The simulation and experiments of a high frequency single stage pulse tube cryocooler with two cooled sinks

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Abstract

In the application of infrared detectors, pulse tube cryocoolers are required to provide cooling power at different temperature ranges simultaneously with light weight and compact construction. Generally, each pulse tube cryocooler can provide cooling power in a certain temperature range with only one cooled sink that is the cold-end heat exchanger. In this paper, a single stage pulse tube cryocooler is designed to provide cooling capacity at different temperature ranges with an extra cooled sink placed in the middle of the regenerator. The axial distribution of volume flow and pressure wave of cryocoolers with middle heat exchanger and without middle heat exchanger are compared theoretically. To verify the simulation results, a series of experiments were also carried out. As a result, the cooling power of cryocoolers with middle heat exchanger was decreased at 80K, and 0.5W @ 88.5K & 0.5W @ 195.8K cooling capacity was obtained simultaneously at 45W input power.

CFD model

This paper proposed a new structure of two cooled sinks in one pulse tube cryocooler: Besides cold end heat exchanger, a new heat exchanger is designed in the middle of the axial pulse tube cryocooler to exchange heat with high temperature gas. Figure1 shows the structure of the pulse tube cryocooler with middle heat exchanger. Figure 2 shows the 3D CFD model of cold finger with and without middle heat exchanger.

