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Introduction

Given that the pulse tube cryocooler (PTC) has no moving parts in its cold head, it has more reliability than the Stirling refrigerator in many space applications. With the development of space technology, the infrared detectors have urgent demands on the high capacity cryocooler at 80K. In this paper, a study on 15W@80K coaxial pulse tube cryocooler was shown. And the design details of the cold finger is presented, including the heat exchanger, regenerator and phase shifter.

Theoretical analysis and experiment on the performance of heat exchanger

The heat exchanger is one of the most important components in a PTC. With the increase of PTC's cooling power, more heat should be transferred to ambient environment. The traditional heat exchanger (shown in figure 1(a)) can't meet current demand, and then a new finned-tube exchanger is designed in this paper (shown in figure. 1(b)).



Figure 1. Two kinds of heat exchangers

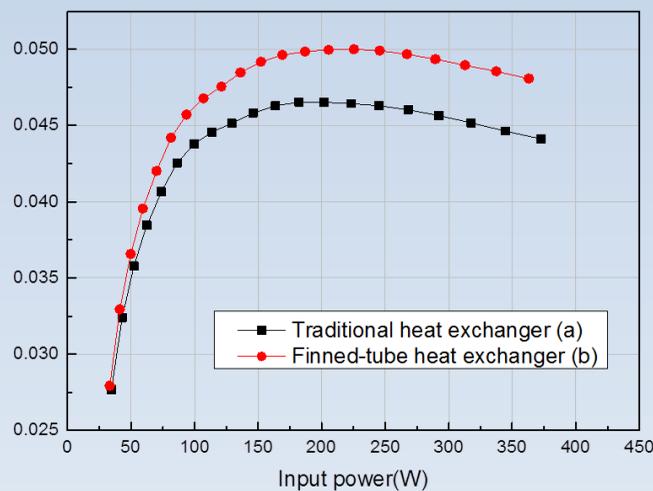


Figure 2. Simulation results of variations of PTC's COP at 80K with the input power

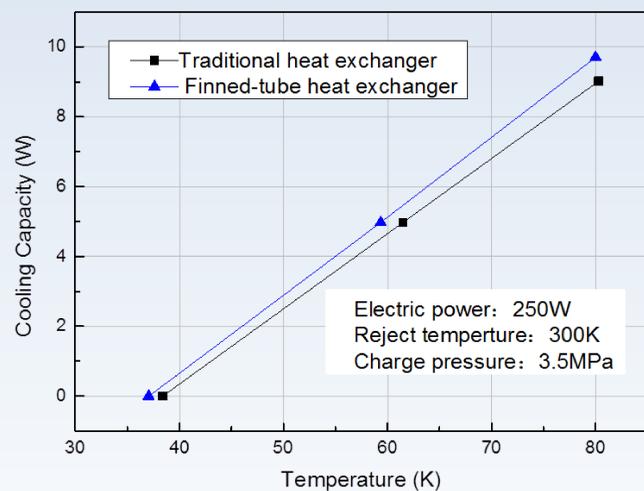


Fig.3 Experimental performance of PTC with two heat exchangers

A theoretical analysis model with SAGE is built. Figure 2 shows the simulation results of variations of PTC's COP with the input power. The results show that the PTC with finned-tube exchanger always offer a better performance than the traditional one.

To validate the results of theoretical analysis, two kinds of heat exchanger are manufactured and tested. Figure 3 shows the performance of the two heat exchangers. It is shown that the PTC with finned-tube exchanger has lower no-load temperature and larger cooling capacity at 80K. Compared with the traditional heat exchanger, to a certain extent, not only is the flow field within the regenerator smoothed by the finned-tube heat exchanger, but also the heat transfer area between fluid and solid is increased by the finned-tube heat exchanger.

Optimizations on the phase shifter

The phase shifter is mainly to shift the phase of the mass flow and pressure wave. An optimal phase relationship means that the mass flow and pressure waves in the midpoint of the regenerator are close in phase, and that the phase range of the mass flow in the regenerator is not too large.

Table 1 The combinations of inertance tubes

| No. | The combination of inertance tubes |
|--------|--|
| Case 1 | $\varnothing 2\text{mm} \times 0.5\text{m} + \varnothing 3\text{mm} \times 2\text{m} + \varnothing 4\text{mm} \times 2.85\text{m}$ |
| Case 2 | $\varnothing 2\text{mm} \times 0\text{m} + \varnothing 3\text{mm} \times 2.5\text{m} + \varnothing 4\text{mm} \times 2.85\text{m}$ |
| Case 3 | $\varnothing 2\text{mm} \times 0.5\text{m} + \varnothing 3\text{mm} \times 2.5\text{m} + \varnothing 4\text{mm} \times 2.85\text{m}$ |
| Case 4 | $\varnothing 2\text{mm} \times 0.5\text{m} + \varnothing 3\text{mm} \times 2.5\text{m} + \varnothing 4\text{mm} \times 2.0\text{m}$ |
| Case 5 | $\varnothing 2\text{mm} \times 0.5\text{m} + \varnothing 3\text{mm} \times 2.5\text{m} + \varnothing 4\text{mm} \times 3.25\text{m}$ |
| Case 6 | $\varnothing 2\text{mm} \times 0.5\text{m} + \varnothing 3\text{mm} \times 3\text{m} + \varnothing 4\text{mm} \times 2.85\text{m}$ |
| Case 7 | $\varnothing 2\text{mm} \times 0.8\text{m} + \varnothing 3\text{mm} \times 2.5\text{m} + \varnothing 4\text{mm} \times 2.85\text{m}$ |

