Experimental Investigation of a G-M Type Co-axial Pulse Tube Cryocooler

K. Yuan, J.T. Liang, Y.L. Ju*

Cryogenic laboratory, Technical Institute of Physics and Chemistry, Chinese
Academy of Sciences, P.O. Box 2711, Beijing, P.R. China

ABSTRACT

A G-M type co-axial pulse tube cryocooler is firstly optimized from three aspects: the dimensional lay out of pulse tube and regenerator, the filling materials in the regenerator and the structure of the cold end heat exchanger. Three different types of phase shifters: needle valves, capillaries and asymmetry-nozzles are employed at hot end of the pulse tube for the adjustment of phase shift between the gas mass flow and pressure oscillations. Influences of DC flow are investigated experimentally. It is found that a proper positive DC flow has positive effects on the cooling performance of the co-axial pulse tube cryocooler.

INTRODUCTION

Due to the absence of mechanical moving component in the low temperature region, pulse tube cryocooler (PTC) has inherent merits in terms of mechanical simplicity, high reliability, low mechanical vibration and low cost[1]. This cryogenic cryocooler has been used for commercial applications such as cooling of infrared devices and sensors, superconducting electronic devices, etc. Among three configurations of the PTC, co-axial structure is the most compact and convenient for actual applications.

The performance of the PTC has been greatly increased by improvements of different phase shifters located at hot end of the PTC[2-4]. For a co-axial PTC, the phase shifters and the coupling heat transfer between the regenerator and the pulse tube, which is introduced by the mismatch temperature profile along the axial-direction of the regenerator and the pulse tube, affect the performance of the cryocooler. In this paper, a G-M type co-axial pulse tube cryocooler is firstly optimized from three aspects. Then, the effects of three different phase shifters and the coupling heat transfer are investigated experimentally by analyzing the external wall temperature profile of the regenerator. It is found that a proper positive DC flow is benefit for the increasing the cooling performance of the co-axial pulse tube cryocooler.

EXPERIMENTAL SETUP

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*Corresponding author. Tel: +86-10-62627302; Fax: +86-10-62564049; E-mail: yonglin@cl.cryo.ac.cn.

