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Effect of medal-shaped PAs on the oscillation conditions of a thermoacoustic prime mover using stability analysis.

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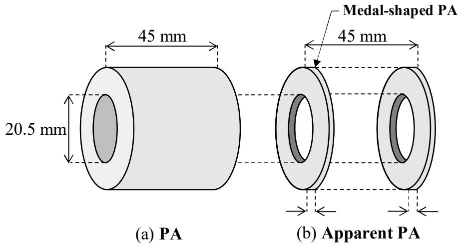
1. Introduction

More than half of the primary energy generated in Japan is wasted as unused heat. The practical application of thermoacoustic systems is expected as a technology for effective use of energy that makes use of low-temperature waste heat[1]. Thermoacoustic systems utilize the thermoacoustic phenomenon, i.e., the mutual conversion of energy between heat and sound. Thermoacoustic systems can deal with various heat sources and can effectively utilize unused heat such as waste heat from factories and solar heat. In addition, they are maintenance-free over the long term because there are no moving parts. On the other hand, the high temperature required to drive the system and the improvement of energy conversion efficiency are issues to be addressed. In this report, we focused on the onset temperature of a loop-tube-type thermoacoustic prime mover: the temperature at which thermoacoustic self-excited oscillation starts.

We propose Phase Adjuster (PA)[2] as a device to lower the onset temperature. PA gives a local reduction of the inner diameter of the tube. The phase difference distribution between the sound pressure and particle velocity inside the tube changes due to the reflection of sound waves at the end face of the PA and the increase in particle velocity inside the PA. The phase change reduces the energy required for oscillation by decreasing the dissipation to the entire system. As a result, the onset temperature of the thermoacoustic system decreases. In order to investigate the low-temperature driving mechanism of a thermoacoustic system using a PA, it is necessary to discuss the effect of sound wave reflection at the end face of PA and the effect of the narrowing area inside PA, respectively. In this report, we investigate the effect of the internal region of PA on the onset temperature of the thermoacoustic prime mover using a stability analysis[3] that ignores the effect of PA end face by linearization.

2. Medal-shaped PA

As for the effect of sound wave reflection on thermoacoustic prime movers at PA end face, Sahashi[4] showed experimentally that the region inside PA where the particle velocity increases is important for improving the energy conversion efficiency. In this report, we ignored the effect of PA end faces and investigated the effect of PA interior regions. Two thin medal-shaped PAs represented PA end faces, which were defined as “Apparent PA”. The schematic is shown in **Fig. 1**. The net length and inner diameter of Apparent PA were matched to those of PA[2] (**Fig. 1(a)**).



(a) PA (b) Apparent PA

Fig. 1 Schematic of PA(a)[2] and Apparent PA(b).

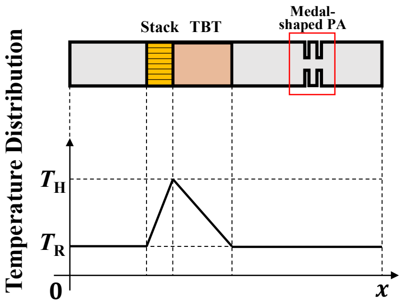


Fig. 2 Schematic of system model and temperature distribution[7].

3. Analysis methods

Ueda et al.[3] introduce stability analysis that calculates the stability limit conditions of thermoacoustic engine using Rott's[5,6] wave equation based on thermoacoustic theory. Stability analysis is a method to evaluate the performance of a thermoacoustic system using transfer matrix method given the geometry, temperature and frequency of the system. In this report, we calculated the stability limit conditions (oscillation conditions) of a loop-tube-type thermoacoustic prime mover using stability analysis. The temperature and frequency that satisfy the oscillation conditions defined as the oscillation temperature and resonance frequency, respectively.

