Contribution ID: **485** Type: **Poster Presentation of 1h45m**

Nonlinear multiscale structural analysis of a superconducting coil and support structure for the helical fusion reactor

Thursday, August 31, 2017 1:45 PM (1h 45m)

The system architecture of a fusion reactor demands an enhanced magnetic field and downsizing to improve plasma-confinement and reduce the difficulties in construction. Since an electromagnetic force induced by a magnet system is proportional to the square of the magnetic field intensity ratio, the stress on the magnet system can be extremely severe. For FFHR, a helical fusion reactor, several design options are being studied. For instance, FFHR-d1A is a steady-state self-ignition demonstration reactor that operates at a magnetic field intensity of 4.7 T; moreover, the helical coil's major and minor radii in this type of reactor are 15.6 and 3.744 m, respectively. Furthermore, FFHR-c1 is a small-size reactor that aims to realize steady electrical self-sufficiency. It has a magnetic field intensity of 7.3 T and 0.7-times reduced major and minor radii as compared with those of FFHR-d1A. According to the latest structural analysis of the magnet system of FFHR-d1A, the maximum von Mises stress in the coil support structure was 764 MPa at a typical thickness of 250 mm. The coil support structure of the reduced-size FFHR-c1, including its thickness, needs modification, otherwise the stress level will exceed 1.8 GPa. Coil components such as the superconductor, sheath, and insulation also need a detailed structural-soundness evaluation. A nonlinear multiscale finite element method analysis was performed to facilitate a detailed investigation of the superconducting coils and their support structure. Consequently, robust designs of the helical coil and its support structure were demonstrated. Moreover, considering a contact and a slide among the component materials in the coil, mechanical behaviors of the components were evaluated.

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Session Classification: Thu-Af-Po4.02

Track Classification: B1 - Superconducting Magnets for Fusion