§6. Temperature Evaluation of the LHD Helical Coils Cooled by Subcooled Helium under Coil Excitation

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The LHD helical coils are not equipped with thermometers due to the problem of electrical insulation. It is therefore impossible to measure the temperature of the coil immersed in subcooled helium. Understanding the coil temperature is essential to prevent the coil quench. In this study, the quasi-one dimensional numerical analysis on the coil temperature was performed by using the simple model of the coil for the purpose of evaluating the coil temperature in the longitudinal direction under coil excitation[1,2]. Fig. 1 illustrates the analytical model which simplifies a 3D configuration of the helical coils, and also the boundary condition of the analysis. The model consists of 3 parts including the helical coil, subcooled He and coil case. Eq. 1 was used in the coil region which combines aluminum stabilized NbTi/Cu superconductors, GFRP and the subcooled He included in the space between the superconductors. In addition, Eq. 1 was utilized in the coil case region which consists of SUS316. Eq. 2 was used in the region of the subcooled He between the coil and the coil case.

$$\rho \cdot c_p \cdot \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + Q_{thick} \quad (1)$$

$$\rho \cdot c_p \cdot \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + Q_{thick} - \rho \cdot c_p \cdot u \cdot \frac{\partial T}{\partial x} \quad (2)$$

where ρ is the density, c_p is the specific heat at constant pressure, T is the temperature, t is the time, x is the longitudinal length, λ is the thermal conductivity, u is the flow, and Q_{thick} is the heat flow per unit volume in the transverse direction. The heat flux at the boundary between each region was given by the following Eq. 3.

$$q = h \cdot \Delta T \quad (3)$$

$$h = c \cdot \Delta T^{1/3} \quad (4)$$

where h is the heat transfer coefficient, ΔT is the temperature difference and c is the constant. Thermal resistance was utilized at the boundary between each region to take into account the pool-cooled coil. Based on the experimental result [3], the heat transfer coefficient of the subcooled helium was used in Eq. 3. In this calculation, the influence of natural convection is not considered in the subcooled helium.

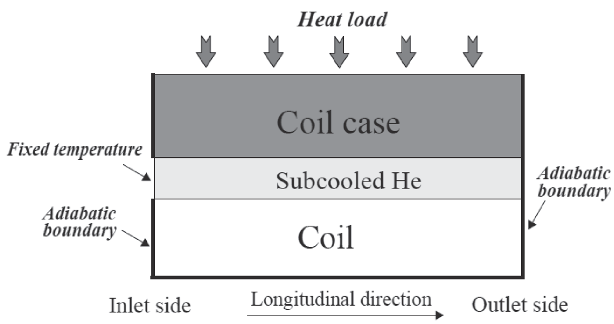

Fig. 1. Analytical model of the LHD helical.

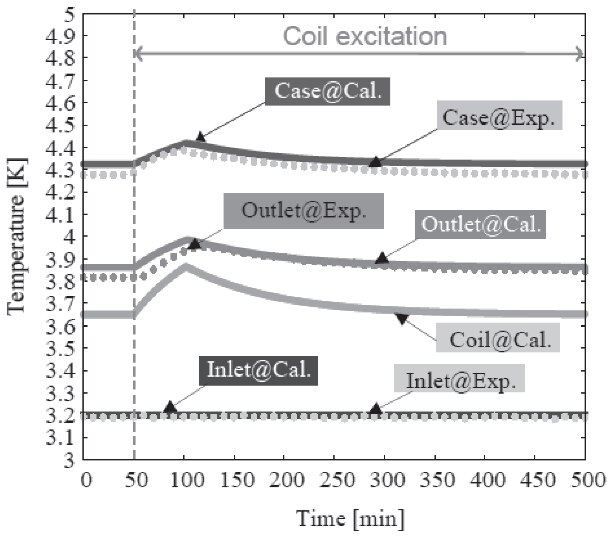

Fig. 2. Temperature profiles in the experiment and calculation under coil excitation from 0 A to 13 kA with the ramp rate of 3.5 A/s. During the coil excitation, the inlet temperature of 3.2 K and the mass flow of 50g/s were kept.

Fig. 2 shows temperature profiles of the coil and the coil case in the experiment and calculation under coil excitation from 0 A to 13 kA with the ramp rate of 3.5 A/s. The calculation matches the experiment closely under the coil excitation as shown in Fig. 2. From the calculation, the coil temperature would be 3.85 K under the rated operation of the cooling system in which the inlet temperature is 3.2 K, and the mass flow is 50g/s. The temperature differences between the coil and the outlet would be small due to AC loss generated in the excited coil.

1） T. Obana, et al.: Abstracts of CSJ Conference, Vol. 76 (2007) p.203
2） T. Obana, et al.: Abstracts of CSJ Conference, Vol. 77 (2007) p.167
3） Dorey, A. P.: Cryogenics (1965) Vol. 5, pp. 146–151