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Experimental investigation of cooling capacity of 4K pulse tube cryocooler in magnetic fields

Takashi Hirayama¹, Takaaki Morie¹ and Mingyao Xu²

¹Technology Research Center, Sumitomo Heavy Industries, Ltd., 19 Natsushima-Cho, Yokosuka-City, Kanagawa 237-8555, Japan

²Precision Equipment Group, Sumitomo Heavy Industries, Ltd., 2-1-1 Yato-Cho, Nishitokyo-City, Tokyo 188-8585, Japan

E-mail: takashi.hirayama@shi-g.com

Abstract. 4K pulse tube cryocoolers are used for various applications such as dilution refrigerators, NMR magnet systems and physical properties measuring systems, etc. In general, these application systems have high magnetic field source to apply magnetic field to cooling objects. Therefore, cryocoolers are inevitably exposed to the magnet field. In order to clarify the effect of the magnetic field on 4K pulse tube cryocoolers, we measured temperature behavior of Sumitomo Heavy Industries, Ltd.(SHI) 4K pulse tube cryocoolers, RP-082B2S, in magnetic fields up to 7.0 T. It is found that second stage temperature only increases slightly and the cooling capacity maintains in the specification of 0.9 W at 4.2 K up to 4.5 T. The experimental results are reported in this paper.

1. Introduction

Since the pulse tube cryocooler was invented in 1964[1], it has attracted many researchers because of its simple structure[2-5]. Pulse tube cryocoolers have beneficial features such as low vibration, high reliability and low motor torque owing to no moving parts in cryogenic region. SHI has been developing pulse tube cryocoolers since 1999. Developments have focused on low vibration and high efficiency at the 4 K region[6-9].

Recently, the improvement of superconductivity technology leads to applying magnetic field become high in various applications such as dilution refrigerators, NMR magnet systems and physical properties measuring systems. As a result, cryocoolers are exposed to high magnetic field. Therefore, the dependence of the magnetic field on the cooling capacity is an important design parameter for these applications. SHI has been investigated cooling capacity of 4K GM cryocoolers in magnetic fields to meet such requirement[10]. However, it is difficult to achieve a high tolerance of a magnetic field because the motor of GM cryocoolers can not be separated from the cold head. The motor is the most weakest component of a cryocooler and it may determine the upper limit of magnetic field tolerance. To solve this problem, pulse tube cryocoolers are considered because the motor of pulse tube cryocoolers can be separated from the cold head.

An experimental investigation of magnetic field dependence of a 4K pulse tube cryocooler was carried out.



2. Experimental set-up

An SHI GM-type 4K pulse tube cryocooler, RP-082B2S, and a water cooled compressor, F-70LP, were used in the experiment. Figure 1 shows the schematic diagram of a RP-082B2S and F-70LP system. The second stage of the cold head is covered with a radiation shield. Additionally, the first and second stages are covered with super insulation (10 layers). Table 1 shows the specification of the RP-082B2S and F-70LP system. The cold head operated at 1.0 Hz and compressor operated at 50 Hz. An SHI cryogen free superconducting magnet with a bore of 150 mm was used to generate magnetic fields. This magnet is capable to generate magnetic field up to 10 T at the magnetic center. Cernox (CX-1050) sensors (Lake Shore Cryotronics) were used for measuring stage temperatures. Typical magnetic field dependent temperature errors $\Delta T/T$ of a CX-1050 sensor are less than 0.1 % up to 2.5 T and -0.15 % up to 8.0 T at 4.2 K [11]. A hall sensor (F. W. Bell) was used for measuring the magnetic field at the second stage.

Figure 2 shows the schematic diagram of a pulse tube cryocooler installed in a superconducting magnet. The magnetic field is applied parallel to the axis of the cold head cylinder. The magnetic center is corresponded to the center of the second stage. Magnetic field strength is adopted at the center of the HoCu2 region in experimental result to correspond with the previous report of a GM cryocooler. The magnetic field at the magnetic center and the center of the HoCu2 region are calculated by magnetic field analysis software. Magnetic field calculation accuracy is confirmed by using a hall sensor at the second stage. Valve unit is set up far from the magnet to avoid motor torque reduction.

