§9. Conceptual Design of an Indirect-cooled Superconducting Helical Coil in FFHR

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FFHR is the name for the conceptual design of an LHD-type heliotron fusion reactor being developed at NIFS. The magnet system of the FFHR includes one pair of helical coils and two pairs of poloidal coils. All coils are made of superconductors. Several cooling schemes, such as forced flow and indirect cooling have been proposed for these superconducting helical coils. We investigated the possibility of using an indirect-cooled superconducting magnet for the FFHR. The major and minor radii of the helical coils are approximately 14–16 and 4 m, respectively. Fig. 1 shows a conceptual design of the cross section of the helical coil. There were 432 superconductors made of Nb_3Sn and a jacketing material. An aluminum alloy was chosen as the jacketing material, because it offers high thermal conductivity and mechanical strength. The cooling panels were placed at every two or four turns of the winding. The cooling panel consists of two parts; a cooling module and a case section as shown in fig. 2. The cooling module is connected to coolant plumbing at outside area of the coil cross section. The case section has to be build continuously same with the superconductor to be strength member while the cooling module can be divided into several parts along winding direction. The coil is wound along the coil case made of stainless steel (SS) and covered with a lid.

The indirect-cooled superconductor has a 50 mm square shape and a 32 mm square Nb_3Sn superconducting region filled with solder. The ratio of the superconductor to the solder is 8:2. The superconductor includes an 18-mm-thick aluminum alloy (6061 T6) and 1-mm-thick insulation. We estimated rigidity for CICC type superconductor and an indirect-cooled type one. The longitudinal rigidity was estimated according to the rule of mixture, using the area fraction of each structural component. The transverse rigidity was calculated by modeling each conductor type with FEM model. Note that in the indirect-cooled type, the material properties of the superconducting region were selected according to the rule of mixture. On the other hand, in the superconducting region in the CICC type it was assumed that it did not contribute to the mechanical rigidity of the transverse direction. The longitudinal rigidity of indirect-cooled and CICC superconductors were estimated at 82 and 109 GPa, respectively. The former coil has a cooling panel, which also contributes to coil rigidity. If the cooling panel has a longitudinal rigidity of 163 GPa, the indirect-cooled coil can provide reasonable overall rigidity compared with the CICC coil. Assuming that the case section in the cooling panel is made of SS316 and no stress concentration occurs, 20% of total cooling panel area can be used for the cooling module. The transverse rigidity of the indirect-cooled and CICC types were 79 and 56 GPa, respectively.

We calculated the stress and strain distribution inside the coil to confirm the stress and strain levels. The axisymmetric model was adopted using the average radius of curvature of the helical coil.[1] The electromagnetic force considered here was in the radial direction of the circular coil since it generated the hoop force inside the coil. It was assumed that the cooling panel had 80% of Young's modulus for SS316. Fig. 3 shows the result of the hoop force analysis with respect to the hoop stress distribution. All stress and strain levels for each component were within the permissible values.

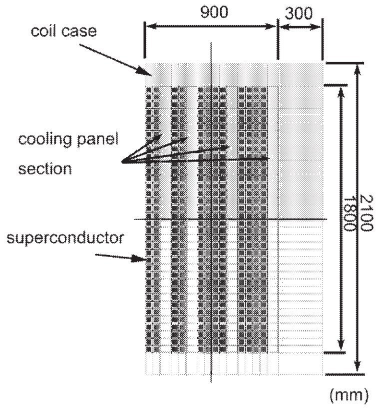

Fig. 1 Cross-sectional view of the conceptual design of the indirect-cooled helical coil.

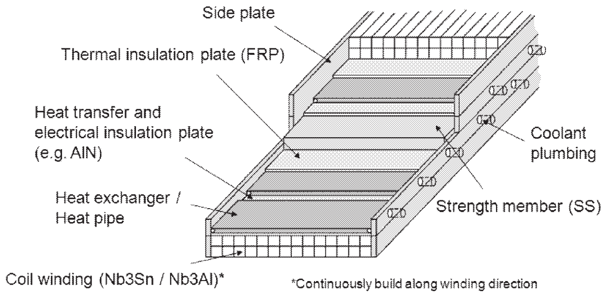

Fig. 2 Schematic design of the indirect-cooled superconducting coil.

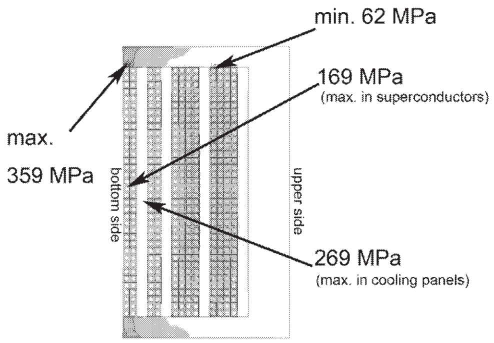

Fig. 3 Hoop stress distribution by the radial electromagnetic force.

1) Tamura, H. et al.: Journal of Physics: Conference Series **97** (2008) 012139