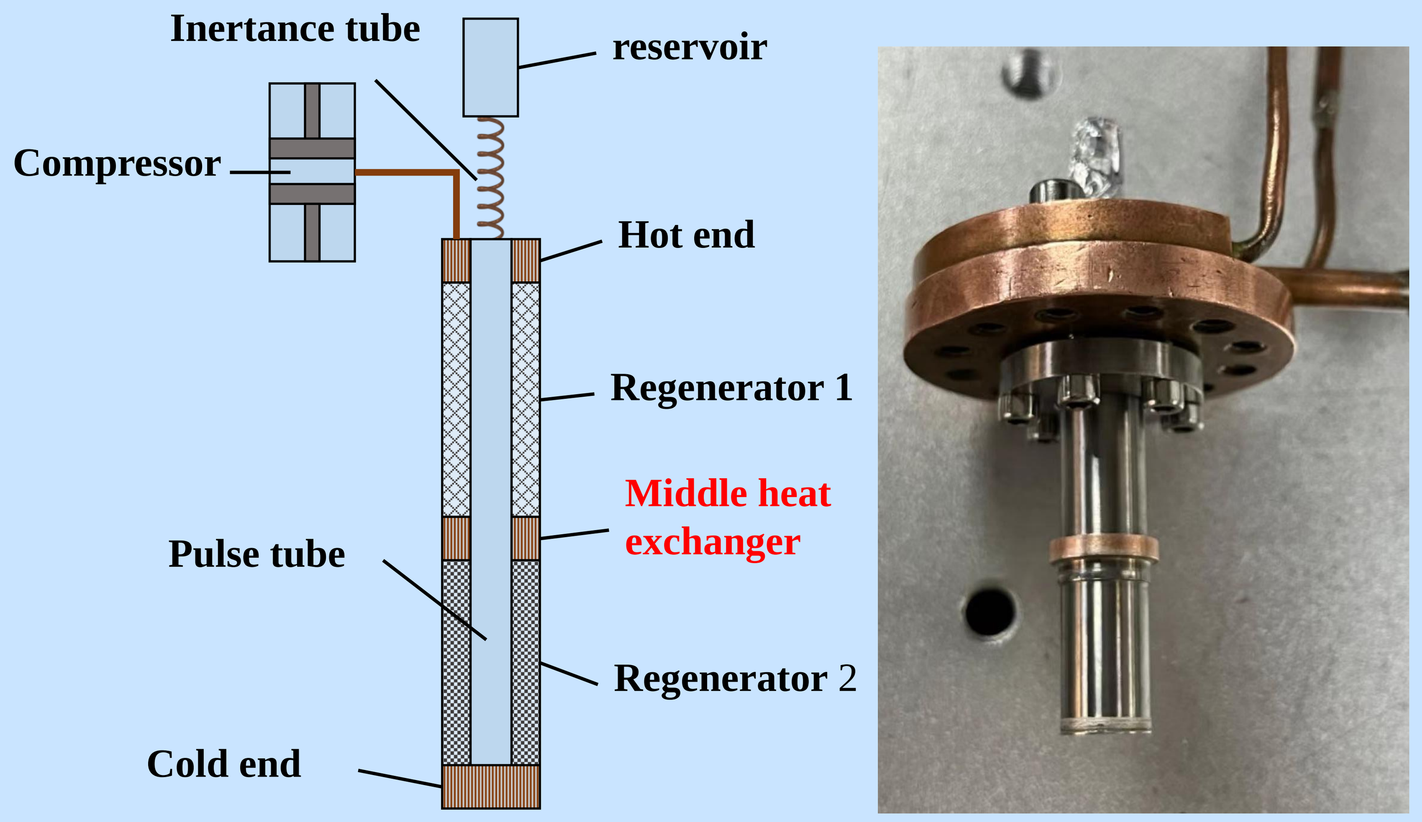


Figure.1 the structure of pulse tube cryocooler with middle