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A prototype of a step-shaped-type miniature thermoacoustic prime mover of the full-length 90mm - Measurement results in oscillation temperatures and frequencies –

全長 90mm の段差型熱音響プライムムーバーの試作
－発振温度と周波数の測定について－

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1. Introduction

We have performed studies of thermoacoustic systems[1-10]. By applying the thermoacoustic effect, it is possible to construct a new eco-friendly system or electrical generator having many important benefits[1-12]. When used as a cooling system, no harmful medium such as chlorofluorocarbons is necessary. Furthermore, this system works with no moving parts. We studied a cooling system with a prime mover by applying the thermoacoustic effect. In our study, energy conversion efficiency was successfully increased and the onset temperature of the system decreased.

In order to widely use these advantages, it is essential to reduce the size of the system. We have mainly studied the loop-tube type thermoacoustic system. However, miniaturization of the loop-tube type thermoacoustic system was considered difficult to machining machine. Therefore, we considered the straight-tube type thermoacoustic system. Hotta et al. succeeded in making a prototype of small systems with one end open[5]. However, when one end of the system was opened, it was impossible to change the working gas and increase the pressure of the working gas. Further, it was impossible to improve the quality of the most important resonate thermoacoustic phenomena. Therefore, we investigated the case wherein both ends of the system were closed[5]. Symko, et al. also conducted research towards miniaturization of the thermoacoustic system[13, 14]. We were inspired by the Helmholtz-type thermoacoustic system in their research. This system is compared to a system with a uniform diameter, and the quality of the resonance has been reported to be larger. Shibata experimentally investigated the step-shaped-type thermoacoustic system. However, there are few reports on this system[6-8].

In this paper, we constructed the prototype of a small step-shape thermoacoustic system with a full length of 90 mm[9, 10]. We report a detailed measurement of the sound field and temperature change of the prototype system.

Based on these results, in the future, we will make small thermoacoustic prime movers. Electricity generated by these small thermoacoustic prime movers is expected to be used as a power source for IoT and wireless sensor networks.

2. Experimental Setup and Method

Figure 1 shows a schematic of the prototype of step-shaped-type miniature thermoacoustic prime mover. The total length of the closed system is 90 mm. A system with a uniform inner diameter of 16 mm is compared to a system with combined tube inner diameters of 16 and 32 mm. The tube length with the smaller inner diameter tube is defined as the “neck.” The larger inner diameter tube is defined as the “cavity.” The cavity and neck lengths were each 45 mm.

A stack with a thickness of 3 mm had laminated stainless steel meshes (#50). The installation position was defined from the left end of the system. Between 8–20 mm from the closed end of the neck, the installation position of the stack was changed by 1 mm.

One end of the stack was heated by a spiral electric heater with an input energy of 38 W. The heater temperature was measured using a K-type thermocouple. The sound pressure was measured using a pressure sensor attached to the closed end of the cavity. The working gas was air at atmospheric pressure.

3. Experimental Results

The prototype that we produced successfully developed thermoacoustic self-excited sound. When the stack installation position was at 18 mm, self-excited sound was observed approximately 18 s after the start of heat input. Figure 2 shows the temperature variation at the heater. Figure 3 shows waveforms of the self-sustained sound pressure measured by a pressure sensor attached to the closed end of the cavity.

The onset temperature was 203°C. The onset temperature was defined as the temperature at the time the sound pressure exceeded 50 $Pa_{p\text{-}p}$. In steady state, the high temperature of the heat exchanger was approximately 320°C. The oscillation frequency was approximately 1.97 kHz. The sound pressure was approximately 420 $Pa_{p\text{-}p}$, as measured by a pressure sensor attached to the closed end of the cavity. Figure 3 shows the experimental onset temperature as a function of the stack position. The results show that changing the stack installation position changed the onset temperature. When the stack installation position was 16 mm, the lowest onset temperature of these studies was achieved: approximately 163°C. When the stack installation position was 9 mm, the highest onset temperature of these studies was achieved: approximately 298°C.

