THREE-DIMENSIONAL INELASTIC EVALUATION OF A CONTROLLED MFE (MAGNETIC FUSION ENERGY) REACTOR MAGNET

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SUMMARY

The toroidal field coils in Magnetic Fusion Energy Reactors are subjected to large forces due to the interactions between the magnetic field and the current carrying conductors embedded in the coils. The purpose of this paper is to deal with the complex stresses caused by these forces as well as additional stresses arising from possible abnormal states in the coil. These forces are perpendicular to the curvature of the coil and directed radially outward. Since the magnetic field varies with distance from the inner coil radius, the forces are non-uniform along the circumferential direction of each magnet. The high stresses incurred must be borne by the coil case surrounding the conductors. In almost all present conceptual designs of MFE reactors of demonstration or commercial size, the coil case is stressed to two-thirds of yield. Should this stress state be increased locally due to an abnormal event inside the coil, local yielding of conductor and case is likely to result, leading to grave consequences. A typical abnormal occurrence causing such a local stress increase is that of a quench, where the superconductor goes through a phase change along a portion of its length and recovers its electrical resistance. When such a state occurs, the conductor may rapidly heat up, inducing large local temperature gradients which can result in severe thermal stresses. Localized failure or even melting of the coil assembly may result.

Analysis of the involved three dimensional stress state is further complicated by the inhomogeneous makeup of large superconducting coils. Layers of superconductor, copper stabilizer, structural steel, and insulators make up a coil cross-section. Previous two dimensional finite element analysis by the authors indicated that even mild temperature rises (on the order of 300°K) could cause significant yielding in a layered coil such as the UWMAK-I design, if the quench occurred at a critical location in the coil.

More refined analysis has been done on the quench problem. One approach was to use a two dimensional code while modeling a circular coil and detailing a portion of the cross-section as far as the steel, copper, and insulator were concerned with layers of elements using the properties of each material. These results, together with the previous ones, showed the three dimensional dependence of the quench problem. Therefore, three dimensional finite element analysis is being done using specially developed elements with material properties based on composite theory to allow a good model for approximating the many layered coil cross-section. Three dimensional stresses in the coil materials under both normal operating and quenched conditions are calculated using the three dimensional composite element model.