Electromagnetic Modeling of the TPX Coils and the Cold Structure

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ABSTRACT

The poloidal field and the vertical stability control coil systems for the Tokamak Physics Experiment (TPX) have time varying currents which breakdown and initiate the plasma current, provide the volt seconds necessary to ramp the plasma current to 2 MA, and maintain the plasma shape and position. The effects of the 3-D eddy currents induced in the cold structure of the machine on the Joule heating of the TF coil support structure, as well as on the quality of the field during the plasma breakdown and initiation phase are analysed in this paper.

INTRODUCTION

The cases around the toroidal field (TF) coil and coil structural support system for the Tokamak Physics Experiment (TPX) [1] are at cryogenic temperatures. The plasma current is initiated and ramped inductively by the poloidal field (PF) system. During the flat top, the plasma is maintained in the neutral position by the currents in the fast vertical position control (FVPC) coils.

The time dependent currents in the PF coils and in the FVPC coils will induce eddy currents in the structure. The attendant Joule heating will show up as an additional load on the cryogenic system.

To initiate the plasma, a poloidal field null ($|B_p|<1$ mT) is maintained within 0.25 m of the breakdown point of the plasma region for about 10 ms during the breakdown. An axisymmetric start-up code [2] has been used for this purpose. Here, the 3-D eddy current effect on the field null quality is compared with the 2-D results.

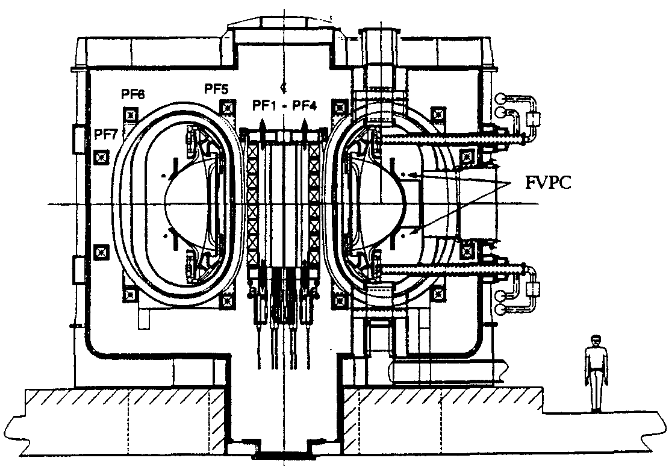

Fig. 1 TPX Elevation View

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Fig. 1 shows an elevation view of the machine with the seven pairs of PF coils and two pairs of FVPC coils. The major radius of the machine is 2.25 m, the plasma current is 2 MA and the toroidal field is 4 T at the major radius.

The structural components included in the analyses are the TF cold structure (TFCS), the vacuum vessel (VV), and the passive stabilizing plates (PSP). These components present multiply connected thin shells. Eddy currents induced in these structures were calculated using a three dimensional thin shell model of the conducting media which assumes that current density is uniform through the thickness.

A view of the structural components of the TF cold structure is shown in Fig. 2. The major components of the structure are the coil cases, and two shells that join the individual TF coils together. The system has both insulated (bolted) and conducting (welded) joints in the outboard region. The bolted joints are every four coils making a quadrant. The inner legs of the TF coils are insulated every other coil.

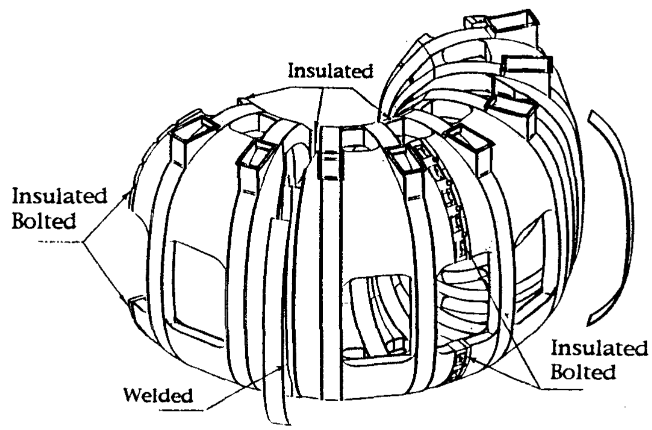

Fig. 2 TPX TF Cold Structure

Taking into account the symmetry of the structure and of the patterns of eddy currents, the model was reduced to one half of a quadrant, as shown in Fig. 3. The quadrants are symmetric and the eddy currents are anti-symmetric with respect to the XOZ-plane.

The vacuum vessel was modeled as a toroidal segment with holes for ports. It is welded and has no insulated edges.

The passive stabilizing plates are also modeled as toroidal segments with boundary conditions permitting current flow in the circumferential direction. The resistivity was modified to account for the fact that the plates are tied to the vacuum vessel wall at several points around the circumference.

