Conceptual design and development of the indirect-cooled superconducting helical coil in FFHR

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FFHR is the name for a conceptual design of an LHD-type heliotron fusion reactor being developed at the National Institute for Fusion Science [1]. All the coils in the FFHR are made of superconductors. An indirect-cooled superconducting coil is considered as candidates for the helical coil in the FFHR. Fundamental geometry of the indirect-cooled superconductor is 50 mm square shape includes insulation. Since the maximum magnetic field at the coil region is around 13 T, Nb_3Sn wires can be used. By using Nb_3Sn, the operation current of the superconductor can be 100 kA and the overall current density is 40 A/mm^2. We are developing Nb_3Sn superconductors jacketed by an aluminum alloy welded by a friction stir welding (FSW) technique. The aluminum-alloy was chosen since it had a high thermal conductivity and mechanical strength. A prototype 10 kA class superconductor which had 17 mm square shape was made to demonstrate the fabrication process and the performance of the conductor. It showed 19 kA transport current at 8 T [2]. Then 2 kA class superconductors made of Nb_3Sn cable and aluminum alloy jacket with the same production process to the previous 10 kA class sample was manufactured to confirm an allowable bending deformation. We succeeded in carrying 11 kA at 8 T with the sample which experienced bend deformations.

We simply compared an apparent rigidity between the indirect-cooled type and CICC type superconductor. The longitudinal rigidity of indirect-cooled and CICC type were estimated 82 GPa and 109 GPa, respectively. Indirect-cooled type coil has a cooling panel which also contributes to the coil rigidity. If the cooling panel has 163 GPa of longitudinal rigidity, the indirect-cooled coil can obtain a reasonable overall rigidity compared with the CICC coil. On the assumption that the cooling panel is consist of a SS case and a cooling mechanism, 20% of the cooling panel area can be used for the mechanism. The cross-sectional rigidity of the indirect-cooled and CICC type were 79 GPa and 56 GPa, respectively. A point to notice is a stress concentration may occur in the CICC. The CICC with the internal plate withstand the cross-sectional deformation only by the side wall area of the conduit and the internal plate. We also calculated stress and strain distribution inside of the coil by using FEM. The electromagnetic force considered here was radial direction of the circular coil since it generated the hoop force inside of the coil. As the result, it was confirmed that the stress and strain for each component were all in the allowable levels.

[1] A. Sagara, et al., Fusion Eng. Des. **81** (2006) 2703.
[2] K. Takahata, et al., Fusion Eng. Des. **82** (2007) 1487.