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Influence of the heat leak on the onset temperature in the straight-tube-type thermoacoustic prime mover: The temperature distribution of the thermal buffer tube

直管型熱音響プライムムーバーにおける発振温度への熱漏れの影響：熱緩衝管の温度分布

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1. Introduction

A thermoacoustic system[1,2] contributes to the reduction of the global environment burden, thereby motivating studies for its practical application.[3,4] Thermoacoustic systems use the mutual conversion of energy between sound and heat. Unused heat sources, such as solar and factory exhaust heat, can be theoretically used to drive heat-driven thermoacoustic systems. Typically, these systems need a higher temperature heat source than the onset temperature of the thermoacoustic spontaneous gas oscillation in order to be driven. Lowering of the onset temperature is required to facilitate its application. Another real issue is the heat leakage, which degrades the efficiency and affects the onset temperature because of the resulting temperature distribution along the tube that is close to the high temperature parts. This tube is called the thermal buffer tube.

A stability analysis using the transfer matrix method has been proposed by Ueda *et al.* [5] in order to calculate the onset temperature of thermoacoustic systems. This method helps to estimate the performance and design a system.[6] However, there is a difference between the analysis and experimental results depending on the conditions. One of the possible causes is in making assumptions about the conditions of some parts such as the stack and thermal buffer tube. In particular, the temperature distribution and the length of the thermal buffer tube are unclear.

In this study, we focused on the temperature distribution along the thermal buffer tube. To determine the influence on the onset temperature, a straight-tube-type thermoacoustic prime mover is experimentally examined by measuring the onset temperature and the temperature distribution on the thermal buffer tube surface.

2. Experimental method

A schematic of the experimental system and the thermal buffer tube are shown in **Figs. 1** and **2**. The straight-tube-type thermoacoustic system consisted of stainless steel tubes. The total length of the tube was 980 mm, and the inner diameter was 42.6 mm. The tube with closed ends was filled with air at atmospheric pressure. The stack was made from ceramic and had a honeycomb structure. The length and channel density of the stack were 50 mm and 900 channel/in^2, respectively. The stack was installed at 250 mm from a closed end. The high-temperature side of the stack was heated by the electric heater. The low-temperature side of the stack was maintained by circulating water at 20°C into the heat exchanger. Sound pressure in the tube was measured by four pressure sensors and confirmed spontaneous thermoacoustic oscillation. The installation positions of the pressure sensors were 0, 470, 880, and 980 mm from a closed end. The temperatures of the thermal buffer tube and high-temperature side of the stack were measured using K-type thermocouples. Thermocouples for the

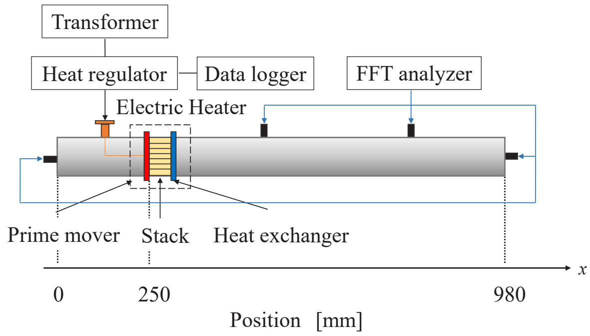

Fig. 1 Schematic of experimental system.

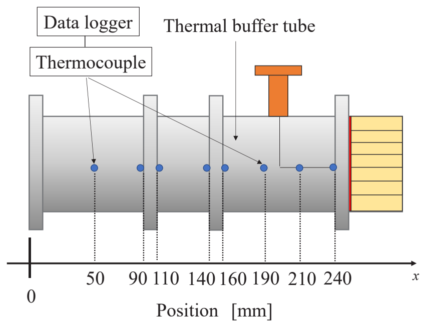

Fig. 2 Schematic of thermal buffer tube.

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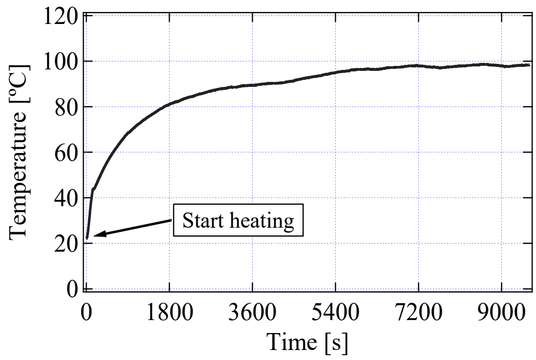
thermal buffer tube were placed at 50, 90, 110, 140, 160, 190, 210, and 240 mm on the outer tube wall.

The experimental procedure was as follows. First, the onset temperature was investigated. By changing the input power using a temperature regulator, the temperature at which spontaneous oscillation occurs was determined with a threshold of 10 Pa in the pressure amplitude. Then, while maintaining the onset temperature, the outer surface temperatures were measured after the temperatures on the thermal buffer tube were stabilized. At the same time, the temperature distribution of the outer surface of the tube was observed by an infrared thermography.

3. Experimental results

The onset temperature obtained by the experiment was 259°C. The time response of the temperature on the thermal buffer tube (x = 240 mm) is shown in **Fig. 3**. This result shows that the outer surface temperature increased and became stable in approximately 7200 s after the start of heating at approximately 98°C. The steady-state temperature distribution on the wall surface of the thermal buffer tube measured using thermocouples is shown in **Fig. 4**. In addition, an infrared photograph of the thermal buffer tube at steady state is shown in **Fig. 5**. In this photograph, the connecting point of the flanged tubes on the left is the high temperature side of the stack, and the closed end direction of the tube is on the right side. It was confirmed that a temperature distribution was formed along the thermal buffer tube. The temperature of the wall closer to the stack was higher. It is considered possible that the heat leak input from the electric heater affected the temperature distribution. Furthermore, the temperature near the closed end (x = 50 mm) was approximately 37°C, which was higher by approximately 10°C than room temperature.



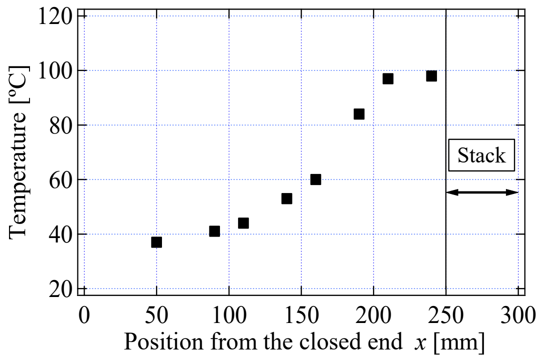


Fig. 4 Steady-state temperature distribution on wall surface of thermal buffer tube.

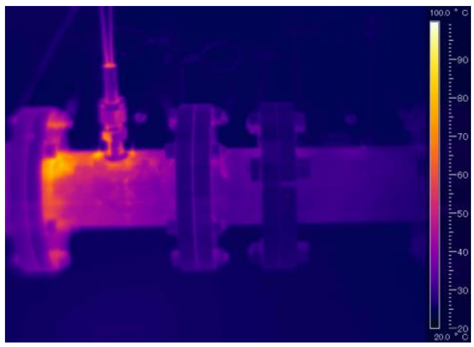


Fig. 5 Infrared photograph of thermal buffer tube at steady state.

4. Summary

In this study, we measured the outer surface temperature of the thermal buffer tube, particularly at steady state. From the measurement results, it was found that the wall temperature rises near the stack, and a considerable temperature distribution was formed on the thermal buffer tube. In future, it is necessary to examine the influence of the temperature distribution on the thermal buffer tube to the onset temperature in detail.

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