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Miniaturization of the loop-tube-type cooling system –Effect of the installation position of heat pump and working gas in the tube–

ループ管方式熱音響冷却システムの小型化について–ヒートポンプの設置位置及び管内の作業流体の影響–

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1. Introduction

A loop tube cooling system uses heat energy as a power source[1)]. Therefore, it is possible to put a loop tube into practical use in different areas. Several reports have described total loop tube lengths greater than 3 m. Further miniaturization is necessary to apply this system to electronic devices such as personal computers. As described herein, to realize a miniature loop tube, an A4 size loop tube (850 mm total length; 24 mm inner diameter) was designed. Furthermore, to assess this system's cooling properties, investigation of the heat pump installation position was carried out. And the loop tube filled with HeAr was driven based on the experimental result. Result shows that cooling from 18.2 °C to 0 °C was achieved.

2. Theory

$\omega\tau$ and the phase difference ϕ between the sound pressure and particle velocity are important for this thermoacoustic phenomenon[2)]. The parameter $\omega\tau$ is represented as Eq. (1). This parameter is regarded as the dimensionless parameter to express the efficiency of heat exchange of the system.

$$\omega\tau = \omega \frac{r^2}{2\alpha} \tag{1}$$

Therein, ω signifies the angular frequency, α denotes the coefficient of thermal diffusivity, and r stands for the stack's channel radius.

Regarding the oscillation of fluid particles in the stack, when the phase difference ϕ is 0°, the oscillated fluid is a traveling wave. In this condition, the relation between sound pressure and particle displacement describes the ellipsoidal locus presented in Fig. 1(a). Under the terms of $\omega\tau$<<1 and with heat exchange between the fluid particle and stack wall done instantaneously, the fluid particle absorbs heat energy from the stack wall with expansion in the area of (2). Subsequently, it is compressed in the area of (1) and emits heat energy to the stack wall. That is to say, the traveling wave transports the heat energy of the area of (2) to the area of (1). On the other hand, when the phase difference ϕ is 90°, the oscillated fluid is a standing wave. In this condition, the relation between sound pressure and particle displacement describes the linear locus presented in Fig. 1(b). Under the terms of $\omega\tau$<<1 and ϕ = 90°, the fluid particle emits the heat energy to the stack wall as it is compressed when moving from (2) to (1). When the fluid particle is displaced from (1) to (2), it absorbs heat energy from the stack wall. Consequently, the standing wave does not transport the heat energy. However, when $\omega\tau$ is close to 1, the standing wave transports the heat energy. In Fig. 1(b), when the fluid particle is displaced from (2) to (1), it initiates heat release of about one-sixth of a cycle behind the commencement of compression because a delay exists in the heat exchange. When the fluid particle is displaced from (1) to (2), it commences heat absorption that is about one-sixth cycle behind the commencement of expansion. Consequently, the stack wall's heat energy in the area of (2) is transported to the area of (1). The method of the contribution of a traveling wave and standing wave to energy conversion is different by $\omega\tau$. Therefore, it is necessary to choose a phase difference ϕ according to $\omega\tau$.

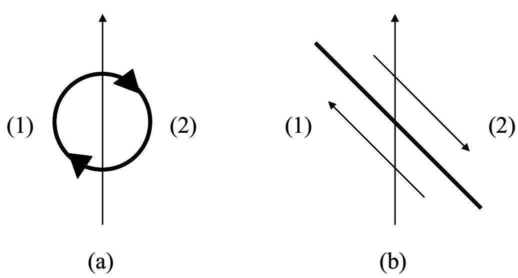

Fig. 1 Schematic illustration of the relation between sound pressure and particle.

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3. Measurements

Figure 2 depicts the experimental system. The loop tube has 850 mm total length and 24 mm inner diameter. The stacks at the prime mover and at the heat pump have channel radius of 0.39 mm and thickness of 19 mm. A K-type thermocouple is applied to measure the bottom part of the heat pump. Furthermore, electric power of 270 W is supplied to an electric heater. The system is filled with argon gas at 0.2 MPa.

