Performance of high frequency miniature pulse tube cryocooler with different cold fingers

Yang Ouyang[1,2], Houlei Chen[1], Enchun Xing[1,2], Qingjun Tang[1], Jia Quan[1], Yuexue Ma[1] & Jingtao Liang[1]
1 Key Laboratory of Space Energy Conversion Technologies, Technical Institute of Physics and Chemistry CAS, Beijing, 100190, China
2 University of Chinese Academy of Sciences; Beijing, 100190, China

Introduction

Space and military applications require limited installation space and load capacity. Therefore, the new refrigerating machine should have the advantages of long life, small volume, light weight and fast cooling rate. High-frequency miniature pulse tube cryocooler not only meets the requirements but also has the advantages of simple structure, low vibration and high reliability.

This study aims to find the relationship between the size and performance of the high-frequency miniature pulse tube cryocooler by using six different cold fingers. The pulse tube cryocooler is composed of linear compressor, cold finger, inertance tube and reservoir. System weight is less than 2 kg, which can cool down from 300 K to 80 K within 3 minutes. Input electrical power is 45 W and the average pressure is 4.2 Mpa. The best cold finger's cooling capacity is 2.2 W at 80 K. The refrigerating efficiency is 4.9% and the relative carnot efficiency is 13%.

Experimental apparatus

Fig.1 High-frequency miniature pulse tube cryocooler (<2 kg) and six different coaxial cold fingers

Table 1 Key dimension of the 6 cold fingers

	Cold fingers					
	CFA	CFB	CFC	CFD	CFE	CFF
Regenerator length (mm)	33	33	33	38	38	38
Regenerator diameter (mm)	10	12	14	10	12	14

Experimental results and discussion

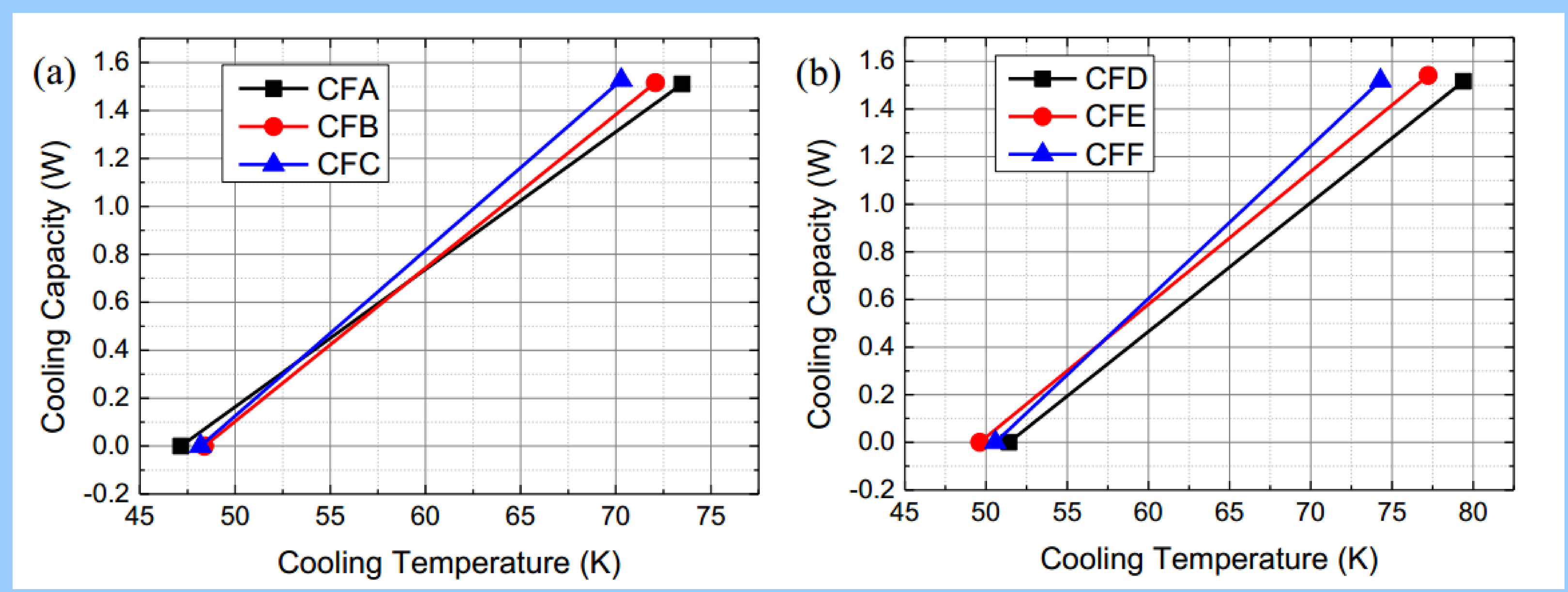

Fig.2 Cooling performance of the cold fingers change with diameter ((a) Regenerator length = 33 mm; (b) Regenerator length = 38 mm).

