CHARACTERISTICS OF A MINIATURE PULSE TUBE COOLER DRIVEN BY THERMOACOUSTIC STANDING WAVE ENGINE

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ABSTRACT

Thermoacoustically driven pulse tube cooler is very promising due to no moving components. As a first step toward realizing a compact-sized pulse tube cooler, we built an ordinary 1/4 wavelength standing wave engine which has performed quite well. Then a miniature co-axial pulse tube cooler is coupled with the engine. By modifying hot reservoir, resonance tube, stacks and other parameters, we have achieved a no-load temperature of 84.4K at pulse tube cold end with pressure ratio 1.12 and frequency 53.9Hz. Some experimental details are introduced here.

INTRODUCTION

Thermoacoustic engines can serve as thermal compressors with no moving pistons. They have attracted lots of attentions recently. When combined with pulse tube coolers, cryocoolers with no moving components can be built. This is very attractive in many application fields. There are some reports on developing thermoacoustically-driven pulse tube cooler[1,2]. The published lowest temperature is about 90 Kelvin. However, the necessity of long resonance tube leads to a size incompatibleness which is an obstacle to putting it into real applications. Recently, the success of replacing resonance tube with dual-opposed supported pistons[3] ignites our interest in building a compact-sized thermoacoustically-driven pulse tube cooler to reach liquid nitrogen temperature. As a first step, we build an ordinary 1/4 wavelength standing wave engine with improved heat exchanger design and use it to drive a miniature pulse tube cooler. The details are introduced below.

EXPERIMENTAL DETAILS

Standing wave engine configuration and performance

The illustration of the standing wave engine configuration is shown in figure 1. The hot reservoir, hot end heat exchanger, stack and water-cooled heat exchanger have an inner diameter of about 80mm. Through a transitional part, the resonance tube of 50mm inner diameter is connected. The length is often changed to find a suitable working condition. Finally, an ambient reservoir of a volume of about 6 liters is connected to the other end of the resonance tube. The heating is realized by cartridge heaters from Watlow company. Hot parts of the system are

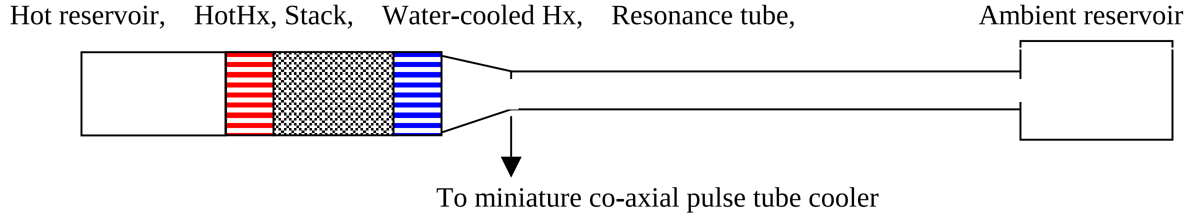

Figure 1. Illustration of integral system

wrapped by material made from ceramic fibre.

Specially for the two heat exchangers which are important parts in the engine, we use EDM (electric discharge machining) methods to manufacture. Figure 2 shows a typical configuration of the water-cooled heat exchanger. The shown channels on the bulk cooper block is for the gas to flow through. Circular channels and holes under the uncutted cooper area, which are hidden by the housing, are for the water to flow. Determination of the fin length and thickness is based on the consideration of heat transfer efficiency and flow resistance. The widths of gas passage for hot heat exchanger and water-cooled heat exchanger is 1mm and 0.5mm, respectively.

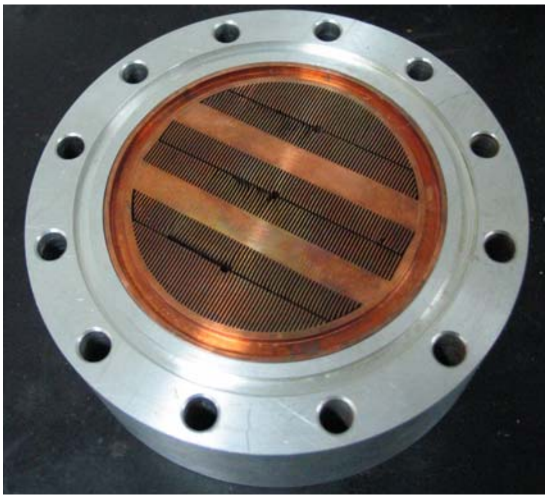

Figure 2. Photo of the water-cooled heat exchanger

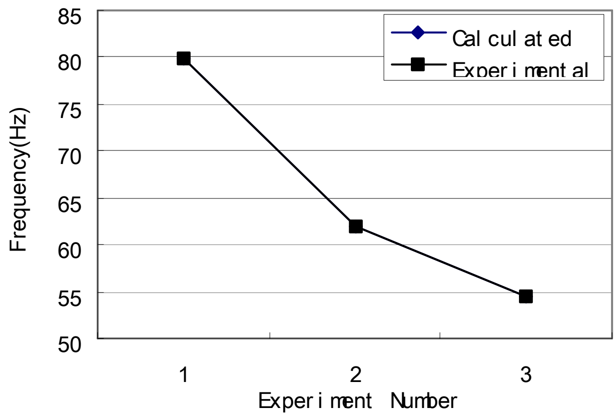

Figure 3. Frequency comparison between experiments and calculations

With the above mentioned configurations we have done experiments to optimize performance. Table 1 lists some typical results. Highest pressure ratio with helium is 1.15, while with nitrogen is 1.22. These results are obtained with no load connected.

