

Experimental Investigation of a 40K Single Stage High Frequency Pulse Tube Cryocooler

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ABSTRACT

A 40K single-stage high frequency pulse tube cryocooler (PTC) has been designed, fabricated and tested. The PTC is designed to provide 2W cooling power at 40K with an input electrical power less than 200 W. A prototype PTC system is built with a compressor and a single-stage coaxial pulse tube configuration. Performance of the PTC is 1.6W at 40K with input electrical power of 175W.

INTRODUCTION

Infrared detectors usually need low temperature environment to achieve a high signal to noise ratio. Cryocoolers with the characteristics of compactness and light weight are the direction to provided this low temperature environment. With the invention of the Oxford-type linear compressor, cryocoolers can reach a lifetime of over five years. PTC, as a new regenerative cryocooler, was originally described in 1964¹. With several development improvements, the low temperature and cooling power of PTCs reached the application requirement. Because of the absence of moving parts at low temperature, a PTC driven by a linear compressor has the potential to achieve high reliability, low vibration and a very long lifetime. As a consequence, high frequency PTCs are becoming a more attractive candidate for cooling infrared detectors.

Long-wave infrared detectors working at a 40 K temperature environment can reach a higher cutoff wavelength. A 40K high frequency PTC that will be used to cool down long-wave infrared detector has been designed, fabricated and tested. The PTC is designed to provide 2W of cooling power at 40K with an input electrical power less than 200W. The PTC system incorporates a compressor with a single-stage coaxial pulse tube configuration. The state of development of 40K high frequency PTC is reported here.

EXPERIMENT

The 40K PTC consists of a maximal swept volume of 6 cc linear compress made in our laboratory and a single-stage coaxial type pulse tube. Inertance tube and reservoir are used for phase shifting. Water cooling of 15°C is used for heat ejecting. Different mesh filling in regenerator, cold heat exchanger and phase shifter (PS) are investigated for optimizing performance of the PTC to 2W @ 40K. Figure 1 is photograph of the 40K PTC. The diameter of regenerator is ϕ 20 mm. Results of experiments on the effects of different parameters are presented as below.

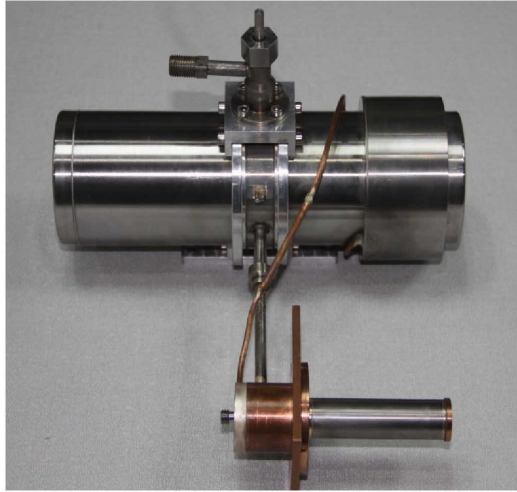


Figure 1. Photograph of the 40K PTC

Regenerator Filling

The regenerator is where the main heat lost occurs in the PTC. Better regenerator loss control can obtain better performance in the PTC. The regenerator was optimized by filling two kinds of mesh with a different mesh size. The lower mesh size was filled in the regenerator near the hot end and the higher mesh size was filled in the regenerator near the cold end. There are three typical filling cases in Table 1.

Performances of the three PTCs are shown in Figure 2. The parameters are electrical input power of 150W, charge pressure of 3.5 MPa, and a frequency of 50 Hz. The no-load temperature of PT 1 is 53.8K, and slope of cooling power is 7.54 K/W. The no-load temperature of PT 2 is 36.6K, and slope of cooling power is 5.76 K/W. The no-load temperature of PT 3 is 44.8K, and slope of cooling power is 6.96 K/W.

Table 1. Regenerator mesh filling cases

Mesh size	400/inch(sheet)	500/inch(sheet)
PT 1	1000	0
PT 2	610	520
PT 3	740	360

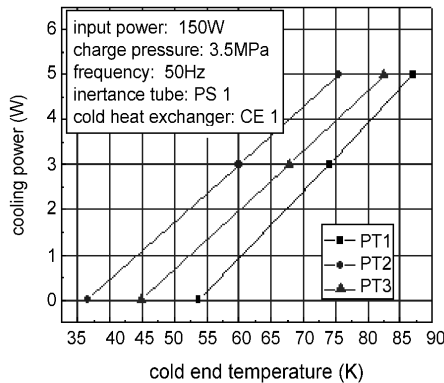


Figure 2. Performances of three cases of regenerator mesh filling

Different mesh filling has a great influence on the performance of the PTC. There exists a best appropriate proportion for mesh filling. The no-load temperature of PT 2 is better than PT 1 by nearly 17K, and is below to 40K. For this reason, PT 2 was chosen for next research phase.

Cold Heat Exchanger

On the base of PT 2, three kinds of cold heat exchanger (CE) are studied. The clearance widths of the cold heat exchangers are different. Clearance width of CE 1 is the largest and CE 3 is the smallest.

Performances of the three cases are shown in Figure 3. The running parameters are electrical input power of 120W, charge pressure of 3.5 MPa, frequency of 50 Hz. The no-load temperature of CE 1 is 37.2K, and slope of cooling power is 8.33 K/W. The cooling power at 40K is 0.34W. The no-load temperature of CE 2 is 34.8K, and slope of cooling power is 8.03 K/W. The cooling power at 40K is 0.65W. The no-load temperature of CE 3 is 33.0K, and slope of cooling power is 7.80 K/W. The cooling power at 40K is 0.90W.

