results

To assess the change of the internal temperature T_N, the normalized internal temperature T_i is defined as

$$T_i = \frac{T_N}{T_m}, \quad (1)$$

where T_m is the average of T_H and T_C; $(T_H+T_C)/2$. When NH_{input}=0, T_i becomes about 0.85. T_i increases with NH_{input}. The maximum value of T_i for each setting position of the stack means the limit value while the sound wave is observed. **Figure 2** shows the relationship between the normalized internal temperature T_i and the amount of work flow generation ΔI. It is seen that ΔI changes in different ways according to the setting position of the stack. In the case of 700 or 1400 mm, ΔI is the maximum at T_i of about 0.85 and decreases as T_i increases. In the case of 1700 mm, ΔI achieves a peak about T_i=1.0 and then decreases as T_i increases. In the case of 900 mm, the maximum is attained at about T_i=1.3. Note that ΔI for 900 mm scaled in the right ordinate in Fig. 2 is ten times larger than the values for other setting positions.

4. Discussion

The variation of ΔI by T_i is discussed using a work source[6]. The work source W is the value to represent the spatial variation of the work flow in the axial direction. That is composed of three terms; the terms of the viscous dissipation, the pressure fluctuation dissipation, and the temperature gradient. While the first and second terms contribute to the decrease of ΔI, the third term contributes to the increase of ΔI. **Figure 3** shows the changing ratio of W and each term for the stack position of 900 mm. They are normalized by the value at T_i =0.85. W depends on the complexion of ΔI seen in **Fig. 2**. It is found that the first and third terms significantly change as T_i increases. While ΔI increases with the third term, ΔI decreases with the first term. So, when the third term proportional to the temperature gradient is increased by suppressing the viscosity dissipation utilizing the change of T_i, ΔI is enhanced. The different complexion of ΔI according to the setting position must be the effect of the viscous dissipation of the first term. Since the viscous dissipation is proportional to the magnitude of the particle velocity, the value of the first term is primarily determined by the particle velocity in the stack. It is known that the particle velocity distribution in the system is determined by the resonance frequency and ΔI increases provided the stack is set at the node of the particle velocity[5]. The present result demonstrates that to increase T_i by setting the stack at such a position as 900 mm of the particle velocity node contributes to the further increase of ΔI. It is also suggested that the increase of T_i results in the decrease of ΔI for the setting position distant from the particle velocity node. Consequently, it is important for increasing the work flow generation to set the internal temperature in the stack in accordance with the particle velocity distribution at the setting position of the stack.

5. Conclusion

The influence of the temperature gradient within the stack on the work flow generation was examined. It is important to obtain a proper

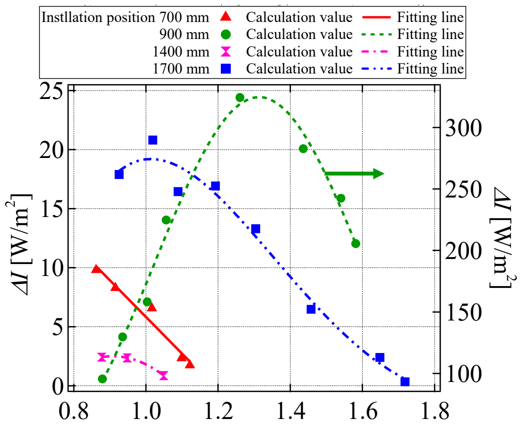


Fig. 2 Relation between ΔI and T_i.

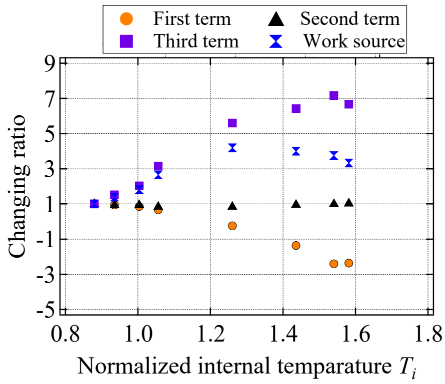


Fig. 3 Relation between changing ratio of work source and T_i for the stack position of 900 mm.

temperature gradient by setting the stack at an appropriate position. The increase of the work flow and thereby the enhancement of the efficiency is expected by controlling the temperature gradient fit for its particle velocity distribution.

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