Design and Optimization of a High Frequency Miniature Pulse Tube Cryocooler

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Abstract

A micro coaxial pulse tube cryocooler has been developed for infrared detection. This paper presents the experimental data of performance and describes the optimization process of a pulse tube cryocooler in detail. With a tiny size and high frequency, this cryocooler is driven by the linear compressor. The combination of inertance tube and buffer is adopted as phase shifter. The effect of the structure and operating parameters on cryocooler performance are investigated through experiments. As a result, the regenerator has dimension of 8 mm diameter, and the optimal frequency is 175 Hz and 225 Hz when the length is 40 mm and 35 mm. It can provide a cooling power of 0.5 W and 0.43 W respectively at 80 K with an 30 W input power.

Experimental system

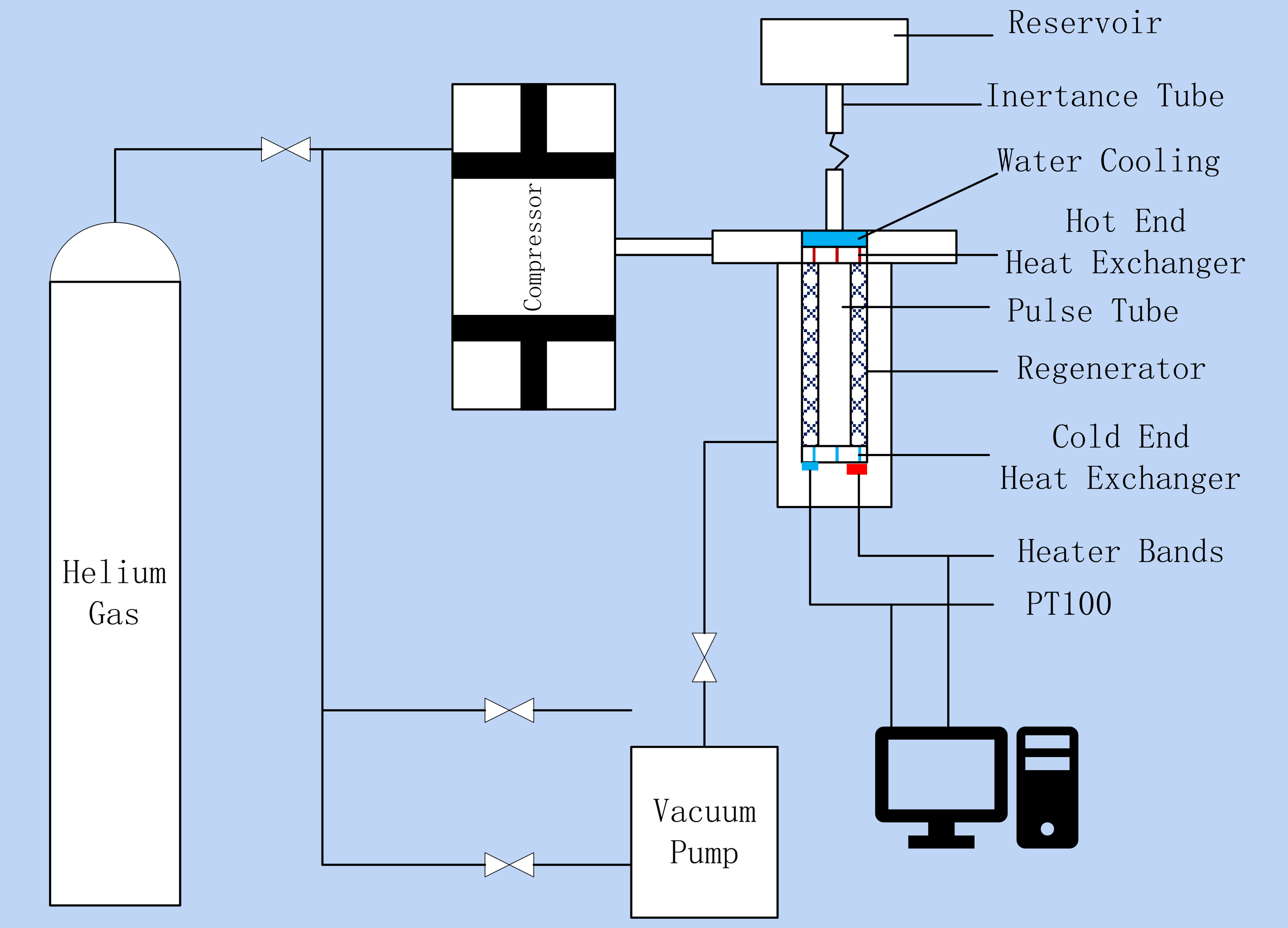

Fig. 1. Schematic of the experimental apparatus

This cryocooler uses a back-to-back moving coil linear compressor in a split configuration with a coaxial pulse tube cold head. The inertance tubes and reservoir are used to obtain the proper phasing. The PT100 and the heater bands installed at the cold tip are used to collect the temperature and cooling power.