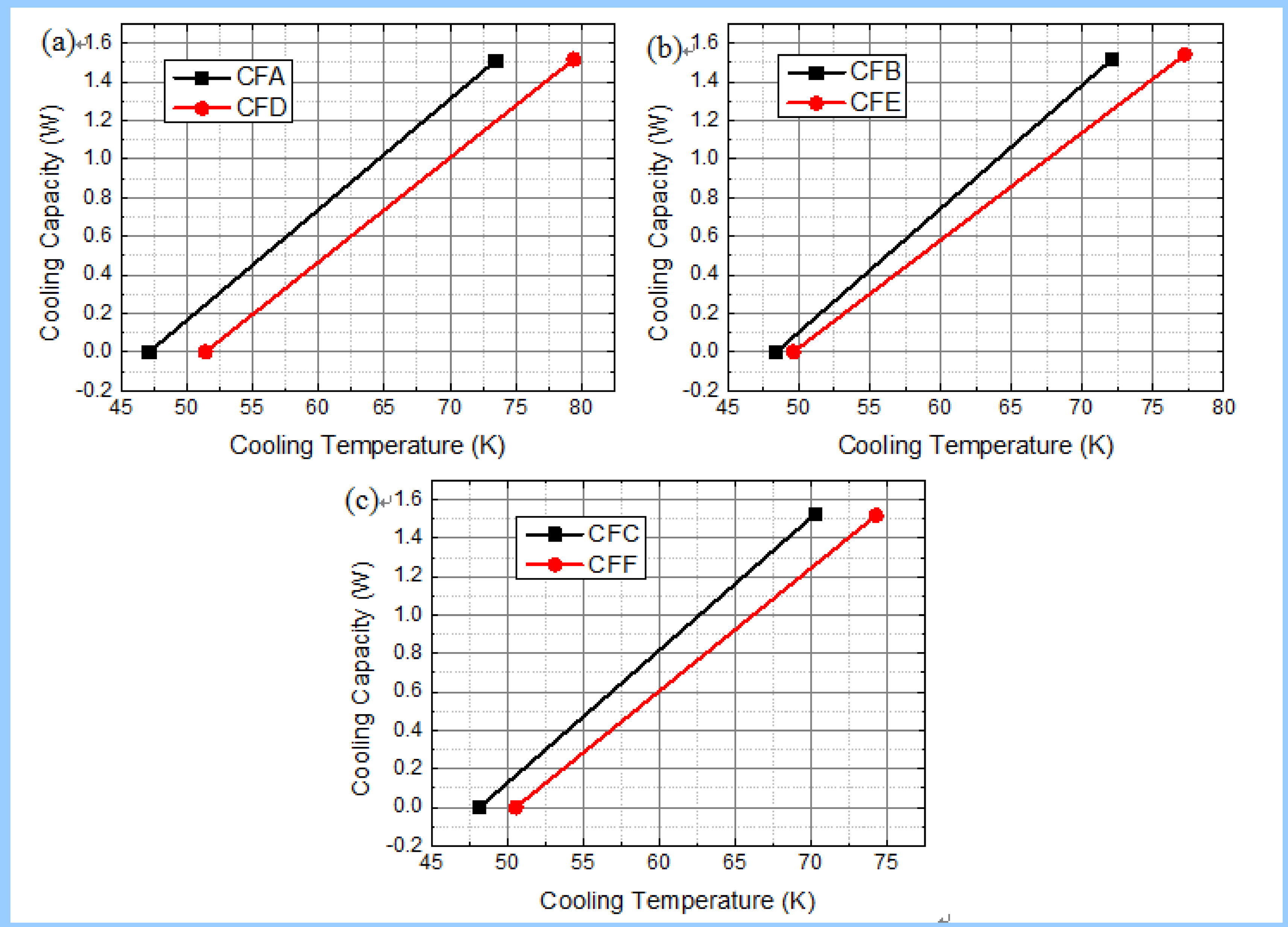

Fig.3 Cooling performance of the cold fingers change with length ((a) Regenerator diameter = 10 mm; (b) Regenerator diameter = 12 mm; (c) Regenerator diameter = 14 mm)

Keep the length of cold fingers constant and the cooling performance of cold fingers change with diameter, shown in fig. 2. When the length of cold finger keeps constant, the cold finger with larger diameter perform better. Fig. 3 presents the experimental results of the cold finger whose diameter is fixed. It can be seen that the cold finger with shorter length has better cooling performance.

