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DESIGN AND ANALYSIS OF THE INTOR TOROIDAL FIELD-COIL STRUCTURAL SYSTEM*

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Summary

The International Tokamak Reactor (INTOR) is a unique collaborative effort among the USA, USSR, EURATOM, and Japan to define the characteristics and objectives of, assess the technical feasibility of, and develop a design for the next major experiment in the world-wide tokamak program. The conceptual design consists of twelve toroidal field (TF) coils, each having a bore of 7.75 X 10.7 meters and a maximum field of 10.8 Tesla. The all-external poloidal field (PF) coil system imposes a very large pulsed field on the TF coil system. The superconducting TF and PF coils are enclosed by a common vacuum cryostat which includes individual enclosures for each TF coil's outer leg. This configuration provides a large "window" through which a complete torus sector can be withdrawn. The purpose of this study was to develop a feasible TF coil structural system design. The various design criteria and their effects on the design are discussed. The rationale supporting the allowable cyclic stress of 200 MPa (29 ksi) is discussed. Support of the TF coil outer legs for the large pulsed out-of-plane loading while maintaining the "window" area and considering the relatively low allowable cyclic stress presented a most difficult design problem. Details of the mechanical design and assembly method are presented. The feasibility of the structural design was investigated using a three-dimensional NASTRAN finite element model (FEM) and by suitable local analyses of critical areas. The FEM consisted of 637 elements and 614 grid points having a total of 5197 degrees-of-freedom for each of the 24 half-segments modeled. Variations of the basic FEM were used to investigate structural load paths of interest. Details of the FEM used and the significant results of the structural analyses are presented. A discussion of the generic advantages and disadvantages of several structural load paths of interest is included.

Design Criteria and Effects

The TF coil support structure must effectively support the magnetic, gravity, seismic, and fault load conditions that will be encountered during the life of the reactor. The TF coil and its support structure is an integral part of the reactor, providing support for the PF coils and access to the torus. Therefore, the TF structural design must follow a systems design approach which allows it not only to meet its own requirements but also the requirements of the total device.

It is important to define a structural load path to support the out-of-plane magnetic loads acting on the TF coil in a manner that is compatible with the torus design and maintenance approach.

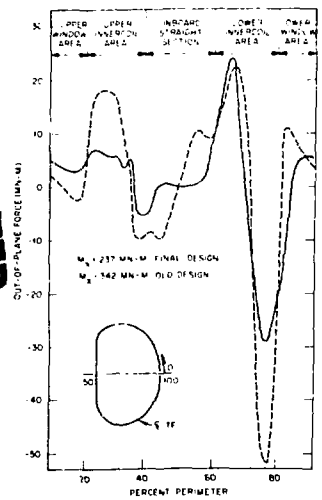
To retain a TF window with sufficient access to accommodate 12 torus sectors requires incorporating either a thick wall TF coil design or a built-up structure arrangement. A thick wall TF case design provides for additional bending stiffness by increasing the coil cross section along the outside of the coil. This approach runs into difficulties in terms of eddy current heating in the thick plates associated with the PF coil field changes plus problems in fabrication and void detection. The structural arrangement selected substantially reduces these problems by incorporating a built-up structure using relatively thin plates with stiffeners.

The magnetic system structural design criteria include conventional stress limits in addition to limits established for peak stress based on crack growth and fracture mechanics considerations. The limit on peak normal stress is dependent upon the number of design pulses and upon the stress ratio f, defined as the ratio of the amplitude of cyclic stress divided by the total stress. In addition, the design allowable is influenced by material properties (fracture toughness, crack growth constants), desired safety factors on stress and cycles, and upon the minimum size flaw which can be guaranteed to be detected during inspection.

During the Phase I Workshop, the engineering group discussed the existing technical level of flaw detection ability, the impact of fracture mechanics evaluations considering the ideas of an initial flaw threshold value and the problem of using fracture mechanics principles in the cryogenics area because of a lack of material data. The outcome of these discussions was to agree that until more research and development work is available for large magnet systems operating at cryogenic temperatures, smooth specimen fatigue data should be used for preliminary design purposes. With the limited data available on stainless steel, an allowable stress of 200 MPa (29000 psi) was suggested using factors of safety of 3 on stress and 20 on number of cycles. The INTOR team concurred with this criterion and adopted it as the stress allowable.

Magnetic Loads

The magnetic forces acting on the TF coil result from self forces of the TF winding plus the interaction of the TF current and the PF coil magnetic field. Each of the 12 toroidal field coils (7.7-m X 10.7-m bore dimensions) has an 11 T peak field at the TF winding. The final PF coil locations and currents produce an overturning moment of 237 MN-M on each TF coil and an out-of-plane force distribution as shown below. Note the locally high loading in the lower outer intercoil region.



TF COIL OUT-OF-PLANE LOAD

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