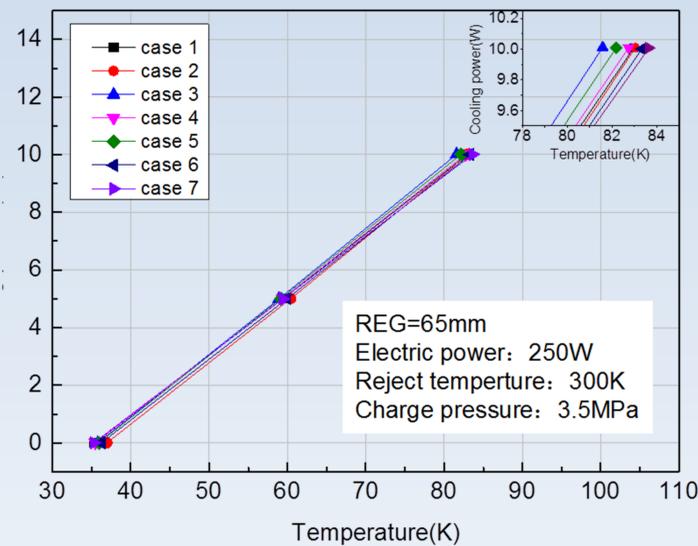


Figure 4. The cooling performance of the PTC with different inertance tubes

According to the primary research, a single inertance tube with a constant diameter has great difficulty in obtaining the desired phase relationship. Thus three-segmented inertance tube with different diameters and length are chosen to achieve suitable phase shift.

Table 1 shows the combinations of inertance tubes. Figure 4 illustrates cooling performance of the PTC with these combination of inertance tubes. The results show that when the cooling power is 10W, the PTC with case 3 has the lowest cold end temperature. So the case 3 is the best combination of inertance tubes.

Optimizations on the length of regenerators

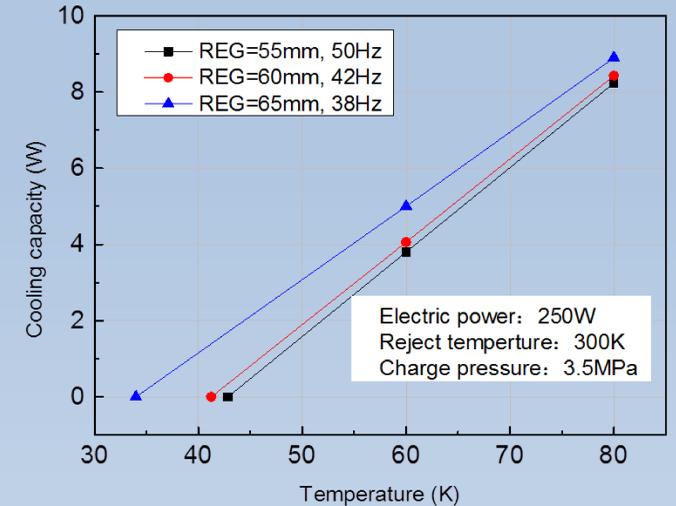


Figure 5. The cooling performance of the PTC with different inertance tubes

The regenerator is one of the most important parts of the pulse tube cryocooler. Three regenerators with different length are designed and tested. The cooling performance of the PTC with the different length of regenerator is shown in figure 5. With the increase of length of regenerator, and the cooling capacity at 80K increases from 8.2W to 8.9W. The longer length of regenerator has the lower axial heat leakage. Thus the 65mm regenerator has the lowest no-load temperature and the highest cooling capacity.

Performance of the pulse tube

Figure 6 describes the details of the PTC's cooling performance. The dotted lines in the graph represent the lines of constant specific. The graph indicates that the constant specific power increases with the increment of input electric power, which illustrates that the efficiency of PTC deteriorates with the increase of the input power.

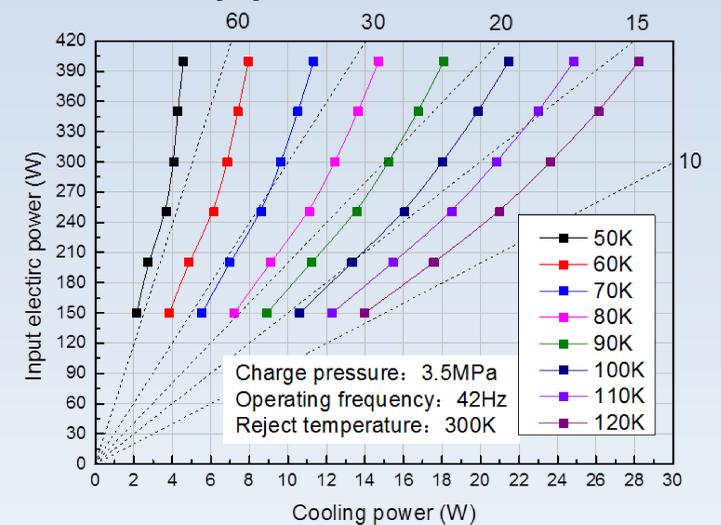


Figure 6 The cooling performance of the PTC at different temperature

Conclusion

A single-stage 15W@80K coaxial PTC has been developed for space infrared detectors cooling. A new finned-tube heat exchanger configuration has been designed and tested, both of experimental and theoretical analysis show that the finned-tube exchanger has a better performance. Meanwhile, length of regenerator and the phase shifter are optimized for higher cooling power of PTC. At present, this cooler prototypes can typically provide the cooling capacity of 15W at 80K with the electric power of 410W at 300K reject temperature.