TBR–2 STRUCTURAL ANALYSIS

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Abstract: We present in this work the structural analysis developed during the TBR–2 tokamak project studies. Starting with electromagnetic interaction forces on each, toroidal and poloidal coils many structural calculations have been carried out using locally developed usual E.M. interaction codes and a finite element method stress code. Following the analysis it has been determined that there is radially inward force of 1235 kN and overturning torque of 243 kNm acting on toroidal coils.

This stress and displacements due to in plane loads have been calculated using a finite element code which show that the maximum stress of 240 MPa and displacement of 0,21 mm can be present at the inner part of the toroidal field coil.

The structural analysis of a tokamak can be divided into three basic subject areas, i.e., a set of coils for plasma current generation, confinement and stabilization; a vacuum vessel to isolate the produced plasma from the atmospheric environment, and a supporting structure to guarantee the machine components position and mechanical integrity under normal or abnormal machine operation.

Each area of concern must be studied under various load conditions, as:

– normal operation loads: electromagnetic forces on the coils and vacuum vessel, heat generated by Joule effect, heat transferred from plasma to vacuum vessel, atmospheric pressure on the vacuum vessel and self–weight of components;

– abnormal operation loads: failure of systems like the electrical power supply, coil cooling and heat flux on the vessel components due to plasma instabilities;

– failure loads: electromagnetic forces on the coils and vacuum vessel, forces due to short–circuit on the coil set or the severe plasma disruption, and high heat deposition associated with these disruptions.

The load conditions for metallic components as coils, vacuum vessel and support structure are analyzed under mechanical stress limit conditions according to ductile, cumulative plastic deformation and fatigue failures. The ductile failure happens when the structure or components are not capable of attending mechanical equilibrium conditions during machine operatin. In order to avoid this type of failure, it is necessary to atend the limits of primary membrane and bending stresses, according to ASME Code /1/. The fatigue and cumulative plastic deformation come from long use in normal operation conditions. This is analyzed by looking at secondary stresses.

Among the three subject areas presented above, we focus in this paper the toroidal field coil *(TFC)* system, which is subjected to the more severe electromagnetic loads. The TBR–2 tokamak/2/ is composed of 16 TFC, each one possessing four turns isolated and packed with fiber glass. Each TFC is subject to three electromagnetic set of loads. First are the loads due to interaction between TFC currents with their own magnetic field, which are parallel to the TFC mid–plane. They result in a load of 1200 kN toward the machine toroidal axe, per each coil, which is equilibrated by the opposite coil. Second are the loads which appears due to the interaction between TFC and the poloidal magnetic field, giving a load normal to the TFC mid–plane, and antisymmetric respect to the machine equatorial plane. The third set of loads appears when one of the 16 TFC is short circuited and, due to the loss of symmetry on the forces distribution in the toroidal direction, unbalanced loads will appear in all other coils. The higher toroidal force reaches 409 kN at the coils adjacent to the short circuited one. The net effect of these loads is a torque moment which has to be balanced between the upper and lower halves of the machine structure.

Stresses on the TFC are calculated using finite element codes. Figure 1 shows stresses in a TFC when the structural supporting bars were placed only at the upper vertical internal side of the TFC. The maximum stress intensity reaches 240 MPa, which is far above the stress intensity limit for normal tokamak operation (60 MPa). This problem has been solved by inserting a rigid column all along the inner vertical hole of TFC assembly, reducing the maximum stress intensity to 33.5 MPa, well within the stress limits (fig. 2). This figure shows also the maximum radial displacement, about 0.21 mm, and the maximum vertical expansion of 0.14 mm.

In the case a short–circuit is presented at one TFC the stress intensity reaches 70 MPa, due to failure loads only. Combining with stresses due to normal operation conditions, a maximum stress intensity of 86 MPa is obtained (Fig. 3), showing a good safety if compared to stress limits under abnormal conditions (180 MPa).

All these values shall be taken into account when the detailed engineering project for TFC is developed, which has been scheduled for this current year.

REFERENCES

/1/ ASME BVP Code, Section III, Nuclear Power Plant Components, 1986 ed., The American Society of Mechanical Engineers, New York, N.Y.

/2/ TBR–2 Project, presented at current IV Latin–American Workshop on Plasma Physics.