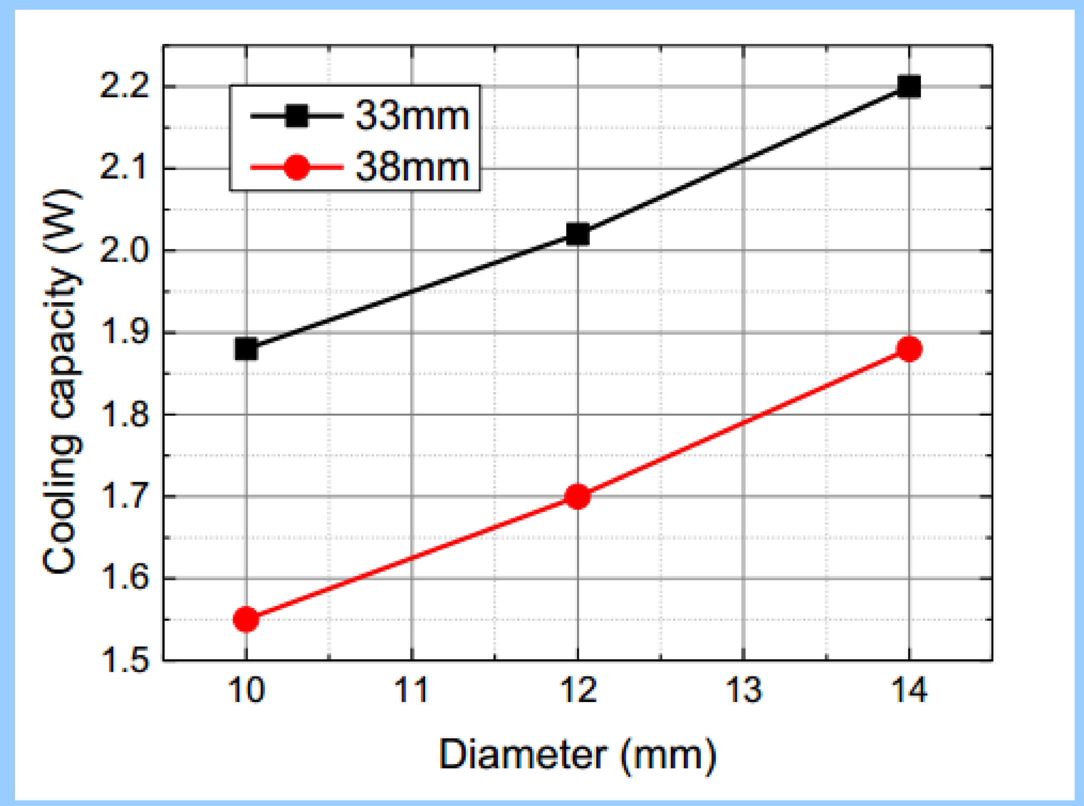

Fig.4 Cooling capacity of different cold fingers

Fig.4 shows the cooling capacity of different cold fingers at 80K. As shown in fig.4, the increasing diameter and the decreasing length of cold finger improve the cooling capacity.

The reasons of this phenomenon are as follows. As the diameter of cold finger increases, the area for the gas to exchange heat becomes larger. Thus, the cooling performance is better. As the length of cold finger decreases, the pressure loss along the way is lessened. So, there could be more delivered acoustic power. Therefore, the shorter cold finger performs better.

Some researchers put forward that the model of a cold finger is closely analogous to the model of a simple a.c. electronic circuit. The dynamic pressure and mass flow at the entrance of the cold finger are analogous to the voltage and current. Then, the cold finger also can be analogous to resistance. We can give a bold guess.

$$R = \frac{cL}{S}$$

Where R is resistance of cold finger, L is length of cold finger, S is cross-section area, c is related to the material and porosity of cold finger. The increasing S and decreasing L lead to a smaller R. The smaller the R is, the better the cooling performance is. It is the same as the experimental results.

