Construction of a thermoacoustic Stirling cooler

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Abstract

An efficient thermoacoustic prime mover has been built by Backhaus and Swift. [Nature **399**, 335(1999)]. They have demonstrated that this engine produces an acoustic power with the thermal efficiency of 30 %. We succeed in developing a thermoacoustic Stirling cooler as its application by inserting a regenerator inside the prime mover. Since this cooler has no moving parts and has a potential to be an efficient device, it is a powerful tool to generate low temperatures.

Key words: thermoacoustics; Stirling cooler

Recently, two important advances have been made in a thermoacoustic Stirling engine where a traveling wave replaces moving parts of a conventional Stirling engine [1,2]. The first is a construction of an efficient thermoacoustic Stirling prime mover [3]. Backhaus and Swift have built the prime mover which converts heat flow Q into work flow I through the Stirling cycle with the thermal efficiency of 30 %. The second is a development of a pistonless Stirling cooler [4]. The cooler has two regenerators in a looped tube. One of the regenerators generates I from Q and the other exchanges the produced I into Q. Both conversions are also executed through the Stirling cycle.

In this paper, we experimentally determine the position, where the Stirling cycle can be performed, on the prime mover developed by Backhaus and Swift. By inserting a regenerator into this position, we construct a new themoacoustic Stirling cooler.

The thermoacoustic Stirling prime mover is schematically illustrated in Fig. 1(a). The present prime mover consists of a looped tube and resonator. Both the looped tube and resonator are made of Pyrex glass with the internal diameter of 40 mm. The length of the looped tube is 1.04 m and that of the resonator is 1.18 m. One end of the resonator is connected with the looped tube and the other is connected with the 2.0×10^{-2} m^3 tank. The looped tube has a 35 mm long regenerator A consisting of a stack of 60-mesh stainless-steel screens. The regenerator A produces I from Q. The hot and cold heat exchangers are placed on both sides of the regenerator. The temperature T_H of the hot heat exchanger is controlled by the input power Q_H fed by an electric heater. The cold one is water-cooled and is kept at room temperature T_R. The apparatus is filled with air at atmospheric pressure. When T_H exceeds 210 °C, a gas column in the

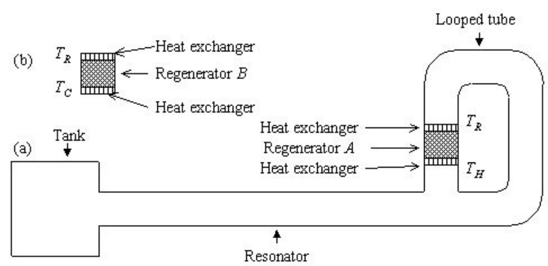

Fig. 1. Thermoacoustic Stirling prime mover and cooler.

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prime mover spontaneously begins to oscillate with the frequency of 41 Hz.

Figure 1(b) shows the second regenerator B to perform a thermoacoustic heat pumping by using the work flow I produced by the regenerator A. Two heat exchangers are also placed at the both sides of this regenerator. One of them is cooled by water and is kept at T_R. The other is exposed to surrounding air and its temperature T_C is measured by a thermocouple.

The Stirling cycle proceeds by thermal interactions between solid wall and a traveling acoustic wave whose phase lead Φ of velocity $U = ue^{i(\omega t+\Phi)}$ relative to pressure $P = pe^{i\omega t}$ is 0. Hence, the cooling regenerator B should be positioned where the phase lead Φ is nearly 0. Before inserting the regenerator B, we simultaneously measured pressure and velocity by pressure sensors and laser Doppler velocimeter [5,6], and observed the distribution of the phase lead Φ in the prime mover.

The distribution of the measured Φ while keeping T_H at 278 °C is represented in Fig. 2. A joint position connecting the looped tube and resonator is taken as an origin $x = 0$ and x is directed anticlockwise in the looped tube. The phase lead Φ gradually decreases from 80 ° to -60 ° with increasing x and is tuned out to be - 20 ° at the center of the regenerator (x=0.9 m). This fact means that Q is mainly converted into I through the Stirling cycle in the regenerator.

Moreover, we see that a traveling wave phase (Φ=0) is formed at x=0.85 m. If the second regenerator B is inserted at this particular position, the energy conversion should be also executed through the Stirling cycle.

In order to build the thermoacoustic Stirling cooler, we modified the experimental apparatus shown in Fig. 1(a) as follows. (1) The Pyrex glass tube was replaced with a thin stainless steel tube. (2) A pressurized gas of a He - Ar mixture was adopted as a working gas because of the possession of its larger thermal penetration depth than air. (3) The length of the resonator and that of the looped tube were changed to 1.0 m and 1.4 m, respectively, to achieve the most powerful performance of the prime mover. (4) The regenerator B was installed in the prime mover and its cold end was positioned at x=0.85 m where Φ is 0 °.

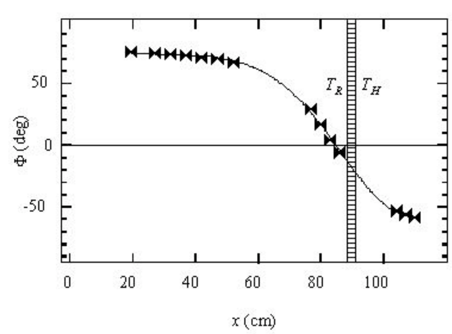

Fig. 2. The axial distribution of the phase lead Φ of U relative to P. A hatched region represents the regenerator A. The line is a guide for the eye.

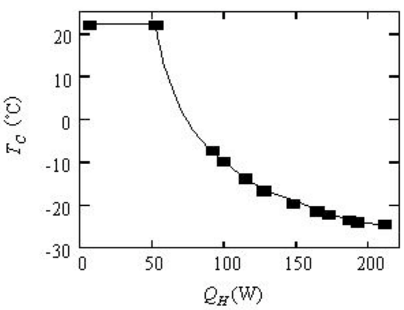

Fig. 3. The performance of the thermoacoustic Stirling cooler. The solid line is a guide for the eye.

Figure 3 shows the performance of the thermoacoustic Stirling cooler with the mixed gas whose ratio of helium to argon was 7 to 3 and mean pressure was 2.6 atm. When Q_H exceeds 50 W, the gas spontaneously begins to oscillate, and as a result, T_C drops. We obtain T_C = -25 °C when Q_H is 210 W.

We succeed in constructing the thermoacoustic Stirling cooler where both the energy conversions of heat flow into work flow and work flow into heat flow are executed by a traveling acoustic wave through the Striling cycle. Since this cooler consists of a few components and has no moving parts, it has a potential to be an efficient device to generate low temperatures.

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