§1. Stability Analysis on the Superconductors for the LHD Helical Coils

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Cryogenic stability of the superconductors used in the helical coils (HC) of LHD has been investigated through experiments as well as numerical analysis. In addition to short sample conductors already tested so far, an R&D coil was fabricated using 11 m of the HC superconductor consisting of NbTi/Cu strands, a Cu-2%Ni-clad aluminum stabilizer and a copper jacket. Figure 1 shows a schematic drawing of the R&D coil. The conductors are wound into double pancakes of each five turns, and they are covered with thick stainless steel casing in order to simulate the real cooling condition of HC. The experiment of the R&D coil was carried out under a bias magnetic field provided by a 9 T split coil. An advantage of this coil sample is that its conductors experience much wider uniform field distribution than that in the previous straight short samples. Moreover, the orientation of the conductor is varied in every direction. These facts should be very useful to simulate the real condition of the HC conductors.

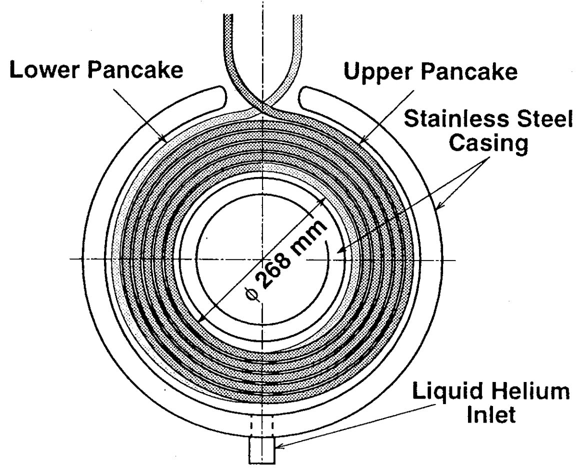

Fig. 1 Schematic drawing of the R&D coil.

One of the most important findings confirmed with this R&D coil experiment is that the conductor becomes transiently unstable with a transport current even lower than the recovery current, as is seen in Fig. 2. Consequently, there is a temporal and finite propagation of a normal zone. This is brought about by the fact that the pure aluminum stabilizer has rather long diffusion time constant (of about 100 ms) and it takes a while before the transport current fully penetrates into the stabilizer 1). Another important observation is that the propagation velocity differs depending on the direction of propagation. In the present case, the propagation velocity becomes faster in the downstream side of the transport current than in the upstream side. The mechanism for causing this difference is still not clear. It may have some electromagnetic origin, since this observation does not depend on the orientation of the conductor sample.

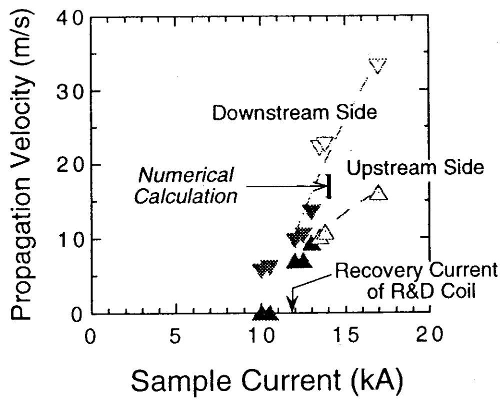

Fig. 2 Propagation velocity vs. transport current measured with an R&D coil (closed triangles) and a short sample conductor (open triangles).

Numerical analysis has been conducted using a sophisticated simulation code developed in NIFS 2), which incorporates realistic temperature and field dependent physical parameters and deals with complicated electromagnetic and thermal processes in the present conductor. Figure 3 shows a typical example obtained by the calculation. As is seen in Fig. 3, the normal zone propagation observed in a short sample could be well simulated by the calculation. The propagation velocity was also evaluated and is plotted in Fig. 2. The present analysis well confirms the transient stability characteristics of the HC superconductors, which explains the mechanism for the quench event of HC during the LHD excitation test.

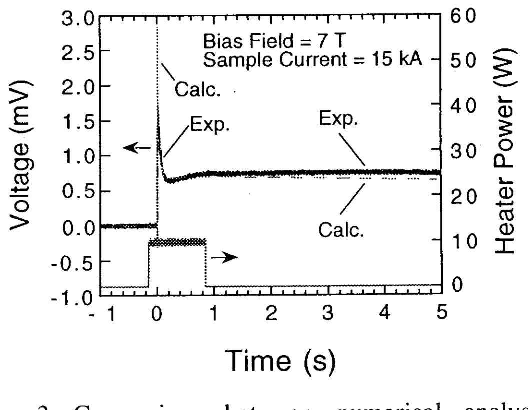

Fig. 3 Comparison between numerical analysis and experimental observation for a longitudinal voltage signal of a short sample conductor.

References
1) Yanagi, N., et al., presented at ASC98, LTB-06.
2) Gavrilin, A.V, et al., presented at ISS 98, SAP-29.