Miniature Pulse Tube Research

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ABSTRACT

High frequency pulse tube coolers have made great progress in the past ten years. The coaxial configuration is the most attractive version to customers because of the similarity to the Stirling expander. For some application such as the standard dewar, the coaxial structure is required and the diameter of pulse tube cryocooler (PTC) cold finger is also an important parameter. A small regenerator diameter, such as 6 mm, is needed for some applications. In this paper, the design and test of a 6 mm diameter coaxial PTC is introduced and compared. The no-load temperature of 67 K with 30 W input power, and about 0.2 W at 80 K cooling power has been achieved. The simulation result is about 10K cooler than the test. This indicates that there is still margin for improvement.

INTRODUCTION

High frequency pulse tube coolers have made great progress in the past ten years.[1, 2] For pulse tube and regenerator arrangements, the coaxial configuration is the most compact one and could increase the strength of the cold finger. It is becoming the most attractive choice to customers because its structure is like a normal Stirling cold head.

For some applications, such as Standard Advanced Dewar Assembly (SADA), a coaxial configuration with a very small diameter, 6 mm, is needed.[3] Simulations and tests have already been performed on this type of configuration.[4]

The difficulty with the 6 mm diameter PTC is the increased system loss. The most evident loss is the ratio of the increased heat conduction loss to the total loss. The adoption of low thermal conduction materials such as Ti alloy is required to solve this problem. In fact, the biggest problem for a miniature pulse tube is the increase in pulse tube loss. When the pulse tube diameter is small, the secondary flow within the pulse tube will play the main role and the enthalpy loss will be very big.[5] The smallest pulse tube suitable for many application is thought to be about 6 mm diameter.

The pulse tube research group at the Technical Institute of Physics and Chemistry, Chinese Academy Science, formerly the Cryogenic Lab, has been concentrating on a coaxial configuration for many years. The smallest 8 mm diamter coaxial PTC has been finished with satisactory performance for some applications.[6] In the past two years, the authors have developed three kinds of coaxial PTCs with reasonable performance with regenerator diameters of 30 mm, 15 mm, and 10 mm. The effort to develop a 6 mm diameter pulse tube has been started recently. Figure 1 is a photo

Figure 1. Photo of four coaxial PTCs with different regenerator diameters

of four different pulse tube cold heads with different regenerator dimensions. The smallest one is a regenerator tube with a diameter of 6 mm.

In this paper, the design and test of the 6 mm diameter coaxial PTC is presented.

NUMERICAL SIMULATION AND ANALYSIS

Since the regenerator tube diameter is fixed at 6 mm, the most important parameter which can be changed is only the pulse tube diameter. Using simulations, the pulse tube dimension can be confirmed.

The first simulation is carried out for the case without a double-inlet. The effect of the double-inlet is evaluated and the refrigeration capacity is determined. Also, the difference in performance between stainless steel (SS) mesh no. 500, and mesh no. 400 are compared.

Figure 2 shows the relation of input PV power vs. lowest temperature for SS mesh no. 400. With increases in the PV input power, Tc goes down quickly at low input power, but at 30 W, the rate of change is slowed. This means that increasing the pressure wave to drop the temperature furhter is almost coming to the end.

Figure 3 shows the effect of the double-inlet for two kinds of meshes with 20 W of PV input power. With double-inlet closed, SS mesh no. 500. produces a temperature about 5 K lower than the SS mesh no. 400. When the double-inlet is opened, this difference decreases to less than 1 K. The double-inlet for SS mesh no. 500. is not very effective. This might be attributed to the higher efficiency or small loss of the regenerator, because double-inlet could decrease the regenerator flow rate and then decrease regenerator loss, a higher efficiency in the regenerator means the loss could be decreased.