The thermoacoustic model used in this report is a loop-tube thermoacoustic prime mover. The calculation model is shown in **Fig. 2**[7]. The total length and inner diameter of the system model were

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3.3 m and 42.6 mm, respectively. The temperature T_R in the system was set to 293.15 K. The working gas in the system was atmospheric air (0.1 MPa). The stack type was 900 cells/inch^2, the channel radius was 0.39 mm, the aperture ratio was 0.82, and the axial length was 50 mm. Section of linear decrease from the temperature T_H at the hot end of the stack to the temperature T_R in the system, i.e., thermal buffer tube length was set to 200 mm. PA and apparent PA were installed at 1100 mm from the hot end of the stack; the length and inner diameter of PA were 45 mm and 20.5 mm, respectively. Two thin medal-shaped PAs were used for Apparent PA. Two medal-shaped PAs were arranged so that the axial length of Apparent PA was 45 mm. The inner diameter of Apparent PA was 20.5 mm. We calculated the oscillation conditions when the thickness of two medal-shaped PAs is varied at the same thickness (**Fig. 1(b)**). When the thickness of one medal-shaped PA is 22.5 mm, the distance between two medal-shaped PAs disappears, which is the same as PA length of 45 mm (**Fig. 1(a)**).

4. Analysis results

Figure 3 and **Fig. 4** shows the results of stability analysis of the onset temperature and resonance frequency versus the thickness of per medal-shaped PA. A thickness of 0 mm per medal-shaped PA indicates that the medal-shaped PA are not installed, i.e., the inner diameter of the loop tube does not change. In addition, a thickness of 22.5 mm per medal-shaped PA indicates that the axial length of PA is 45 mm. **Figure 3** shows that the onset temperatures without PA and with PA were 603 K and 388 K, respectively. In other words, the installation of PA in the tube lowered the onset temperature by 215 K. Focusing on the trend of onset temperature change with increasing medal-shaped PA thickness, the onset temperature decreased exponentially in the range of thickness of 2-10 mm per medal-shaped PA. In the range of 10-22.5 mm, there is almost no change in onset temperature. Therefore, although increasing the narrowing area promotes reduction of onset temperature, that effect is small when the thickness of per medal-shaped PA increases above 10 mm. As shown in **Fig. 4**, however, the effect of the medal-shaped PA thickness on the resonance frequency is decreases linearly each time thickness of medal-shaped PA increase, regardless of the range of narrowing area.

5. Summary

We investigated that the effect of the internal region of PA on the onset temperature in a loop-tube-type thermoacoustic prime mover using stability analysis. The decreasing trend of onset temperature due to medal-shaped PAs decreased exponentially in the range of 2-10 mm thickness per medal-shaped PA; there is almost no change in the range of 10-22.5 mm. The resonance frequency, however, changed linearly regardless of the thickness per medal-shaped PA.

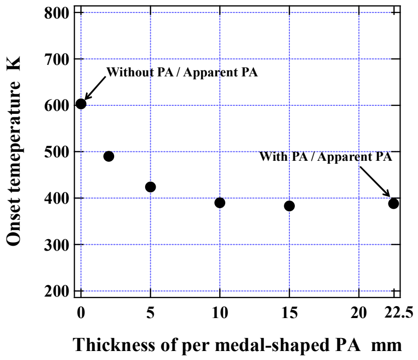

Fig. 3 Onset temperature vs thickness of per medal-shaped PA.

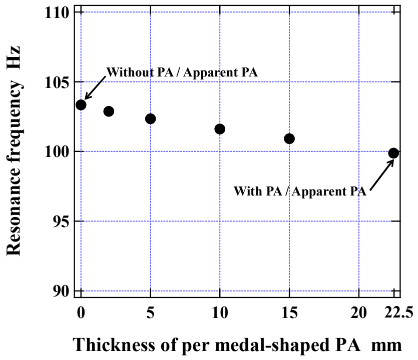

Fig. 4 Resonance frequency vs thickness of per medal-shaped PA.

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