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THE EXPERIMENTAL STUDY OF A SINGLE-STAGE G-M REFRIGERATOR WITH THE REGENERATOR SET OUTSIDE THE CYLINDER

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ABSTRACT

In this paper, a single-stage G-M refrigerator with the regenerator set outside the cylinder is presented. The experimental system for testing the performance of the cryocooler was constructed. The lowest temperature was 14K when the operating frequency was 0.6 Hz. The cooling capacity of 4.4W has been obtained at 20K. The effects of operating parameters of the refrigerator on cooling performance were also experimentally studied.

INTRODUCTION

The introduction of multi-layer structural regenerators with magnetic materials has greatly improved the performances of multistage G-M refrigerators at low temperature range[1][2]. GM cryocoolers are now widely applied to many cryogenic systems, such as cryopump, cryostat, SIS mixer cooling, helium recondensation in a superconducting MRI magnet and cooling of small superconducting magnets[3][4]. Up to date, a great deal of efforts have been put into the improvement of the cooling performances of 4K GM refrigerators by using various experimental apparatuses[5][6]. Some attention presently is given to adjust the structure of the GM cryocooler to meet the requirement of its special applications, as well as to improve its operation liability and stability. In the case of cooling cryoelectronics devices, in order to achieve the proper performance of the cryoelectronics devices, the disturbance of the magnet field of the magnetic regenerator materials must be reduced. Based on the above reasons, a new-type GM refrigerator operating at liquid helium region was designed and constructed[7]. Its major structure features are that the warm stage and the cold stage displacers were driven separately and the warm stage was used to precool the cold stage for removing

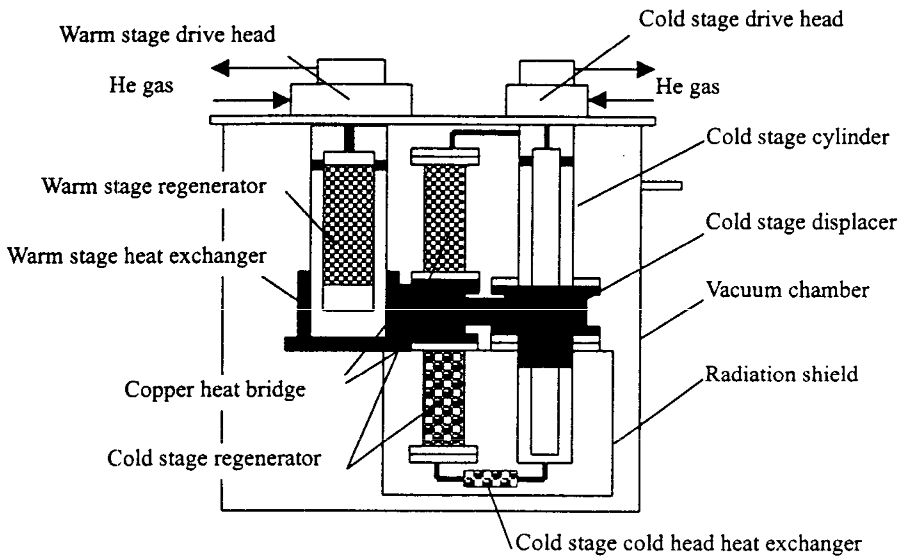

Figure 1. Schematic diagram of experimental apparatus for a new-type 4K GM cryocooler

heat losses from ambient environment, the cold stage regenerator was put outside the cylinder, and the cold head heat exchanger at the cold stage was somewhat different from the conventional one. The new-type refrigerator shown in Figure 1 is flexible in constructing experiments. It also can be used as a test station for the researches of GM coolers. In this paper, we preliminarily tested the performance of the cold stage GM refrigerator that can be used for a kind of single-stage cryocooler different from the conventional co-axial structure. Some results were obtained [7]. This paper also describes the principal design features of the single-stage GM refrigerator.

EXPERIMENTAL APPARATUS

Figure 2 shows the schematic of the single-stage GM cryocooler used as the experimental machine. The regenerator was placed outside the cylinder. The solid displacer reciprocated in the cylinder, driven by an AC induction motor. The cycle speed could be varied by changing the power supply frequency. The stroke of the displacer was 25mm. The displacer was divided into three parts. The middle part is a copper block. The rest of the displacer was made of textolite. They were connected by epoxy adhensive.

The regenerator outside the cylinder and the cylinder were also divided into three parts in order to precool the cold stage of the 4K GM cryocooler shown in Figure 1. The cylinder and regenerator are both longer than that of a conventional single-stage refrigerator to reduce the shuttle and conduction losses. The high temperature and low temperature parts of the cylinder and the regenerator are both stainless steel pipes. The middle part of the cylinder is a copper circular.

