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A study on sound field control in a thermoacoustic cooling system using a phase adjuster -Understanding by sound field and *P*-*ξ* curve-

Phase Adjuster による熱音響冷却システムの管内音場制御に関する研究 -管内音場と *P*-*ξ* 線図を用いた理解-

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1. Introduction

We propose a loop type thermoacoustic cooling system(loop-tube)[1-2] as a technique to address environmental problems. This system attracts attention as environmentally-friendly and future cooling system. This system continues to attract attention as an environmentally friendly cooling system with no harmful cooling medium or moving parts. Moreover, it can use solar and waste heat energy.

Improvement of the energy conversion efficiency in the prime mover is necessary for practical use of loop-tube. We infer that the energy conversion efficiency in the prime mover is improved because it is changed by the sound field. Consequently, we proposed the phase adjuster [2] as a device to control the sound field in a loop-tube. When the phase adjuster is put in the loop-tube, the sound field is controlled by reflection at the edge face of the phase adjuster and the boundary condition that particle velocity is increased within the phase adjuster.

The phase adjuster's optimum configuration can be estimated easily if we can understand sound field control in detail. In this study, we circumstantially measured the sound pressure when we set phase adjusters of four diameters in the loop-tube. Using the results, we calculated the *P*-*ξ* curve for visual depiction of the sound field condition, and analyzed sound field control using the phase adjuster.

2. Theory: *P*-*ξ* curve

In the prime mover, the intensity generated in the stack corresponds to energy amplified per second. Accordingly, energy conversion in the prime mover is discussed in terms of the generated intensity. The intensity, expressed as the following equation, is the energy passing through a unit area per second.

$$I = f \oint P d\xi \qquad (1)$$

The intensity depends on the *P*-*ξ* curve area. In fact, the energy conversion efficiency in the prime mover is estimated using the *P*-*ξ* curve area.

3. Experimental system

A block diagram of the measurement system is portrayed in Fig. 1. The system was constructed using a stainless steel tube with 3.3 m total length and 42 mm inner diameter. The system was filled with argon at atmospheric pressure. The prime mover stack was a 50 mm-long honeycomb ceramic with a 0.45 mm channel radius. The heat pump was eliminated intentionally because we specifically sought to examine the prime mover. A spiral-type electrical heater inserted at the top of the stack served as the heat source; a heat exchanger to maintain the system at room temperature was placed at the lower part of the stack. The phase adjuster length was 45 mm; the inner diameters of four types were changed from 10.5 mm to 34.5 mm at 8 mm intervals. The distance from the heater to left side of the phase adjuster was 1125 mm. We experimented using four types. Additionally, for comparison, we took measurements in the case without the phase adjuster.

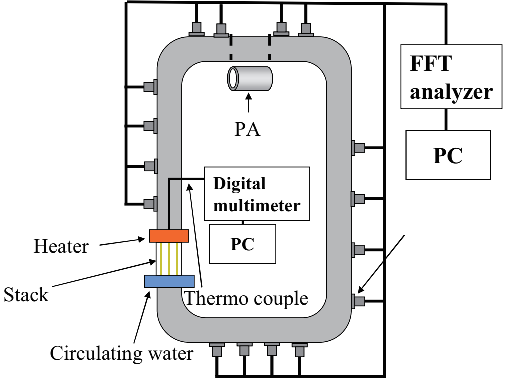

Fig. 1 Experimental system.

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Heating power of 330 W was supplied for 600 s using a heater. The temperature at the top of the stack was measured using K-type thermocouple. Additionally, pressure sensors (PCB Piezotronics Inc.) were set on the system wall to measure the sound pressure in the loop-tube.

The intensity, sound pressure, particle velocity, and phase difference between the sound pressure and the particle velocity were calculated using a two-sensor power method[3] with pressure measurement results. Furthermore, the *P*-ξ curve was produced using the calculated results.

