§1. Design of Helical Coil Winding

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On-site winding of the helical coils of LHD will start this autumn. They are pool-cooled superconducting coils. Figure 1 shows the cross section of the helical coil. The major parameters are shown in Table 1. By lowering bath temperature from 4.4 K to 1.8 K, central toroidal field is planned to be enlarged from 3 T to 4 T. The mechanical structures should be designed for 4 T operation. The helical-coil conductor was determined to satisfy fully stabilized criterion[1]. The recovery current of the coil should be larger than the nominal current. The conductor consists of Nb-Ti/Cu strand cables, pure aluminum stabilizer with Cu-2%Ni clad, and copper sheath. The size of the conductor is 12.5 mm by 18.0 mm. Electrical insulators between conductors are settled at intervals to arrange cooling channel. The thickness of turn to turn insulator and layer to layer insulator are 2.0 mm and 3.5 mm, respectively. Since the helical-coil conductors are unable to sustain the large electromagnetic force by themselves, they are designed to be packed into a thick can that is fastened by a cylindrical supporting structure. Ground insulation is planned to be directly pasted on the helical-coil can. The thickness is more than 3 mm.

Critical current, recovery current and stability margin of the conductor were measured in short sample tests. The measured recovery current was just 13.0 kA in 4.4 K and 7 T at wetted surface fraction of 0.5. A representative distribution of the transverse component of the magnetic field in the helical coil is shown in Fig. 2. It becomes zero near the core of the helical coil and becomes gradually higher toward the edge. On the contrary, the load per unit length on each insulator between the conductors becomes larger toward the core of the coil. At the core region where the magnetic filed is low, the wetted surface fraction of conductors can be decreased in order to reduce the stress on the insulators without degrading the recovery current. On the other hand, the fraction can be increased at the edge of the coil to enhance the stability of the coil, because the load on the insulators is small[2]. In the case that the wetted surface fraction is 0.5 everywhere, the recovery current of the coil is calculated to be 13.43 kA. It is larger than the nominal current by 3.3 %. Considering the degradation of heat transfer by packaging or manufacturing error of the dimension of the insulator, the margin of the recovery current would not be enough. In the case that the fraction is changed by three steps of 3/8, 1/2 and 2/3, the recovery current of the coil would be enhanced to 15.12 kA without enlarging the stress on the insulators. Furthermore, by increasing number of steps of grading, the stability for superconducting coil can be more enhanced. Final design will be finished soon.

Table 1 Major parameters of the helical coil

item	Phase I	Phase II
Major Radius/Minor Radius	3.9 m/0.975 m	
Number of Turns	450	
Bath Temperature	~ 4.4 K	~ 1.8 K
Central Toroidal Field	3 T	4 T
Maximum Field in Coil	6.9 T	9.2 T
Nominal Current of Conductor	13.0 kA	17.3 kA
Current Density	40 A/mm^2	53 A/mm^2

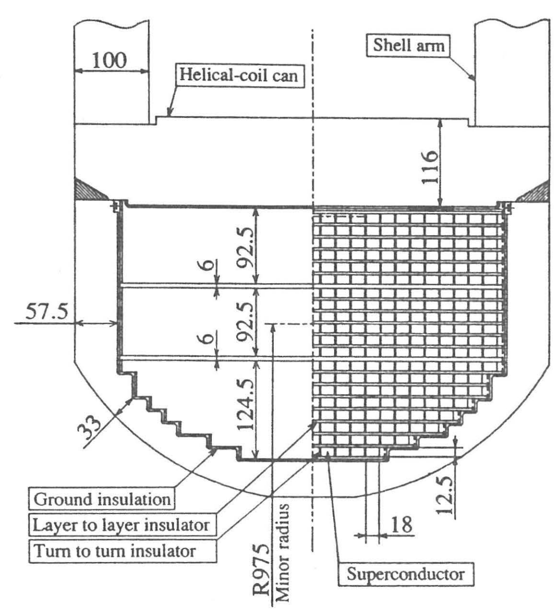

Fig. 1. Cross section of the helical coil

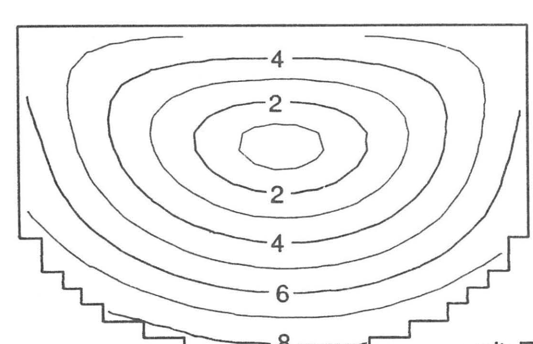

Fig. 2. Transverse magnetic field in the helical coil (at the top position in #1-o mode at Phase II)

References
1) T. Satow et al., Fusion Eng. Des., 20 (1993) 67-72.
2) S. Imagawa et al., Proc. of the 8th US-Japan workshop, Wisconsin, March 17-19 (1993) 9-12.