§14. Superfluid Refrigeration Technologies for Large Superconducting Magnet

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The superconducting magnets of helical coil for large helical device (LHD) was cooled down by normal fluid helium (He I) at 4.4K and plasma experiments with B = 2.9T was carried out successfully at the 3rd experiment campaign. However, we'll cool down the superconducting magnets of the helical coils by superfluid helium (He II) at 1.8K and conduct plasma experiments with B = 4T in the 2nd stage of experiment plan. In the case of using He II as a coolant for the superconducting magnets of the helical coils, we need to change the method of refrigeration without significant change of inner cryogenic component such as the helical coils and the support structure. This is the reason why its size, structure, and arrangement of pipes and circulation systems for He II will be restricted strongly in space. Therefore, the heat transport characteristics of pressurized He II will be influenced seriously.

To use He II for cooling down the superconducting magnets of the helical coils, it is necessary to examine the heat transport characteristics of He II from the viewpoints of the cryogenic stability and the quench protection. Because heat generated in the superconducting magnets of the helical coils are removed through the cooling channels, it is especially important to understand the heat transport characteristics of He II in the cooling channels of the superconducting magnets of the helical coils. However, the helical coils for the LHD are so huge that the heat transport characteristics are investigated experimentally. So we have investigated the heat transport characteristics by means of the numerical analyses.

In the previous report, we tried to take numerical analyses on He II heat transport in the short straight channels by the finite element method with a set of equations based on two fluid model. Those equations follows. 1)

Continuity equation;

$$\nabla \cdot \rho\vec{v} = 0 \tag{1}$$

Momentum equation of total fluid;

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla \cdot (\rho\vec{v}\vec{v}) = -\nabla p + \eta\nabla^2\vec{v} + \vec{G} \tag{2}$$

Momentum equation of superfluid;

$$\frac{\partial}{\partial t}(\rho_s\vec{v}_s) + \nabla \cdot (\rho_s\vec{v}_s\vec{v}_s) = -\frac{\rho_s}{\rho}\nabla p + \rho_s s\nabla T - A_{GM}\rho_n\rho_s(\vec{v}_n - \vec{v}_s)^3 + \vec{G} \tag{3}$$

Energy equation;

$$\rho c\frac{\partial T}{\partial t} + \rho c\vec{v} \cdot \nabla T = f^{-1}(T)^{\frac{1}{3}}\nabla \cdot (\nabla T)^{\frac{1}{3}} \tag{4}$$

where,

$$f^{-1}(T) = \frac{\rho^2 s_\lambda^4 T_\lambda^3}{A_{GM}}\left[\left(\frac{T}{T_\lambda}\right)^{5.7}\left(1 - \left(\frac{T}{T_\lambda}\right)^{5.7}\right)\right]^3 \tag{5}$$

$$A_{GM} = \frac{\rho}{(11.3)^3\rho_s\eta_n} \tag{6}$$

$$\vec{G} = [0 \quad g(\rho_0 - \rho)]^T \tag{7}$$

As a result, we obtained good agreement with the experimental facts about simple figurations, such that were dealt with in the previous analyses. From now on, it is necessary to apply these to more complicated channels like the cooling channels of superconducting magnets of helical coils. So we must investigate heat transfer characteristics from superconductors of helical coils to He II and heat transport characteristics of model coils immersed in He II.

On the other hand, there are electromagnetic problems in the superconductors of helical coils, for example normal propagation and AC losses. These problems cause heat generations and so heat transport characteristics in the cooling channels are made worse. For discussions about the cryogenic stability as the helical coils, it is necessary to consider those heat generation problems. Fortunately, numerical analysis code for problems of normal propagation in the superconductors of helical coils have been developed by Dr. Gavrilin and Dr. Yanagi at NIFS. 2,3) To operate the helical coils safely in the 2nd stage of experiment plan, we must evaluate cryogenic stability of helical coils cooled by He II, using both numerical analyses on heat transport of He II in the cooling channels and normal propagation in the superconductors of the helical coils.

References

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2) Yanagi, N. et al. : MT-16 (Florida 1999) 9C-351.
3) A. V. Gavrilin, et al. : Adv. in Superconductivity XI (1999) pp.1447-1450.