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References

1. S. Sakamoto and Y. Watanabe, Jpn. J. Appl. Phys. 45, 9257 (2006).
2. S. Sakamoto, Y. Imamura, and Y. Watanabe, Jpn. J. Appl. Phys., vol.46, no.7B, pp.4951-4955, 2007.
3. S. Sakamoto, Y. Orino, S. Kawamoto, Y. Inui, T. Ikenoue, and Y. Watanabe, 7th Forum Acusticum 2014.
4. K. Hotta, S. Sakamoto, D. Tsukamoto, and Y. Watanabe, Jpn. J. Appl. Phys., vol.49, 07HE17, 2010.
5. K. Hotta, master thesis in Doshisha Univ.
6. K. Shibata, S. Sakamoto, K. Kuroda, Y. Nakano, T. Onaka, and Y. Watanabe, J. Acoust. Soc. Am., vol.131, no.4, pp.3265, 2012.
7. K. Shibata, S. Sakamoto, Y. Nakano, and Y. Watanabe, Jpn. J. Appl. Phys., vol.52, 07HE06, 2013.
8. K. Shibata, master thesis in Doshisha Univ.
9. S. Kawamoto, S. Sakamoto, Y. Orino, Y. Inui, T. Ikenoue, and Y. Watanabe, IEICE Technical Report, vol.113, no.284, US2013-57, pp.19-24 in Japanese.
10. S. Kawamoto, master thesis in Univ. of Shiga prefecture.
11. T. Yazaki, T. Biwa, and A. Tominaga, Applied Physics Letters, vol.80, issue 1, id.157, 2002.
12. S. Backhaus, and G. Swift, Nature, vol.399, pp.335-338, May, 1999.
13. G. Symko, E. Abdel-Rahman, Y. S. Kwon, M. Emmi, and R. Behunin, Microelectronics Journal, vol.35, pp.185-191 2004.
14. B. J. Andersen, and O. G. Symko, J. Acoust. Soc. Am., vol.125, no.2, pp.787-792, 2009.

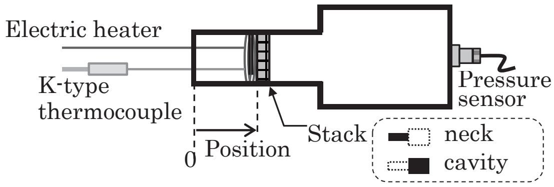

Figure 1 Schematic diagram of a step-shaped-type miniature thermoacoustic prime mover.

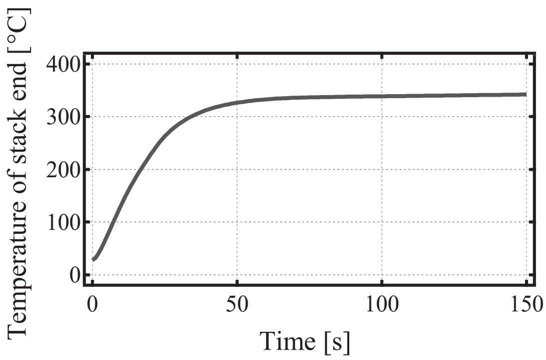

Figure 2 Temperature variation of the hot stack end. The stack position is 18 mm from the end of the neck. The stack length is 3 mm.

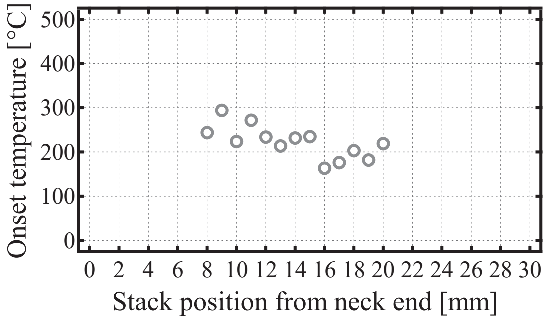

Figure 3 Experimental onset temperatures as a function of the stack position.

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