§ 1. Results of Stability Test in Subcooled Helium with the R&D Coil for the LHD Helical Coil

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The operating currents of the LHD helical coils are restricted below about 90% of the design current because a normal zone has propagated dynamically at several times at almost the same current [1]. An R&D coil, as shown in Fig. 1, was made of the same conductor to estimate the effect of lowering temperatures on the cryogenic stability. It was wound by layer winding of 24 turns and 12 layers. The magnetic field becomes the highest at the middle turn of the first layer, which is the testing region for the cryogenic stability. The value is 6.9 T at 13 kA, same as the LHD helical coil. The wetting surface fraction of the first layer is 67%, same as the turns at the highest field of LHD helical coil. Thermometers are installed not only on the conductors but also in the cryogen to examine the temperature differences in the coil.

The cryogenic stability of the R&D coil was examined in the saturated and subcooled helium. The flow diagram of the R&D system is shown in Fig. 2. Liquid helium is supplied from the bottom of the R&D coil. It is exhausted through current leads to the current-leads tank. The inlet helium is subcooled by a pre-cooler, which is evacuated by two cold-compressors. Tape heaters are inserted between the conductor and the layer to layer spacer for initiating a normal zone. The heating duration is set to 20 ms to put as much energy as possible adiabatically. The propagation was detected by voltage taps. The heater at the bottom of the middle turn of the first layer was mainly used.

In saturated helium of 4.4 K and 0.12 MPa, the minimum current to begin propagation is 10.7 kA. The necessary heat input for the propagation becomes less at the higher currents, as shown in Fig. 3. The normal zones were propagated only one side at less than 11.4 kA. The direction is same as $\boldsymbol{J_S}\times\boldsymbol{B}$, where the $\boldsymbol{J_S}$ is the vector of the transfer current from the superconducting strands to the aluminum stabilizer, and $\boldsymbol{B}$ is the magnetic field vector. At 11.4 and 11.5 kA, the normal zones were propagated both side, and recovered from the upper area in the middle turn. Namely, finite length of normal zones propagated both sides. The propagating velocity at the direction of $\boldsymbol{J_S}\times\boldsymbol{B}$ is almost twice as the opposite direction. At 11.6 kA, the normal zones started recovering once from the middle turn, but rapid propagation was followed. The cooling condition was considered to be deteriorated by accumulation of helium bubbles.

In subcooled helium at 0.12 MPa, the minimum currents to begin propagation are increased up to 11.4 and 11.6 kA at 4.2 and 3.8 K, respectively, as the temperatures in the R&D coil. Figure 4 shows these points compared with the LHD helical coil. The necessary heat input is increased by 10 to 20% for the saturated helium. The rapid propagation was followed at 12.1 and 12.2 kA at 4.2 and 3.8 K, respectively, in spite of one-side propagation.

Reference
1) S. Imagawa, et al., IEEE Trans. Appl. Supercond., Vol. 11 (2001) 1889-1892.

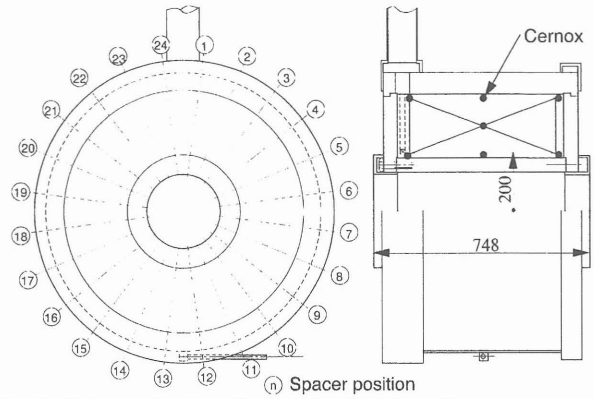

Fig. 1. Schematic drawing of the R&D coils.

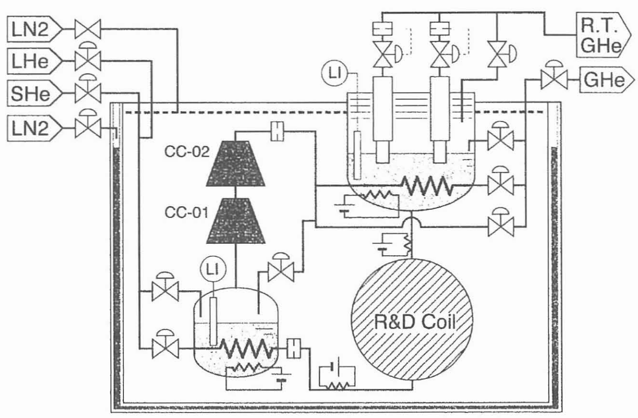

Fig. 2. Flow diagram of the subcooled system.

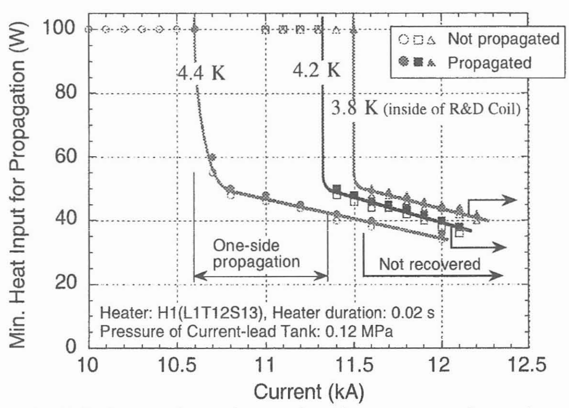

Fig. 3 Minimum heat input for the propagation of a normal-zone in the R&D coil in a subcooled helium.

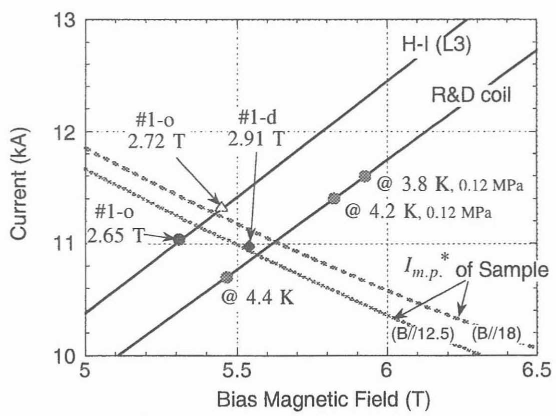

Fig. 4. Dynamic normal-zone propagating current $I(m.p.)$* of the composite conductor for the LHD helical coil.