§2. Optimization of the Distribution of Mass Flow in the Helium Cooling System of the LHD

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The LHD helical coil is planned to be cooled by subcooled helium to reduce the coil temperature and to improve its performance.1) The temperature of the subcooled helium rises when a heat is input.2) It is important to hold sufficient mass flow rate of subcooled helium as well as to reduce the helium temperature in this cooling system. The present helium refrigerator/liquefier for LHD is estimated to have an excess supply capacity of more than 2 kW. Helium mass flow rate of about 50 g/s can be expected to be supplied using this excess capacity.

The maximum flow rate that can be used for helical coil cooling is not clearly understood, since the cooling channels are connected in parallel for supporting structure cooling, superconducting bus line cooling, helical coil cooling, etc. The objective of the present study is to clarify the maximum flow rate for helical coil cooling or the minimum flow rate for the other components cooling by the present cooling system.

We need to evaporate liquid helium in the helical coil vessel by a heat deposition with heaters in order to obtain a flow rate more than 5 g/s of the amount of evaporation equivalent to the constant heat leakage (about 100 W), because the helical coil cooling system does not have a liquid helium return-line. At first, a performance test of these heaters has been carried out. Ten heaters were attached at the exit of the helical coil vessel before the 9th cycle test. We tried to input about 1 kW to the ten heaters to get about 50 g/s of mass flow rate of subcooled helium. But, described as follows, we could not increase the heater input power up to 1 kW because of a poor bonding of the heaters.

The temperature of Heater 4 reached 50 ℃ under the condition of the constant heater input power of 313 W, as shown in Figure 1. We can know from this figure that not only the Heater 4 temperature reached 50 ℃ but also the temperature of the all heaters continued to increase after 75 minutes' heat input. This fact suggests poor bonding between heaters and piping.

For the next step of this study, the excess capacity of the helium refrigerator/liquefier has been measured. We have gradually increased the liquefaction rate by increasing the mass flow rate through turbines T1-T3 and T4-T5. While the liquefaction rate has been increasing, the liquid helium level in the storage vessel has been kept constant at the present value (22%) by enhancing the heat input power to a heater in the storage vessel.

The helium mass flow rate in the cold box has been increased from 700 g/s to 760 g/s spending three hours. As a result, we could increase the excess capacity of the refrigerator/liquefier from 1.37 kW to 2.19 kW keeping the liquid helium level in the storage vessel constant. In this period, the mass flow rate from the compressor was kept constant, while the flow rate in the cold box was increased corresponding to the decrease in flow rate in the by-pass circuit. The flow rate in the by-pass circuit was 310 g/s when the flow rate in the cold box was 760 g/s. This means that the compressor has sufficient margin in its capacity for this refrigeration power enhancement.

Since the required refrigeration capacity for helical coil cooling is estimated to be 1.6 kW, more than 0.5 kW of refrigeration capacity can be used for supporting structure and superconducting bus line cooling. This result means that we can supply a sufficient amount of subcooled helium to the helical coil maintaining the present level of the refrigeration capacity for the cooling of the other parts.

We will clarify the optimal distribution of the helium mass flow rate in the cooling system when the flow rate of 50 g/s for the helical coil is kept after the repair of bonding the heaters.

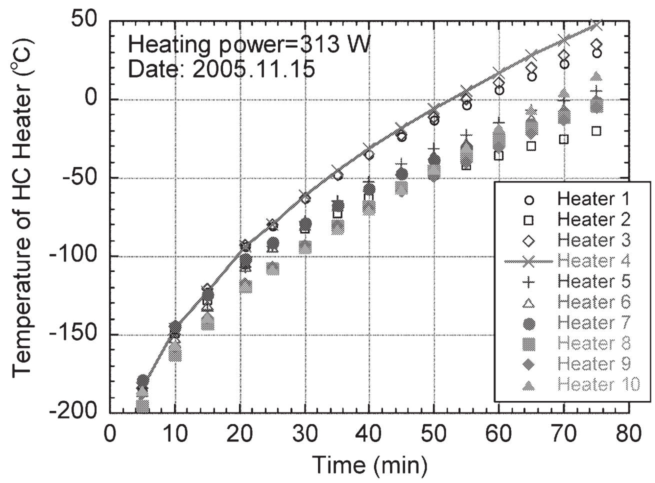

Fig. 1. Temperatures of HC heaters at heating power of 313 W.

1) Imagawa, S., et al., Fusion Engineering Design, to be published.
2) Hamaguchi, S., et al., IEEE Trans. on Applied Superconductivity 14 No. 2 (2004) 1439.