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Fundamental study on the position of CPA in a thermoacoustic prime mover using stability analysis.

安定性解析を用いた熱音響プライムムーバーにおける CPA の位置に関する基礎検討

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1. Introduction

A system that employs thermoacoustic phenomena is a thermoacoustic system[1-4]. The advantage of the thermoacoustic systems is that they are external combustion engines with no choice of heat source. There are several challenges in the practical application of the thermoacoustic systems. One of them is that the high onset temperature of thermoacoustic systems limits the temperature range that can be used for various heat sources. The usefulness of thermoacoustic systems is enhanced if they can provide heat input for a wide range of heat temperatures, from low to high-temperature heat sources. Therefore, the onset temperature of the system should be kept low so that the thermoacoustic system can efficiently use various heat sources. Ceperley[5] showed that a traveling wave-type heat engine, which focuses on the phase of sound waves propagating through a thermoacoustic system, is beneficial in terms of efficiency. This indicates that the traveling wave phase converts energy efficiently in the thermoacoustic effects. It has been suggested in various systems related to thermoacoustic engines that lowering the onset temperature leads to efficient energy conversion depending on the phase of the traveling wave. As an approach to reduce the onset temperature of a thermoacoustic system, it is expected that adjusting the phase of the traveling wave can realize a more efficient thermoacoustic system. We have proposed a Phase Adjuster (PA)[6-12] that can adjust the phase easily and inexpensively. The PA locally reduces the inner diameter of a cylindrical tube and adjusts the phase of particle velocity by increasing the particle velocity. Thus, the PA contributes to improving the cooling performance[6] and energy conversion efficiency[7] of a thermoacoustic system, also showed to reduce the onset temperature[8,12]. Sakamoto *et al*. have considered the effect on a thermoacoustic system using a Conical Phase Adjuster (CPA)[11] in which the inner diameter of the PA is reduced to a conical shape. However, reduction of onset temperature has not been investigated in detail.

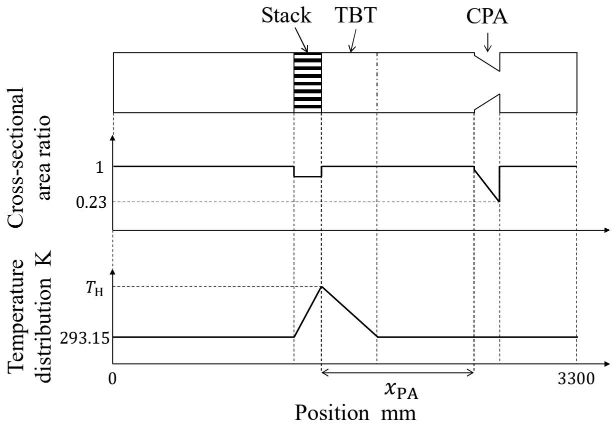

Fig. 1 Analytical model, cross-sectional area ratio, and temperature distribution of the CPA in the stability analysis.

In this report, we employed CPA, which is expected to reduce the onset temperature by adjusting the phase of a thermoacoustic system and numerically assessed the effect of its installation position on the onset temperature of the thermoacoustic system using stability analysis[13-15].

2. Analysis methods

In this report, the stability critical condition in a loop-tube-type thermoacoustic prime mover was calculated using the stability analysis, which is a numerical method based on the thermoacoustic theory, proposed by Ueda *et al.* [13-15]. The onset temperature is defined as the temperature satisfying the stability critical condition. The stability analysis is based on the equation of the sound wave in the tube based on the long wavelength approximation of Rott[16,17] linearized in one dimension by cross-sectional averaging and is investigated using the transfer matrix method. The prediction of the onset temperature of the system using the stability analysis has been experimentally verified by our group[9,10,12], and its effectiveness had been demonstrated.

A schematic of the loop-tube-type thermoacoustic prime mover model used in the stability analysis is shown in **Fig. 1** The total length of the system was 3300 mm, and the inner diameter of the tube was 42.6 mm. The system model consisted of tube 1, stack, thermal buffer tube (TBT), tube 2, CPA, and tube 3. The stack was 600 cells/inch^2, the channel radius was 0.47 mm, the porosity was 0.81, and the axial length was 50 mm. The length of the thermal buffer tube was 200 mm. The temperature in the resonance tube was assumed to be constant at 293.15 K, and the temperature gradient between the stack and thermal buffer tube was assumed to be linear. The inner diameter of CPA was 40 mm at the high-temperature end of the stack and 20.5 mm at the other side. The axial length of CPA was 45 mm. The installation position of CPA x_{PA} was calculated as the distance from the high-temperature end of the stack to the starting point of CPA in increments of 50 mm in the range of 800-1500 mm. The onset temperature of the thermoacoustic prime mover was analyzed stability by varying the installation position of CPA x_{PA}.

3. Analysis results

Figure 2 shows the results of the stability analysis of the onset temperature for CPA and without PA. All resonance modes were analyzed using 1-wavelength resonance. In the stability analysis, the onset temperature without PA was 570 K. The lowest onset temperature of CPA was 390 K at x_{PA} = 1150 mm from the high-temperature end of the stack when CPA was installed in the range of 800-1500 mm. The stability analysis showed that the onset temperature when CPA was placed was 180 K lower than that without PA, that is, the installation of CPA in a loop-tube-type thermoacoustic prime mover reduced the onset temperature by 32 %. Therefore, it suggests that CPA has the effect of adjusting the phase in a tube and lowering the onset temperature of a thermoacoustic system.

4. Summary

In this report, we constructed a model with CPA installed in a thermoacoustic prime mover using stability analysis and calculated the onset temperature. The results showed that the onset temperature had reduced by placing CPA in a certain position.

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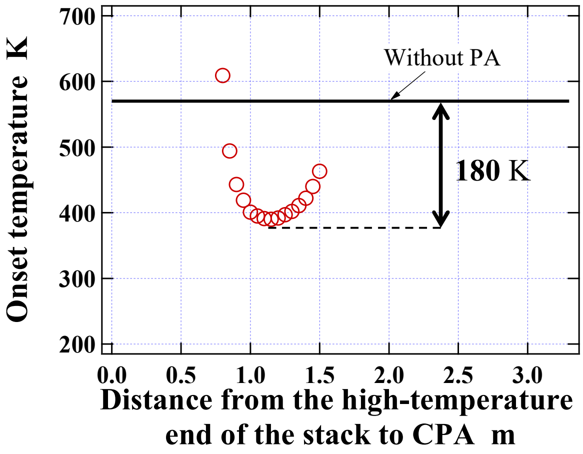

Fig. 2 Onset temperatures as the distance from the high-temperature end of the stack in the stability analysis.

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