FINITE ELEMENT METHODS FOR ANALYSIS OF TOROIDAL FIELD COILS IN FUSION DEVICES*

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SUMMARY

This paper presents a unified analytical approach to the structural analysis of the toroidal field coils in large Tokamak fusion devices. The techniques are applied to the toroidal field coil of the Doublet III fusion device currently being constructed by General Atomic Co. for ERDA. The Doublet III toroidal field coil consists of 144 copper D-shaped turns. The turns are approximately 4.5 meters high by 2.7 meters in width and are designed to carry a current of 195 000 Amperes resulting in a magnetic field strength of 40 kilogauss at a radius of 1.4 meters. Since the materials used in the construction of the toroidal field coils are selected with emphasis on their electrical rather than mechanical properties, an accurate and rapid assessment of the stresses and strains throughout the coil is essential for an economical and successful design. The finite element approach is shown to be easily adapted to this task.

Derivations are presented for all the pertinent equations along with a brief description of the basic finite element theory necessary to implement the analytical techniques. A brief discussion is presented on recent applications of finite element methods for the direct calculation of the magnetic field strengths.

The spatial distribution of the electrical potential and the associated current densities is solved using a finite element model consisting of eight node isoparametric quadrilateral elements. The magnetic field strength at any point in the coil is computed from the application of Ampere's law using the current densities and the equivalent nodal point currents obtained from the finite element solution. The magnetic body forces acting on the coil are computed from the cross product of the current density vector j and the magnetic field strength vector B. Provision is allowed for computation of the in-plane components of the magnetic body forces as well as the out-of-plane torsional load components acting on the coil from the interaction of the toroidal field coil currents with the magnetic field from the poloidal field coils (E coils). These torsional loads must be accurately determined so that an adequate torque-resisting structure can be designed to surround the toroidal field coils. Once the body forces are known, the displacements, stresses and strains are calculated using standard finite element theory.

A numerical example is presented demonstrating the versatility of the finite element method in solving the various field problems using a single model. The sample is a preliminary analysis used in the sizing of the field coils for the Doublet III fusion device. Computer generated contour plots are generated for easy visual display of the results.

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