§2. Operation, Control and Performance of the Subcooling System for the LHD

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Helical coils of the Large Helical Device (LHD) are large scale superconducting magnets for heliotron plasma experiments. The helical coils had been cooled by saturated helium at 4.4 K, 120 kPa until 2005. An upgrade of the cooling system was carried out in 2006 to lower the operation temperature of the helical coils and then a cooling operation for the plasma experiments was taken from Aug. 2006 to Mar. 2007. In this report, the operation, control and performance of the upgraded cooling system are described.

Fig. 1 is the schematics of the upgraded cooling system for the LHD helical coils. A cryostat was installed at the helical valve box to generate subcooled liquid helium at 3.0 K, 120 kPa. Ten heaters were also attached on outlet pipes of the helical coils to evaporate surplus liquid helium. The cryostat consists of a saturated helium bath with a heat exchanger and a heater, a series of two centrifugal cold compressors with gas foil bearing and two valves. The bath is evacuated by the cold compressors up to 3.0 K. The supplied liquid helium (LHe) to the helical coils is subcooled in the heat exchanger. The mass flow rate of the supplied LHe is controlled by the ten heaters at the outlet of helical coils. The designed mass flow rate of the supplied LHe is 50 g/s.

Fig. 2 shows the temperature profiles of the cold compressor line when the rotation speeds of the cold compressors were increased. Open marks express the temperature profiles of the line. The solid line shows the rotation speed of the 1st cold compressor (CC1), the dashed line that of the 2nd cold compressor (CC2). In this case, the mass flow of the supplied LHe was 50 g/s. The rotation speeds could be increased within 30 min. from 700 Hz (waiting operation) to about 1,500 Hz (subcooling operation). In the subcooling mode, the inlet and outlet temperature of the cold compressors were 3.0 and 7.25 K, the inlet and outlet pressure 23.8 and 112 kPa, respectively. The mass flow of the gas helium through the cold compressors was 15.8 g/s. From the results, the heat inputs of the both cold compressors were calculated to be 349 W. The efficiency of the each cold compressor was evaluated to be 66 % (CC1), 63 % (CC2).

Fig. 3 displays the temperature and mass flow of the supplied LHe to the helical coils during a cool-down operation from saturated temperature to 3.0 K at the saturated helium bath. Open marks show the temperature profiles of the supplied LHe, while the solid line the mass flow. In this case, the supply valve of the helical coils kept 60 % open. In the present operation, the mass flow of the gas helium through the cold compressors was regulated by the power of the heater in the saturated helium bath, increasing the rotation speed of the cold compressors. As a result, the designed mass flow of the subcooled helium at 3.0 K, 120 kPa could be generated at the heat exchanger and supplied to the helical coils stably, when the heater power was 45 W. At that time, the inlet and outlet temperature of the helical coils was 3.2, 3.8 K, respectively. It was found that the upgraded cooling system satisfies the requirements.

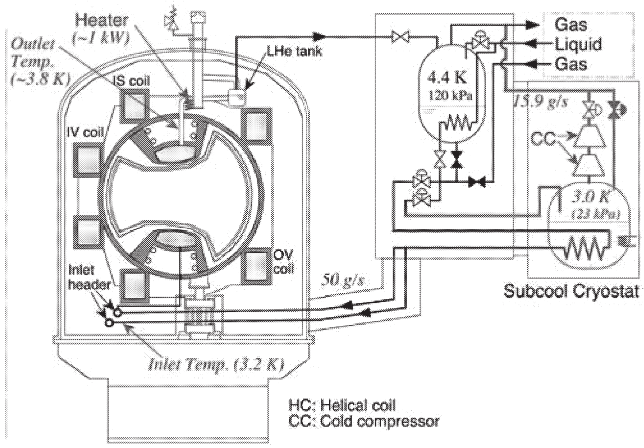

Fig. 1. Schematics of the upgraded cooling system for the LHD helical coils.

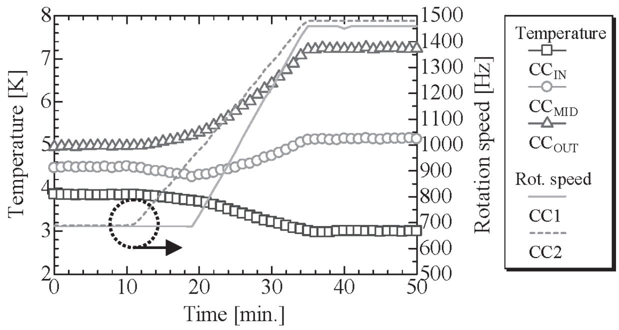

Fig. 2. Temperature profiles of cold compressor line during increase of rotation speeds of cold compressors. (CC1: 1st cold compressor, CC2: 2nd cold compressor)

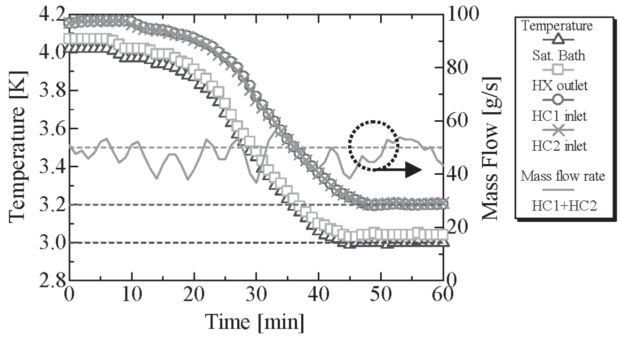

Fig. 3. Temperature profiles and mass flow of supplied LHe to the helical coils. (HC: helical coil, HX: heat exchanger)