Optimization process

The length of regenerator

Different lengths of regenerator cause changes of internal phase shift between the mass flow and pressure. Five sets of regenerators with length variation are selected, and the filling proportion of stainless steel screen is consistent. The inertance tubes and operating frequency are adjusted to ensure the best performance of each set.

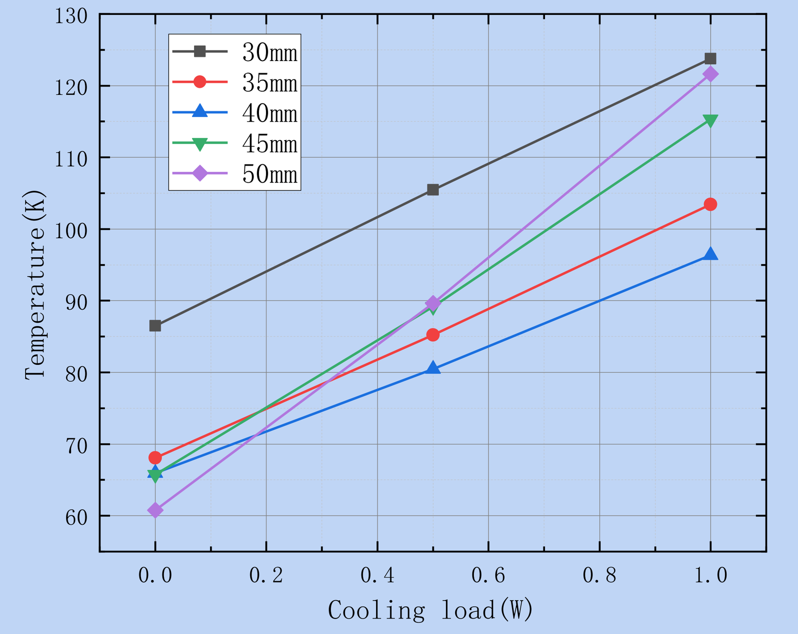

Fig. 2. The cooling load at different lengths

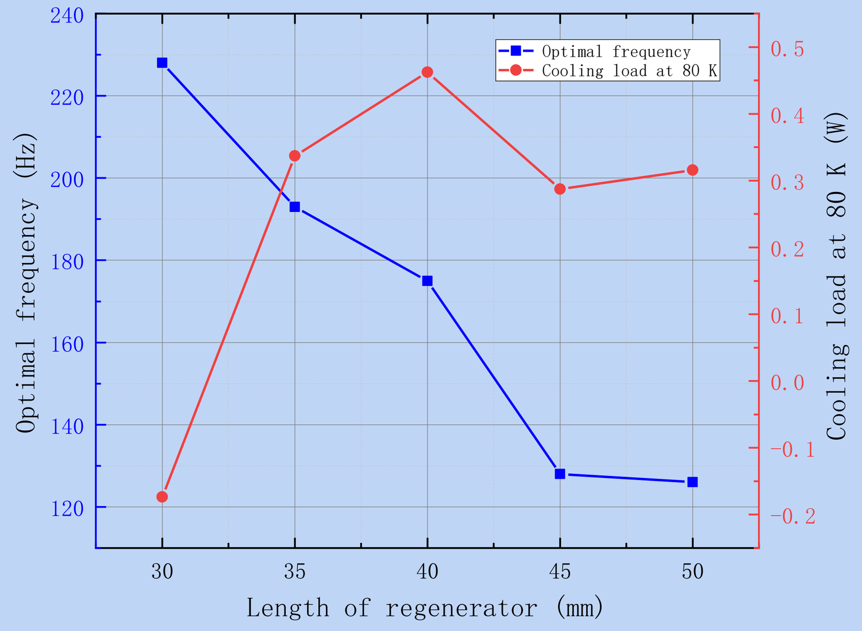

Fig. 3. The parameters at different lengths

Figure 2 shows the cooling capacity of each regenerator with 30 W input power, which indicates that the no-load temperatures of the cryocooler decrease with the increase of the length. The cooling ability of 30 mm regenerator substantially declines because of the growth of the temperature gradient and axial heating loss. This kind of loss can be reduced if the needed temperature of the cold head increases, which means there are greater advantages to apply shorter cold finger in higher temperature zone, they can reach the similar performance while taking into account the size issue.

