# 2P4-10

## Resonance mode control by superposition of external sound waves in standing-wave thermoacoustic system
## -Relationship between viscous boundary layer and resonance mode-
## 外部重畳音波による熱音響システムの共鳴モード制御
## ―粘性境界層と共鳴モードの関係―

Yuya Kurata[1†], Shin-ichi Sakamoto[2], Kazuki Shiraki[1], Koto Hiramatsu[1],
Yuto Kawashima, and Yoshiaki Watanabe[1] ([1]Doshisha Univ.; [2]Univ. of Shiga Pref.)
倉田　侑弥[1†], 坂本　眞一[2], 白木　一希[1], 平松　康斗[1], 川島　裕斗[1], 渡辺　好章[1]([1]同志社大,[2]滋賀県立大)

### 1. Introduction

To practically use a thermoacoustic system, the improvement of conversion efficency is necessary. Two points are important for the enhancement of the energy conversion efficiency; active heat exchange and stable resonance mode. The technique to heat the interior of the stack has ever been proposed for more efficient thermal conversion[1]. Furthermore, techiques such as the local reduction of inner radius of the system[2] and the local heat input to the sytem[3] have been also proposed. The technique to control the resonance mode is discussed in this paper. For realizing the resonance mode control, it is necessary to introduce a new acoustic boundary condition in the system. Concerning the technique to realize the acoustic boundary condition, it has already been reported that the heat exchange is advanced by externally superposing a sound wave to the working fluid with the self-excited vibration in the standing-wave thermoacoustic system[4]. In this report, to develope further the previous paper, the technique to activate heat exchange and stabilize resonance mode by leading the self-excited vibration of the fluid particles in the thermoacoustic system to the fundamental resonance mode is proposed.

In the experiment, the position of the stack is selected so that the self-excited vibration takes place at higher modes. By externally superposing the sound of the fundamental mode to the stable self-excited vibration, the transition of the resonance mode of the system to the fundamental mode is obsereved. In addition, the attention is focused on the thickness of the viscous boundary layer in the flow path as the contributing factor for the change of the resonance mode.

### 2. Experiments

The schematic of the experimental system is shown in Fig. 1. A straight-tube thermoacoustic system of a 2000 mm total length and a 42 mm inner diameter is constructed. The one end is closed and a loudspeaker (TOA Co., TU-750) is set at another end. A new coordinate whose origin (*x*=0) locates at the vibrating surface of the loudspeaker of the left end is settled as illustrated in the figure. The working fluid is atmospheric air. A honeycomb ceramics with flow path radius of 0.55 mm and length of 50 mm is used for the stack whose cold end locates at *x*=1200 [mm]. By setting an ordinary temperature heat exchanger (circulating water) at one end of the stack (*x*=1200 [mm]) as well as a high-temperature heat exchanger (an electric heater) at another end (*x*=1250 [mm]), the temperature difference is given between both ends of the stack. The input to the heater is kept constant at 200 W. The system shows a stable self-exited vibration at the resonance frequency with 1.5 wavelengths of full tube length. From the speaker, the continuous sinusoidal sound wave with a fundamental frequency of the system is supplied to the system with a stable self-excited vibration. Two conditions for the input electric power to the speaker of 5 and 10 W are examined. When the thermal equilibrium is attained at each condition of the speaker input, the temperatures at both ends are measured with K-type thermocouples. In addition, the sound pressure in the system is measured with the crystal-type pressure sensor (PCB Co., 112A21) set at *x*=150, 450, 850, 1950 and 2000 [mm].

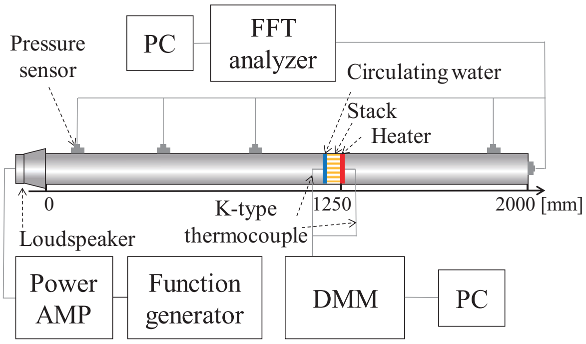

Fig.1 Experimental setup.