The no-load temperature of CE 3 is lower by 2K than CE 1, and the slope of the cooling power is slightly higher. Because the cross-sectional area of CE 3 is smaller than the other cases, the velocity across the section is larger, and it will increase the convection heat transfer coefficient and enhance the heat exchanging. Therefore the heat resistance is reduced and the slope of cooling power is increased.

Phase Shifter

At the beginning of the phase shifter design, a 500 cc reservoir is used. To decrease the weight of the reservoir, a 25 cc and a 52 cc volume reservoirs with matched inertance tubes are designed for the PTC. Information on the inertance tubes and reservoirs is found in Table 2.

Performances for the three cases are shown in Figure 4. The results were test with the conditions of electrical input power of 120W, charge pressure of 3.6 MPa, frequency of 50 Hz. The no-load temperature of PS 1 is 33.0K, and slope of cooling power is 7.80 K/W. The no-load temperature of case 2 is 39.3K, and slope of cooling power is 8.03 K/W. The no-load temperature of PS 3 is 36.0K, and slope of cooling power is 8.32 K/W.

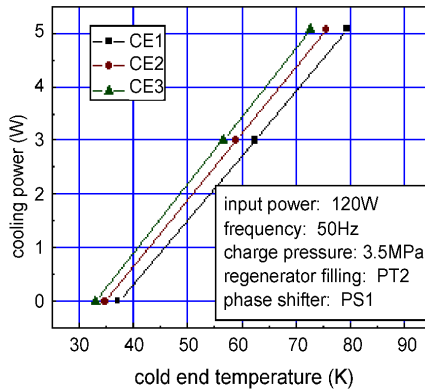


Figure 3. Performances of three cases of cold heat exchanger

Table 2. Different phase shifter cases

Phase shifter	Inertance tubes(mm)	Reservoirs(cc)
PS 1	$\Phi 2 \times 1500 + \Phi 3 \times 1500$	500
PS 2	$\Phi 2 \times 2000 + \Phi 3 \times 1500$	25
PS 3	$\Phi 2 \times 2000 + \Phi 3 \times 1500 + \Phi 4 \times 500$	52

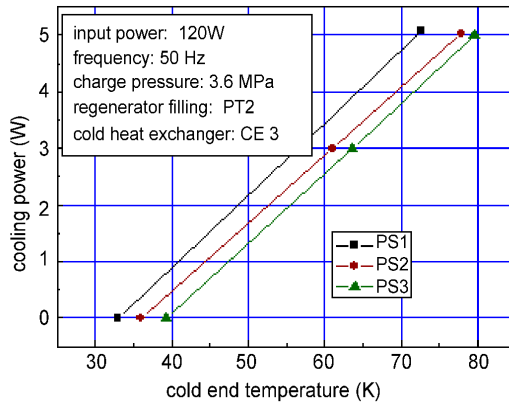


Figure 4. Performances of three cases of phase shifter

The no-load temperature of PS 1 is lower by 3.0K than PS 3, and the slope of the cooling power is slightly increase, because the larger volume of reservoir can achieve better phase angle and larger flux through the cold end.

Performance of the PTC

Based upon the regenerator, the cold heat exchanger and phase shifter experimental results, PT 2 for the regenerator, CE 3 for the cold heat exchanger and PS 1 for the phase shifter are adopted for the PTC. Performance of the PTC with different input electrical power were test, and are shown in Figure 5. The results were test with the following conditions: water cooling of 15°C, a charge pressure of 3.6 MPa, and a frequency of 54 Hz. The lowest temperature of 29.78K and 1.6W cooling power at 40K are achieved with an input electrical power of 175W.

CONCLUSIONS

The regenerator, cold heat exchanger and phase shifter are optimized for 40K PTC. There exists an best appropriate proportion for the mesh filling. The no-load temperature of PT 2 is better than PT1 by nearly 17K. A smaller clearance width of cold heat exchanger can achieve a lower

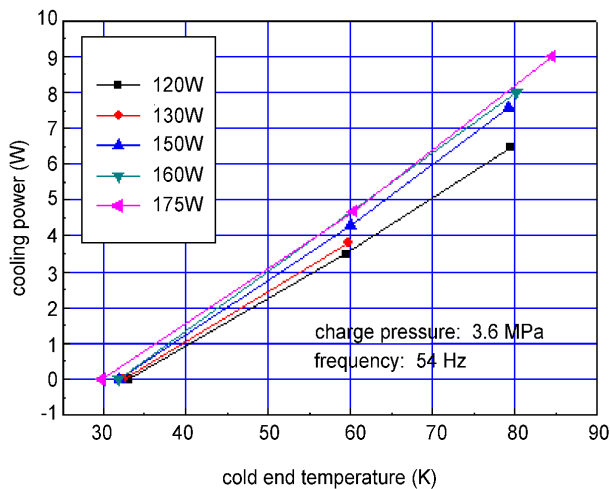


Figure 5. Performances at different input electrical power

temperature and slightly increased slope of cooling power. The performance of the 40K PTC are a low temperature of 29.78K and a 1.6W cooling power at 40K with an input electrical power of 175W.

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