Experiment Study of a Coaxial Pulse Tube Cryocooler

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ABSTRACT

For the purpose of cooling an infrared aerospace application, a one-stage coaxial pulse tube cryocooler (PTC) driven by a linear compressor has been designed, manufactured and tested at Shanghai Institute of Technical Physics (SITP), Chinese Academy of Sciences (CAS). The PTC is composed of an assembly of a compressor, a cold finger, an inertance tube and a gas reservoir. The optimization of the PTC is discussed in analytical terms. An experimental setup has been designed and fabricated to carry out experimental investigations on the PTC and the experimental result of its performance is presented, which shows that the PTC can offer cooling capacity between 40K and 170K and over 6W of cooling capacity can be achieved at 60K with only 195W of electric power yielding a relative Carnot efficiency of about 12%. In addition, the influence of the reject temperature is presented and investigated in detail for a thorough understanding of the PTC system.

INTRODUCTION

Pulse tube and Stirling cryocoolers are widely used in aerospace and other demanding application because they have some important characteristics, such as long life, lightweight, and high efficient. Compared with Stirling cryocoolers, pulse tube coolers (PTCs) are especially suitable for cooling space infrared photo detectors. There are two reasons for this: First, PTCs can operate without moving parts in the cold fingers, which results in low vibration and thus its lifetimes can become longer; Second, after some critical technical problems are solved, the PTC efficiency is improved continually and the PTCs' relative Carnot efficiency can reach 20%, which is higher than a Stirling cryocoolers' efficiency. For these two reasons, PTCs have been developed in recent years [1-3].

A single-stage coaxial PTC has been designed, manufactured and tested at Shanghai Institute of Technical Physics (SITP), Chinese Academy of Sciences (CAS). The PTC is designed to cool an infrared detector and can provide up to 6W of cooling capacity at 60K with less than 200W of electrical power. The following sections give an overview of the optimization and the successful experiments of the coaxial PTC. The PTC's cooling capacity has been tested at temperatures between 40K and 170K and the influence of the reject temperature is presented and investigated in detail for a thorough understanding of the PTC system.

CRYOCOOLER DESIGN

The coaxial PTC system consists of a compressor, a cold finger (including aftercooler, regenerator, cold head and pulse tube), an inertance tube and a gas reservoir as shown in Fig. 1 and Fig. 2.

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For the design of the PTC, a dual opposed piston compressor, with a maximum swept volume of 8.2 cc, was designed and built. The compressor is able to offer more than 200W input power with more than 75% efficiency and its lifetime is more than 50,000 hours.

Heat exchangers made of copper are designed and fabricated as slits configurations. Each slit's size is optimized to achieve a high efficient heat transfer.

The regenerator is a key component in a PTC system and has a typical micro-porous metallic structure, where the system working gas flows periodically. However, the regenerator is always poorly understood. There are much irreversible thermal and hydrodynamic losses that play a crucial role in the efficiency of the PTC cycle. As a consequence, the regenerator needs further research and requires an optimized design together with pulse tube, phase shifter (an inertance tube and a certain volume of constant reservoir) and other components. Some annular 316L stainless steel gauzes are chosen as the regenerator's matrix and its measured porosity is about 70%.

The pulse tube is also made of 316L stainless steel, and it is a hollow tube. Gas in the middle portion will form a temperature gradient to insulate both ends of the pulse tube [4]. A large volume is needed for the pulse tube to ensure that its compression and expansion processes are adiabatic. However, too large of a volume of the pulse tube normally has the consequence of larger dead space and phase shift. Thus the pulse tube needs to be optimized together with other components before a suitable size can be chosen.

Also, an optimum inertance tube is helpful to improve PTC performance by adjusting phase angle of mass and pressure of the PTC system. An inertance tube along with a gas reservoir is optimized in order to obtain the optimum phase shift of about 60° at the point of the interface before the inertance tube.

The PTC system is also strictly conserved with a maximum inlet pressure of 4.0 MPa. Helium is chosen as the working gas. The system operating frequency is around 50 Hz .

CRYOCOOLER EXPERIMENTS

The single stage coaxial cryocooler has been tested with 150W input power at a 295K reject temperature. The PTC cold head can be cooled quickly and its temperature will be able to reach 44K in 10 minutes, as shown in Figure 3. The PTC's lowest temperature is about 36K.

Figure 4 plots the input power versus the cooling capacity in isotherms. This figure shows the performance of the PTC at a cold head temperature of 60K, 80K and 100K . Some measurements were taken over a range of input powers between 50W and 200W and the cooling capacity changes from 1W to 6W at 60K, and from 4W to 14W at 100K. The PTC can obtain 6W at 60K cooling temperature with an input power of 195W. Its relative Carnot efficiency is around 12%. Also, cooling capacity of 14W can be achieved at 100K with a relative Carnot efficiency of 16%.

