§4. Operation and Control of Helium Subcooling System with Cold Compressors for LHD Helical Coils

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Helical coils of the Large Helical Device (LHD) are large scale superconducting magnets for fusion plasma experiments. The cooling system was upgraded in 2006 in order to improve the cryogenic stability of the coils by lowering the temperature with subcooled helium as the coolant. In the upgrade, a cryostat was installed in order to subcool the supplied helium at 120 kPa and ten heaters were attached on the outlet pipes of the coils in order to control the mass flow rate of the supplied helium through the coils by evaporating the surplus liquid helium. The supplied helium is subcooled at a heat exchanger of a saturated helium bath in the cryostat. A series of two centrifugal cold compressors are utilized in the subcooling system to reduce the bath pressure and temperature. After the upgrade, an operating method for the steady state operation have been developed and then the subcooled helium of designed mass flow rate of 50 g/s at designed temperature of 3.2 K has been supplied to the coils stably during steady state subcooling operations.[1-2)]

Cold compressors should be operated within an appropriate range of the mass flow rate of helium gas in order to escape from surge and choke.[3-4)] However, the helium mass flow rate varies significantly when the rotational speed of the cold compressors is changed. Thus, it is very important to develop the operating method during the increase/decrease of the rotational speed. In the present study, an automatic transition method from/to the subcooling operation has been examined in order to operate the subcooling system safely and stably.

Based on the previous results,[2)] an optimal arrangement of control of a bypass valve and a heater in the bath have been developed for the smooth transition. Fig. 1 shows time traces of the set up value for the rotational speed of the cold compressors, the opening degree of the bypass valve, the set up value for the input power of the heater (3 times of the set up value equal to the heater power) and the mass flow rate of the helium gas through the cold compressors in the period of the automatic transition process. The mass flow rate through the cold compressors was automatically controlled by the heater in this process. The set-up value was 18.0 g/s. It took less than 30 minutes (target) to complete the each transition process from/to the subcooling operation. The process was achieved thanks to the suitable opening/closing of the bypass valve because the mass flow rate of the cold compressor changed too greatly to control that in the operating range of the heater in the saturated helium bath. As a result of the present examination, the heater could be operated within 12-52 % of the maximum power and the mass flow rate of the cold compressors was in the range from 17.4 g/s to 18.6 g/s.

Fig. 2 shows the performance curve of the cold compressors during the increase/decrease of the rotational speed of the cold compressors. Open circles show the performance during the present examination, while open squares show a targeted performance when the rotational speed of the cold compressors increased gradually by controlling the mass flow rate of 18 g/s manually. It was found that the present performance was consistent with the targeted performance. This means that the automatic transition was achieved keeping a stable and safe operation of the cold compressors. Consequently, the reliable subcooling operations of the system have been achieved over 6,000 hours for three years by applying the steady state subcooling operation and the present automatic transition method.

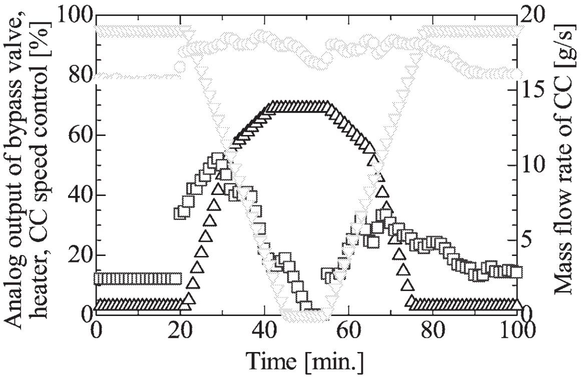

Fig. 1. Time traces of the set up value of each control equipment with the mass flow rate through the cold compressors. △: bypass valve, □: heater, ▽: rotational speed of the cold compressors, ○: mass flow rate.

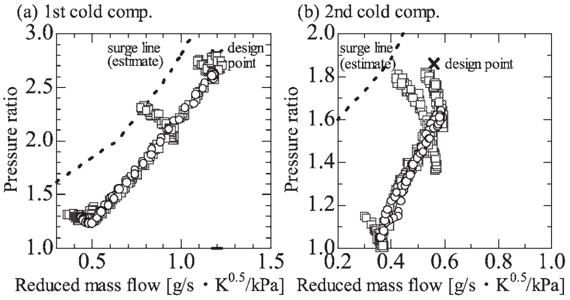

Fig. 2. Performance curve of the cold compressors during the automatic transition process with targeted performance.

1) Hamaguchi, S. et al.: Advances in Cryogenic Engineering **81** (2008) 2617
2) Hamaguchi, S. et al.: Proceedings of ICEC22 / ICMC 2008 (2009) 811
3) Martinez, A. et al.: Advances in Cryogenic Engineering **51** (2006) 1384
4) Bezaguet, A. et al.: Proceedings of ICEC17 (1999) 145