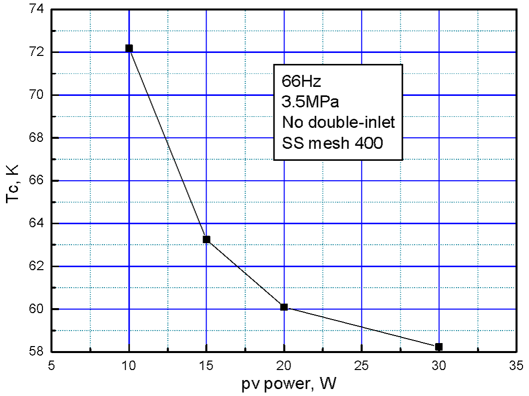

Figure 2. Change of lowest Tc with input pv power

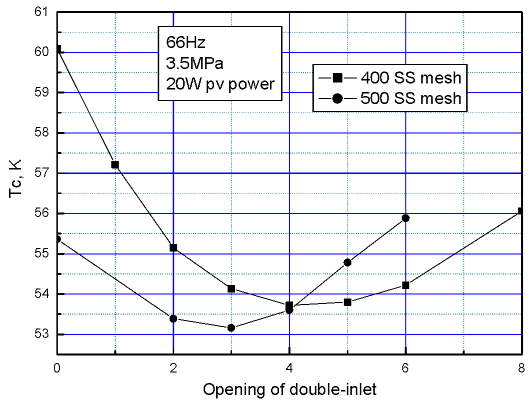

Figure 3. Effect of double-inlet on lowest temperature for two cases

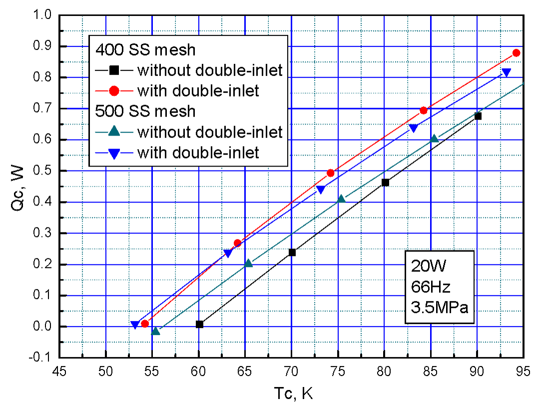

Figure 4. Comparison of cooling capacity for several cases

Figure 4 is a comparison of refrigeration capacity. Because the SS mesh no. 500. produces a higher flow resistance loss and the pressure wave in pulse tube is small, this results in a small slope of Qc vs. Tc when compared with SS mesh no. 400. Without the double-inlet and below 90 K, SS mesh no. 500. produces better results than the SS mesh no. 400. With the double-inlet, because the lowest temperature is a small difference, SS mesh no. 400. produces better results when the temperature is higher than 65 K.

EXPERIMENTAL RESULTS AND ANALYSIS

Many experiments have been carried out based on the simulation, design and fabrication. Two pulse tube diameters have been tested; the later one is optimized to get the better results and is introduced here. For this version, two are finished with SS mesh no. 400. and mesh no. 500. separately just like in simulation.

Figure 5 is the change of refrigeration temperature Tc with input power for SS mesh No. 400, with and without double-inlet. Compared to Fig. 2, without double-inlet, the lowest temperature is about 20 K higher in experiments. This reveals the complexity of small cooler system; there are losses that the simulation can not predict. On the other hand, the double-inlet is much better than that the simulation results; the double-inlet could further decrease the temperature of about 7 K in Fig. 3 while test results show the difference of 14 K at 30 W input power. This change partly compensates for the above-mentioned 20 K difference. This phenomenon of the double-inlet is common for some coolers and it shows the advantage of double-inlet to compensate for system losses to a certain extent.

Figure 6 shows the relation of Qc vs. Tc for SS mesh no. 400. With 30 W of input power, the cooling power could be 0.2 W at 80 K. With 40 W of input power, the cooling power is around 0.29 W at 80 K. This is the best result reported for the 6 mm diameter coaxial PTC. Compared to Fig. 4, both the cooling power and the slope are small.

Figure 7 shows the results for SS mesh no. 500. Contrary to the simulation, the refrigeration temperature, Tc, for SS mesh no. 500. is higher than the temperature for mesh no. 400, while the effectiveness of the double-inlet is similar. This test shows that in theory the SS mesh no. 500. may gain better results for certain cases, but for a real system some losses are included, therefore, it may not work as predicted.

Figure 8 is a comparison of the cooling power for SS mesh no. 400 and mesh no. 500. Because of the the higher flow resistance of SS mesh no. 500, the slope for it is evidently small. It is similar to Fig. 4.

Finally, the operating frequency is now discussed. This problem is closely related to the efficiency of compressor. If the PTC dimension is changed, the best frequency or resonance frequency will change greatly for a fixed compressor. Only near the resonance frequency of compressor, there will be higher PV power output and better refrigeration effect. Figure 9 is the relation of frequency and refrigeration temperature. The best frequency is near 66 Hz. In fact, the cooler should be run at around 50 Hz, although the compressor must be adjusted for this frequency.

