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Short communication

18.6 K single-stage high frequency multi-bypass coaxial pulse tube cryocooler

Liubiao Chen [a,b], Hai Jin [a,b], Junjie Wang [a,*], Yuan Zhou [a], Wenxiu Zhu [a], Qiang Zhou [a,b]

[a] Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, CAS, Beijing 100190, People's Republic of China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China

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ABSTRACT

A single-stage high frequency multi-bypass coaxial pulse tube cryocooler (PTC) has been developed for physical experiments. The performance characteristics are presented. At present, the cooler has reached the lowest temperature of 18.6 K with an electric input power of 268 W, which is the reported lowest temperature for single-stage high frequency PTC. The cooler typically provides 0.2 W at 20.6 K and 0.5 W at 24.1 K with the input power of 260 W at 300 K ambient temperature. The cooperation phase adjustment method of multi-bypass and double-inlet shows its advantages in experiments, they might be the best way to get temperature below 20 K for single-stage high frequency PTC. The temperature stability of the developed PTC is also observed.

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1. Introduction

10–40 K temperature range is an important research direction for high frequency pulse tube cryocooler. Temperature below 40 K is needed in space application, condensed matter physics, and some other fields [1–3]. Multi-stage structure is generally required for PTC to reach low temperature. However, the single-stage configuration is much simpler than that of multi-stage. Single-stage high frequency PTC is attractive to customers because of its mechanical simplicity, high reliability, and low vibration. Therefore, many attempts have been made to achieve a lower temperature with single-stage structure. Giessen has reported a single-stage PTC reaching 26.1 K with 250 W input power, which is the reported lowest temperature for single-stage high frequency PTC without multi-bypass, and providing 0.2 W cooling power at 30 K with input power 200 W [4]. In the 1990s, Lockheed Martin developed a no-load temperature 23 K, 0.32 W/35 K single-stage multi-bypass in-line PTC, but the structure is similar to two-stage configuration [5]. Yang reported a single-stage multi-bypass coaxial PTC that can get a lowest temperature of 23.8 K and 0.6 W/35 K with 200 W input power recently [6]. A coaxial single-stage PTC has been developed in our group last year (identified as P-06), a lowest temperature of 19.3 K and 1 W/38.9 K with input power 200 W was achieved; its compressor and pulse tube are connected with a connecting tube [7].

In order to get a higher cooling capacity than that of P-06, we have recently developed a more compact PTC in which the compressor and pulse tube are coupled together (identified as P-07). At present, a lowest temperature of 18.6 K and 0.2 W/20.6 K has been achieved. P-07 will be applied to a physical property measurement system where different kinds of materials will be cooled down to 20–40 K to measure their physical properties.

It should be mentioned here that the reported results are not just one design and one test, but the fruit of a long research and development program. The most important achievement is the lowest temperature, since it is the first time for a single-stage high frequency PTC to reach a temperature of 18.6 K.

2. Cryocooler description

For practical reasons, the coaxial arrangement is adopted in our design. The schematic and the photo of the PTC are shown in Figs. 1 and 2 respectively. A dual-opposed linear compressor TC2221 is used to drive the PTC. As Fig. 1 shows, an optimized three-segment regenerator is employed for the purpose of minimizing the flow resistances and keeping the necessary thermal penetration depth along the whole regenerator at the mean time. Table 1 gives the key dimensional parameters of the three-segment mixed regenerator.

Multi-bypass, double-inlet and inertance tube accompanied with a gas reservoir, are adopted as the phase shifters. Multi-bypass, invented by Zhou and Han is a good way for PTC to reach lower temperature [8]. A part of gas flow in or out the pulse tube is introduced by means of a connection between the

* Corresponding author. Tel.: +86 10 82543758; fax: +86 10 62564050.
E-mail addresses: clb608@163.com (L. Chen), wangjunjie@vip.sina.com (J. Wang).

