Investigation of DC flow effects on a 4K two-stage pulse tube cryocooler

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Abstract. Sumitomo Heavy Industries, Ltd. (SHI) has been continuously developing 4K GM-type pulse tube cryocoolers for cooling superconducting magnets and pre-cooling ultra-low temperature refrigerators, such as dilution refrigerators, etc. In a double-inlet or a 4-valve GM-type pulse tube cryocooler, there is a gas circulation, called DC flow, generated by the pulse tube, the regenerator and the orifice. The performance of a pulse tube cryocooler is strongly dependent on the rate of such kind of flow. It is possible to improve the performance by optimizing the rate. In order to optimize the rate, a bypass line with a small valve is installed between the warm end of the pulse tube and the low pressure side of the compressor. The second stage cooling capacity at 4.2 K was improved by about 0.25 W after optimization of the rate by adjusting the opening of the valve. The details of the experiment results will be reported in this paper.

KEYWORDS: cryogenics, pulse tube cryocooler, 4K cryocooler, DC flow.

1. Introduction

Owing to its low vibration and high reliability, pulse tube cryocooler has been widely used for cooling superconducting magnets and pre-cooling ultra-low temperature refrigerators. SHI has been developing pulse tube cryocoolers for such applications.[1-4]

In a double-inlet or a 4-valve pulse tube cryocooler, there is a loop configured by the regenerator, the pulse tube and the double inlet orifice or the on-off valves at the pulse tube warm end. Through this loop, a gas circulation, called DC flow, is generated. A DC flow greatly affects the cooling performance of a pulse tube cryocooler, so optimization of its rate is required to achieve the best performance.[5-7]

SHI has been investigating the effect of a DC flow in a pulse tube cryocooler for the purpose of developing a higher efficiency pulse tube cryocooler.

The experimental evaluation results will be reported in this paper.

2. Experiment apparatus

The configuration of a pulse tube cryocooler used for this experiment is shown in figure 1. The effect of a DC flow was investigated in a two-stage 4K pulse tube cryocooler. In order to easily install a DC
flow valve, a pulse tube cryocooler with a remote valve unit was selected for the test. (figure 2) As shown in figure 1, the warm end of the second stage pulse tube is connected to the low pressure line of the compressor using a bypass line with a small valve, called DC flow valve.

The frequency of the gas oscillation which is generated by the compressor is 1.7 Hz. The high and low pressures of the compressor are about 2.0 MPa and 0.9 MPa, respectively. The gas flow lines between the compressor and the pulse tubes are connected through needle valves to adjust the flow rate. 30 W and 1.3 W heat load are added to the first and second stages.

The second stage temperature is measured using a RuO sensor, and the temperature of the first stage and the temperature profile of the pulse tubes are measured with PtCo thermometers. All sensors are connected to a current supply at the room temperature with CuNi wires, and the heat conduction through the wires is negligible.

![Figure 1](image1.png)

**Figure 1.** Schematic of a two-stage pulse tube cryocooler with temperature sensors for measuring temperature profile.

![Figure 2](image2.png)

**Figure 2.** Picture of a two-stage pulse tube cryocooler with a remote valve unit.
3. Experiment results
The DC flow rate was adjusted by changing the DC flow valve opening. The temperature at each point where a sensor is mounted is measured at each valve opening. Thus the relation between the DC flow rate and the cooling capacity of the pulse tube cryocooler as well as the temperature profile of the pulse tubes was investigated. The results are summarized in table 1 and figure 3, 4.

| DC flow valve opening (turns) | T_1st stage (K) | T_2nd stage (K) |
|------------------------------|----------------|-----------------|
| 0                            | 47.23          | 4.53            |
| 0.1                          | 55.31          | 4.28            |
| 0.5                          | 55.83          | 4.29            |
| 1.0                          | 63.32          | 5.26            |

The experiment results show that the cooling performance is strongly dependent on the opening of the small valve.

Figure 4 shows the cold temperature front advances when the DC flow valve opening is set to an optimum position and the cooling capacity at the second stage increases. This tendency is similar to the results in reference 8. The second stage temperature decreased from 4.53 K to 4.28 K with 1.3W heat load. From our experiment results, it is known that the specific cooling capacity is about 0.1 W per 0.1 K at the second stage for this system. Therefore, the cooling capacity at the second stage increased about 0.25 W.

It also shows that if the valve opening is too large, the temperature profile significantly changes and the cooling capacity gets worse. Figure 3 shows that the temperature profile of the first stage pulse tube also changes as the valve opening varies and the cooling capacity at the first stage decreases. When the valve is opened, the temperature of the first pulse tube is increased. When the valve is opened, the gas flow from the cold end to the warm end is generated in the second stage pulse tube. With an optimized valve opening, reasonable DC flow is generated, which results in a cooling capacity improvement at the second stage. However, in the first stage pulse tube, a gas flow from the warm end to the cold end is generated, which results in an extra heat conduction loss from room temperature. Accordingly, the cooling capacity at the first stage decreases.
4. Conclusion
The dependence of the cooling performance on the rate of a DC flow was investigated. By installing a bypass line between the warm end of the pulse tube and the low pressure side of the compressor, the cooling capacity at the second stage has been improved by about 0.25 W at 4.2 K. Meanwhile, the temperature profile along the pulse tubes was measured. The results show that, a DC flow, of which direction is from the cold end of the pulse tube to the warm end, was generated. As expected, a better cooling performance at the second stage has been achieved with such kind of DC flow.

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