§29. Studies on Thermal Characteristics of Superconducting Coil Cooled by Subcooled He I

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Superconducting magnets of the helical coils for the Large Helical Device (LHD) have been operated by saturated helium at the temperature of 4.4 K and pressure of 120 kPa. Up to now, plasma experiments have been carried out at a magnetic field lower than 3 T successfully. However, the operating field has not reached the design value of 3 T. So, it is considered that the superconducting magnets of the LHD helical coils will be cooled with the subcooled He I to achieve the nominal field of 3 T. To use subcooled He I as a coolant for the superconducting magnets of the LHD helical coils, the cooling characteristics and stability of superconducting magnets in subcooled He I have been studied.1)

An R & D coil was fabricated with superconductors for the LHD helical coils. The coil design was based on the LHD helical coils. The design magnetic field applied to the superconductors of the coil was 6.9 T at 13.0 kA (same as LHD). The winding consisted of 24 turns and 12 layers. The cooling channels were formed by the superconductors and FRP spacers, with the gaps being 2 mm (turn) and 3.5 mm (layer) as in the LHD helical coils. The ratio of the area exposed to subcooled He I to the area covered with FRP spacers was 67 % at the innermost layer (same as LHD). The inner radius of the coil was 200 mm and the outer radius was 395 mm. The 28 thermometers were attached on the surface of the FRP spacers in the coil to measure the temperature of subcooled He I in the cooling channels. Subcooled He I as a coolant was supplied from the bottom of the coil. The coolant flow went from the top end of the coil to a bath of current leads. A heater was inserted between a spacer and a superconductor at the bottom of the center turn of the innermost layer.

In the present experiments, the coil was immersed with flow in the subcooled He I. The supplied helium temperature was 3.1 or 3.5 K. The pressure of the bath of the current leads was set to 120 kPa. The mass flow rate of the subcooled He I was 5-10 g/s throughout the present experiments. In the stability tests, heat input from the heater to the superconductors was 30-100 W for 20 ms. The steady state temperature distribution of the subcooled helium in the cooling channels was measured while the coil was cooled down. The transient helium temperature changes were also observed when normal zone propagations occurred in the stability tests. 2-3)

Fig. 1 shows the temperature distribution of the subcooled helium in the cooling channels of the coil under the steady state. Open marks and dashed lines show results of the first experiment in December 2002, while solid marks and solid lines results of the second experiment in October 2003. TH19, TH23 and TH27 were located in the lower part of the coil, close to the inlet of the subcooled He I. TH21 and TH25 were situated in the upper part of the coil, close to the outlet of the coolant. The temperature in the coil was uniform except for TH19, TH23, TH27 (lower part) and TH21, TH25 (upper part) owing to very high heat conductivity of the superconductor, which utilized aluminum as a stabilizer. As a result, stable operation of the coil cooled with subcooled He I is expected because the degradation of the stability caused by the difference of the local temperature exist scarcely in the coil. However, the temperature in the upper part of the coil (TH21, TH25) was higher than that of the other points because of the arrangement of the cooling channels where the subcooled He I was stagnant.

The heat leak estimated from the increase of the helium temperature in the coil was 20 W in the first experiment. After the test facility was warmed up at room temperature, a 4 K shield, which consisted of a copper plate covered with super insulation, was added in order to decrease the heat leak. The 4 K shield was installed around the coil vessel and was attached on the bath of the current leads as a thermal anchor. Consequently, the helium temperature in the coil decreased by about 0.3 K and the estimated heat leak reduced to 7 W.

In the stability tests, the heat generated in the coil was removed by the flow of subcooled helium. The mass flow rate of supplied subcooled He I was 8.9 g/s in a certain stability test. It was assumed that the difference of the enthalpy between supplied subcooled He I and the coolant at the outlet of the coil contributed only to the cooling of the coil. The amount of heat, which should be removed, was the increase of the enthalpy of both the superconductor and helium in the coil. Consequently, the estimated recovery time was 28 minutes, which was 93 % of the experimental result, in the case of mass flow of 8.9 g/s. Since this estimation was in good agreement with the experimental result, the validity of this assumption was proved. The estimated time depended strongly upon the mass flow rate. The helium temperature will, therefore, return to the initial temperature faster if the mass flow rate can increase.

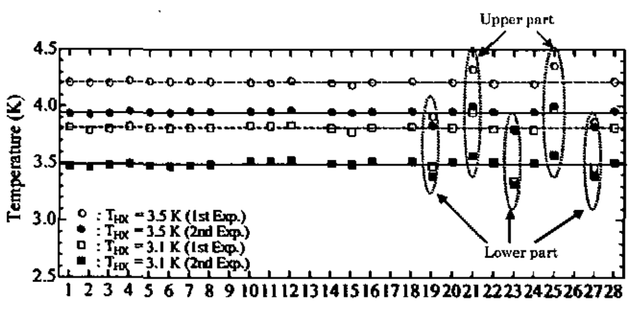

Fig. 1. Temperature distribution of subcooled He I in cooling channels of the R & D coil under steady state condition.

Reference

1) Imagawa, S., et al., IEEE Trans. Appl. Supercond., 11, (2001) 1889

2) Hishinuma, Y., et al., IEEE Trans. Appl. Supercond., to be published.

3) Imagawa, S., et al., IEEE Trans. Appl. Supercond., to be published.