THE EXPERMENTAL STUDIES OF THERMOACOUSTIC COOLER

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Abstract

The experimental studies of the thermoacoustic cooler consisting of acoustic loop-tube were carried out. One focusing was the time profiles of temperature variations caused by the sound generation. The other focusing was the movements of frequency components at the start of the sound generation. As the sound generation was started, both the temperatures at the second stack and near the first stack were simultaneously decreased. At the second stack, the temperature was decreased by 22 degrees.

It was found that the process of the sound generation was divided into two phases. In the first phase, the fundamental component was dominant. In the second phase, the sound pressure steeply increased and the higher harmonics components appeared by the nonlinear effects or the higher mode standing waves.

Introduction

Recently cooling media of the substitute for chlorofluorocarbon have been appointed as greenhouse-gasses, and their exhaustion has been restricted. On the other hand, the thermal source density has rapidly increased in such products as consumer-electronics, automobiles and business machines due to their miniaturization and technical advance. Then the necessity of heat release has also been rapidly increased. A quick establishment of the basic technology to develop a cooling system which combines reduced size, small weight, high quality, high reliability, no use of poisonous gas and long life must be absolutely imperative for our future.

If a new cooling system can be attained with use of thermoacoustic effect, such a useful cooling system may be possible. To construct such a cooling system is the purpose of these studies. In this paper, we measure the time profiles of the temperature variations and the movements of frequency components to improve the efficiency of the thermoacoustic cooler.

Thermoacoustic Effect

The thermoacoustic effect has an aspect as an energy transport of work and heat following the interaction between heat and sound, as well as another aspect as an energy conversion of work into heat or the inverse one of heat into work. A sound energy can be transferred into a heat energy by this effect, and vice versa [1].

Loop-tube

A loop-tube was employed as the thermoacoustic system in these studies. Fig. 1 diagrammatically illustrates the experimental setup. In the tube, air or the mixture of air and helium gas was filled as working fluid.

The stacks consist of tubules made from low specific heat materials. The loop-tube is made by metallic tubes connected with 90 deg elbows to result in 3.2m total length of the loop. Two stacks sandwiched with heat exchangers are set in the tube. The heat exchanger A under the Stack 1 is heated with an electric heater, and water is circulating in the heat exchangers B in order to keep the reference temperature. This makes the temperature gradient in the Stacks.

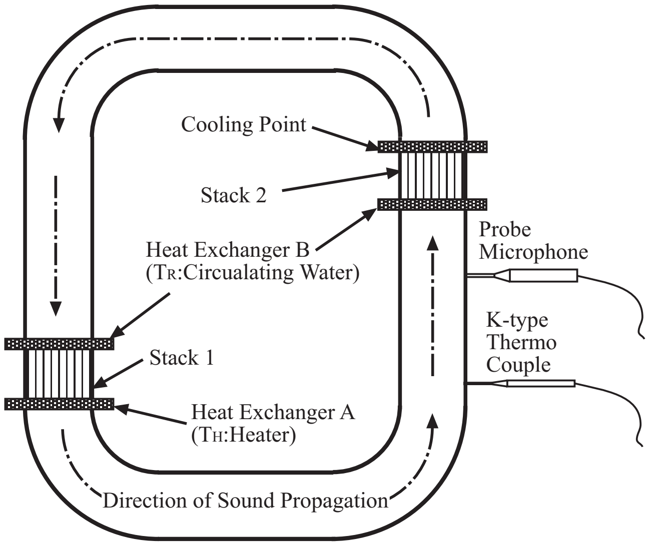

Fig. 1 Block diagram of measurement system for sound pressure and temperature variation.

Experiment

The waveform and amplitude distribution of the sound pressure as well as the time profiles of the temperature variations in the loop-tube were measured. The measurement was conducted at the center axis of the tube. The sound pressure and the inner temperature were detected with a probe microphone (B&K, 4182) and K-type thermocouple, respectively.

Experimental Result and Discussion

Time profiles of temperature variations

Fig. 2 shows the experimental results under the condition that air was filled in the tube as working fluid at atmospheric pressure. The starts of the sound generation are indicated with arrows in each figures and the temperature at the beginning of the measurement was defined as reference temperature: 0. The horizontal axis indicates the time changes after the heater was switched on. 300 seconds later the heater was switched off. The measurement of the temperature had been carried out 180 seconds after the heater was switched off. At the measuring point of 315mm from the heater, the temperature rose slowly. About 100 seconds later, the sound generation was observed and the temperature started to fall. It is considered to result from the energy conversion of the thermoacoustic phenomena from the heat energy to the sound energy. At the point of 1620 mm, the temperature started to fall just after the sound generation started and had decreased by 4 degrees before the heater was switched off. At the point of 3120 mm, the temperature did rise not after the heater was switched on but after the sound generation started. It is considered that heat from the heater was absorbed at the heat exchanger B, just after the heater was switched on, and that the heat energy generated by thermoacoustic phenomena was not absorbed after the sound was generated. This thermoacoustic heat energy was not radiant heat nor conducted heat from the heater and was generated on the opposite direction of sound energy. After the heater was switched off, at the point of 315 mm the temperature rose and at the point of 3120 mm fell. This regarded the results from the acoustic streaming generated by the sound pressure as high as 156 dB in the loop-tube. At the other measuring points, the temperature did not change.