heat exchanger

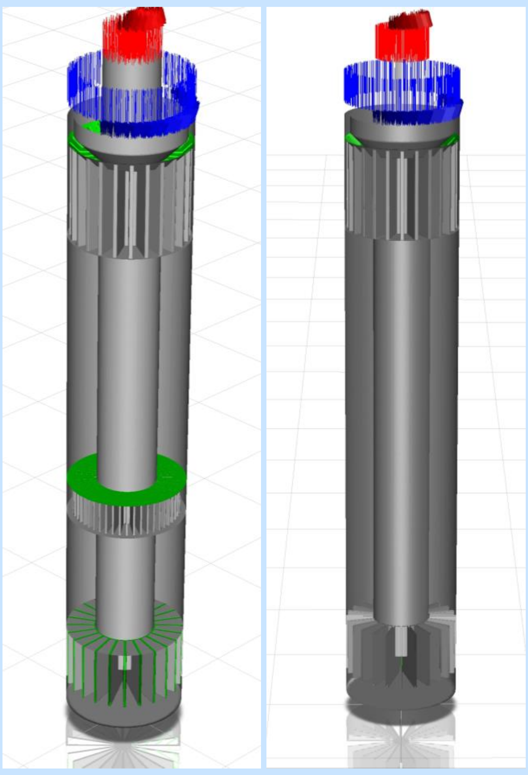
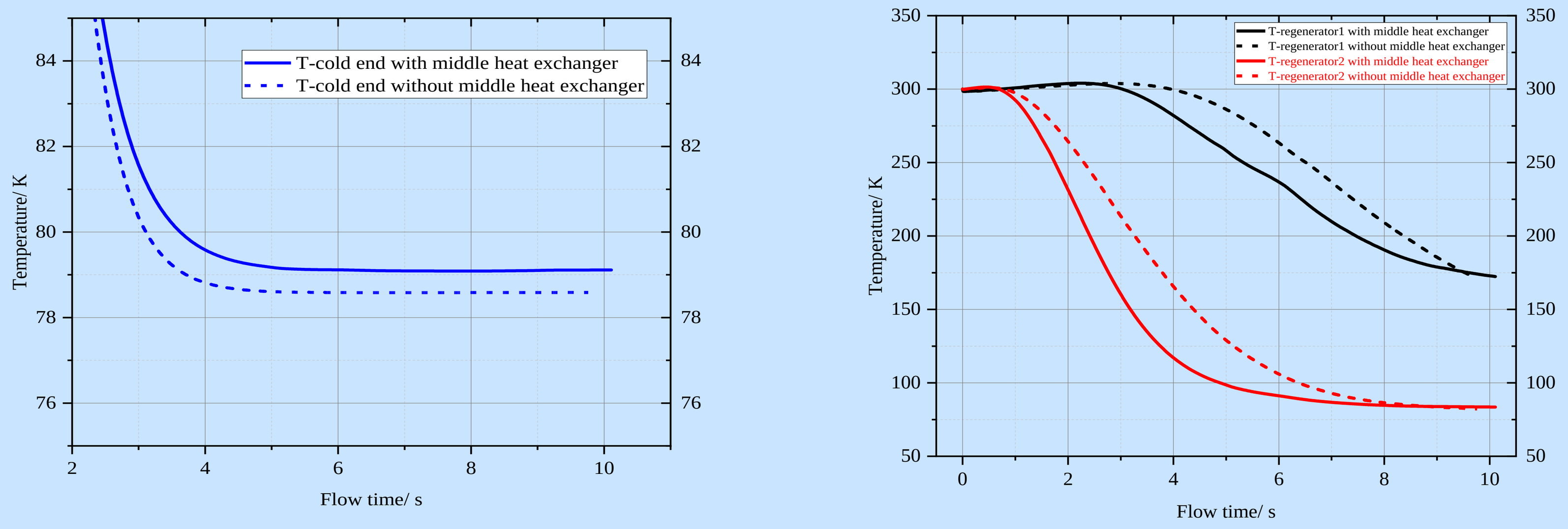


