§10. Superconducting Magnet and Support Structure of the FFHR-d1

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FFHR-d1, which is four times the size of the LHD, comprises three types of superconducting coils: a pair of helical coils, inner vertical poloidal coils, and outer vertical poloidal coils. The geometric positions of these coils are similar to the corresponding positions in the LHD. The magnetic field strength at a coil winding torus center is 4.7 T, and the stored magnetic energy is 160 GJ. Structural designs for the coil support structure equipped with large apertures for the maintenance port have been introduced[1].

Both the helical coil and the coil support structure in the LHD-type helical reactor exhibit a continuous structure throughout their circumference. To estimate the magnetic field distribution in the coil, it is necessary to define a coil cross-sectional shape. The bottom area of the helical coil should be curved to prevent interference against the plasma vacuum vessel. We designed the cross section of the helical coil as shown in Fig. 1. The magnetic field distributions and the electromagnetic forces induced by the coils were calculated based on this cross section. The maximum electromagnetic hoop force was 70 MN/m, while the maximum EM overturning force was 10 MN/m.

The ideal coil support structure is a thick torus surrounding the helical coils. Since the electromagnetic force along the helical coil winding is required to be sustained, the coil support structure was designed on the basis of the following concepts: the support, which was made of 300 mm–thick stainless steel (SS) 316; there was a vacuum gap of 200 mm between the support and the vacuum vessel except for the coil bottom region. The vertical field coils were surrounded by 200 mm–thick SS and were connected to the support; apertures were increased in size. A stress and deformation analysis was performed on the structure, using this fundamental model. Fig. 2 shows the fundamental design of the coil support structure with the results of the analysis with respect to the von Mises stress distribution. The von Mises stress was maximum at the corner area of the port region. The maximum stress of 600 MPa is the permissible limit for SS 316 at cryogenic temperature. A maximum deformation of 32 mm appeared near the upper outer vertical coil. Fig. 3 shows an enlarged deformation plot in the area near the bottom region of the helical coil. The displacement toward the plasma side was 7 mm.

The total weights of the magnet system (coils with support structure) are estimated to be 22000 tons (calculated from the FEM model). Because the amount of deformation of the magnet system is large, a flexible support is desirable. The LHD-type support post with a “folded multi-plate” design was also suitable for the FFHR-d1 from both mechanical and thermal viewpoints[2]. It is known that the total weight of the coil support is proportional to the stored magnetic energy, and actual superconducting fusion devices have been in close agreement with this viral theorem[3]. With a stored magnetic energy of 160 GJ, the total weight can be estimated to be between 10000 (theoretical) to 30000 tons (extrapolation from actual devices). The total weight of the magnet system is probably reduced to lower than 20000 tons by optimizing.

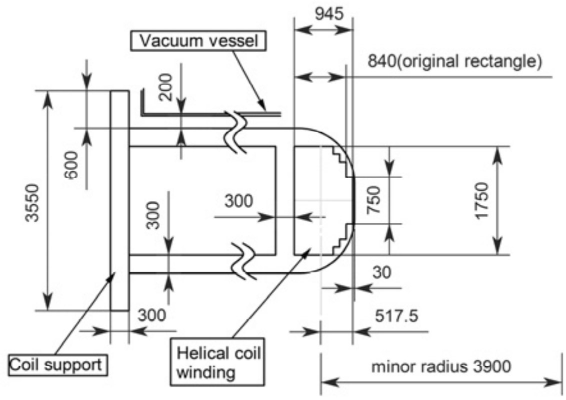

Fig. 1. Cross section of the helical coil perpendicular to the coil winding direction.

Fig. 2. Results of structural analysis.

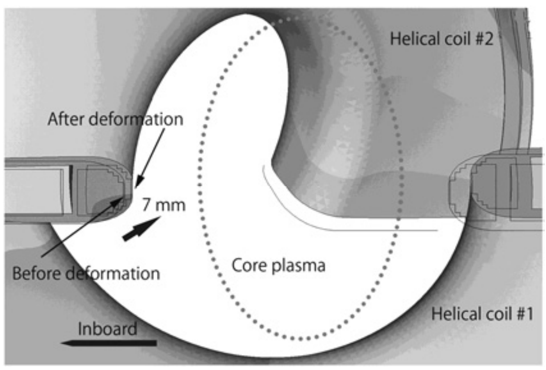

Fig. 3. Amount of deformation near the helical coil.

1) Tamura, H., et al.: to be published in Fusion Eng. Des. (2013).
2) Tamura, H., et al.: Plasma and Fusion Res. **3** (2008) S1051.
3) Takahata K.: Journal of Plasma and Fusion Research **81** (4) (2006) 273 (in Japanese).