The phosphor bronze screens were stacked at the high temperature part of the regenerator. The copper spheres were sintered into a copper tube as its middle part. A combination of the triple-layer materials composed of lead spheres, Er_3Ni and $ErNi_2$ grains was stuffed in sequence from the hot to the cold end in the low temperature part of the regenerator. The cold head heat exchanger was located at the cold end of the

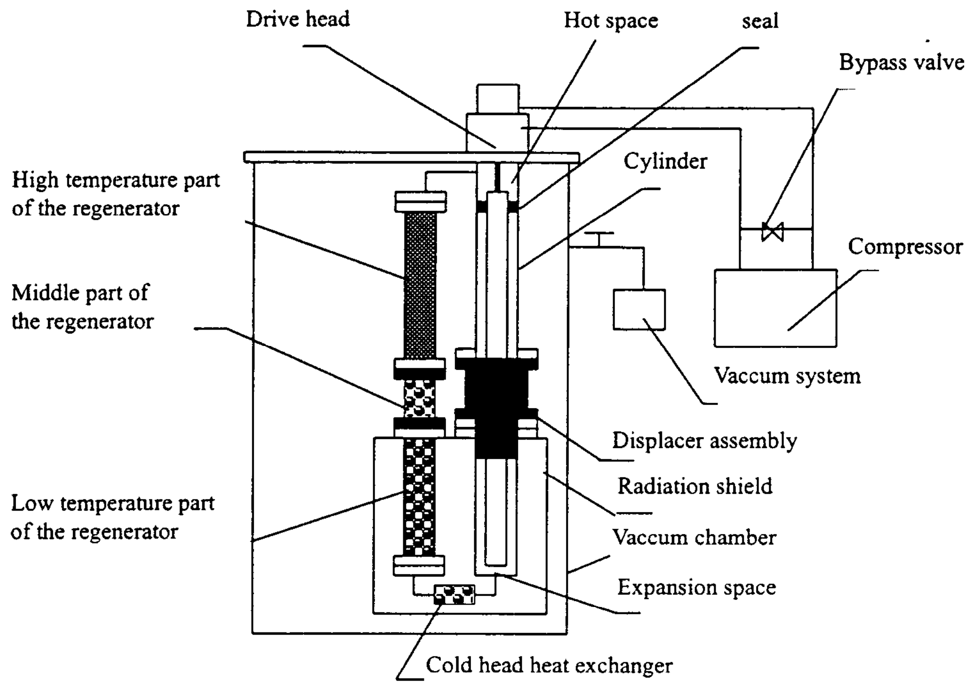

Figure 2. Schematic diagram of experimental apparatus for a single-stage GM cryocooler

Table 1. Main structural parameters			
Cylinder	Diameter(mm)		40
Regenerator	High temperature part	Diameter(mm)	50
		Materials	Phosphor bronze meshes
	Middle part	Diameter(mm)	30
		Materials	Copper spheres
	Low temperature part	Diameter(mm)	45
		Materials	lead spheres, Er_3Ni and $ErNi_2$ grains
Stroke(mm)	25		

regenerator, which was easily processed by sintering copper spheres into a copper tube to increase the heat transfer area per unit volume. A radiation shield was attached to the lower portion of the cryocooler to prevent the radiant heat from room temperature. Two Rh-Fe resistance sensors with 0.1K accuracy were respectively installed at the middle of the regenerator and at the cold head heat exchanger for the cooling temperature measurement. The Manganin wire was wound around the cold head heat exchanger as electric heater. The main structural parameters are shown in Table 1.

EXPERIMENTAL RESULTS AND ANALYSIS

Cool Down Curves

Figure 3 shows the cool down curve of the single-stage GM refrigerator. The inlet and exhaust pressures of the compressor were respectively 2.08MPa and 0.70MPa. The cycle frequency was 1Hz. Tc is the temperature measured at the end of the cold head heat exchanger that was close to the expansion space. Treg is the temperature of the middle portion of the regenerator. It can be seen from Figure 3 that the cool down rate of Tc was much faster from the room temperature to 30K than that from 30K to the lowest temperature. Treg reached about 160K when Tc was about 16K. The cool down time is within 100 minutes. We concluded that the performance of the regenerator was better at the low temperature portion than that of the high temperature portion.

Effects of Cycle Frequency and Pressure Range on Cooling Performance

The effects of cycle frequency on no-load cooling temperature are indicated in Figure 4. The two curves were obtained under different operating pressure range. Here the operating pressures mean the inlet and the exhaust pressures of the compressor. One can observe that there exists the same optimum cycle frequency for the single-stage cryocooler under both kinds of operating condition. The optimum cycle frequency was 0.6Hz in the experiment.

It also can be seen that the cooling temperature varied with the operating pressure range. The ratio of the inlet pressure over the exhaust pressure of 1.86/0.50MPa is larger than that of 2.08/0.70MPa. The pressure differences are almost the same. Because the PV work diagram doesn't represent the cooling capacity when the cooling temperature is lower than 100K[8], we simply evaluated the ideal cooling capacity of the refrigerator and the heat loss under different operating pressures. It was found that the ideal cooling capacity was higher under 1.86/0.50MPa than that under 2.08/0.70MPa, and the major heat loss under the former was smaller than that under the latter. Therefore, the cooling performance was improved.

