§2. Completion of Helical Coils for LHD

Imagawa, S., Satow, T.

Helical coils of LHD were completed by the end of 1996. It took six years to fabricate the helical coils that include superconductors, a special winding machine, helical coil cases, winding work and top covers of the cases. The main feature of these coils is high accuracy of the coil position within ±2.0 mm in spite of the complicated figure. For shaping the conductors nearby the coil with high accuracy, we selected the medium sized conductor of pool-cooled type. Against large electromagnetic forces, the conductors are packed into thick cases (HC can) which are supported by an outer shell structure, as shown in Fig. 1.

In order to keep the stress in the conductors within elastic region, average elastic modulus of the coil should be higher than 5 GPa. We developed insulator with high compressive modulus over 22 GPa, and we planned to control the average gaps between layers within 0.065 mm while winding. Besides, the assembling gaps between the coil and top covers of the HC cans should be diminished by welding. We have successfully managed the average gaps while winding[1]. The maximum relief by slant of each conductor was controlled under 0.30 mm by reshaping process, and the average relief of each layer was successfully kept within 0.10 mm. Since we filled the room-temperature-cured resin under the layer to layer insulator, the effective residual gaps between layers were attained within 0.05 mm. At the 19th layer, we measured elastic modulus of the coil and confirmed to attain the demanded value. After winding, the top covers were fitted on the coils and welded very carefully. We have attained the assembling gaps within 0.5 mm, and the shrinkage by welding was successfully controlled from 0.5 to 1.3 mm.

For high accurate manufacturing, we adopted the method to wind the conductors directly on the HC cans which was manufactured with high precision of 0.50 mm as standard deviation. Besides, we developed the winding machine with thirteen numerically controlled driving axes. The position of conductor in the overturning direction was controlled by the thickness of cotters at both sides, and the errors were suppressed within ±0.5 mm. The increase of the minor radius has an apparent tendency that it is large at inside. The reasons are the geometrical increase and decline of shaping accuracy caused by the larger torsion angle. This component corresponds to a decrease of major radius, which was only 0.25 mm among the 20 layers. The standard deviation of the differences of minor-radii in each layer was kept within 0.35 mm. Still, the difference between average minor radii of each layer of two helical coils was kept within 0.2 mm. We have attained the required winding accuracy. After winding, top covers of the HC cans with arms were set on the coils and welded very carefully. After that, outer parts of plasma vacuum vessel were fixed on the winding core tentatively. The entire assembly was set into the supporting shell, and the arms were welded to the shell. We come up with new ideas for each welding to protect the coil and to suppress deformation. According to the law of propagation of errors, the standard deviation (σ) of errors for position of all conductors are estimated to be 0.60 mm before welding to the shell. The deformation of the HC cans caused by further work should be kept under 1 mm to keep 3σ within 2 mm finally.

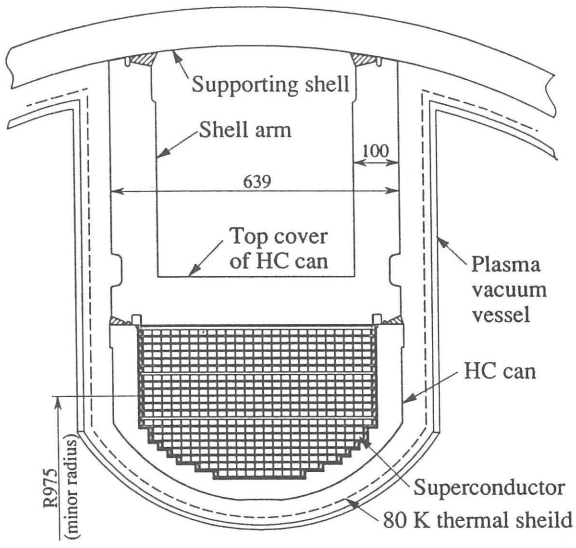

Fig. 1. Cross-section of the helical coil

References

1) S. Imagawa, et al., Proc.of 19th Symposium on Fusion Technology (1996) PE10.