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中国科学院理化技术研究所
Technical Institute of Physics and Chemistry, CAS
中国科学院空间功热转换技术重点实验室
Key Laboratory of Technology on Space Energy Conversion, CAS

Experimental Study of High-efficiency Single-stage 30 K Coaxial Pulse Tube Cryocooler

Yanen Li [1,2], Nailiang Wang [1✉], Miguang Zhao [1✉], GuoPeng Wang [1], Min Gao [1,2], Bin Yang [1,2], Geyang Li [1,2] and Ye Yuan [1,2]

[1] *Key Laboratory of Technology on Space Energy Conversion, Technical Institute of Physics and Chemistry, CAS, Beijing 100190, China*

[2] *University of Chinese Academy of Sciences, Beijing 100190, China*

Abstract

The operating temperature of 30 K is crucial for long wave infrared and very long wave infrared detectors. To achieve cooling at 30 K, two-stage pulse tube cryocooler(PTC) have been employed in most previous studies. However, these systems are complex in structure. The development of single-stage 30 K high-efficiency PTC presents significant challenges but holds great importance for 30 K long-wave infrared detectors. We designed a single-stage coaxial PTC with double inlet orifice, and we conducted extensive optimization experiments on this cryocooler. With 200 W input power and a hot end temperature of 285 K, the PTC achieved a cooling capacity of 1.6 W/30 K, corresponding to a relative Carnot efficiency of 6.8%.

Experimental system

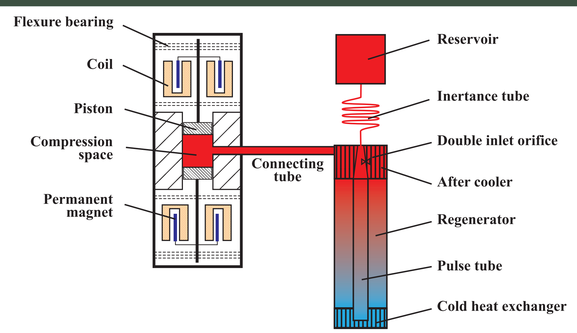


Fig. 1. Schematic diagram of the PTC

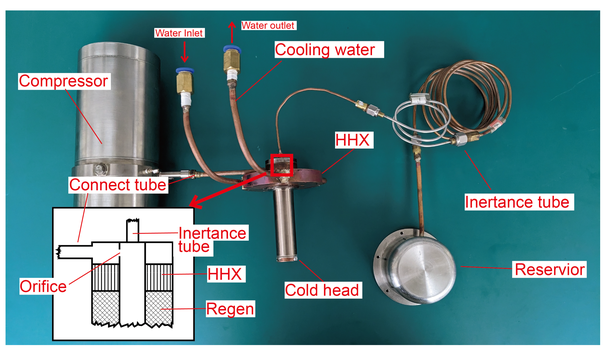
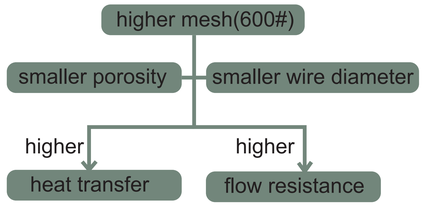


Fig. 2. Actual picture of the PTC

The schematic diagram and actual picture of the PTR are shown in Fig. 1 and Fig. 2. We have adopted a orifice at the hot end of the pulse tube as a double inlet valve.

Experiments and discussion

Number	Regen length	Matrix screen
Cold finger 1	80 mm	500# SS, filling length 80 mm
Cold finger 2	80 mm	500# SS, filling length 40 mm 600# SS, filling length 40 mm
Cold finger 3	90 mm	500# SS, filling length 45 mm 600# SS, filling length 45 mm



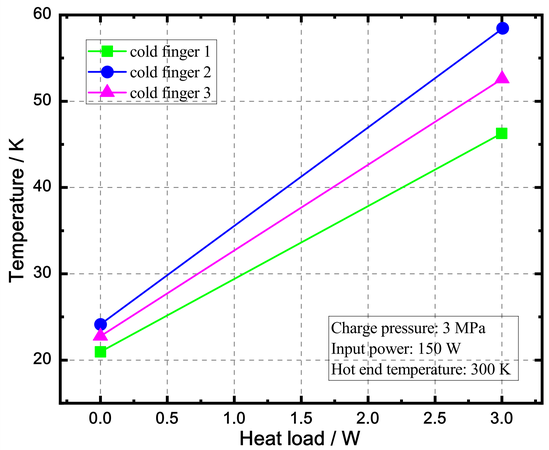


Fig. 3. Performance of PTC with different cold finger

500-mesh or 600-mesh stainless steel wire mesh were used for regenerator filling, and three regenerators were filled using different methods. Compared to the 500-mesh scree mesh, the 600-mesh screen mesh has smaller porosity and wire diameter, allowing for more effective heat transfer but also resulting in higher flow resistance. As shown in Figure 3, Cold finger 1 exhibited superior performance, so Cold finger 1 was chosen as the cold finger of the 30 K PTR.

