§15. Methodological Study of Structural Analysis for Helical Coil

Tamura, H., Yanagi, N., Goto, T., Takahata, K., Imagawa, S., Sagara, A.

A simple calculation method can be useful for making a mechanical estimation of many design parameters in the early design phase. A simplified axisymmetric coil model having the mean radius of curvature of the helical coil (HC) has been proposed to evaluate stress distribution inside the coil [1, 2]. To ensure precision, the mechanical behavior of the HC for several models were calculated, and the differences among them were investigated. Various supporting configurations were considered for the 3-D models, with reference to the FFHR2m2.

The curvature at the center orbit of the HC at each location changes with the circumferential toroidal angle. In case of FFHR2m2, the mean radius of curvature through the circumference is calculated to be 6.69 m. An electromagnetic (EM) force was applied considering the actual magnetic field distribution. We considered only the EM force of the HC, since many coil support methods are available not only for HC but also for poloidal coils (PCs). The PCs may be supported together with the HC or individually.

Five types of FE model were prepared: the 2-D axisymmetric, quasi 3-D, full torus shell support, torus shell with port section, and widely divided shell models. In all the models, the HC section had the same cross-sectional geometry. The EM force was applied to each element of the HC section in the FE model by transforming the force to the surface pressure on the element. Since the EM force distribution changed along the circumference, an averaged EM force at each element's position was applied in the 2-D axisymmetric model. A constant value was added to the averaged EM hoop force so that the total over the cross-section was equal to the maximum overall hoop force in this case. Fig. 1 shows the 2-D axisymmetric model and the applied EM force distribution. The quasi 3-D model actually had a 3-D geometry, but it did not have a support structure, as shown in Fig. 2. The boundary conditions applied to the quasi 3-D models were cyclic boundary at the edge and restricted out-plane deformation of the cross-section perpendicular to the winding direction, which realizes the assumption that the HC is supported by a thick toroidal structure. The support structure of the detailed 3-D models was essentially a torus shell. We considered the three models shown in Fig. 3.

As the result of the calculations, the distribution of stress / strain / deformation in the 2-D axisymmetric model was similar to that of the innermost region of the 3-D models. The maximum amount of deformation for each model, the maximum von Mises stress in the coil section, and the maximum hoop strain in the coil section, are given in Table 1. The results for the 2-D and quasi 3-D models were almost the same. The 3-D torus shell with ports was the typical support structure. The difference in stress between the 2-D model and the 3-D torus shell with ports was approximately 19%, and the difference in hoop strain was 17%. Although the 2-D model could estimate the maximum value of deformation, its location could be identified only in the 3-D models. The quasi 3-D model could predict the deformed shape to a certain extent.

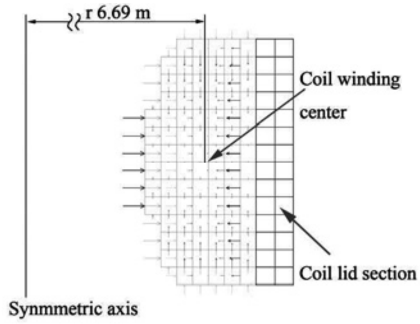

Fig. 1. 2-D axisymmetric model and EM force.

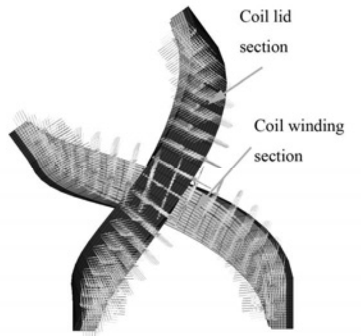

Fig. 2. Quasi 3-D model with applied EM force distribution

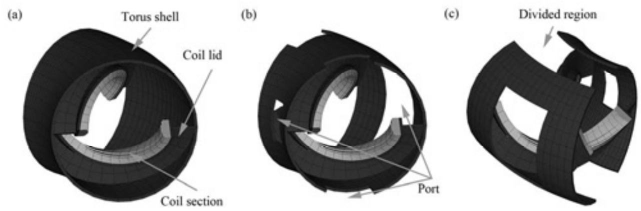

Fig. 3. 3-D FE models: (a) full torus shell, (b) torus shell with port, (c) widely divided shell.

Table 1. Maximum deformation, stress, and strain.

Calculation model	Amount of deformation (mm)	Von Mises stress in the coil winding (MPa)	Hoop strain in the coil winding (%)
2-D axisymmetric	13	245	0.21
Quasi 3-D	15	262	0.22
3-D full torus shell support	15	182	0.14
3-D torus shell with port	18	206	0.18
3-D widely divided shell	24	236	0.21

1) Tamura, H. et al.: J. Phys.: Conf. Ser. **234** (2010) 032055.
2) Tamura, H. et al.: Plasma and Fusion Research **5** (2010) S1035.