§2. Evaluation of a GM Cryocooler by Equivalent Change of Regenerator Configuration

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Regenerative 4K cryocoolers have been used frequently in fusion areas because the cryocoolers are able to make easily the low temperature environment, and apply to the basic studies for fusion science, such as small size system, neutron irradiation and so on. However, the cooling efficiency of the 4K cryocoolers is insufficient. Much electric input power is required to maintain the temperatures of 4K level. To improve its efficiency, we developed a new method regarding a regenerator configuration for 4K Gifford-McMahon (GM) cryocooler[1]. This paper presents the new method and the experimental results.

A schematic diagram of the two-stage GM cryocooler is shown in Fig. 1. Two calibrated silicon (Si) diode thermometers and electric heaters are attached at each stage to measure the temperatures and cooling power, respectively. A radiation shield that is cooled with the first stage covered the second stage and cylinder. The model of cold-head and water cooled compressor are RDK-408D2 (SHI) and C300G (SUZUKISHOKAN), respec tively. The electric input power of the compressor is 7.3 kW at 60 Hz. The experiments have been carried out the operating frequency of 1.2 Hz and the initial charging pressure of helium gas of 1.6 MPa.

The new regenerator configuration with an inserted bakelite rod in the second stage regenerator is shown in Fig. 2. A bakelite rod is inserted in the $HoCu_2$ part (hereinafter called "$HoCu_2$-rod"), (a), and a bakelite rod is inserted in the Pb part (hereinafter called "Pb-rod"), (b). These bakelite rods are inserted as a dummy volume, so that the regenerator configuration can be changed equivalently by adjusting the geometry of the bakelite. Table I gives the dimensions of the second stage regenerator housing.

Figure 3 shows the experimental results of the cooling power measurements as a function of bakelite volume. The bakelite volume of 0% means a two-layer of $HoCu_2$ and Pb without bakelite rod (hereinafter called "normal"). According to the figure, the cooling power of the normal at 4.2 K and 40 K achieves 1.28 W and 44.0 W, respectively. In the case of $HoCu_2$-rod, when a bakelite volume of 2.7 cm^3 is used, the cooling power of the first and second stages is the same as the normal. After that, the second stage cooling power decreases with increasing bakelite volume, whereas the first stage cooling power improves. In the case of the Pb-rod, the second stage cooling power is improved with a bakelite volume of 5.5 cm^3. Its cooling power reaches 1.30 W. When the bakelite volume is 9.3 cm^3, the cooling power is decreased to 1.26 W. However, its rate of reduction is less than with the $HoCu_2$-rod. The first stage cooling power with the Pb-rod improves with increasing bakelite volume.

The new method is able to equivalently change the regenerator configuration so that different configurations can be quickly evaluated. The optimum bakelite volume of approxi mately 5 cm^3 that is one tenth of the Pb part regenerator volume was established.

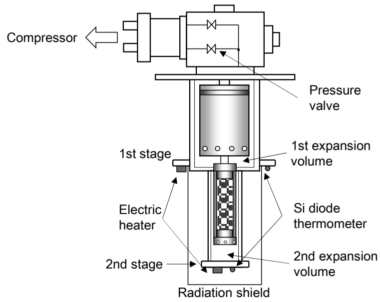

Fig. 1. Schematic diagram of the two-stage GM cryocooler.

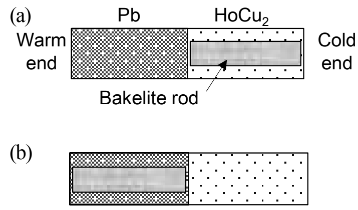

Fig. 2. Structures of the second stage regenerator: (a) $HoCu_2$-rod, and (b) Pb-rod.

Table I. Dimensions of the second stage regenerator housing of the Pb and $HoCu_2$ parts.

Regenerator housing	Inner diameter [cm]	Length [cm]	Cross-sectional area [cm^2]	Volume [cm^3]
Pb part	3	7	7.1	49.5
$HoCu_2$ part	3	7	7.1	49.5

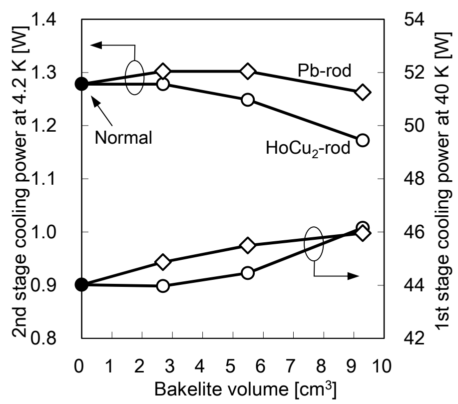

Fig. 3. Cooling power results at 4.2 K and 40 K as a function of bakelite volume.

1) Masuyama, S., Hiratsuka, Y, and Numazawa, T.: *Cryocooler* **18**, 271-276 (2015)