§10. Development of a High Efficiency Cryocooler for Cryogen-free Cooling System

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The advantage of cryogen-free systems is that a refrigerant facility which cools a low temperature apparatus, such as superconducting systems, is unnecessary. To construct this superb system, the directly cooling method with regenerative cryocooler will be one of the leading candidates. However, it is difficult to cool all areas in a large system by using one cryocooler. From the point of view, we have proposed a distributed cooling method that can be adapted for a large system including a fusion system. This concept is that the many cryocoolers, which are distributed to each cooling part, directly cool a whole system. Therefore, high efficiency cryocoolers are required at the desired temperatures. As the first step to achieve the distributed cooling system, two researches were carried out in this year: (1) development of a high efficiency single stage pulse tube cryocooler (PTC); and (2) investigation of cryocooler cooling current lead.

A schematic diagram of the developing single stage PTC is shown in Fig. 1. This PTC is operated by 4-valve mode with four solenoid valves that are controlled by suitable timing at the operating frequency of 2 Hz. Two needle valves, which are located at the warm end of pulse tube, adjust the alternative flow rate of helium gas. The total length from the warm end (room temperature) to the cold end is approximately 250 mm. This PTC is operated with a compressor of an electric input power of 7.3 kW. The initial charging pressure of helium gas is 1.6 MPa. A photo of the 4-valve PTC at room area is shown in Fig. 2. Two solenoid valves of the right side connect to the warm end of regenerator, and two solenoid valves of the left side and two needle valves connect to the warm end of pulse tube.

One of the required factors to achieve the high efficiency cryocooler is regenerator efficiency. Increasing the regenerator efficiency decreases enthalpy loss in the regenerator. From the numerical analysis for regenerator[1)], a stainless steel screen of 200-mesh was chosen and packed in the regenerator as a single layer. The experimental result showed the lowest temperature of 29.4 K. Next, stainless steel meshes at the low temperature side were replaced to lead (Pb) spheres with a diameter of 0.2 mm. This is because the specific heat of Pb is larger than that of stainless steel at temperatures below 70 K. Achievable lowest temperature as a function of Pb and stainless steel (SUS) mesh ratio is shown in Fig. 3. Replacing the Pb spheres effectively acts on a decrease in cold stage temperature. The optimum Pb ratio is 30%, and the lowest temperature of 23.4 K achieves. The results prove that a quantity of Pb spheres closely relates to the regenerator efficiency.

The directly cooling method with regenerative cryocooler can be applied to the current leads in the fusion systems needing superconducting technologies at this time. The current lead consists of a normal conductor and a superconductor. In general, the cold end of normal conductor and the warm end of superconductor are electrically connected and thermally anchored at the liquid nitrogen temperature. Decreasing the temperature of this connecting point reduces the heat loss of liquid helium. From the calculation, the heat loss of the current lead at the temperatures from 30 to 4.2 K reduces to 65%, compared with the loss at the temperatures from 77 to 4.2 K. This result shows that the cryocooler cooling current lead is very effective. The developing PTC will be applied to the current lead to achieve the cryogen-free system as the first step.

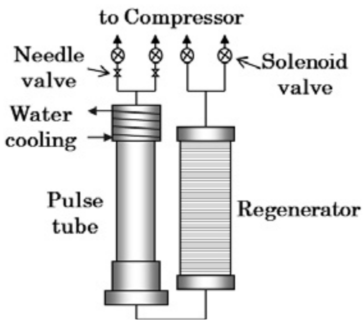

Fig.1 Schematic of the 4-valve pulse tube cryocooler

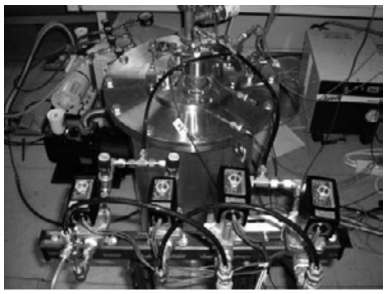

Fig.2 Photo of the 4-valve pulse tube cryocooler at room area

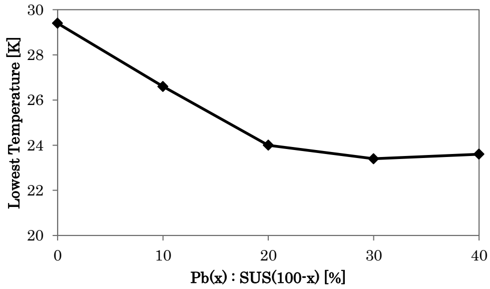

Fig.3 Achievable lowest temperature as a function of Pb ratio

1) Masuyama, S. et al.: Abstract of CSJ Conf. **83** (2010) 54.