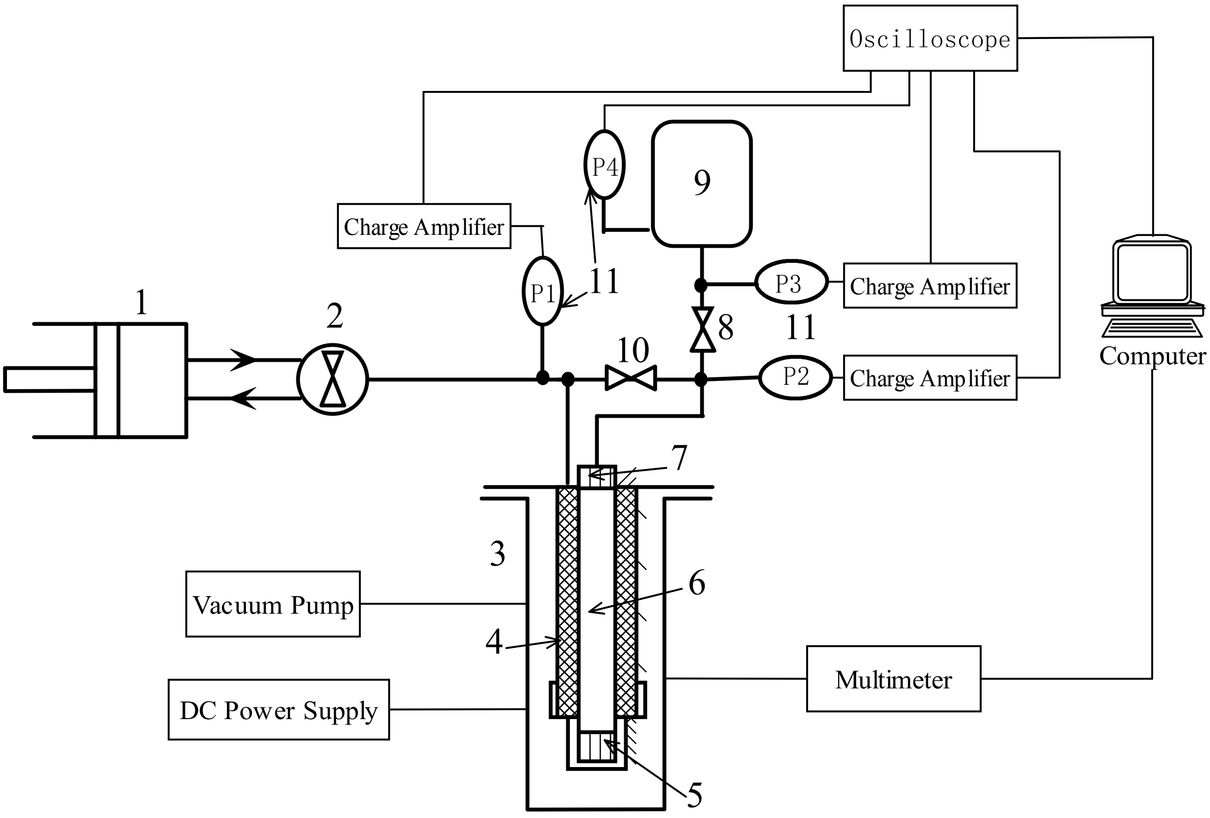

Figure 1. Schematic diagram of the experimental apparatus.

1 compressor, 2 rotary valve, 3 vacuum chamber, 4 regenerator, 5 cold heat exchanger, 6 pulse tube, 7 hot heat exchanger, 8 orifice, 9 reservoir, 10 double inlet, 11 pressure transducer

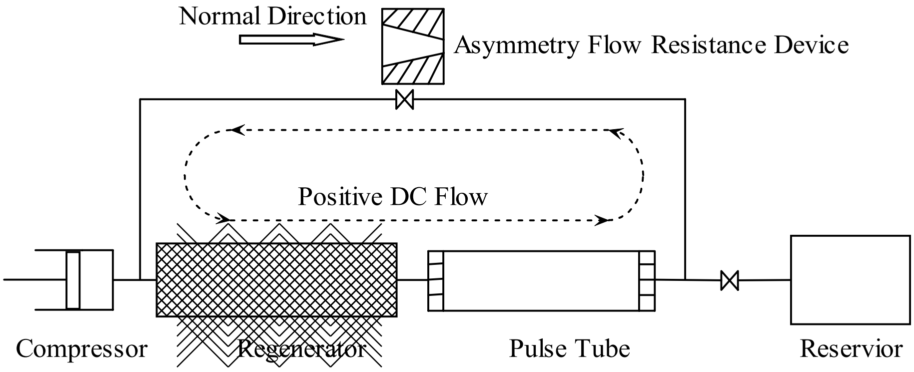

Figure 2. The direction of asymmetrical flow resistance devices and DC flow in PTC.

The schematic diagram of the experimental apparatus is shown in Fig. 1. The input power of the compressor is about 1.1kW. The operating frequency of the rotary valve can be adjusted from 1 to 10 HZ. The pulse tube is made of nylon with a wall thickness of 1.2mm and is placed inside the annular stainless steel screens in the regenerator.

Three different types of phase shifters, the needle valve, the capillary and the asymmetry-nozzle, are used at the hot end of the pulse tube. For the asymmetrical flow resistance devices such as the needle valve and the asymmetry-nozzle, the flow resistances across positive and negative direction are different in one cycle. In this paper, the asymmetrical flow resistance devices are defined as used in normal direction when the gas flow directs from the inlet of the

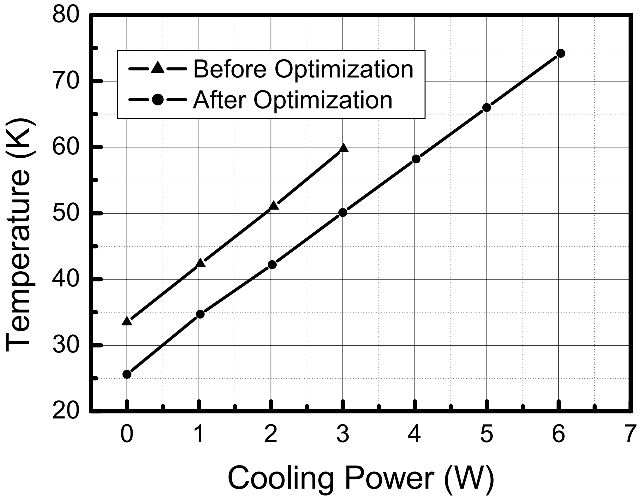

Figure 3. Cooling performance of the PTC before and after the optimization.

regenerator to the hot end of the pulse tube via the double inlet valve encounters smaller resistance, otherwise we define that they are used in reversed direction, as shown in Fig. 2.