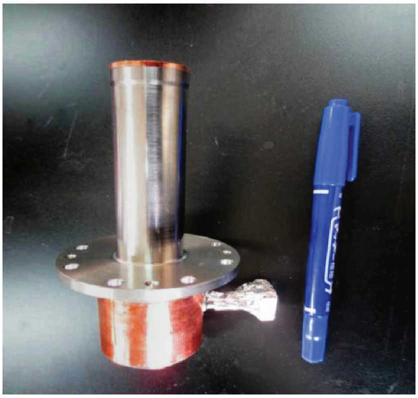

Figure 1. Picture of the cold finger

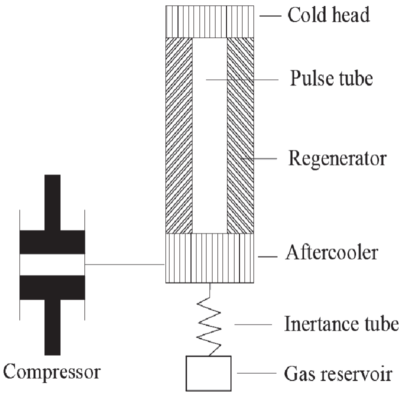

Figure 2. Schematic of the coaxial PTC

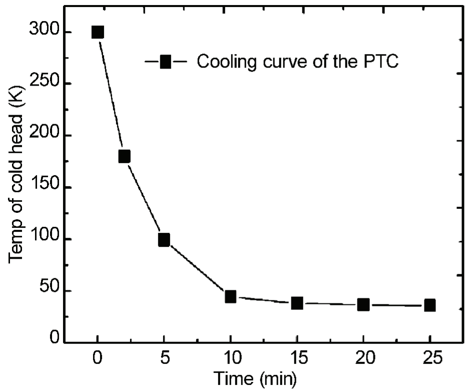

Figure 3. Cooling curve of the PTC

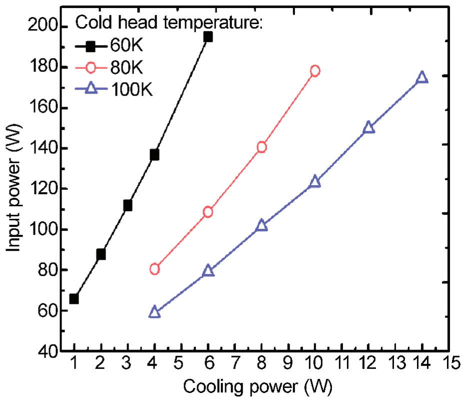

Figure 4. Cooling performance map

The effect of the reject temperature on the PTC performance is shown in Figure 5. When only the efficiency of the compressor is pursued, there is no problem operating above an input power of 200W. There is a tendency for a decrease in PTC cooling efficiency with increasing reject temperature.

When the PTC operates at a cooling capacity of 5 W and 60 K, the PTC input power increases from 162W to 202W as the reject temperature increases from 285 K to 315 K. Its increasing slope is about 13.3W per 10K. Also, the experimental data shows that the slope increases as the reject temperature increases. When the reject temperature increases from 285 K to 295 K, just 8W input power is needed to increase. When the reject temperature increases from 305 K to 315 K, the increased input power goes up to 20W. The reject temperature, especially higher reject temperature, has a great influence on the PTC cooling performance.

CONCLUSION

A single stage coaxial pulse tube cryocooler has been designed, built, and tested at SITP. The PTC can be cooled down quickly and its lowest temperature is about 36K when its input electric power is up to 150W. The performance of the PTC has been measured at a cold head temperature of 60K, 80K and 100K, respectively. The PTC can obtain 6W at a cooling temperature of 60K when its input electric power is up to 195W input power and its relative Carnot efficiency is about 12%. In addition, the influence of reject temperature has been presented. Some experiments show that the PTC input power increases from 162W to 202W as the reject temperature increases from 285 K to

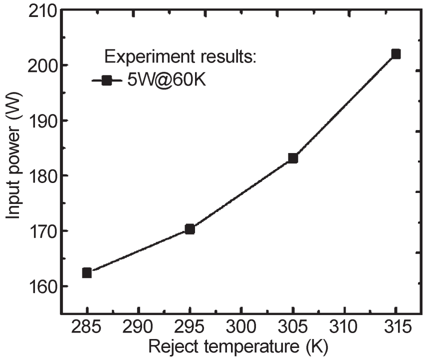

Figure 5. Input power versus reject temperature

315 K. The reject temperature, especially higher reject temperature, has a great influence on the PTC cooling performance.

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