Experiment on a Single-stage GM Type Pulse Tube Cryocooler near 20K

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An experiment on a single-stage GM type pulse tube cryocooler was presented in this paper. The minimum temperature 22.4K and cooling power 5.65W at 80K were obtained with 2kW input power, when the double-inlet measure consists of two parallel needle valves in the inverse directions, and the regenerator matrix consists of phosphor bronze screens and stainless steel screens of 247 mesh alternation. During 24-hour uninterrupted operation, the cold head temperature fluctuation is less than 0.3K.

INTRODUCTION

With the development of superconductor, the need for stable and reliable cryocoolers near 20K is increasing. Many cryocoolers can meet this requirement, including Stirling, GM and pulse tube coolers[1]. Without moving parts at the cold end, pulse tube cryocooler is better than Stirling and G-M cooler in the aspects of operating time and reliability. So it is significant to make practicable researches on pulse tube cryocoolers.

During the past years, much progress on pulse tube cryocooler has been made. With a four-valve structure, a minimum temperature 20.5K was obtained when 2.4kW power was inputted [2]. With sintering matrix in the cold end, a minimum temperature 24K was obtained by W.J. Sun [3]. When the double-inlet mode consists of two parallel needle valves in the inverse directions (named double-valved configuration), and the matrix was filled with lead sphere at 1/3 space of regenerator near cold head, a minimum temperature 14.7K was obtained with 4kW power input [4]. Furthermore, the minimum temperature of a single-stage pulse tube cryocooler with the double-valved configuration was below 13K, driven by a 13kW compressor [5]. It indicated that DC flow in the pulse tube refrigerators will be controlled well with double-valved configuration. This new structure is verified again in our experiment on a single-stage GM type pulse tube cryocooler and presented in this paper.

EXPERIMENTAL APPARATUS

A single-stage pulse tube cryocooler used in this experiment is shown in Figure 1. The experimental apparatus consists of a helium compressor (1), rotary valve (2), regenerator (3), cold end heat exchanger(4), pulse tube(5), hot end heat exchanger(6), double-inlet valves (7,8), orifice valve (9), reservoir (10). The regenerator and pulse tube are made of stainless steel tubes with outer diameter, wall thickness and length of $\phi 20\times 0.3\times 210$mm and $\phi 14\times 0.5\times 220$mm, respectively. The reservoir volume is 0.5l. The regenerator matrix consists of phosphor bronze screens and stainless steel screens of 247 mesh alternation. The double-inlet mode is double-valved configuration, which consists of two parallel needle valves (SWAGELOK, SS-6MG-MM) in the inverse directions.