Figure 2. The 3D CFD model of cold finger with and without middle heat exchanger

CFD simulation results

The cooling curve of the cryocoolers is shown in figure 3. It's shown that the cold end without the middle heat exchanger can achieve lower temperature because it has a better ability of pumping heat from the cold end to the hot end. As the results shown in figure 3.a, the temperatures of the regenerator without middle heat exchanger are higher than that of the regenerator with middle heat exchanger at the first time, which means more heat is pumped from the cold end to the hot end. Besides, the cooling rate is faster in the regenerator without middle heat exchanger, and the temperatures get lower than that of regenerator with middle heat exchanger in about 10 seconds. It's shown that the performance of cold finger with middle heat exchanger has been affected to some extent.



a. Cooling curve of the cold end b. Cooling curve of the regenerators

Figure 3. cooling curve of cryocoolers

Figure 4 shows that the middle heat exchanger will affect the amplitude of velocity and pressure. The porosity of middle heat exchanger is much smaller than that of the stainless-steel screen, so that the pressure amplitude in the middle heat exchanger is larger. The increased pressure causes a sudden increase in velocity amplitude, which will lead to jet flow and insufficient heat transfer in the cold finger.

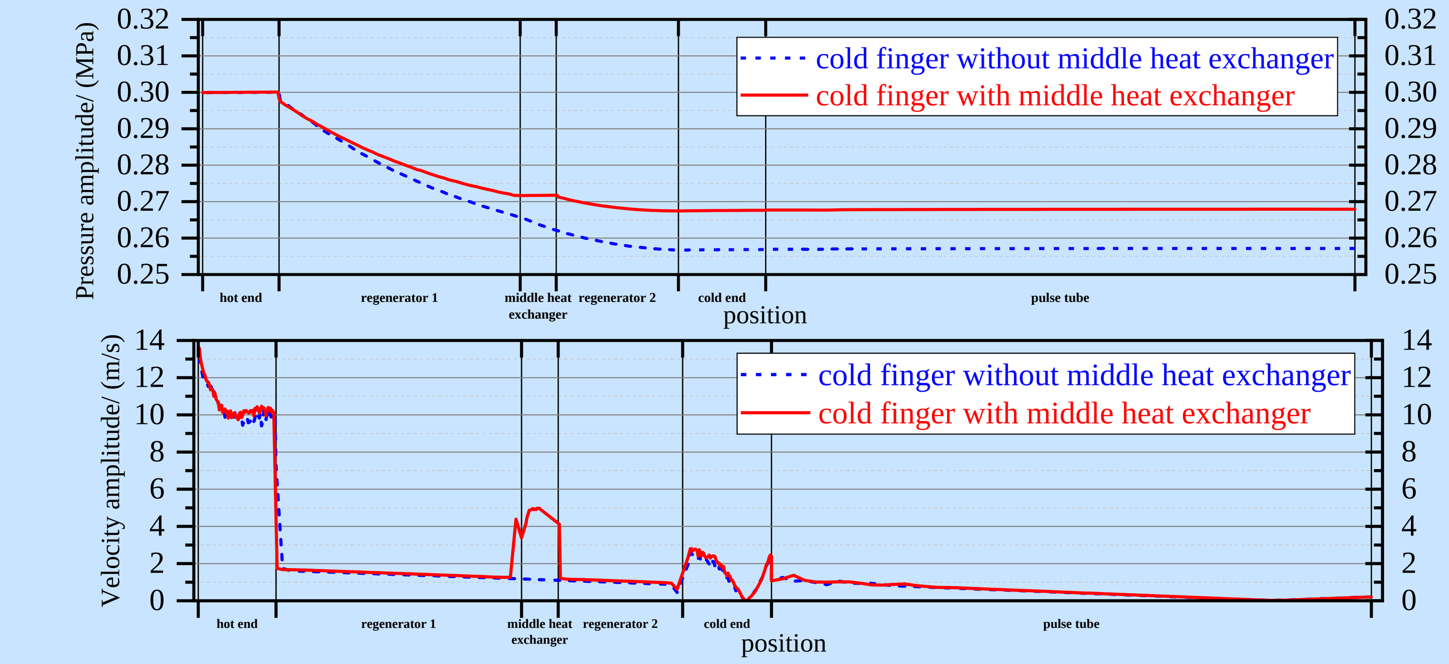
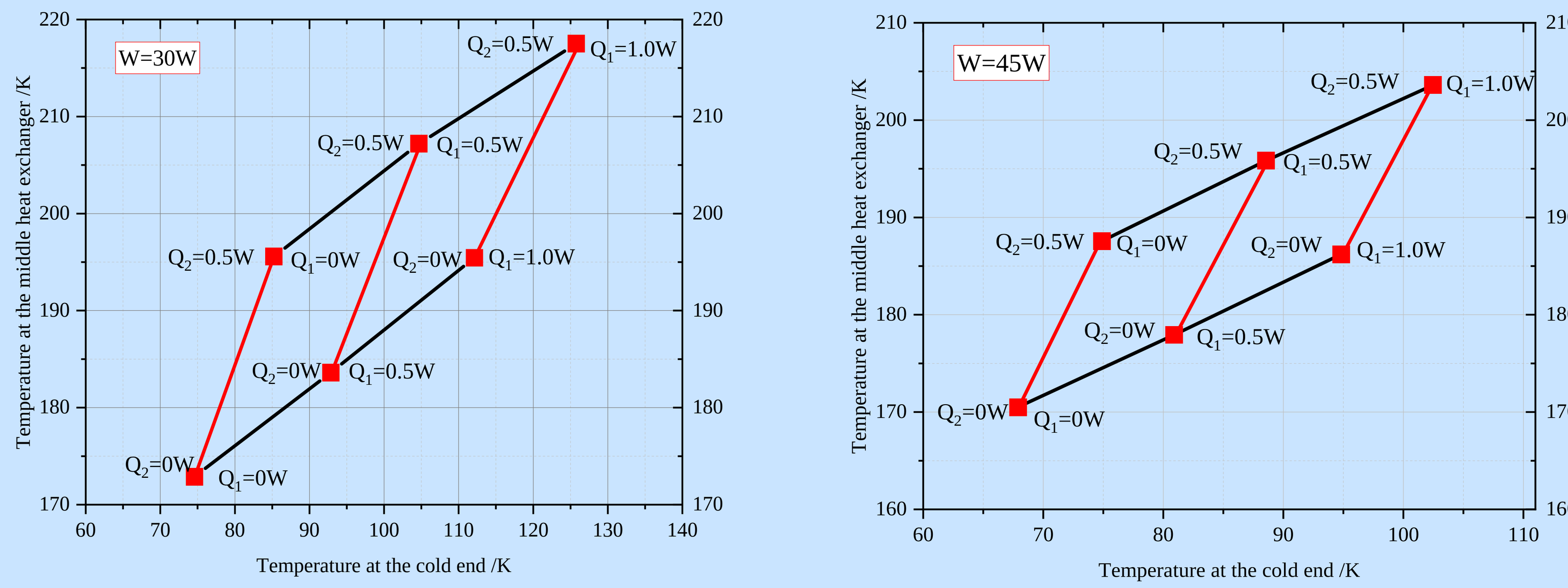


figure 4. Comparison of pressure and velocity amplitude of the cold finger with and without middle heat exchanger