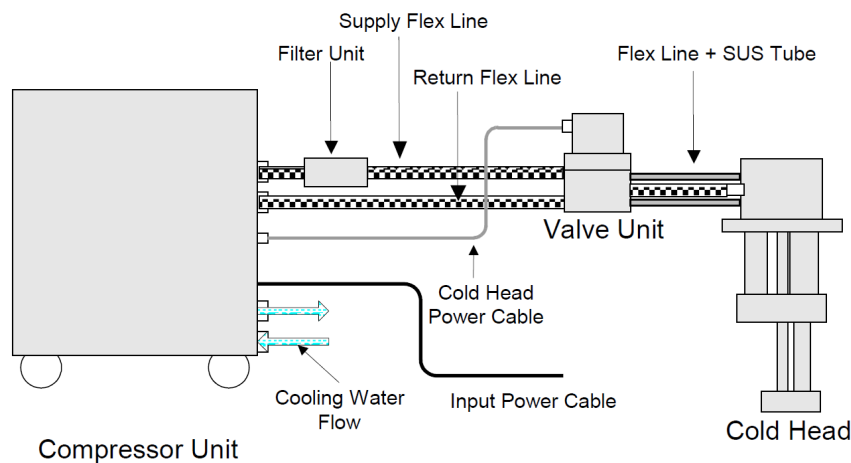


Figure 1. Schematic diagram of a RP-082B2S and F-70LP system.

Table 1. Specification of a RP-082B2S and F-70LP system [12].

Item	Specification
Cooling capacity of first stage	35 W at 45 K
Cooling capacity of second stage	0.9 W at 4.2 K
Orientation	Vertical only
Power consumption (50 Hz)	7.7 kW
Lowest temperature	<3.0 K (Reference only)

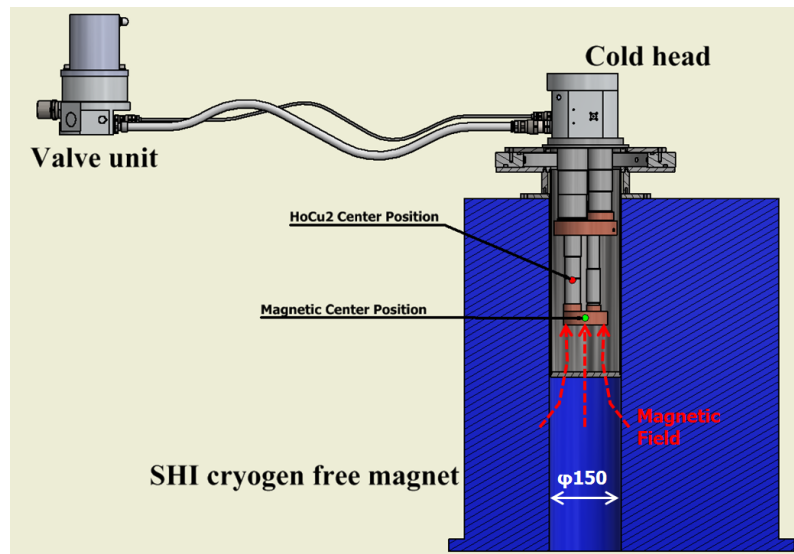


Figure 2. Schematic diagram of the experimental setup.