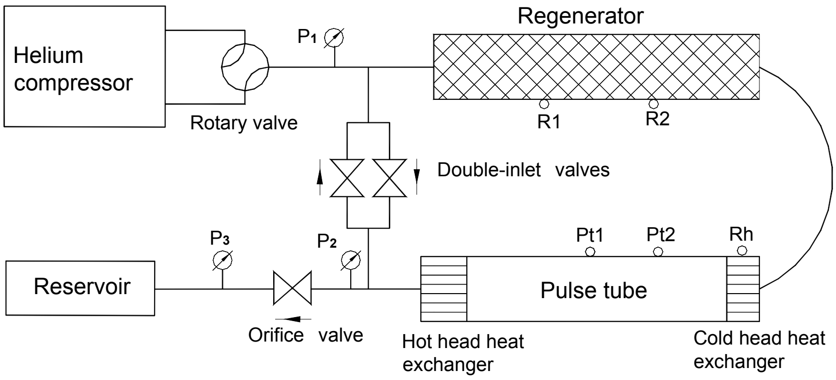

Figure 1 Schematic diagram of a single-stage GM type pulse tube cryocooler

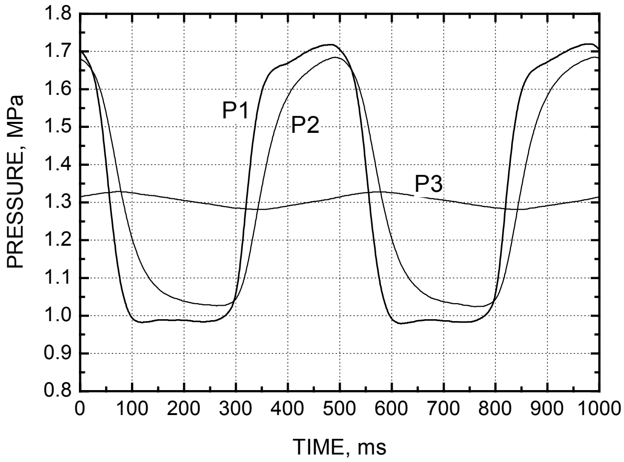

Figure 2 Pressure wave at the minimum temperature

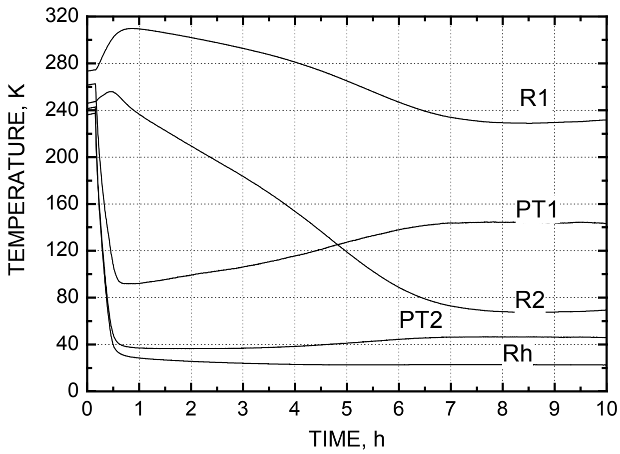

Figure 3 Cooling temperature curve

A rhodium-iron thermometers and four Pt100 thermometers (R1, R2, PT1, PT2) are used to measure the temperatures of the cryocooler. Three piezoelectric pressure sensors (type KPY 46R, Siemens) are used for monitoring the dynamic pressure at the hot end of the regenerator and pulse tube, and reservoir, as shown in Figure 1. Based on the heat balance method, manganin wires wrapped around the cold head are used to measure the cooling power at the cold head. Temperatures and cooling power recordings are accomplished by means of a PREMA multimeter (type 5017SC) through one NI GPIB card into a computer together with pressure recordings through one NI Lab-PC-1200 data acquisition card. All of them can be displayed easily by LabVIEW software in the computer.

RESULTS AND DISCUSSION

The experiments operate with a charge pressure of 1.40 MPa (absolute pressure) and a frequency of 2 Hz. Pressure waves of various measuring points at the minimum temperature are shown in Figure 2. The mean value of P1, the pressure located at the hot end of the regenerator is 1.35MPa, and its pressure ratio is 1.75. The amplitude of P2, the pressure located at the hot end of the pulse tube is a little smaller than that of P1, and its pressure ratio is 1.64. The amplitude of P3, the pressure of the reservoir, is very small, and its pressure ratio is 1.04.

After the optimization of the valves opening, the minimum temperature 22.4K with no load was obtained, with the input power of the compressor 2kW. As shown in Figure 3, after the cryocooler operated for 3 hours, the temperature at the cold end of the pulse tube reached about 24K, another 6 hours later, the minimum temperature 22.4K was obtained. R1 and R2, the temperatures located on the regenerator, increased in first half an hour, then began to decrease, which may be due to the influence of

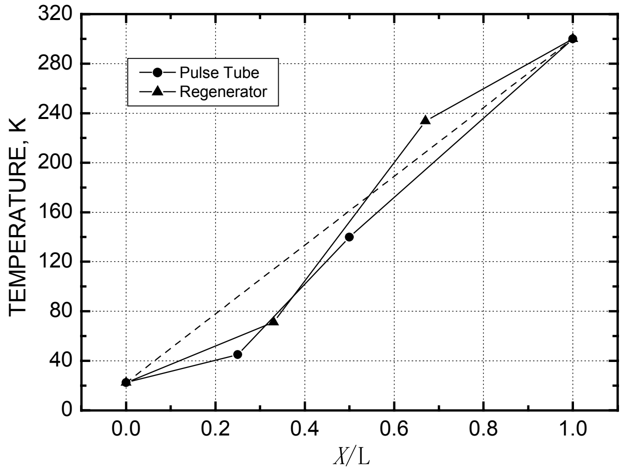

Figure 4 Temperature distribution

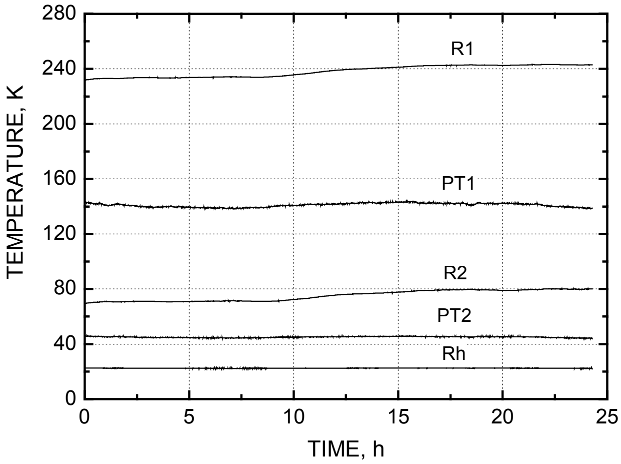

Figure 5 Temperature fluctuation

the length of the regenerator. By shortening its length, better performance of the cryocooler is expected.