The cooling temperature was 14.5K under the inlet and the exhaust pressure of 1.86/0.50MPa. It was 15.6K under 2.08/0.70MPa when the cycle frequency was 1Hz. For the former the lowest temperature of 14K was obtained at the operating frequency of 0.6 Hz.

Cooling Capacity

Figure 5 gives the cooling capacity of the single-stage GM refrigerator. It indicates that the lowest cooling temperature was 15.6K and the cooling capacity was 4.4W at 20K, under the operating pressure of 2.08/0.70MPa and the cycle frequency of 1Hz.

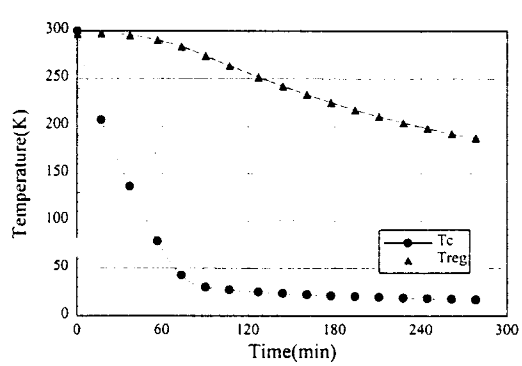

Figure 3. The cool down curve

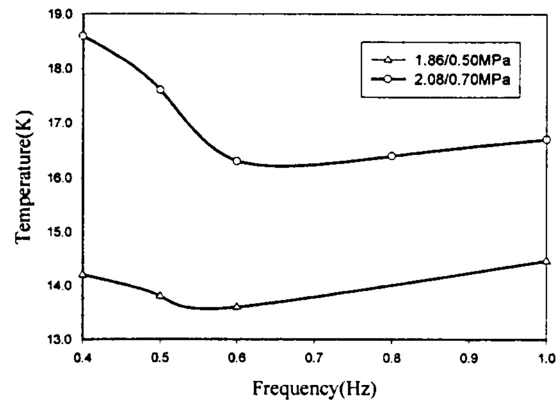

Figure 4. Effect of cycle frequency on no-load temperature under different operating pressure range

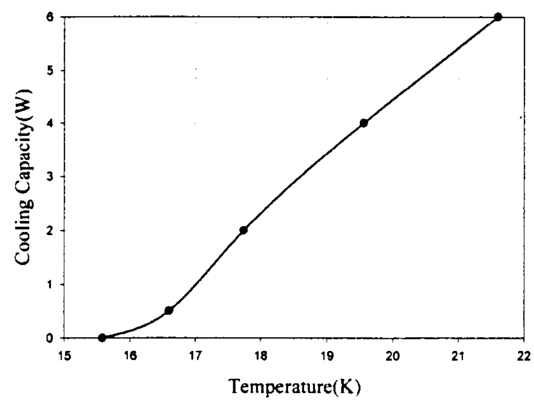

Figure 5. Cooling capacity of the GM refrigerator

In addition, the new-type G-M refrigerator shown in Figure 1 has successfully been operating at liquid helium region. The lowest temperature was 4.6K under the operating pressure of 1.90/0.70MPa when the operating frequency was 0.4 Hz. The cooling capacity of larger than 6 W has been obtained at 10K[5]. The further improvement has been planned.

CONCLUSIONS

1. A new-type single-stage GM refrigerator with the regenerator set outside the cylinder was fabricated and preliminarily tested. The lowest temperature was 14K when the operating frequency was 0.6 Hz. The cooling capacity of 4.4W has been obtained at 20K.
2. There exists the optimum cycle frequency for the cryocooler when the operating condition was changed. The operating pressure range has a large effect on the cooling performance.

3. In the new-type single-stage machine, because the regenerator was located outside the cylinder, there is no limitation on the regenerator structure. The larger regenerator diameter can be made than that of displacer to reduce the pressure drop across the regenerator. It is also convenient to change the geometry sizes and materials of the regenerator to investigate their effects on cooling performance and then to optimize the structure parameters. It becomes easier to measure the temperature and pressure profiles along with the regenerator and the cylinder to study the working mechanism of the cryocooler. The heat transfer efficiency of the cold head heat exchanger can be improved by putting it between the regenerator cold end and expansion space where its heat transfer area per unit volume can be easily increased.

4. In the new-type GM cryocooler at liquid helium region, the regenerator matrix does not move along with the displacer, so the oscillation of the magnet field of the matrix does not exist. There is less magnetic noise because the magnetic matrix is static. It also becomes easy to meet the ratio of regenerator volume over cold chamber volume, which is important to a 4K GM cooler. Because of the parallel structure of the new-type machine, the operating parameters of the first-stage and second-stage can be optimized separately to reach the optimum cooling performance. Finally, the refrigerator is reliable because the seal operates at the room temperature.

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