Development of 1.5W 4K Two-Stage Pulse Tube Cryocoolers with a Remote Valve Unit

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ABSTRACT

Sumitomo Heavy Industries, Ltd. (SHI) has been continuously improving the efficiency and reducing the vibration of a 4K pulse tube cryocooler. Recently, a 1.5W 4K pulse tube cryocooler (PTC) with a remote valve unit has been developed. The valve unit of the cryocooler is split from the cold head by a flexible gas line and two stainless pipes. When the valve unit is split with 1 m lines, the cooling capacity is reduced because of increased pressure drop and dead volume. The typical cooling capacity of the prototype unit is 35 W at 43.5 K at the first stage and 1.35 W at 4.13 K at the second stage when the compressor is operated at 50 Hz. The cooling performance load map and the performance with respect to the opening of the second stage orifice will be reported in this paper.

INTRODUCTION

SHI has been developing 4K pulse tube cryocoolers for various applications[1-3]. 1W 4K pulse tube cryocoolers, RP-082B2, and same series with a remote valve unit, RP-082B2S are currently released. In the RP-082B2S unit, vibration has been greatly reduced by splitting the valve unit from the cold head at the expense of a cooling capacity degradation of about 0.1 W at 4.2 K[4, 5].

Lately, applications for pulse tube cryocoolers, e.g. dilution cryocoolers, need more cooling capacity. Owing to the recent unstable supplement of liquid helium, the demand for high cooling capacity 4K cryocoolers has been increasing.

Recently, SHI developed a more efficient pulse tube cryocooler based upon an existing model, RP-082B2S. The pulse tube and regenerator cylinder size are redesigned to increase the ideal cooling capacity. In an SHI 1W 4K pulse tube cryocooler, DC flow rate[6], which can significantly affect the cooling capacity, is not fully optimized. In order to optimize the DC flow rate at the second stage, an additional orifice is installed between the warm end of the second stage pulse tube and the low pressure side of the compressor[7]. By optimizing the DC flow rate, a significant cooling capacity improvement at the second stage has been achieved.

As a result of the above-mentioned redesign, a significant cooling capacity improvement has been achieved. A typical cooling capacity of a prototype unit with a remote valve unit is 35 W at 43.5 K at the first stage and 1.35 W at 4.13 K at the second stage when the compressor is operated at

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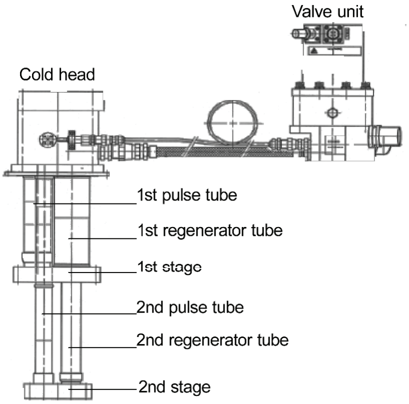

Figure 1. Outline drawings of a 1.5W 4K PTC.

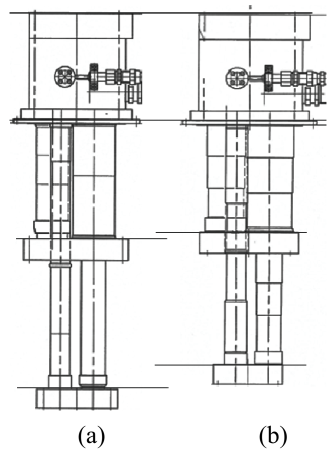

Figure 2. Cold heads of 4K PTCs: (a) 1.5 W 4K PTC; (b) 1W 4K PTC

50 Hz with an input power of 7 kW. The cooling performance load map and the performance with respect to the orifice opening are reported in this paper.

OUTLINE OF THE SYSTEM

Outline drawings of a 1.5W 4K pulse tube cryocooler with a remote valve unit are shown in Figure 1. Cold heads of a 1.5W 4K pulse tube cryocooler and a 1W 4K pulse tube cryocooler are compared in Figure 2.

In order to increase the ideal cooling capacity, the size of the pulse tube and regenerator cylinder diameters are enlarged. As shown in Figure 2, the length of the second pulse tube and the second regenerator tube are extended and the diameters are enlarged. The amount of regenerator material is increased, proportionally. There are only minor changes in the first pulse tube and the first regenerator tube. In a 1W 4K pulse tube cryocooler, two orifices are used to adjust the phase difference between the pressure and the displacement of refrigerant gas. In a 1.5W 4K pulse tube cryocooler, an additional orifice is used to adjust the DC flow rate. The optimization of DC flow rate is critical for improving the cooling capacity, especially at the second stage.

EXPERIMENTAL RESULTS

A typical load map of a prototype unit is shown in Figure 3. The cryocooler is operated by an F-70 compressor and has an operating frequency of 50 Hz. The filling pressure is 1.65 MPa.