The time profiles of the temperature variations measured after working fluid was replaced with the mixture of air and helium gas at atmospheric pressure is shown in Fig. 3. At the point of 1620 mm comparing to the case of air, a faster rise in temperature is seen just after the sound generation. At the other points similar results were shown. At the point of 3120 mm a temperature drop is confirmed as much as 22 degree.

Pressure waveform in tube

The waveforms of sound pressure in the tube filled with air at atmospheric pressure are shown in Figs. 4 and 5. The measuring points were 755 mm and 1480 mm from the heater counter-clockwise. The first region of Fig. 5 is magnified, shown as Fig. 6. It is seen that, although the generated sound in the tube gradually grows first, it rapidly increases when a certain threshold is attained. After an overshooting is followed, a gradual increase is confirmed. The oscillating frequency seems to be selected in the system right after the sound generation starts. Then, probably because of oscillation, the sound pressure rapidly increases. Furthermore, the overshooting after

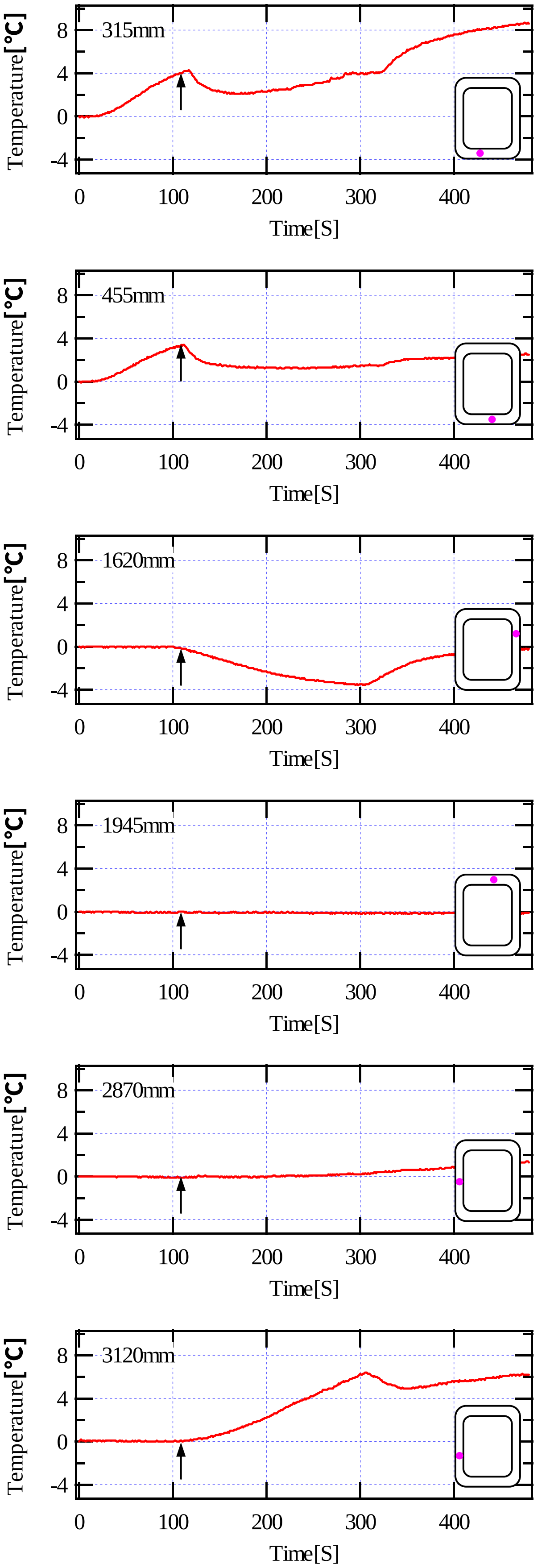

Fig. 2 Temperature variation in the loop-tube filled with air.