4. Experimental results

The *P*-ξ curve in position 0.4 m from the circulating water is shown in Fig.2. The ellipsoidal area, gradient, and width are important for comparison. The ellipsoidal area is the intensity of one cycle. We can evaluate the sound field by the ellipsoidal gradient because the ellipsoidal gradient depends on the amplitude ratio between the sound pressure and the particle displacement and their phase difference. In this regard, the amplitude ratio between the sound pressure and the particle displacement is defined as 1:1 for sound pressure of 8000 Pa. In addition, the particle displacement is 0.02 m because the *P*-ξ curve is shown as the quadrate for which the maximum value of the vertical axis in the *P*-ξ curve is 8000, and for which the maximum value of horizontal axis is 0.02. The ellipsoidal width depends on the phase difference between the sound pressure and the particle displacement. The ellipsoidal gradient of the condition with phase adjusters of inner diameters of 34.5 mm and 26.5 mm in position 0.4 m from the circulating water indicated a similar tendency to that of the ellipsoidal gradient of a condition without the phase adjuster. The sound pressure and the particle displacement were unchanged. The phase difference between the sound pressure and the particle displacement was positive by the ellipsoidal gradient. Differences of ellipsoidal width were apparent. The phase difference between the sound pressure and the particle displacement differed according to those three conditions. The ellipsoidal width is greater when the phase difference between the sound pressure and particle displacement is close to 90°; it is smaller when closer to 0°. Therefore, the phase difference between the sound pressure and particle displacement was wide in conditions with the phase adjuster having 26.5 mm inner diameter. The ellipsoid became nearly circular with the phase adjuster of 18.5 mm inner diameter. Therefore, the mean amplitude ratio between the sound pressure and the particle displacement was 1:1; the phase difference between the sound pressure and the particle closed at 90°. The ellipsoidal gradient in a condition with the phase adjuster of 10.5 mm inner diameter was distinctly different from those of other conditions. The sound pressure was smaller than the particle displacement, as seen from the perspective of the amplitude ratio between the sound pressure and the particle displacement. The phase difference between the sound pressure and the particle displacement was negative.

The ellipsoidal area differed according to several conditions; the area of the *P*-ξ curve in the stack also differed according to several conditions because area of the *P*-ξ curve at position 0.4 m from circulating water was close to the area of the *P*-ξ curve in the stack. From these results, it was inferred that the energy conversion efficiency was changed.

4. Conclusions

We presented *P*-ξ curves to illustrate the sound field and cycle of fluid in the loop-tube. From this investigation, we obtained more data for the *P*-ξ curve than from previous studies, and we determined characteristics of sound field control using the phase adjuster.

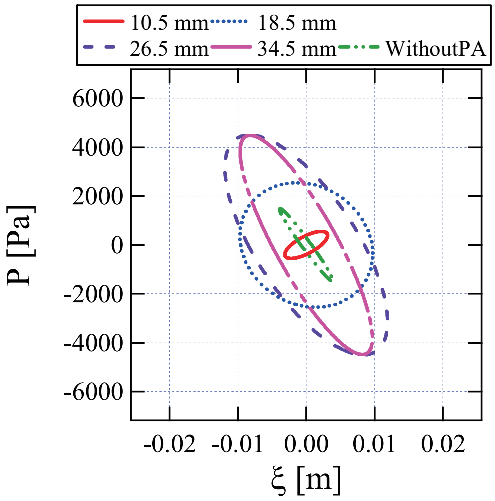

Fig. 2 *P*-ξ curve in position 0.4 m from the circulating water.

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References

1. A. Tominaga, Y. Narahara and T. Yazaki: J. Low Temp. Phys. **54**(1984) 233.
2. S. Sakamoto and Y. Watanabe: Jpn. J. Appl Phys. **45**(2007) 9257.
3. A. M. Fusco, W. C. Ward, and G. W. Swift: J. Acoust. Soc. Am. **91** (1992) 2229–2235.