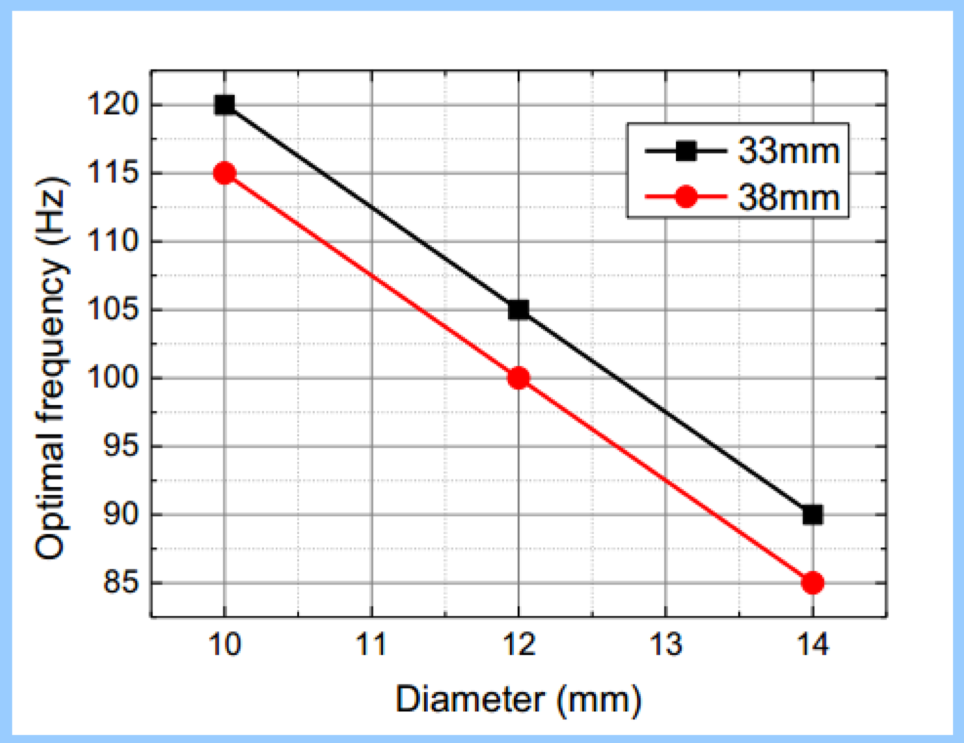

Fig.5 Optimal frequency of different cold fingers

Fig.5 gives the optimal frequency of different cold fingers with the same inertance tube and reservoir. It illustrates that the optimal frequency increases with the decreasing diameter and length of the cold finger. In general, the optimal frequency rises as the volume of the cold finger lessen. Comparing CFA to CFF, it is apparently that CFA is smaller than CFF, but CFA has the same cooling capacity as CFF, and CFA's optimal frequency is higher than CFF's. Therefore, it's easy to know that the volume of the cold finger can be further reduced by increasing the operating frequency.

It can be explained as follows. Firstly, the gas moving distance reduces as the operating frequency rises. Then, the temperature difference the gas experiencing in reciprocating motion decreases, which improves the refrigerating efficiency. Secondly, the rising frequency can increase the number of refrigeration cycles per unit time. Thus, the cooling capacity can be improved. Thirdly, the mass flow lessens as the volume of cold finger reduces, which deteriorates the cooling performance of cold finger. These advantages and disadvantages cancel out each other. Therefore, increasing frequency can keep the cooling capacity stable as the volume of cold finger reduced.

Conclusion

The characteristics of cold fingers with different diameter and length are investigated in this paper. The experimental results show that the increasing diameter and the decreasing length of cold finger will improve the cooling performance within the experimental data range. The reason for this is that the area for the gas to exchange heat becomes larger as the diameter of cold finger increases and the pressure loss along the way is lessened as the length of cold finger decreases. All the cold fingers can cool down from 300 K to 80 K within 3 minutes. The best cold finger's cooling capacity is 2.2 W at 80 K. The pulse tube Cryoclooer's refrigerating efficiency is 4.9% and the relative carnot efficiency is 13%. Simultaneously, while using the same inertance tube and reservoir, the optimal frequency of cold fingers increases with the decreasing diameter and length of the cold finger.