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Effect of Sub-Loop Tube on Energy Conversion Efficiency of Loop-Tube-Type Thermoacoustic System

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ABSTRACT

For the practical application of a loop-tube-type thermoacoustic system, it is important to improve its energy conversion efficiency. We propose a loop-tube-type thermoacoustic system with a diverging sub-loop tube. The sub-loop tube diverges from the main loop tube and rejoins it so that the sub-loop tube forms a loop. The main loop tube is 0.85 m high and 0.5 m wide, with 3.3 m total length. The sub-loop tube's length from the upper side to the lower side is 0.45 m. The sub tube position is changed so that the distance from the heater to the upper part of the sub tube is 1.73, 1.83, or 1.93 m. The pressure, the phase difference between the pressure and particle velocity, and the sound intensity were calculated using a two-sensor power method with pressure measurement results. The smallest phase difference distribution was observed when the sub-loop tube is connected at 1.93 m. The highest sound intensity of 13 kW/m^2 was obtained at the prime mover top end, when a sub-loop tube was connected at 1.93 m. Because the sound intensity was 0.65 kW/m2 when a sub-loop tube was not connected, it was increased about 20-fold by connecting a sub-loop tube. The decrease in the phase difference indicates that the phase difference in the prime mover became a traveling wave phase, and this raises the energy conversion efficiency from heat to sound.

INTRODUCTION

Energy depletion and environmental problems are looming as important social problems. Thermoacoustic systems applying thermoacoustic effects offer solutions to these difficulties. By applying the thermoacoustic effect, it is possible to construct a new system having many unique advantages[1–8]: the effective use of waste heat and the absence of poisonous cooling media and moving parts. However, this system presents some issues that must be overcome before this method's practical use. As described herein, we specifically examine the energy conversion efficiency from heat to sound energy. Various examinations[1–17] were conducted by Yazaki, Biwa, Swift, Backhaus and others to increase energy conversion efficiency. Their experimental results underscore the necessity of observing the state of the generated sound in a system. In the energy conversion component—the prime mover—the phase difference between the sound pressure and particle velocity must become a travelling wave phase. However, it is difficult for a thermoacoustic system to control the phase difference in an energy conversion component because the generated sound in the system is a thermoacoustic self-sustained sound. We have proposed some methods[13–17] to control the phase of the generated sound in the prime mover in a loop tube. As described in this report, we propose a loop-tube-type thermoacoustic system with a diverging sub-loop tube. The sub-loop tube diverges from the main loop tube and rejoins it; thereby, the sub-loop tube forms a loop. The sub tube position was changed so that the distance from the heater to the upper part of the sub tube was either 1.73, 1.83, or 1.93 m.

EXPERIMENTAL SETUP AND METHODS

A block diagram of the measurement system is presented in Fig. 1. To determine the effect of the sub-loop tube, a heat pump was not used. The top of the stack is defined as a distance of 0 m. The tube center is the axis; clockwise is defined as the positive direction. The system was constructed with a stainless steel tube that was 0.85 m long and 0.5 m wide, with 3.3 m total length. Its inner diameter was 42 mm. The system was filled with air at atmospheric pressure. The stack was a 50-mm-long honeycomb ceramic with a channel radius of 0.45 mm. 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 the reference temperature was placed at the lower part of the stack. The inner diameter of the sub-loop tube was equal to that of the loop tube: 42 mm. Figure 1 shows that the sub-loop tube's length from the upper side to the lower side was 0.45 m. The sub tube position was changed so that the distance from the heater to the upper part of the sub tube was either 1.73, 1.83, or 1.93 m. Heating power of 330 W was supplied for 600 s using an electrical heater. Pressure sensors (PCB Piezotronics Inc.) were set on the system wall to measure the sound pressure in the loop tube. Measurements of sound pressure were started and continued for 900 s after the heat energy was supplied. The preure, the phase difference between the pressure and particle velocity, and the sound intensity in the system were calculated using a two-sensor power method[9, 10] with pressure measurement results.