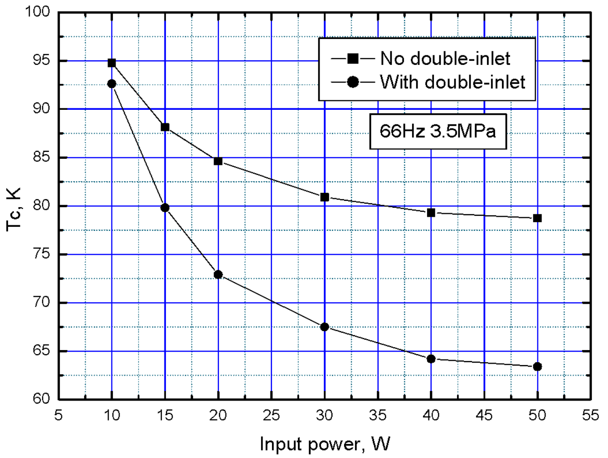

Figure 5. Change of refrigeration temperature with input power

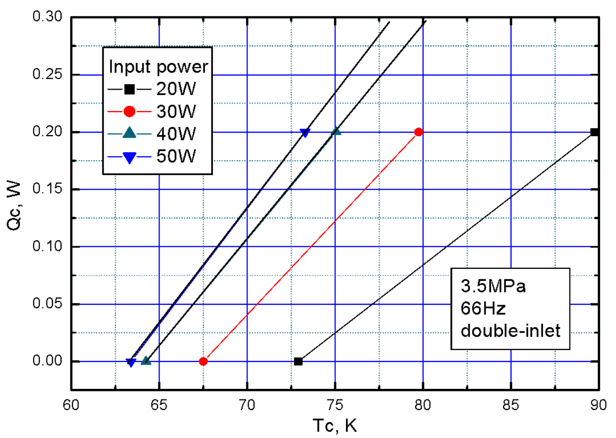

Figure 6. Cooling performance of dia.6 mm coaxial PTC with SS 400 mesh

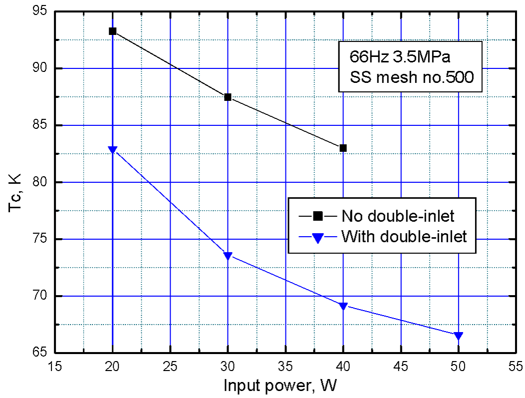

Figure 7. Experiments results for SS 500 mesh.

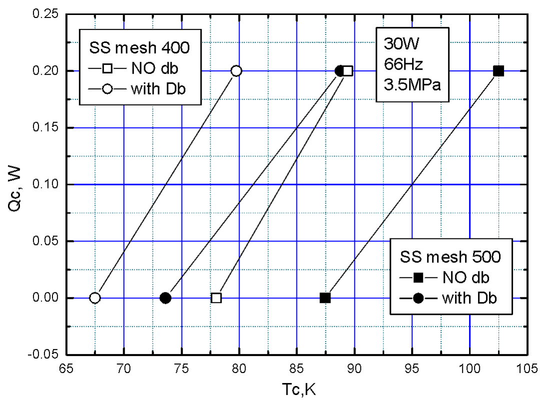

Figure 8. Comparison of cooling power and their slopes.

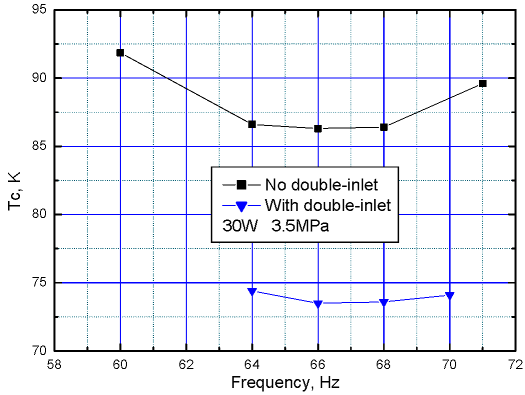

Figure 9. Relation of frequency and refrigeration temperature

CONCLUSIONS

This paper introduces the design and experimental results of a 6 mm diameter coaxial PTCs. Although there is still a big difference between the simulation and experiment, this PTC could provide 0.1 - 0.3 W at 80 K cooling capacity with less than 40 W of input power. This research shows that a 6 mm PTC is not only feasible, but could perform better for certain applications.

ACKNOWLEDGMENTS

This work is supported by Natural Sciences Foundation of China (50206025).

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