Four copper-constantan thermocouples (Type T) are arranged along the external wall of the regenerator. The temperature of the cold tip is measured by a Pt-100 resistant thermometer. Three small quartz differential pressure transducers (KISTLER, Type 601A), connected to a charge amplifier (KISTLER, Type 5011) having a high natural frequency (150 kHz), are used tomeasure the transient pressure wave. Another pressure transducer is mounted on the reservoir to measure the charge pressure, as shown in Fig. 1. The cooling power of the PTC is measured by a DC power supply (HP 6634A).

EXPERIMENATAL RESULTS

Optimization of the PTC

First, the PTC is optimized from three aspects: the dimension of the cryocooler, the filling material in the regenerator and the structure of the heat exchanger at the cold end. Fig. 3 compares the cooling performance of the PTC before and after the optimization. It is clear that both the lowest temperature and the cooling power are improved remarkably. The PTC can reach the temperature range of below 30K and has the cooling capacity of about 6.0W at 75K. These experiments and all the following experiments are carried out with the charge pressure of 1.45MPa.

Results with the Needle Valve

The orifice valve is used in normal direction and adjusted to optimum opening (0.89 turns). The double inlet valve is used in normal direction and adjusted to optimum opening (3.0 turns) first, and then the double inlet valve is reversed with the previous opening. Fig. 4 compares the lowest temperatures of the PTC with the double inlet valve used in both directions under different operating frequency. It is found that the double inlet valve used in normal direction leads to lower temperature. The temperature rise of unit cooling power is about the same.

Results with the Capillaries

The capillaries, which are symmetrical flow resistance devices, consist of stainless steel tube with inner diameter of 0.6mm and outer diameter of 1.0mm. First, the capillary is used as the orifice; we change the length of the capillary to find the optimum length for the orifice pulse tube

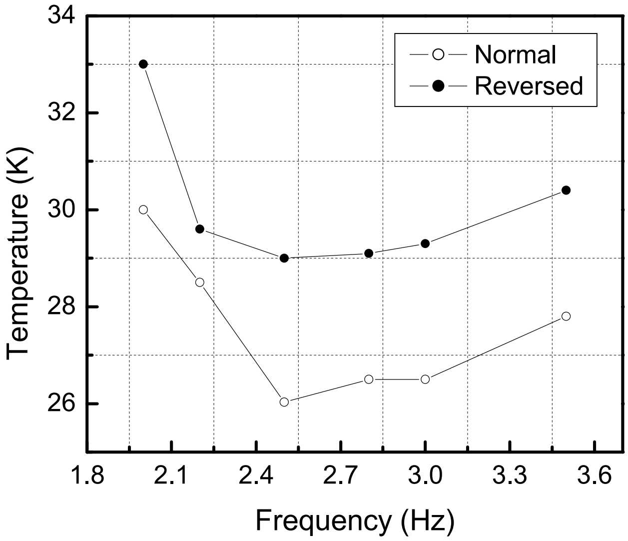

Figure 4. The lowest temperatures of the PTC with the double inlet valve used in both directions.

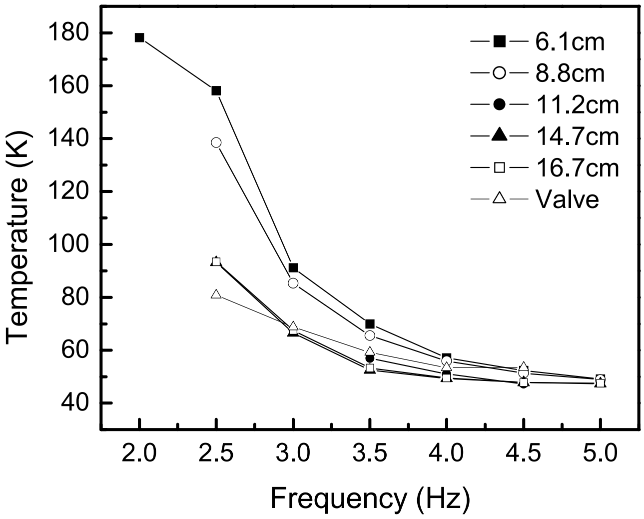

Figure 5. The relationship between the lowest temperatures of the OPTC and operating frequency.