Figure 3 displays the optimal frequency and the cooling load at 80 K of each regenerator. A negative value indicates that the cryocooler cannot reach 80 K under that condition. With the increase of the length, the total length of the inertance tubes increase and the optimal frequency decrease.

The matrix in the regenerator

The specie and filling method of matrix have an obvious influence on the cooling capacity of cryocoolers. The stainless steel screen is used due to the features of small hydraulic diameter and high heat transfer coefficient. Changing proportion of these two kinds of meshes and the testing results are showed in Figure 4. The best performance is achieved when proportion of #600 mesh is 75%.

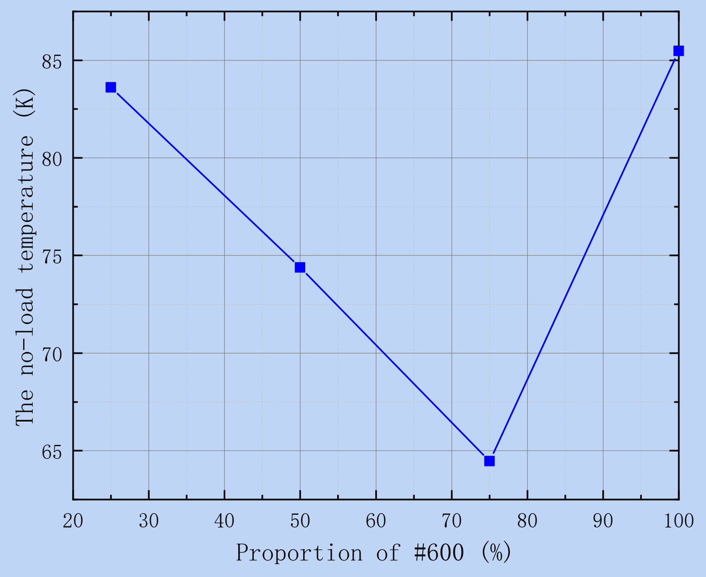

Fig. 4. The lowest temperature at the different proportion of #600

The hot end heat exchanger

The variables of hot end heat exchanger include the numbers and width of channels, which mainly affect the area of gas-solid heat transfer(AHT) and gas-flowing(AGF). The AHT and AGF of one group are defined as 1H and 1F, and five groups of structure are set to find the optimal exchanger.