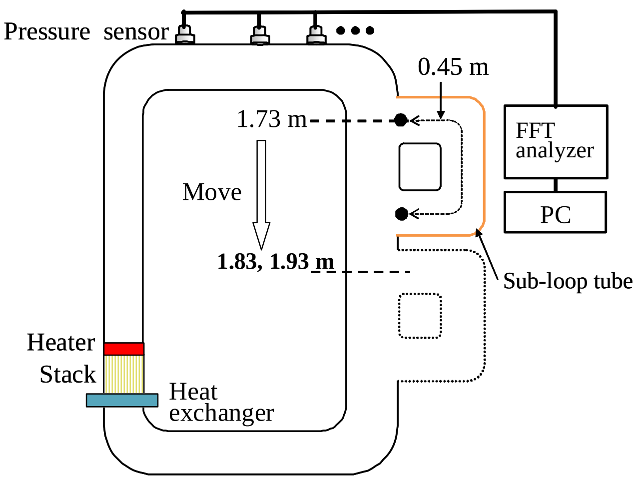

Figure 1 Experimental setup of the loop-tube-type thermoacoustic system.

RESULTS AND DISCUSSIONS

Figures 2–5 show sound pressure distributions in a loop tube with and without the sub-loop tube. Figure 2 shows the sound pressure distribution without the sub-loop tube. Figures 3, 4, and 5 respectively show sound pressure distributions with the sub-loop tube at 1.73 m, 1.83 m, and 1.93 m. The results show that the generated sound pressure is the highest, greater than 5.5 kPa, when a sub-loop tube is connected at 1.73 m. Because the generated sound pressure is 2 kPa when a sub-loop tube is not connected, it was increased about 2.8 times by connecting a sub-loop tube. Moreover, results show that the position of the antinode of sound pressure changes with the connecting position of a sub-loop tube. The sound pressure loop moved as the connecting position of the sub-loop tube is moved. This movement indicates that phase in the prime mover has changed.

Figures 6–9 show the sound intensity distributions in loop tubes with and without the sub-loop tube. Figure 6 shows the sound intensity distribution without the sub-loop tube. Figures 7, 8, and 9 respectively show sound pressure distributions with the sub-loop tube at 1.73 m, 1.83 m, and 1.93 m. The results show that the sound intensity is the highest, about 13 kW/m^2 at the prime mover top end, when a sub-loop tube is connected at 1.93 m. Because the sound intensity is 0.65 kW/m^2 when a sub-loop tube is not connected, it is increased about 20-fold by connecting a sub-loop tube.

Figures 10–13 show distributions of the phase difference between the sound pressure and particle velocity in a loop tube with and without the sub-loop tube. Figure 10 shows the distribution of the phase difference between the sound pressure and particle velocity without the sub-loop tube. Figures 11, 12, and 13 respectively show distributions of the phase difference between the sound pressure and particle velocity with the sub-loop tube at 1.73 m, 1.83 m, and 1.93 m. The results show that the position of the zero crossing of the phase difference moves with the sub-loop tube connecting position. It is confirmed that the sound field in the loop tube is controlled by connecting the sub-loop tube from these results. Because the sound pressure loop and the position of the zero crossing of the phase difference moves as the connecting position of the sub-loop tube is moved. It ii considered that this movement of sound pressure loop and the position of the zero crossing of the phase difference by connecting the sub-loop tube have changed the phase difference in the prime mover. The change in this phase difference raises the energy conversion efficiency from heat to sound at a certain connecting position because it has become a traveling wave phase. The results show that the sound intensity is the highest, about 13 kW/m^2 at the prime mover top end, when a sub-loop tube is connected at 1.93 m. Because the sound intensity is 0.65 kW/m^2 when a sub-loop tube is not connected, it is increased about 20-fold by connecting a sub-loop tube.

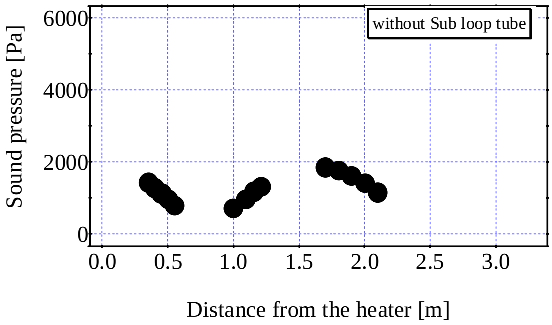

Figure 2 Sound pressure distributions without the sub-loop tube.

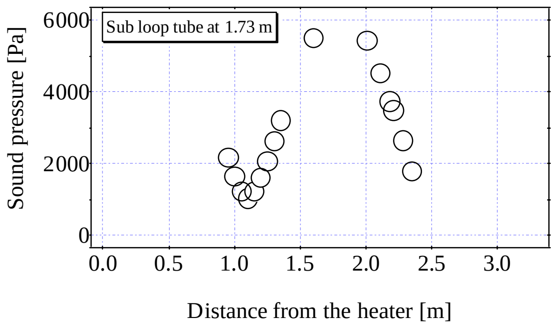

Figure 3 Sound pressure distributions with the sub-loop tube at 1.73 m from the upper end of the prime mover stack.