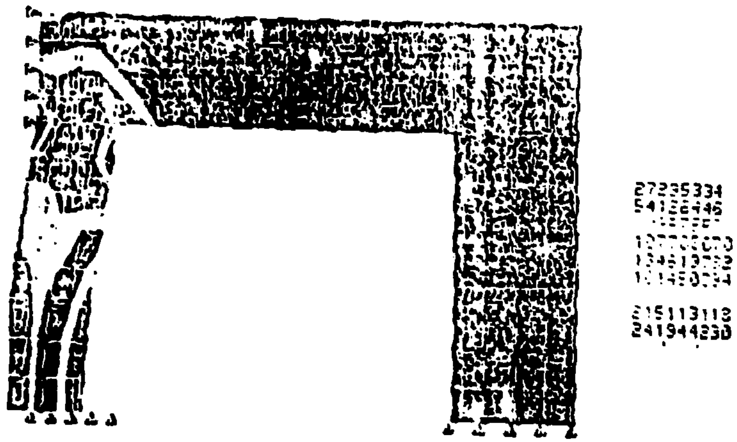

Fig. 1 - Stress in the toroidal field coil due to in-plane forces for the case of locally supported bars (max. stress = 242 MPa).

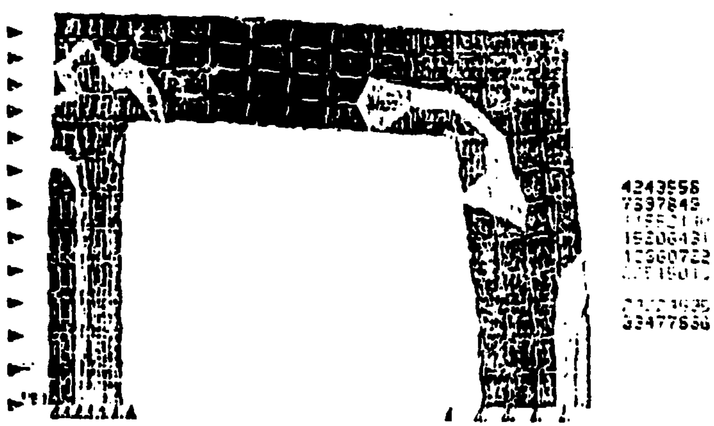

Fig. 2 - Stress in the toroidal field coil in the case of central fiberglass column (max stress = 33.5 MPa).

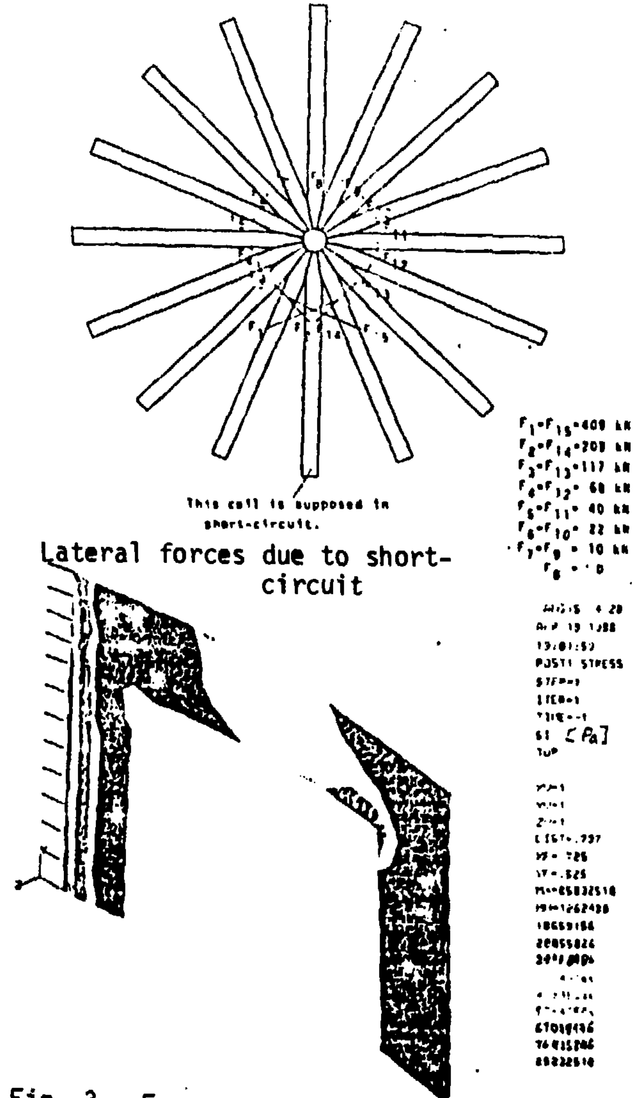

Fig. 3 - Forces and stress in the toroidal coil due to in-plane forces (max. stress = 86 MPa).