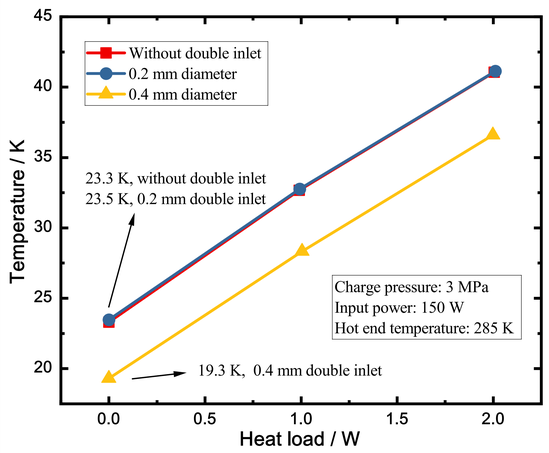


Fig. 4. Performance of PTC with different diameter of double inlet orifice

For double inlet orifice, a larger orifice diameter results in a greater DC mass flow rate, which can potentially negatively impact the performance of the cryocooler. Appropriately diameter of orifice can reduce the no-load temperature of the cryocooler. As shown in Figure 4, we measured the performance of the cryocooler with double inlet orifice diameters of 0, 0.2, and 0.4 mm. When the orifice diameter was 0.4 mm, the cryocooler exhibited excellent performance. Therefore, we selected a double inlet orifice diameter of 0.4 mm.

Performance

Component	Parameters	Matrix screen
Compressor	diameter of piston swept volume compression ration	25mm 9.6cc 1.27
Connecting tube	length, diameter	100 mm, 6 mm
Cold finger	length of regen diameter of regen diameter of pulse tube matrix	80 mm 25 mm 10.7 mm 500# SS screen, porosity 0.613
Operation	charge pressure frequency	3 MPa, 36 Hz

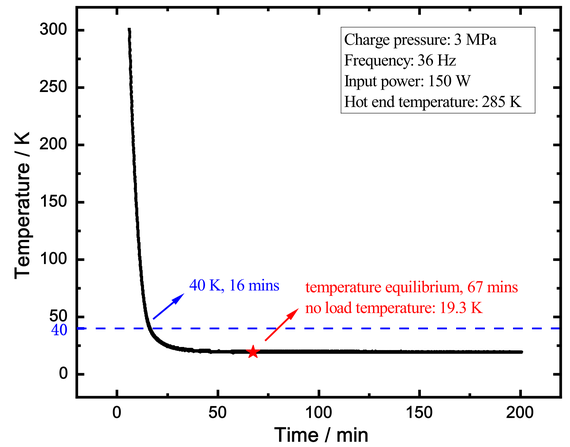


Fig. 5. Cooling curve of the 30 K PTC

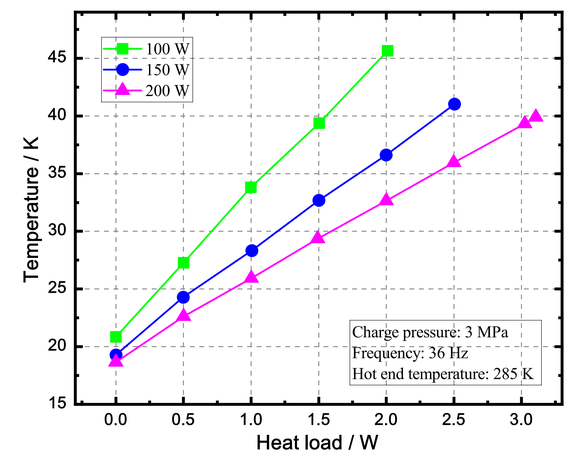


Fig. 6. Performance of the 30 K PTC

★ Cooling from 300 K to 40 K, 16 minutes
Equilibrium temperature 19.3 K, 67 minutes.
150 W input power, 285 K reject temperature

★ no-load temperature 18.7 K , 1.6 W/30 K
200 W input electrical power, 285 K reject temperature

Acknowledgements

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