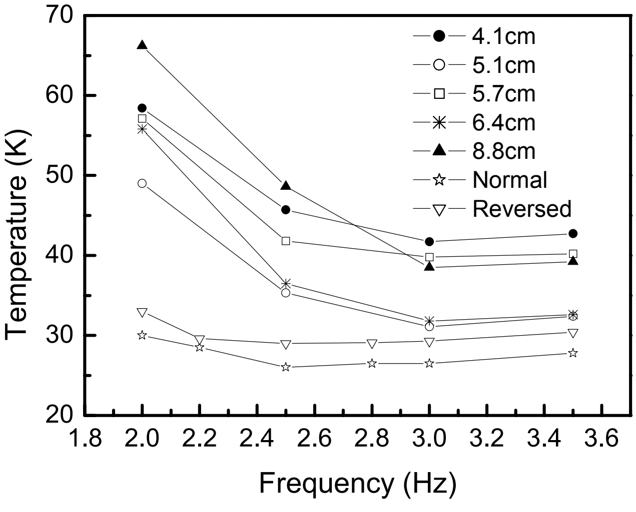

Figure 6. The relationship between the lowest temperatures of the DPTC and operating frequency.

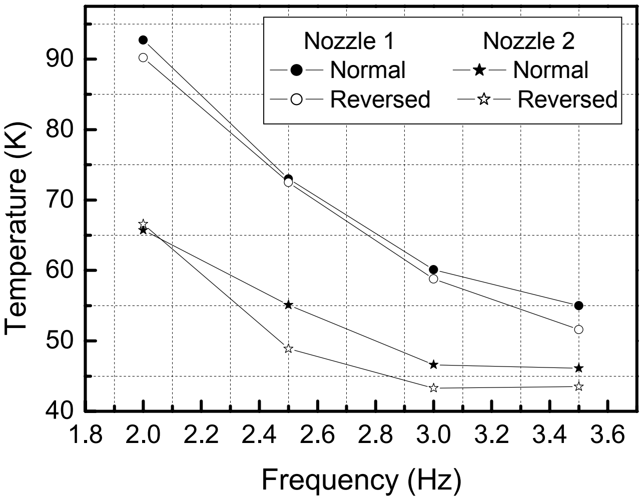

Figure 7. The lowest temperatures of the PTC with the asymmetry-nozzles used in both directions.

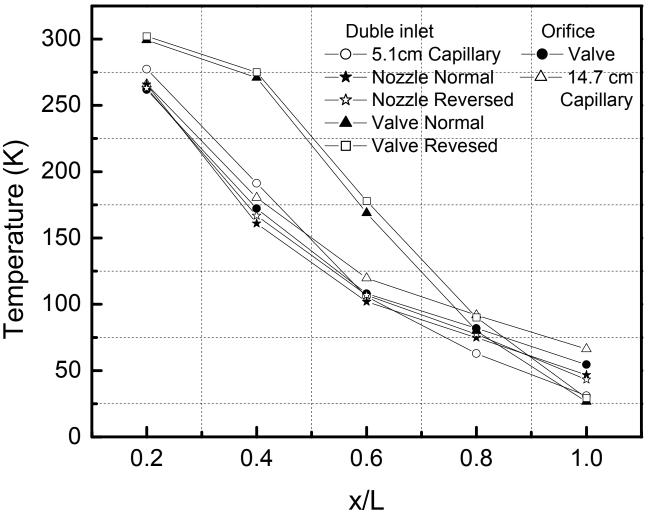

Figure 8. External wall temperature profiles of the regenerator with different phase shifters.

cryocooler (OPTC) with the double inlet valve closed. Fig. 5 gives the relationship between the lowest temperatures of the OPTC and the operating frequency with different capillaries. The results with needle valve are also shown in Fig. 5 (the curve marked as valve). For OPTC the optimum length of the capillary is 14.7cm. Then, the capillary is used as the double inlet with the valve at the orifice kept in optimum opening. With the same procedure, we find that the optimum length of the capillary for the double inlet is 5.1cm, which is illustrated in Fig. 6. The results with needle valve are also shown in Fig. 6 for comparison (the curve marked as normal and reversed).

Results with the Asymmetry-nozzles

Two asymmetry-nozzles are used as the double inlet, in which nozzle 1 is more asymmetrical than nozzle 2. Fig. 7 shows the relationship between the lowest temperatures of the PTC and the operating frequency using the two asymmetry-nozzles. It is found that the asymmetry-nozzles used in reversed direction leads to lower temperature. The difference of the temperature under the two directions varies from 0.5K to 6.2K.