In this section, two experiments to measure the sound field in the loop tube and the cooling temperature are described. In the first experiment, the phase difference ϕ is calculated from two-sensor power measurements[3] without a heat pump. In the second experiment, the heat pump installation position is changed and the cooling temperature is measured. Furthermore, the loop tube filled with HeAr was driven based on the experimental result.

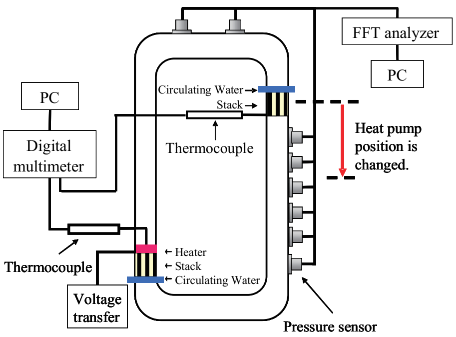

Fig. 2 Schematic of measurement system.

4. Results and Discussion

Figure 3 presents the distribution of the phase difference and related to the cooling temperature when the heat pump installation position is changed. From Fig. 3, it is confirmed that the distribution of phase difference occurs in the axial direction in the loop tube. Moreover, the phase difference is inverted at 460 mm distance from the topside of the prime mover. The cooling effect is obtainable on the A4 size loop tube. Additionally, results show that the cooling temperature differs according to the installation position of the heat pump because the phase difference changes according to the point in the loop tube and the efficiency of energy conversion differs according the phase difference. When the heat pump is installed at 525 mm distance from the topside of the prime mover, the cooling temperature peaks. The peak cooling temperature is 10.2 °C. Figure 3 shows that the phase difference is about 70° at the point where the peak cooling temperature is obtained. Because the $\omega\tau$ is 17 at the heat pump, a delay exists in the heat exchange between the fluid particle and the stack wall. A standing wave also contributes to energy conversion when the delay arises. Therefore, it is thought that the cooling temperature peaks at the point of obtaining 70° of phase difference. Experimental results confirmed that the cooling temperature peaks when the heat pump is installed at the point of 525 mm distance from the topside of the prime mover in the A4 size loop tube.

Figure 4 presents the cooling temperature when the A4 size loop tube filled with HeAr was driven based on the experimental result. Result shows that cooling from 18.2 °C to 0 °C was achieved.

5. Summary

As described herein, the A4 size loop tube was designed and an investigation of the heat pump installation position to improve cooling properties was carried out. Its optimal installation position was confirmed. Furthermore, the loop tube filled with HeAr was driven based on the experimental result. Result shows that cooling from 18.2 °C to 0 °C was achieved.

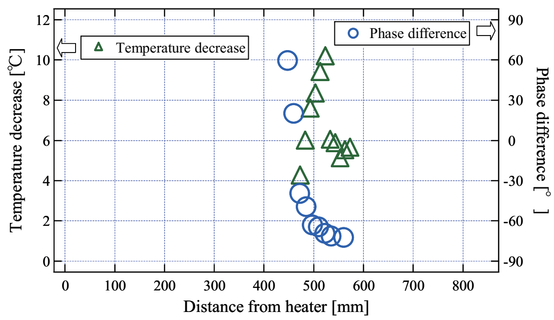

Fig. 3 Distribution of phase difference and temperature decrease as a function of distance from the heater.

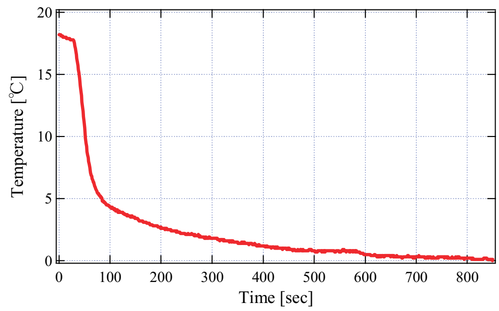

Fig. 4 Temperature variation by using experimental result.

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