§4. Accuracy of Winding of Helical Coils for LHD

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Accuracy of the position of coils is very important for magnetic fusion devices to produce a fine rational magnetic surface. In LHD, error of the position for each coil is required to be within 2 mm, which is corresponding to 5×10^{-4} of the major radius. This value is derived to reduce the width of undesirable magnetic islands into one tenth of the plasma minor radius in the cases of low mode deformations, for example, eccentricity or axial inclination between a helical coil and other coils.

The helical coils for LHD are pool-cooled superconducting coils under on-site winding from January of 1995. Since the electromagnetic forces on the conductors are too large to withstand by themselves, they are designed to be packed into thick cases (HC cans) which are finally supported by an outer supporting shell. According to the structural analyses, welding was adopted for all joints of these structures to ensure the large electromagnetic force. In order to keep accuracy of the helical winding, we adopted the method to wind conductors directly on the HC cans which should be manufactured with high precision. Because of the regulation for transportation on road, each 1/20 sector of the HC cans was manufactured in a factory and transported to the site. All the 1/20 sectors were machined by large scale numerical controlled (NC) machinery with high accuracy of ±0.2 mm, and ground insulation was directly pasted on the can and cured by autoclave method to keep the tolerance of thickness within ±0.2 mm. At first, we prepared a ring-shaped winding core with high accuracy of ±0.2 mm. All the sectors of the HC cans were set on the core and welded each other. By adopting two-stage welding, the deviation and the maximum value of deformation by welding were successfully suppressed under 0.12 and 1.0 mm, respectively. The HC cans were completed with absolute accuracy of 1.5 mm. For high accurate winding, we developed the winding machine with 13 NC driving axes [1]. We manage the shaping error of the conductor within 10%, the maximum relief by slant of each conductor within 0.30 mm. The slant and the position of the conductors are measured by laser distance meter from base surfaces of the HC can. Using the measured data, all insulators between layers have been machined by a NC planer with justifying the minimum thickness. The deviation of position of the conductors relative to the HC can have been kept within ±0.5 mm. The difference between average minor radii of each layer of two helical coils has been kept under 0.2 mm shown in Fig. 1. We have confidence in attaining the required accuracy.

After winding, top covers with arms will be set on the cans and welded. Next, the entire assembly will be set on the outer supporting shell, and the arms will be welded to the shell. After that, the winding core will be cut down into small pieces and removed. According to the law of propagation of errors, the deformation of the HC cans caused by each welding should be kept under 1 mm to attain the accuracy of 2 mm finally.

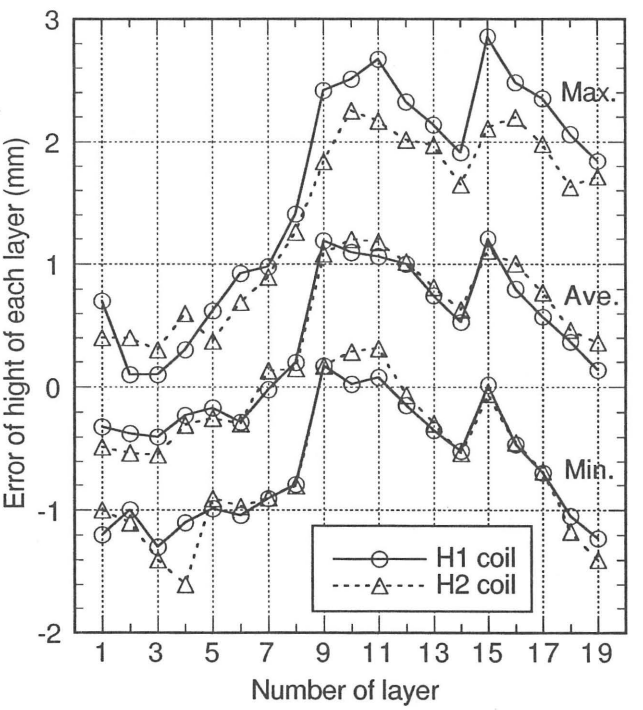

Fig. 1. Accuracy of helical coil winding in minor radius up to the 19 th layer.

References

1) S. Imagawa, et al., Construction of Helical Coil Winding Machine for LHD and On-site Winding, IEEE Transactions on Magnetics (will be published)