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Applying stainless-mesh stacks to improve cooling performance of a thermoacoustic cooling system with diameter-expanded prime movers

拡大プライムムーバー型熱音響システムの冷却能力向上に向けたメッシュスタックの利用

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1. Introduction

A thermoacoustic system with multi-stage prime movers having an expanded diameter was suggested for decreasing the onset temperature.[1)] We developed a prototype thermoacoustic cooling system[2,3)] by applying this method. The experimental results showed that the cooling system can be driven by a lower temperature, and the cooling point temperature was decreased by 5.8 K from 20°C. However, an analysis of the results showed that the heat flow component that prevents cooling increased with increasing input power. This heat flow component is proportional to the temperature gradient and the square of the particle velocity. We explored the effect of expanding the diameter of the heat pump in order to decrease the particle velocity. As a result of this experiment, the particle velocity in the heat pump decreased and the cooling performance improved.[4)] However, further research is needed to further improve the cooling performance.

Previous studies have confirmed that the progressive wave was dominant in the sound field in the loop tube. The heat flow, which depends on the amplitude of the progressive wave, is expected to increase by narrowing the heat-pump stack channel radius. This study discusses the use of a stainless-steel mesh stack, which has a channel radius narrower than that of the stacks used in previous studies, in the heat pump.

2. Heat flow

The total heat flow[5)] caused by the thermoacoustic phenomenon is written as:

$$Q = Q_{\mathrm{P}} + Q_{\mathrm{S}} + Q_{\mathrm{D}}, \quad (1)$$

where Q_{P} is the heat flow component that originates from the progressive wave and is proportional to the sound pressure and particle velocity. Q_{P} is a major component for cooling by the progressive wave. Q_{P} is expressed as

$$Q_{\mathrm{P}} = -\frac{1}{2} A \,\mathrm{Re}\{g\} |p||u| \cos\phi, \quad (2)$$

where p, u, and ϕ denote the complex sound pressure, particle velocity, and phase difference between the sound pressure and particle velocity, respectively. A is the cross sectional area of the flow channel. The coefficient Re$\{g\}$, in Eq. 2, is described as a function of the dimensionless thermoacoustic parameter, $\omega\tau_\alpha$.[6)] ω is the angular frequency and $\tau_\alpha = r^2 / 2\alpha$ is the thermal relaxation time, where r and α are the stack channel radius and thermal diffusivity, respectively. For small $\omega\tau_\alpha$, Re$\{g\}$ is almost unity. For large $\omega\tau_\alpha$, Re$\{g\}$ is almost zero. In summary, Re$\{g\}$ becomes closer to unity by narrowing the stack channel radius, increasing Q_{P}.

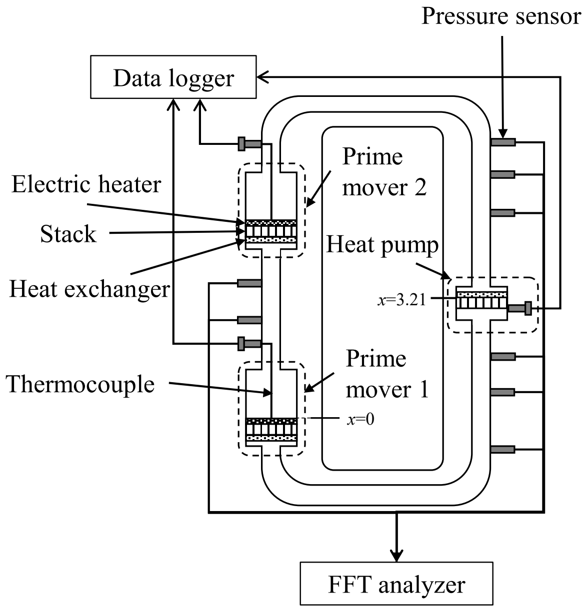

Fig. 1 Experimental system.