Besides experiments, we also use our own program to simulate the performance of the engine. The calculation shows good agreement on frequency with the experimental data. Based on this, we found the engine actually works at a mode somewhere between 1/4 wavelength and 1/2 wavelength. This indicates the ambient reservoir is not large enough. However, calculation of the pressure amplitude and temperature distribution gives rather big deviation, which needs to be further improved.

Table 1. Typical performance of the thermoacoustic engine

Average pressure (bar)	Resonance tube length (m)	Stack mesh number	Heating power (Kw)	Pressure ratio	Frequency (Hz)
35	3.5	15	2.0	1.15	82.7
33.4	5.0	15	2.0	1.12	64
35.7	6	8	2.5	1.12 (with PTR)	53.9

Pulse tube cooler performance

The pulse tube cooler is provided by PTR group in our institute. It is co-axial and works with double-inlet mode. The outside diameter of the regenerator is about 10mm. The regenerator material is stainless steel mesh with mesh number being 400. Due to the convenience of driving the pulse tube cooler with linear compressor, we test the basic performance of the cooler with similar working conditions which may be provided by the thermoacoustic engine. Table 2 gives some typical experimental results. After these preliminary tests, we have a rough feel of how well the pulse tube cooler performs.

Table 2. Typical experimental results of the pulse tube cooler driven by a linear compressor

Frequency (Hz)	Average pressure(bar)	Pressure amplitude(bar)	Cold end temperature (K)
50	30	2.0	86.0
50	30	2.25	83.7
60	30	2.0	92.6
60	30	2.25	88.5

Performance of the pulse tube cooler driven thermoacoustically

Hot end of the pulse tube cooler introduced above is originally cooled by a fan. The heat transfer capability is quite limited as shown through experiments. So when coupling with the thermoacoustic engine, we insert a water-cooled heat exchanger before the inlet of the pulse tube cooler's regenerator, which helps to improve the performance. Figure 4 gives the best result obtained up to now. With pressure ratio 1.12 and frequency 53.9Hz, the lowest no-load temperature of pulse tube cold end is 84.4K. The heating power is 2.5Kw. Unfortunately, when the cold end was still slowly cooling down, some trouble happened, which forced us to stop the experiment for a while.

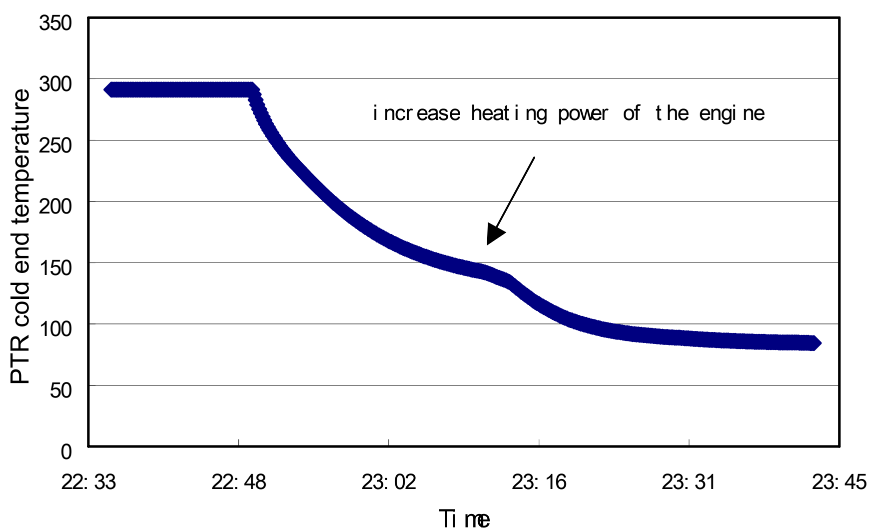

Figure 4. Cool-down curve of the pulse tube cooler cold end

CONCLUSION AND DISCUSSION

With an ordinary 1/4 wavelength thermoacoustic engine, the pulse tube cooler reached a no-load lowest temperature of 84.4K with a pressure ratio 1.12 at frequency 53.9Hz. This indicates the possibility of obtaining liquid nitrogen temperature with small pressure amplitude, thus leading to a 80K cryocooler with no moving components at all.

Better working conditions still needs to be found, such as better stack meshes, resonance tube diameter and bigger ambient reservoir. Simulation also needs to be improved to help the design.

Meanwhile, pulse tube cooler needs to be carefully designed for thermoacoustically driven condition, which means the pressure ratio available is not high compared with mechanical compressor.

Further experiments will be done to eliminate the inconvenient resonance tube.

ACKNOWLEDGMENTS

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