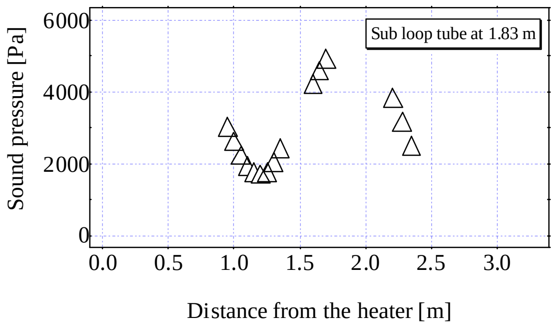

Figure 4 Sound pressure distributions with the sub-loop tube at 1.83 m from the upper end of the prime mover stack.

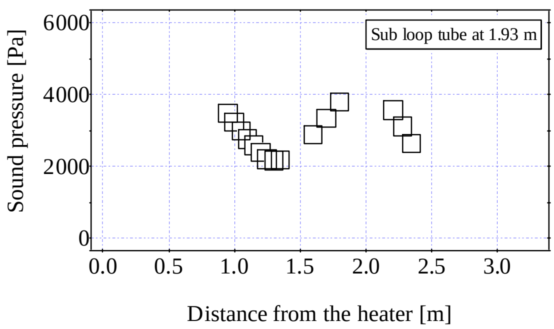

Figure 5 Sound pressure distributions with the sub-loop tube at 1.93 m from the upper end of the prime mover stack.

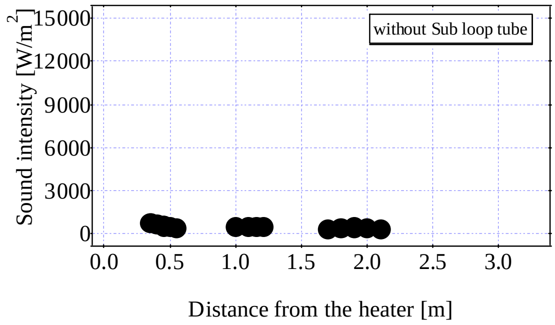

Figure 6 Sound intensity distributions without the sub-loop tube.

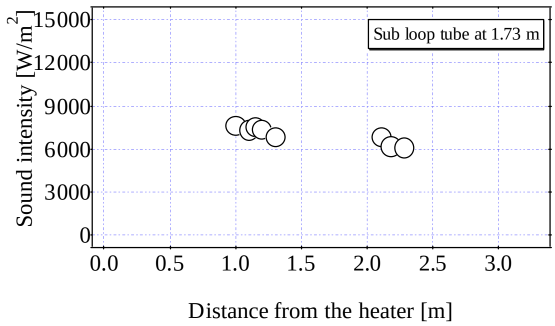

Figure 7 Sound intensity distributions with the sub-loop tube at 1.73 m from the upper end of the prime mover stack.

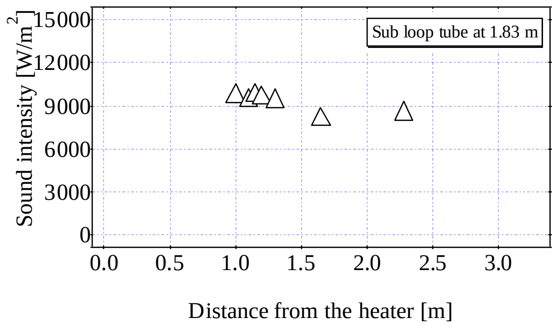

Figure 8 Sound intensity distributions with the sub-loop tube at 1.83 m from the upper end of the prime mover stack.

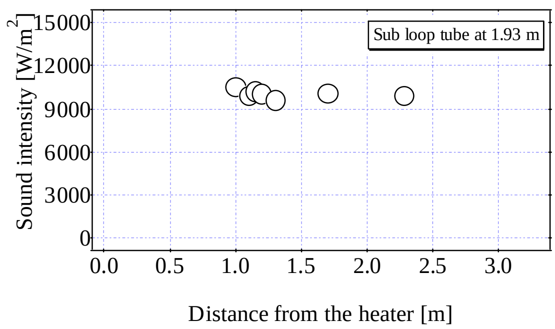

Figure 9 Sound intensity distributions with the sub-loop tube at 1.93 m from the upper end of the prime mover stack.