3. Experiment

Figure 1 shows a schematic of the experimental system. The loop tube is composed of stainless tubes filled with atmospheric air. The total length of the loop tube was 5.12 m. The inner diameter of the resonance tube was 42.6 mm. The length and inner diameter of the prime movers were 300 and 100 mm, respectively. The stacks in the prime movers were ceramic honeycombs, which

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had a length of 50 mm and a channel density of 900 cell/in^2. An electric heater was used as a heat source in each prime mover. Water at room temperature about 25°C was circulated through the heat exchangers. The distance between the prime movers was 1.0 m. The length and inner diameter of the heat pump were 130 and 100 mm, respectively. The heat pump was installed 3.21 m away from the high-temperature side of the stack in prime mover 1. The stack used in the heat pump was constructed by randomly stacking stainless-steel wire mesh screens to a thickness of 20 mm. The number of openings in one linear inch of screen was 50. The diameter of the screen wire was 0.1 mm. In the experiments, the input power for each prime mover was identical and changed in a stepwise manner from 30 to 300 W. The cooling point temperature was measured using a K-type thermocouple. The sound pressure in the loop tube was measured using pressure sensors. The distribution of the sound field was estimated based on a two-sensor method[7)] and the equations for sound propagation in tubes.

4. Results

Figure 2 shows the dependence of the cooling temperature on the input power in comparison to the results obtained with a ceramic honeycomb. The vertical axis shows the temperature difference between the cooling point temperature and room temperature. The cooling performance with a ceramic honeycomb decreased when the input power was increased over 150 W, whereas the performance with a stainless-mesh stack increased. The distribution of the sound field in the loop tube for an input power of 50 W is shown in **Fig. 3**. These stacks made little difference to the distributions of the sound fields. These experimental results show that the use of the stainless-mesh stack in the heat pump improves the cooling performance, indicating the increase of the heat flow that originates from the progressive wave.

5. Conclusion

To improve the cooling performance of the thermoacoustic system with diameter-expanded two-stage prime movers, we investigated the effect of the stack used in the heat pump. The cooling performance was improved by using a stainless-mesh stack with narrower flow channels. This improvement is probably caused by an increase in the heat flow that originates from the progressive wave.

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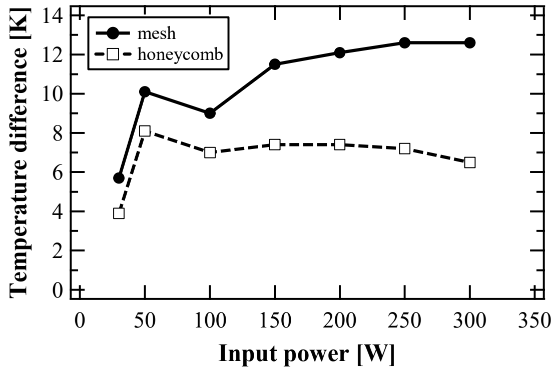
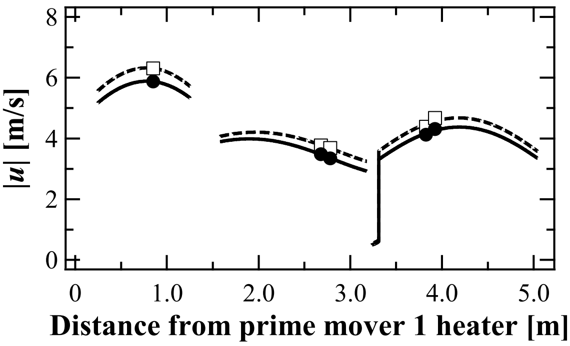
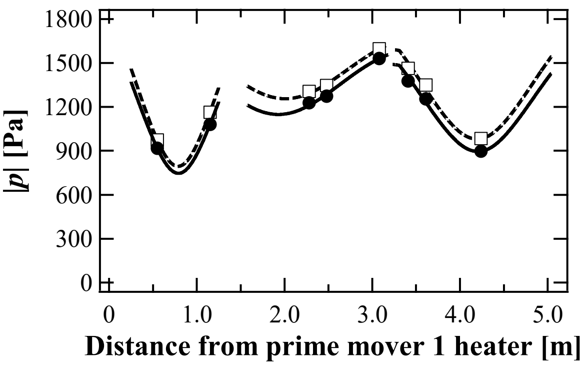


Fig. 2 Temperature difference.



(a) Particle velocity



(b) Sound pressure

Fig. 3 Distribution of sound field.

—●— : mesh   –□– : honeycomb

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