External Wall Temperature Profile of the Regenerator

The external wall temperature profile of the regenerator with different phase shifters at the hot end is shown in Fig.8, where the x-coordinate is the ratio of the distance from the thermometer to the hot end of the regenerator (x) to the regenerator length (L). Here, the temperature at the cold end of the regenerator is considered the same as the temperature of the cold tip.

The temperature profiles of the regenerator and pulse tube are generally considered as an indirect judgment of the DC flow direction in the double inlet pulse tube cryocooler (DPTC)[5]. Due to the difficulties of measuring the temperature profile along the pulse tube in co-axial PTC. We only measure the external wall temperature profile of the regenerator, which is controlled by both the DC flow and the coupling heat transfer. Fortunately, we can analyze the DC flow by comparing the regenerator temperature profile of the DPTC with that of the OPTC, where exists no DC flow component. In the present study, DC flow is defined as positive when directed from the hot end of the pulse tube to the inlet of the regenerator via the double inlet valve and as negative for the opposite direction, as shown in Fig. 2.

We find in Fig.8 that the external wall temperature profiles of the regenerator are non-linear for OPTC due to the coupling heat transfer. Compared with the temperature profiles of the OPTC, the temperature profiles with valve, which are far above that of the OPTC, indicate a positive DC flow in the PTC. Similarly, the temperature profile with the 5.1cm capillary indicates a smaller positive DC flow. Because the temperature profiles of the asymmetry-nozzle are only a slightly below the temperature profiles of the OPTC, the DC flow component with the nozzle is very small, although its direction is uncertain.

DISCUSSION

Control of the DC Flow

Using the asymmetrical flow resistance devices is a practical way to control the DC flow in the DPTC. The performance of the PTC varies remarkably by using the asymmetrical flow resistance devices under different directions as shown in Fig. 4 and Fig.7. We divide the DC flow into two parts; one part is generated by intrinsic asymmetry of the PTC, and the other part is introduced by the asymmetry of the flow resistance devices in the hot end. In the experiments, we change the later part of the DC flow by changing the direction of the asymmetrical flow resistance devices.

The Effect of the DC Flow in Co-axial PTC

The lowest temperature is achieved by using the needle valve in normal direction as can be seen in Fig. 8.In this case, the DC flow in the PTC is smaller than that of using the needle vale in reversed direction, and larger than that of using the 5.1cm capillary. This can be clearly found by comparing the temperature profile curves in Fig. 8. The results with needle valve are much better than that of asymmetry-nozzle, which has a much small DC flow. This can be explained by considering the structure of the co-axial PTC. In co-axial PTC, the cold tip is also the connector between the regenerator and the pulse tube. A proper positive DC flow adds an additional gas flow, which is cooled by the regenerator, from the cold end of the regenerator to the pulse tube. This gas flow can cool the cold tip and has positive effects on the cooling performance of the PTC, although it raise the temperatures of the regenerator and pulse tube at the hot end and deteriorate the heat exchange efficiency of the regenerator at the same time.

CONCLUSIONS

A G-M type co-axial pulse tube cryocooler is firstly optimized from three aspects: the dimensional layout of the regenerator and the pulse tube, the filling materials in the regenerator and the structure of cold end heat exchanger. The results indicate that both the lowest temperature and the cooling power of the PTC are improved remarkably. Then, needle valves, capillaries and asymmetry-nozzles are used as hot end phase shifters respectively. It is found that using the asymmetrical flow resistance devices is a practical way to control the DC flow in the DPTC, and a proper positive DC flow has positive effects on the cooling performance of the co-axial PTC.

ACKNOWLEDGMENT

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REFERENCES

1. Radebaugh R., "Pulse Tube Cryocoolers for Cooling Infrared Sensors", *Proceedings of SPIE* Vol.4130 (2000), pp.363.
2. Mikulin E.I., Tarasov A.A., Shrebyonock M.PP., "Low Temperature Expansion Pulse Tube", *Adv. Cry. Eng.*, vol. 29 (1984), pp.629.
3. Zhu S., Wu P.P., and Chen Z., "Double Inlet Pulse Tube Refrigerator-an Important Improvement", *Cryogenics*, vol. 30 (1990), pp.514.
4. Kanao K., Watanabe N. and Kanazawa Y., "A Miniature Pulse Tube Refrigerator for Temperature Below 100K", *Cryogenics*, vol. 34 (1994) supplement, pp.167.
5. Charles I., Duband L., and Ravex A., "Permanent Flow in Low and High Frequency Pulse Tube Coolers: Experimental Rresults", *Cryogenics,* vol.39 (1999), pp.777.