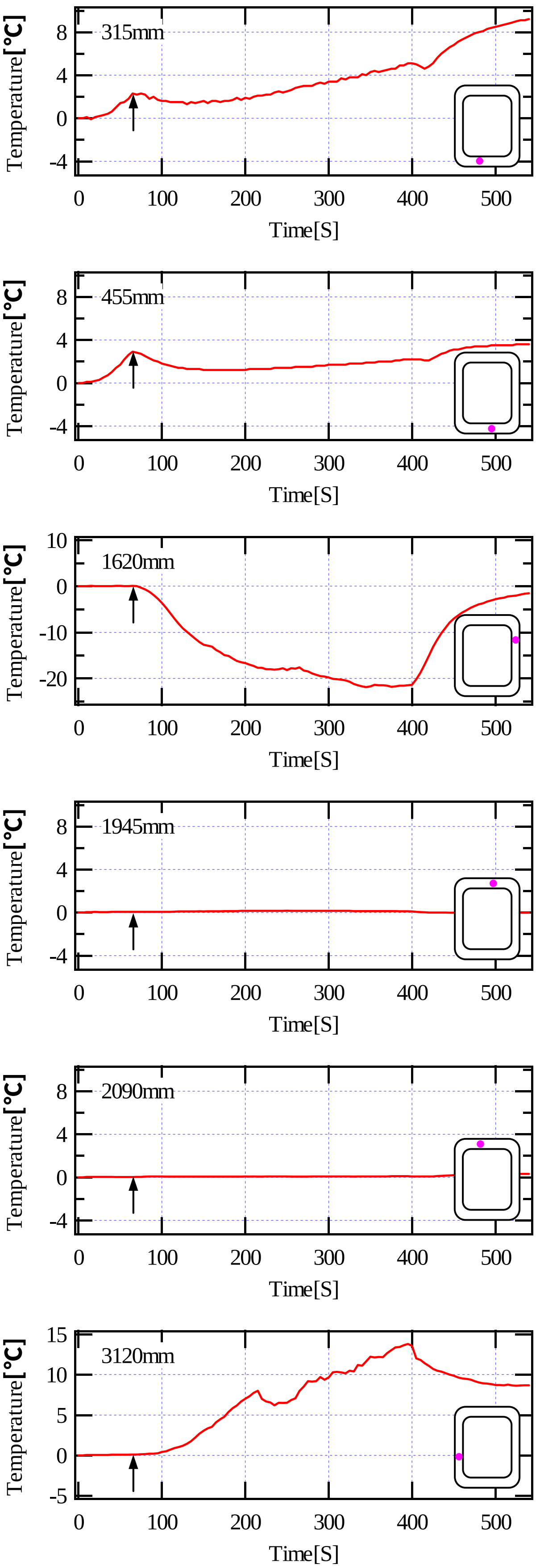

Fig. 3 Temperature variation in the loop-tube filled with the mixture of air and helium gas.

the rapid increase is presumed to be a phenomenon to search a stable point for mutual exchange of heat and sound during the multiple rotations of sound within the loop-tube. Thereafter the acoustic pressure slowly increases because the average temperature of working fluid rises, while the oscillation continues. The maximum sound pressure of 156 dB was observed at the anti node near the Stacks. It was found that the process of the sound generation was divided into two phases. In the first phase, the fundamental component was dominant. In the second phase, the sound pressure steeply increased and the higher harmonics components appeared by the nonlinear effects or the higher mode standing waves. The frequency spectra for the waveforms at the timings A to D in Fig.6 are shown in Fig.7. It is seen that the oscillation frequency is selected at the beginning of the sound generation rather than the duration A to B in Fig.6, and a rapid increase then takes place. At the timing C, the second harmonic is generated. Further at the timing D, the generation of the higher harmonics is also found. Thus the sound wave within the tube suffers strong nonlinearity. Thereby an acoustic streaming may occur in the tube.

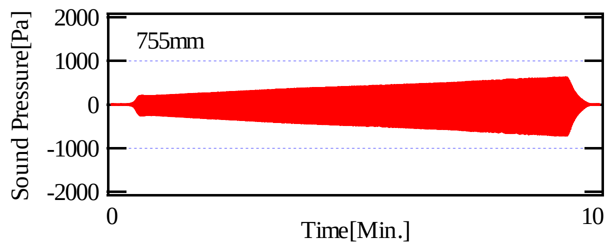

Fig. 4 Observed waveform in the loop-tube filled with air at 755mm.

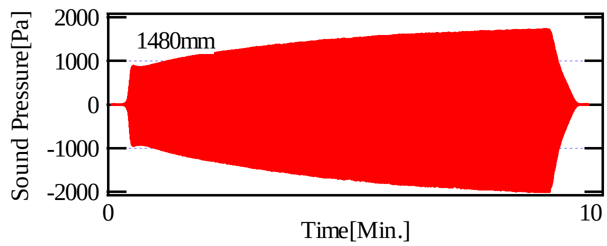

Fig. 5 Observed waveform in the loop-tube filled with air at 1480mm.