Experiment results

The performance of the pulse tube cryocooler with middle heat exchanger is shown in figure 5. The operation frequency and the phase shifter have been experimentally optimized for minimum cooling temperature. A no load temperature of 67.9K at the cold end and 170.5K at the middle heat exchanger was obtained with 45W input power and an operating frequency of 111Hz and the cooling capacity of 0.5W @ 88.5K & 0.5W @ 195.8K was obtained simultaneously.



a. with 30W input power b. with 45W input power

Figure 5. The cooling performance of the cold finger with middle heat exchanger

As shown in figure 6, in the same condition, the cold end temperature of cold finger with middle heat exchanger is higher, and there are three reasons for this situation. Firstly, the middle porosity of middle heat exchanger is much lower than that of the screen, which will cause larger pressure loss in the regenerator. Secondly, the middle heat exchanger made by copper has better thermal conductivity than stainless-steel screen, and that will cause larger axial heat conduction losses. Thirdly, the experimental results were based on same length of cold finger, so the thickness of filler of the cold finger with middle heat exchanger was insufficient, which caused poor cooling capacity.

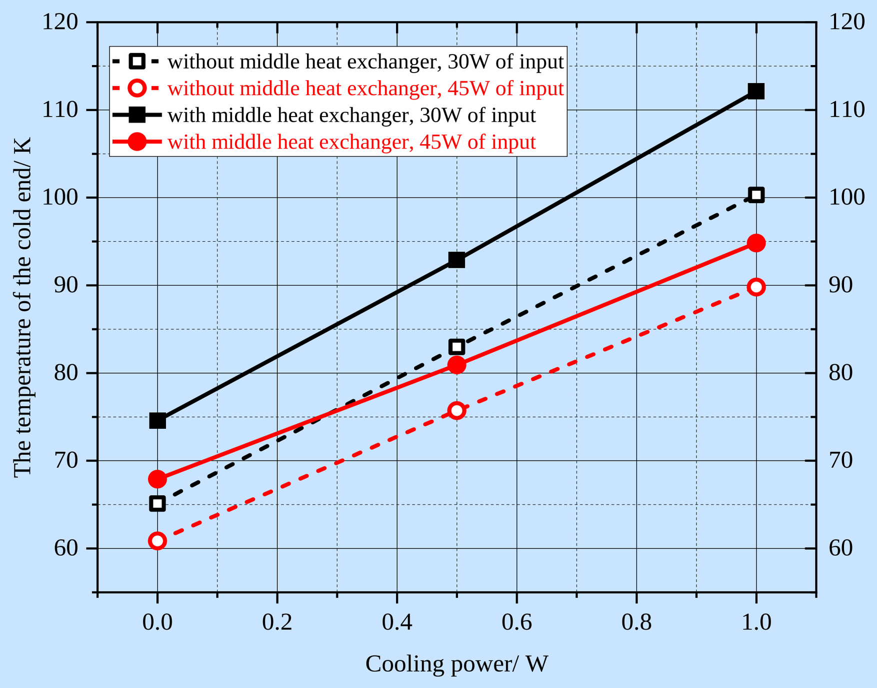


figure 6. Cooling performance of cold finger with and without middle heat exchanger

Conclusion

This paper uses a middle heat exchanger to exchange cooling power in the middle of the regenerator. A 3D CFD model was established to analyze the influence of middle heat exchanger on the cold finger. Experiments were carried out to verify the simulation results. With 45W input power and an operating frequency of 111Hz, the cooling capacity of 0.5W @ 88.5K & 0.5W @ 195.8K was obtained simultaneously. This paper has proved the feasibility of obtaining cooling power at different temperatures simultaneously with single stage pulse tube cryocooler. To improve the performance of the cryocooler, a series optimization will be carried out in the future.

Acknowledgement

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