3. Experimental results and discussions

Figure 3 shows the magnetic field dependence of stage temperatures with specification heat load. Figure 3a shows the magnetic field dependence of the first stage temperature. Figure 3b shows the magnetic field dependence of the second stage temperature. The second stage temperature only increases slightly and the cooling capacity maintains in the specification up to 4.5 T. However, the second stage temperature shows an abrupt increase at a magnetic field of 4.0 T. On the other hand, the first stage temperature decreases slightly and maintains in the specification up to 7.0 T. A small window in the Figure 3a shows an expanded first stage temperature axis. Thus, it is found that the first stage temperature also has abrupt change point at a magnetic field of 4.0 T. In general, the first stage temperature decreases as the second stage temperature increases. Therefore this first stage behavior is a side-effect of second stage temperature changes. More detailed experimental test and numerical calculation of cryocooler are needed to clarify the reason of the abrupt second stage temperature increase around 4.0 T.

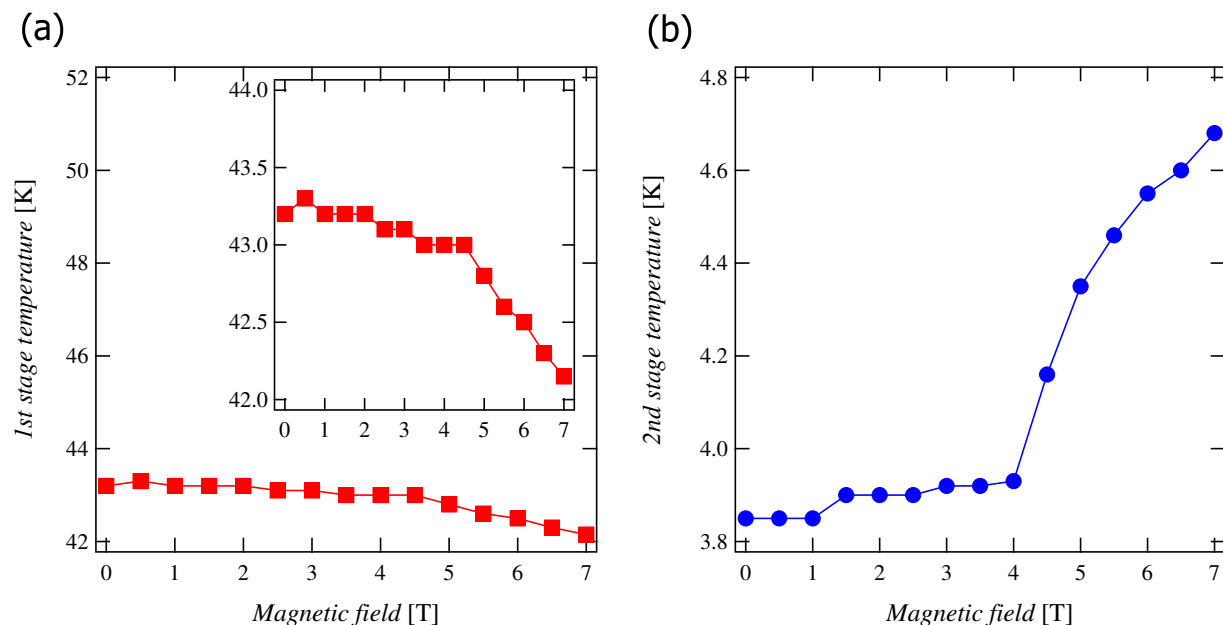


Figure 3. Magnetic field dependence of (a) first stage temperature, (b) second stage temperature.

4. Conclusion and future work

We investigated the magnetic field dependence of an SHI 4K pulse tube cryocooler, RP-082B2S, up to 7.0 T. It is found that the second stage temperature only increases slightly and the cooling capacity maintains in the specification of 0.9 W at 4.2 K up to 4.5 T. In general, pulse tube cryocoolers have benefit such as low vibration, long maintenance interval and low magnetic noise. According to these results, high magnetic field tolerance can also be considered as a benefit of a pulse tube cryocooler. Thus, it is possible to meet high magnetic field application requirements with a pulse tube cryocooler.

For future work, the reason of the second stage temperature increase at a magnetic field of 4.0 T will be investigated by numerical calculation.

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