§ 22. FEM Analysis on the Transient Cryogenic Stability of the LHD Helical Coils

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As the application of superconducting coils progresses, it is required to advance their performance with high stability and reliability so that coils can be operated at higher magnetic field and larger current. In order to simultaneously satisfy the other demand of high cost performance, the cryogenic stability of superconducting coils becomes marginal. In this respect, new evaluation schemes for cryogenic stability should be developed by including transient features of normal-zone propagation.

In the present studies, composite-type superconductors stabilized with a large cross-section of pure aluminum are treated. Numerical simulation codes based on finite element method (FEM) have been developed especially to analyze the normal-zone propagation observed in the aluminum-stabilized superconductor used for the helical coils of the Large Helical Device (LHD). The electromagnetic and thermal processes are simultaneously solved in this code. We confirmed that a two-dimensional FEM code well described the normal-zone propagation observed in short-sample tests of the present superconductor. In this simulation, the minimum input energy required for an initiated normal-zone to propagate was evaluated. When the normal-zone reaches to a threshold length, it continuously propagates and this threshold length depends not on the duration and spatial length of the external heat input but on the operation conditions specified only by the applied magnetic field and the conductor current. The minimum input energy becomes larger as the magnetic field and current become larger. The simulation results show that a normal-zone easily propagates for the operation conditions given by the magnetic field > 6 T and conductor current > 11 kA.

In the present analysis, it was found that the cooling property at the surface of the conductor plays an important role. The simulation results show that the transient stability is degraded by the existence of spacers since the propagation velocity of a normal-zone becomes faster at the conductor regions covered by spacers due to the reduction of heat flux from the conductor surface to liquid helium. Thus, it is also required to include precise cooling characteristics, which is not possible within the framework of two-dimensional analysis and a three-dimensional FEM code should be developed. Moreover, the recent experimental results on the R&D coil conducted at NIFS shows that in some conditions, a normal-zone propagates only in one direction along the conductor, and it forms a so-called "traveling normal-zone". The effect of Hall electric field generated at the normal-zone fronts, where the transport current is transferred from the superconducting strands to the metal stabilizers, is considered to cause the asymmetrical normal-zone propagation. It is possible to include this effect into the new 3-D code and the model will be verified.

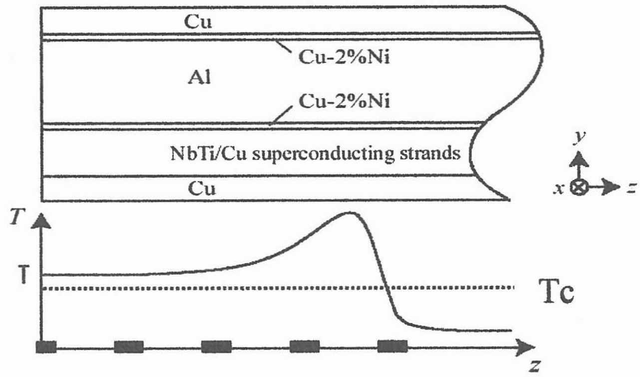

Fig. 1 Schematic model of the configuration of the aluminum-stabilized superconductor included in a two-dimensional FEM code. Spacers are distributed along the longitudinal direction on the conductor surface.

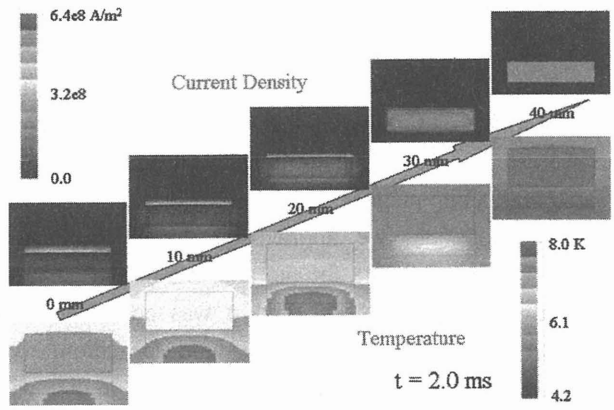

Fig. 2 Preliminary results obtained by the new three-dimensional FEM code. The spatial distributions of the current density and temperature at 2 ms after the input of a heat disturbance are plotted in the cross-section of the superconductor along the longitudinal direction.

References

1) S. Noguchi, et al., IEEE Trans. Appl. Supercond. 9 (1999) pp. 624-627.
2) N. Yanagi, et al., IEEE Trans. Appl. Supercond. 9 (1999) pp. 1113-1116.