Considering the temperature gradient at the measuring points during the stable period of the whole system, the temperatures of hot end of both pulse tube and regenerator are assumed to be 300K(ambient temperature). The temperature gradient of the whole system was analogous with linear distribution, as shown in the Figure 4. However, the temperature R1 was a little higher than expected, maybe due to the excessive length of the regenerator.

Temperature stability is quite important to decide the refrigeration performance of pulse tube cryocoolers. In the pulse tube cryocoolers, the refrigeration process is controlled by the mass flow rate through each component in the system. The mass flow rate through each component has a different amplitude and different phase with each other. The stable mass flow rate through each component (such as regenerator, pulse tube, orifice, double-inlet valves and heat exchangers) is such an important factor to keep the refrigeration temperature stable. Temperature fluctuations at various measuring points are shown in Figure 5 and 6. The temperature fluctuation amplitude of Rh, the minimum temperature, is lower than 0.3K. The rest: PT1≤2K，PT2≤0.5K，R1≤5K，R2≤5K, which is analogous with the experiment results of a single-stage pulse tube cryocooler by Y.L.Jiang and a two-stage pulse tube cryocooler by J.L.Gao [6,7].

Considering the maximum cooling power as the goal, opening of the valves was optimized. And a cooling power of 5.65W at 80K was obtained, shown in Figure 7. When the valves were set to the optimum opening at which the minimum temperature was obtained, a cooling power of only 4.30W could be obtained at 80K. On the contrary, at the optimum opening at which maximum cooling power at 80K was obtained, the temperature with no load was only 31K. In sum, the opening of the valves in different temperature ranges is different with one another, which is important to the future gas mixture refrigeration experiment.

CONCLUSION

With the double-inlet mode consisting of two parallel needle valves in the inverse directions, the minimum temperature of 22.4K and a cooling power of 5.65W at 80K were obtained on a single-stage GM type pulse tube cryocooler. During 24-hour uninterrupted operation, the minimum temperature fluctuation is less than 0.3K, which could meet the requirement of the application in the realm of superconductivity. At about 20K, the volume specific heat capacity of helium is much higher than those of the stainless steel screens and phosphor bronze screens, so the performance of the regenerator was deteriorated. Through optimization of the regenerator matrix (filled with lead spheres or magnetic materials), and shortening the length of the regenerator, the minimum temperature with no load can be expected to be lower, and the refrigeration performance could still be improved, all of which are what we

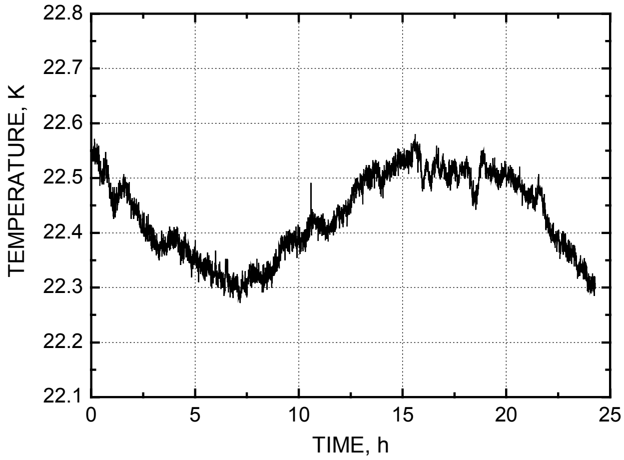

Figure 6. Cold head temperature fluctuation for 24 hours

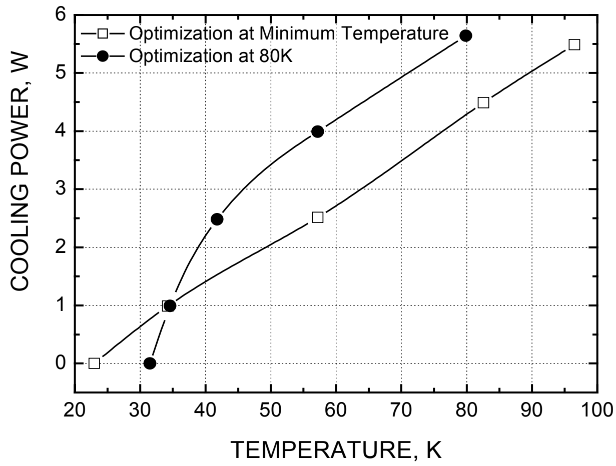

Figure 7. Cooling power with different valve setting

are planning to do.

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