§5. Design Progress on the High-Temperature Superconducting Coil Option for FFHR

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The conceptual design studies on the heliotron-type fusion energy reactor FFHR are being conducted on both physics and engineering issues [1]. The present design gives a major radius of ~17 m with a toroidal magnetic field of ~5 T and the stored magnetic energy of ~160 GJ. We propose that helical coils of a continuous manner and a huge size be constructed by prefabricating half-pitch segments with high-temperature superconductors (HTS); the segments are then jointed on site as illustrated in Fig. 1(a). We consider the YBCO coated-conductor be a good candidate based on the recent development of wire production technology. Figure 1(c) shows an example of the HTS conductor design with 100 kA current to be operated at magnetic field of ~13 T and temperature > 30 K. We have successfully carried out a short sample test of a 10 kA-class scale-down conductor with high stability.

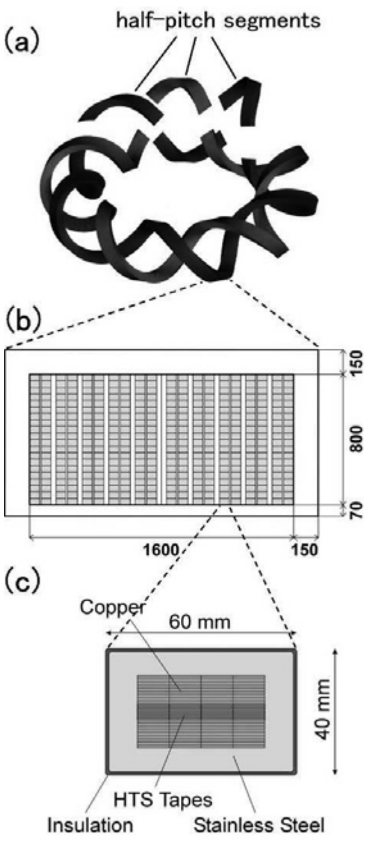

Fig. 1 Conceptual images of (a) segmented-type fabrication, (b) the coil pack and (c) a 100 kA HTS conductor to be applied for the FFHR helical coils.

Using HTS conductors and segmented fabrication, it would also be feasible to employ the pancake winding for the helical coils rather than the layer winding which has been considered as standard for helical coils. The pancake windings are supposed to have many advantages, such that the coil-leads could be extracted from the outside region of the coil package, the plumbing for coolants could be simplified, and stronger mechanical support is given inside a coil package. Figure 1(b) shows a cross-sectional image of the helical coil package with the pancake winding method.

In order to analyze the electromagnetic stress and strain inside the helical coil package, a numerical analysis employing the finite element method has been conducted using ANSYS. As the first step, the helical coil was modeled as a solenoid coil having the equivalent winding radius of 5.5 m. The Young's modulus of the coil structure (stainless-steel) and the HTS conductor (using a stainless-steel jacket) was given as 200 GPa and 167 GPa, respectively. The maximum magnetic field is set at 13 T at the innermost layer of the coil. We divide the calculation in two parts: first we take the electromagnetic forces due to the axial and radial magnetic field separately, and then using the superposition theorem, we evaluate the Von Mises equivalent stress. Figure 2 shows the analysis result, which shows that the equivalent stress at the innermost layer is at ~400 MPa level, which is still sufficiently lower than the yield strength of stainless-steel.

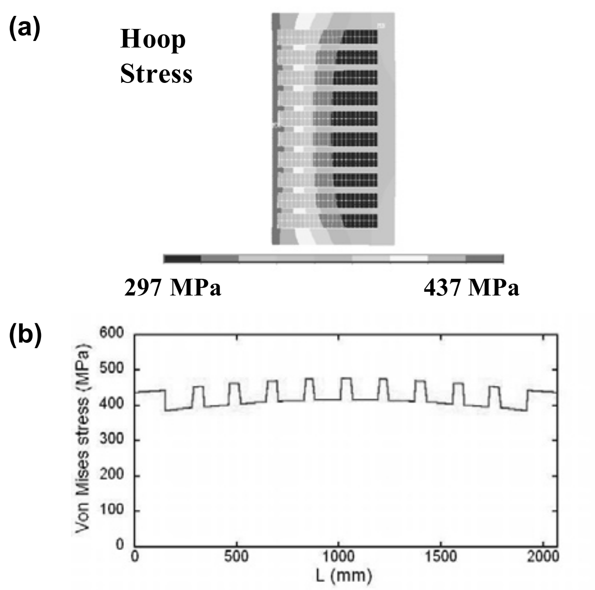

Fig. 2 (a) Distribution of hoop stress in a solenoid coil model of the FFHR helical coil by considering the radial electromagnetic force. (b) The Von Mises equivalent stress along the innermost layer of the coil case.

1) Sagara, A., et al., Fusion Eng. Des. 83 (2008) 1690.
2) Yanagi, N. et al., Plasma Fusion Res. 5 (2010) S1026.