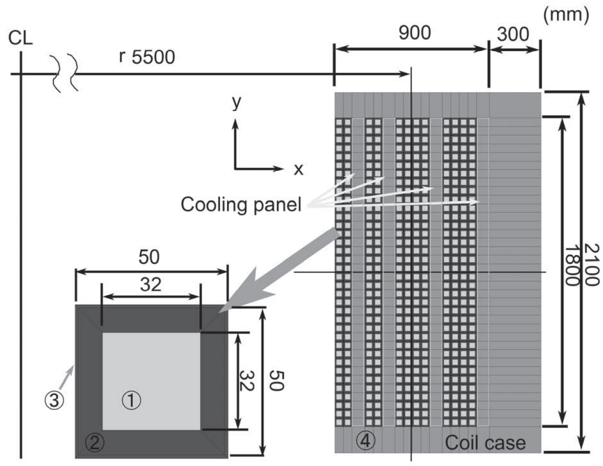
§3. Mechanical Behavior Analysis of Superconducting Magnet in FFHR

Tamura, H., Takahata, K., Mito, T., Imagawa, S., Sagara, A.

The experimental results of the LHD have shown that a LHD-type fusion power reactor has many advantages such as a steady-state nature and a lack of plasma current operation. FFHR is a conceptual design of the LHD-type heliotron power reactor. The superconducting magnet system in the FFHR consists of one pair of helical and two pairs of poloidal coils. Among several design parameters considered thus far, here we focus on FFHR2m1. The helical coil of FFHR2m1 has a major radius of 14 m, a magnetic energy of 120 GJ and a maximum field of 13 T in the cross-section of the coil. An aluminium-alloy-jacketed Nb_3Sn superconductor and indirect cooling using cooling panels within the coil was proposed as a candidate magnet system for the helical coil as an alternative method for a forced-flow cooling magnet. We evaluated the mechanical behaviour of the helical coil in the FFHR with indirect cooling using a three-dimensional axisymmetric model, considering not only the overall force and deformation but also the detailed stress and strain distribution in the cross section of the coil[1)].

The helical coil of the FFHR has a complex three-dimensional structure. The curvature of the coil winding changes with the toroidal angle. It is believed that a circular coil that has an average curvature similar to that of an actual helical coil can sufficiently estimate the mechanical behaviour of the coil. The average radius of curvature of the helical coil was 5.5 m at the centre of the cross-section of the coil. As shown in fig. 1, the structure had a rectangular cross-section of 1.8 m in width and 0.9 m in height. In addition, there were 432 superconductors made of Nb_3Sn with an aluminium-alloy jacket. The current flow in each superconductor was 100 kA. The cooling panels were placed at every two or four turns of the winding. The insulator used in the superconductors was unknown; therefore, we assumed that alumina ceramics with resin were used for insulation. An electromagnetic force was applied as the body force by multiplying the current density and the magnetic field in the superconducting region, considering the actual magnetic field distribution. ANSYS 10.0 was used for calculation, and the three-dimensional harmonic axisymmetric solid element was adopted. The material properties of the superconducting region were selected according to the rule of mixture. The other components were treated as isotropic materials.



1: Nb3Sn wire, 2: aluminium alloy, 3: insulator, 4: stainless steel

Fig. 1. Geometry of the analytic model.

Fig. 2 shows the result of the hoop force analysis with respect to the hoop strain distribution. The strain by the hoop force obtained by this analysis was 0.173% at the bottom centre of the superconductor. A maximum hoop stress of 336 MPa appeared in the stainless steel cooling panel in the innermost area. Maximum stress against the overturning force is observed when the force reaches the peak value through the circumferential angle. The result at the circumferential angle of 28 degrees was forcused on in the overturning force analysis. A compressive stress of 229 MPa was applied to the cooling panel section. The stress in the radial or circumferential direction was not as high as the compressive stress.

The stress and strain values in the coil were sufficiently low compared with the allowable level for each material. The hoop force was more effective than the overturning force for the generation of stress and strain. The thickness of the structural material of the coil case can be reduced further than that assumed in the FEM model. Indirect cooling with the aluminium-jacketed Nb_3Sn superconductor can be used for the helical coil in the FFHR.

1) Tamura, H., et al., JPCS **97**, 012139 (2008).

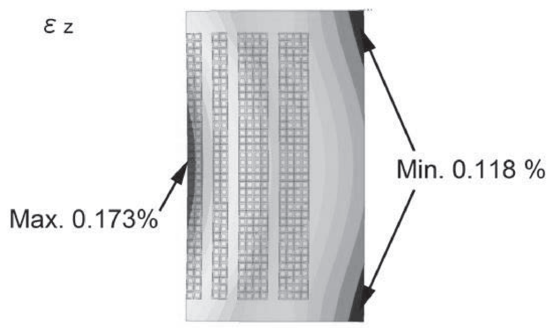


Fig. 2. Hoop strain by the radial electromagnetic force.