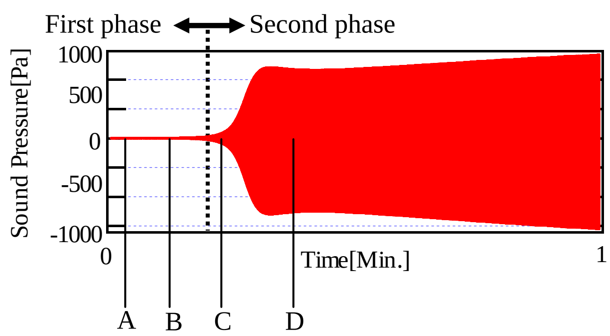

Fig. 6 The time axis expansion of the first region of Fig. 5.

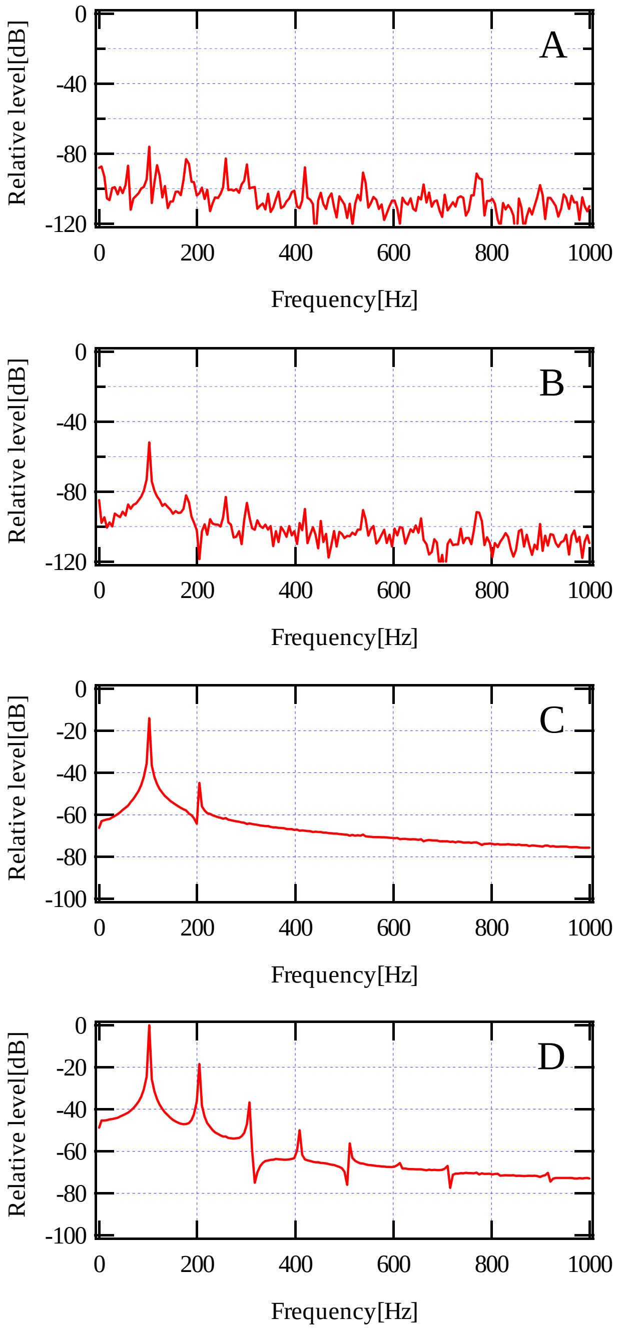

Fig. 7 Change of observed spectrum at 1480mm from heater in the loop-tube filled with air.

Conclusion

In this study it was succeeded that the heat energy was converted to the sound energy and transported as a sound energy and finally the sound energy was converted to the heat energy again. In the process of the energy conversion from sound to heat, the temperature was decreased by 22 degrees. The present experimental results indicate the possibility to construct a new cooling system on the thermoacoustic phenomena.

The efficient energy conversion is important for the thermoacoustic cooling system. In this experiment, however, the rise of the temperature was observed at some points where the temperature was not intended to rise. Also the DC flows such as the acoustic streaming was observed, which was caused by the higher harmonicas components. It is presumed that they cause the low efficiency of the cooling system.

In the next step, the experiments will be carried out to resolve these issues and to construct the thermoacoustic cooling system as the commercial cooling system.

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