The second stage is covered with a radiation shield attached to the first stage. The whole cylinder, including the radiation shield, is wrapped with a few layers of multilayer insulation. The first stage temperature is measured with a PtCo sensor and the second stage temperature is measured with a PtCo sensor (Chino) and a RuO sensor (Scientific Instruments). Heat is applied to both stages with a heater and Manganin wires to measure the cooling capacity.

The minimum temperatures are 24.3 K at the first stage and 2.63 K at the second stage. A typical cooling capacity is 35 W at 43.5 K at the first stage and 1.35 W at 4.13 K at the second stage.

The input power of the compressor is about 7.2 kW when reaching stable temperature with 40 W at the first stage and 1.5 W at the second stage. The maximum input power is about 9.0 kW shortly after starting up.

The cool-down curve is shown in Figure 4. With no heat load, it takes about 70 minutes for the first stage to reach 40 K and about 60 minutes for the second stage to reach 4 K.

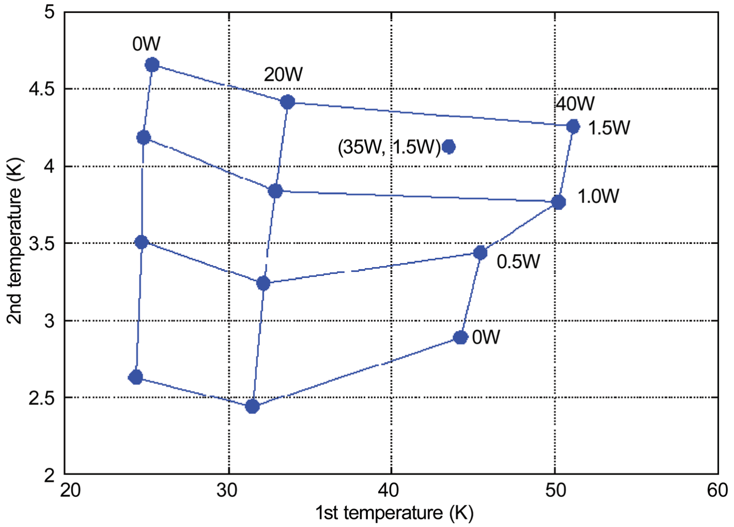

Figure 3. Load map of a1.5W 4K PTC.

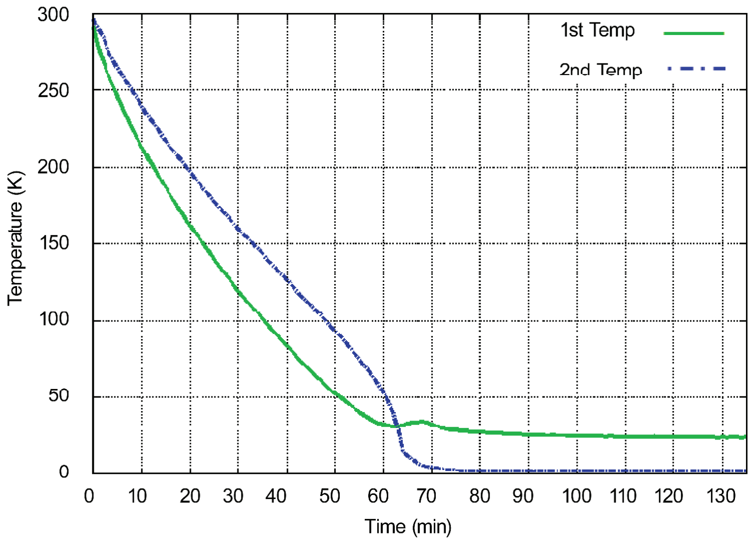

Figure 4. Cooling down curve of a 1.5W 4K PTC prototype unit.

Table 1 shows the cooling performance with respect to the opening of the second stage orifice. The temperature change at the second stage is very small even though the opening of the orifice varies about 1 turn. It means that the robustness of the second stage cooling capacity with respect to the orifice opening is improved compared to a RP-082B2S unit. As a result, it is expected that the long-term stability can be improved.

CONCLUSION

A 1.5W 4K pulse tube cryocooler has been developed and a significant cooling performance improvement, especially at the second stage, has been achieved.

A typical cooling capacity is 35 W at 43.5 K and 1.35 W at 4.13 K or 40 W at 51.2 K and 1.5 W at 4.26 K. With 40 W and 1.5 W heat load, the input power is about 7.2 kW.

Table 1. Cooling Capacity Change with respect to the Opening of the Second Stage Orifice

Opening of 2nd orifice (turns)	1st temperature with 36W (K)	2nd temperature with 1.5W (K)
3.5	48.2	4.20
4.0	48.0	4.20
4.3	47.5	4.21

The change in the second stage temperature with respect to the opening of the second stage orifice is small. It is expected that long-term stability can be improved.

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