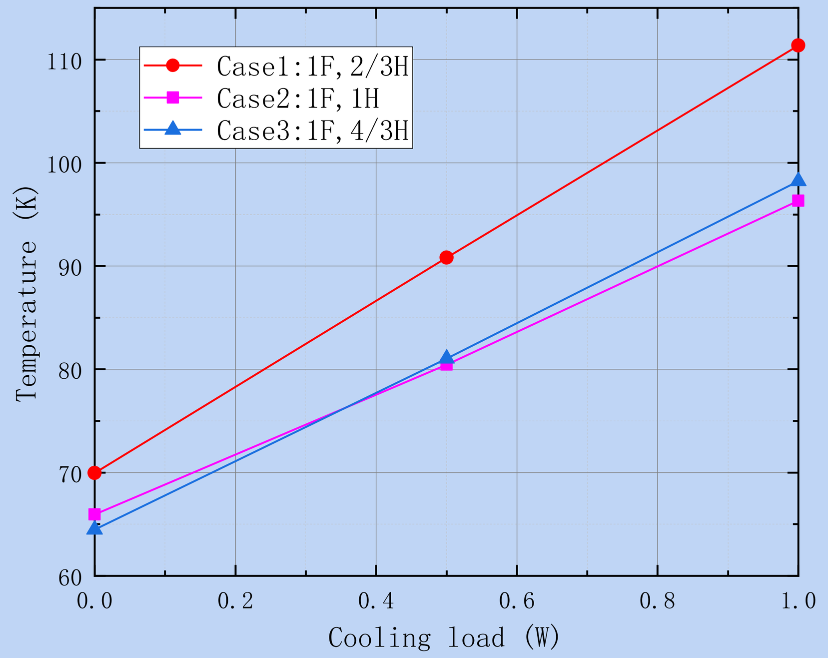

Fig. 5. (a) The cooling power in Case1,2,3

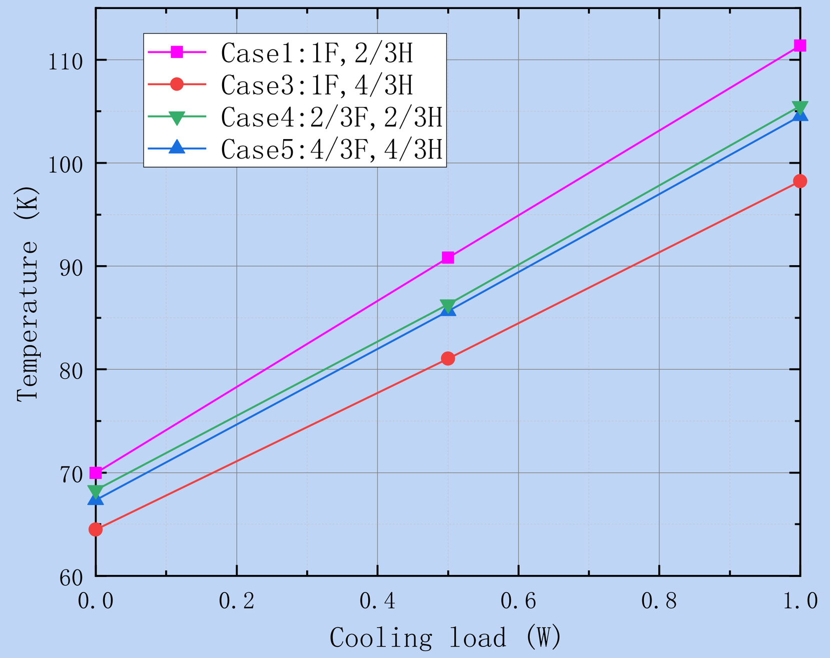

Fig. 5. (b) The cooling power in Case1,3,4,5

Figure 5 (a) shows the results of case1,2,3 that to increase AHT while controlling AGF is identical by decreasing the width of channels and increasing the numbers of channels. The heat transfer coefficient and the gas flow resistant are both improved. The no-load temperature declines with the growth of AHT, which suggests that such changes of structure are advantageous.

Similarly, maintaining AHT that is the number of channels is unchanged and the results of case 1,3,4,5 are displayed in Figure 5 (b). To compare the case1,4 and case3,5 respectively, the heat exchanger with the smaller AGF has the better cooling capacity as a possible result of the increase in gas flowing velocity.

The charge pressure

The filling pressure is related to the amplitude of the mass flow and pressure, the no-load temperature and the optimal frequency with 2-5 MPa filling pressure are tested, and the results are showed in Figure 6.

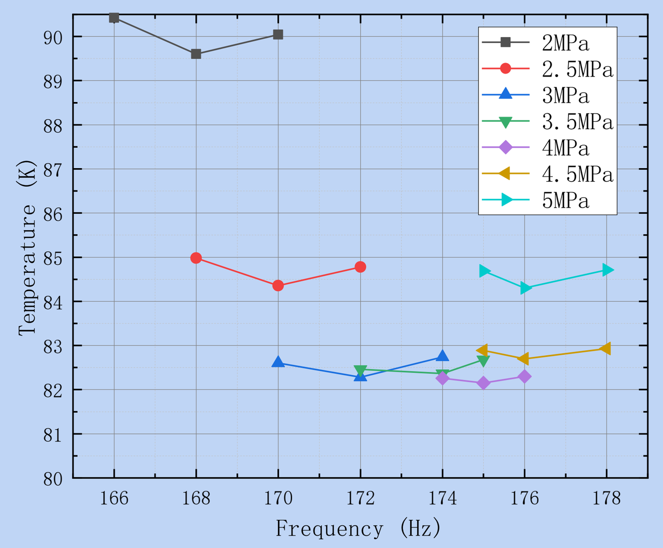

Fig. 6. The optimal frequency with different charge pressure

Conclusions

This paper presents the optimization of a micro pulse tube cryocooler and shows the test results. At 283 K reject temperature, this micro cryocooler can reach the lowest temperature of 65 K and provide 0.5 W cooling power at 80 K with 30 W input power when the regenerator is 40 mm long, and for 35 mm size, it can provide 0.43 W at 80 K. With 10 W electric power input, these two lengths can obtain 0.8 W or 0.5 W cooling power at 150 K respectively.

Acknowledgement

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