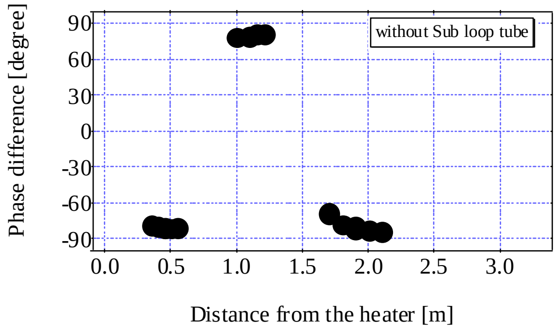

Figure 10 Distributions of the phase difference between the sound pressure and particle velocity without the sub-loop tube.

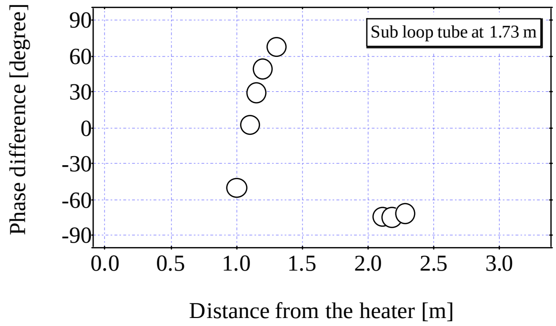

Figure 11 Distributions of phase difference between the sound pressure and particle velocity with the sub-loop tube at 1.73 m from the upper end of the prime mover stack.

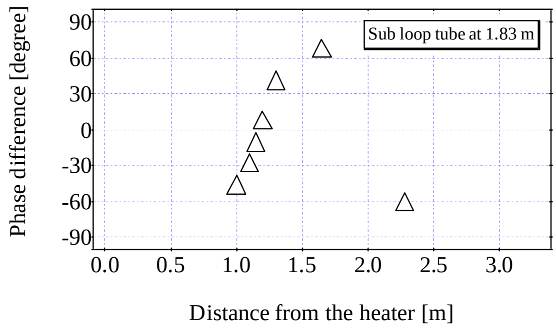

Figure 12 Distributions of phase difference between sound pressure and particle velocity with the sub-loop tube at 1.83 m the upper end of the prime mover stack.

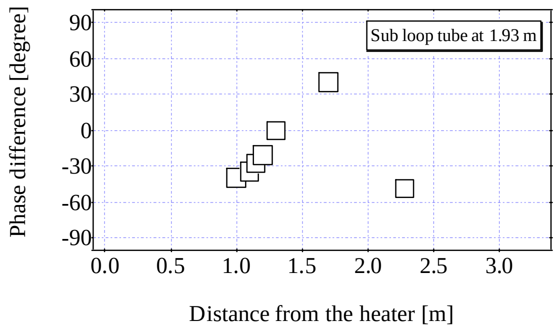

Figure 13 Distributions of phase difference between the sound pressure and particle velocity with the sub-loop tube at 1.93 m from the upper end of the prime mover stack.

CONCLUSIONS

As described in this paper, we propose a loop-tube-type thermoacoustic system with a diverging sub-loop tube. The sub-loop tube diverges from the main loop tube and rejoins it. Consequently, the sub-loop tube forms a loop. The sub tube position was changed so that the distance from the heater to the upper part of the sub tube was either 1.73, 1.83, or 1.93 m. Among the three positions of the sub-loop tube used in this experiment, no sub-loop tube satisfies all the conditions simultaneously to increase the sound intensity. The sub-loop tube position changes all the parameters: sound pressure, particle velocity, and phase difference between sound pressure and particle velocity. Our experimental results confirmed, however, that the sound intensity with any sub-loop tube is much higher than that without a sub-loop tube, and that it differs according to the sub-loop tube position. It is confirmed that the sound field in the loop tube is controlled by connecting the sub-loop tube from these results. Because the sound pressure loop and the position of the zero crossing of the phase difference moves as the connecting position of the sub-loop tube is moved. It is considered that this movement of sound pressure loop and the position of the zero crossing of the phase difference by connecting the sub-loop tube have changed the phase difference in the prime mover. The change in this phase difference in the prime mover became a traveling wave phase, raises the energy conversion efficiency from heat to sound.

ACKNOWLEDGEMENTS

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