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ctwc0333@mail4.doshisha.ac.jp

## 3. Results and discussion

The change of the resonance mode from the stable self-excited vibration due to the sound-wave superposition in the case of 10 W speaker input is shown in Fig. 2. The system resonates with 1.5 wavelengths of full tube length (red spectrum in Fig. 2) in the stable self-excited vibration state. When externally superposing the sound wave, the mode shifts to the fundamental one (blue spectrum in Fig. 2) resonating with a half wavelength of full tube length.

The thickness of the viscous boundary layer $\delta_v$ significantly contributes to the decision of the resonance mode. If $\delta_v$ where the acoustic vibration is inactive occupies most of the flow path of the stack, fluid particles cannot fully conduct the heat exchange with the flow path wall. It has been reported that, since the system expands the region capable of heat exchange in such a case, the resonance shifts to the higher mode capable of self-excited vibration with a thinner $\delta_v$[5]. Based on this idea, $\delta_v$ is considered as the contributing factor for the change of the resonance frequency here. The calculated $\delta_v$ is shown in Fig. 3. The theoretical value 0.42 mm of $\delta_v$ at the fundamental mode turns out to occupy the majority of the flow path radius of 0.55 mm. Therefore the situation that the heat exchange cannot be well conducted is understandable. In this case, to make possible the sufficient heat exchange, the higher resonance mode (with $\delta_v$ of 0.24 mm) with 1.5 wavelengths of full tube length turns out to be excited. On the other hand, if the acoustic vibration of the fundamental mode is externally superposed on such a vibration excited at the higher mode, the temperature of the working fluid in the flow path lowers due to the activated conversion from heat to sound[4]. Since the lowered temperature of the working fluid results in the reduction of $\delta_v$, the feedback system is constructed where the vibration of the fundamental mode is further accelerated and the region capable of heat exchange simultaneously expands in the flow path. Namely, because $\delta_v$ at the fundamental mode (Fig. 3 c) is decreased compared to the case without superposition of the sound wave (Fig. 3 a), the region capable of heat exchange in the flow path increases and then the resonance shift to the fundamental mode is supposed to occur.

## 4. Conclusion

In the standing-wave type thermoacoustic system with self-excited vibration at the higher mode, the resonance mode of the system was successfully controlled to the fundamental mode by externally superposing a sound wave to resonate at the fundamental mode. Furthermore, paying attention to the thickness of the viscous boundary layer, the decreased thickness of the viscous boundary layer and the expanded region capable of heat exchange that were both induced by superposing the sound wave were supposed to make possible the resonance at the fundamental mode.

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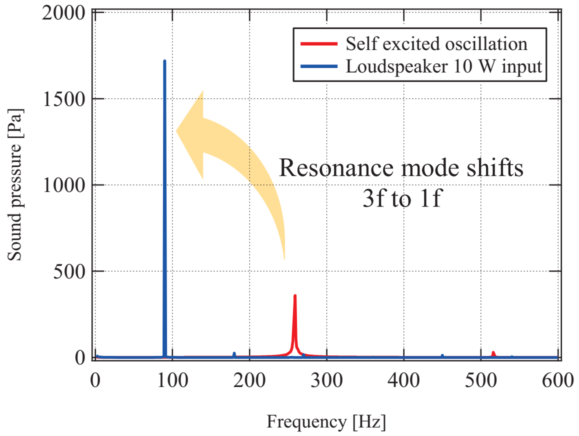

Fig.2 Resonance mode shift by external superposition of sound wave.

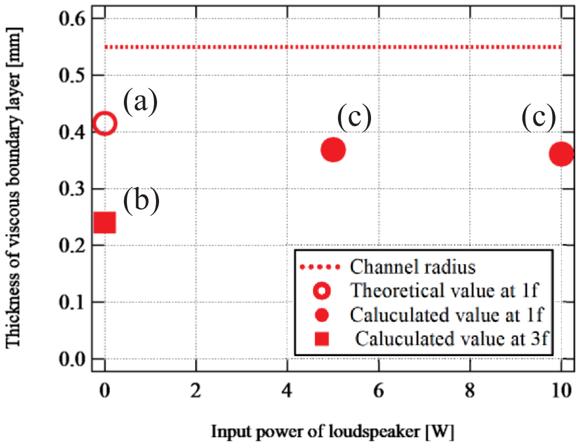

Fig.3 Thickness change of viscous boundary layer by external superposition of sound wave.