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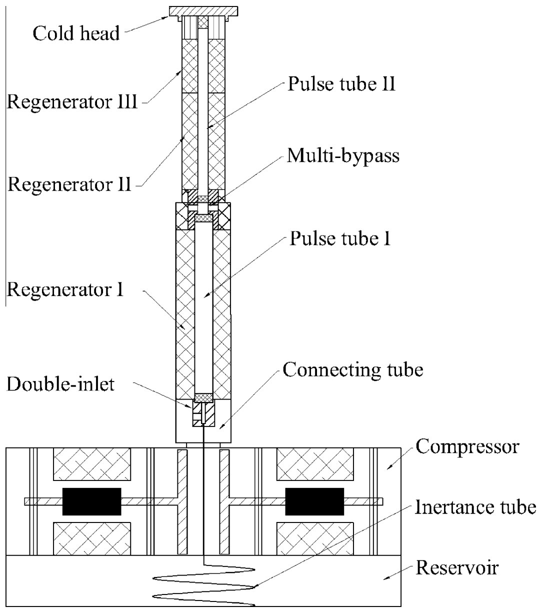

Fig. 1. Schematic of the high frequency coaxial PTC with multi-bypass and double-inlet.

Fig. 2. Engineering model of the developed PTC.

middle of regenerator and the middle of the pulse tube. Coaxial design makes it easy to use the multi-bypass technique to improve the refrigeration performance. As Fig. 1 shows, multi-bypass is realized by drilling small holes in the middle of the pulse tube. In order to reduce the gas flow disturbance caused by the gas flow in or out of the pulse tube, it is necessary to add screens in the connecting part of the pulse tube [9], 10 layers of 80# copper screen were added in this PTC. Double-inlet has also been proven to be an effective means to increase the thermodynamic performance of the PTC, which has been used widely since 1990s [10]. We use needle valve as double-inlet during the process of preliminary optimization, but needle valve has disadvantages as a product, because its opening may change with time; besides, O-ring sealing is generally needed, which may lead to gas leakage after prolonged operation. A simplified configuration with fixed symmetrical nozzle (as Fig. 3 shows) instead of needle valve was adopted at last, which will be beneficial for long life application. However, the optimization of nozzle is much more difficult than that of needle valve, as its opening cannot be adjusted continuously and each change of it requires a repeated experiment. Besides, the machining accuracy of a nozzle, which is of small dimension, cannot be guaranteed. Sometimes, the experiment results of the two nozzles that fabricated with the same design drawing may be quite different.

A simple device is developed to solve the problem discussed above. The schematic of the system is showed in Fig. 4. To facilitate selecting the needed opening, we measure and record the flow rate Q at the same given constant pressure P1 (P1 is 0.2 MPa in this paper) before the nozzle or multi-bypass is adopted. For example, the flow rate Q of the needle valve is measured when its opening is optimum, then we choose a nozzle that has the same or similar flow rate. Though with the same flow rate, the results of the nozzle and needle valve are not always the same, our effort has shown the possibility to get a similar or even better result with further optimization for nozzle. The relative test results of nozzle and needle valve can refer to Ref. [7].

Table 1
Key parameters of the three-segment mixed regenerator.

Segment	Inner diameter (mm)	Length (mm)	Regenerator matrix
Regenerator I	26	55.5	350# SS
Regenerator II	18	16.5	450# SS
Regenerator III	18	20.0	500# SS

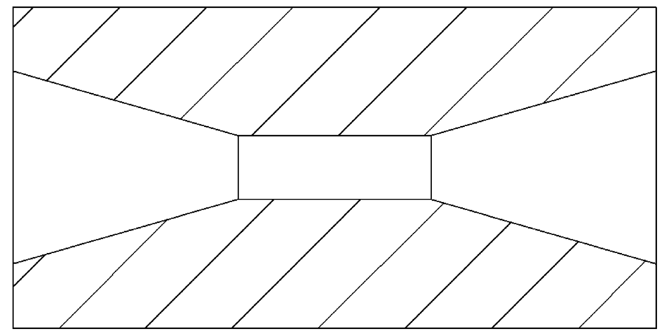

Fig. 3. Structure of the nozzle for double-inlet.

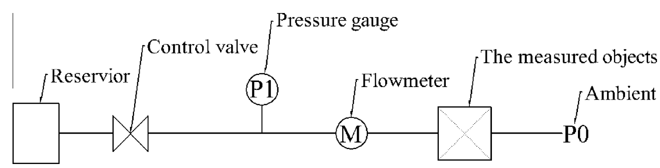

Fig. 4. Schematic of the measurement system for multi-bypass and double-inlet.

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