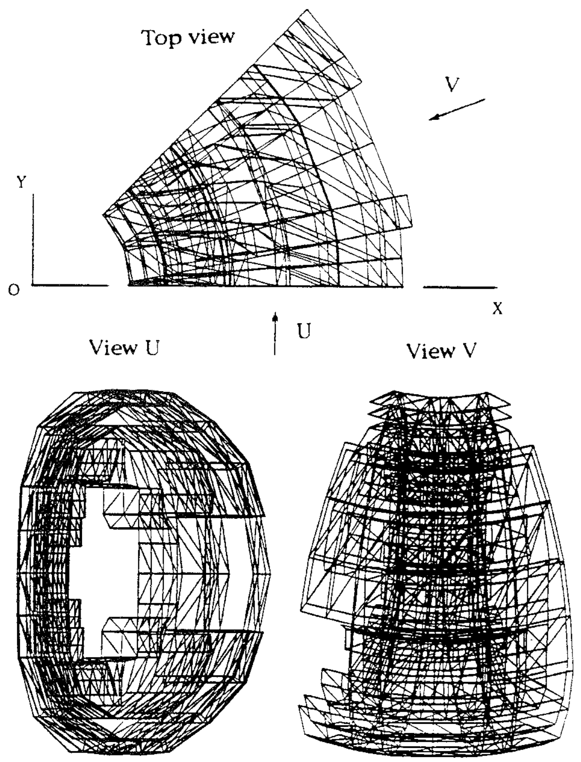

Fig. 3 The Finite Element Model

JOULE HEATING ANALYSES

The 3-D thin shell eddy current program, EDDYCUFF [3], was used to analyze the eddy currents and Joule losses in the cold mass of TPX.

The fast vertical position control coils were modeled by two current loops, placed at R=2.82 m, Z=+/-0.706 m with builds of dR=0.038 m, dZ=0.070 m. The currents in the two loops are opposite to each other and vary in time as shown in Fig. 4. Since the current versus time variation is of a random nature, only a one second interval was considered to obtain the average of the power deposited in the structure.

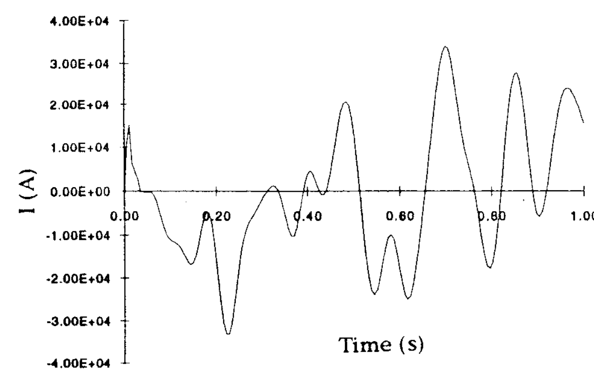

Fig. 4 Currents in the FVPC Coils

The magnetic fields due to the PF coils were not taken into account, since the eddy currents produced in the TF cold structure by these coils are symmetric with respect to the geometric symmetry plane Z=0, whereas the eddy currents produced by the vertical stability control coils are anti-symmetric with respect to the same plane. Since these two systems of currents are orthogonal, their total Joule losses are equal to the sum of the Joule losses of the two systems of currents taken individually.

Fig. 5 shows the instantaneous power dissipation in the TF cold stricture versus time for the FVPC scenario. The solid line is for the basic model defined above including the VV and the PSP. The dashed line is for a subsidiary model which consists only of the TF cold structure. Comparison of the results for the two cases shows the significance of taking into account the screening effect of the VV and the PSP.

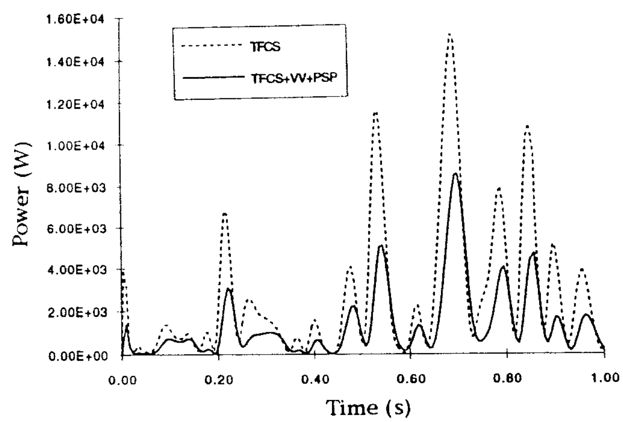

Fig. 5 Power Dissipation in the TF Cold Structure

The distribution of the average power deposition among the structural components of the basic model is shown in Table 1. It shows the value of 1.39 kW for the TF cold structure which is only 8% of the total power dissipated. The maximum power dissipation of 83% of the total occurs in the PSP.

TABLE I.
Power Deposition in the Structural Components

Component	TFCS	VV	PSP	Total
Aver.power, W	1.39E+03	1.47E+03	1.38E+04	1.67E+04
%	8%	9%	83%	100%

The typical eddy current pattern in the cold structure is shown in Figs 6 and 7. Fig. 6 shows that the maximum eddy currents occur in the passive plates aligning to the FVPC coils. Fig. 7, in which only the TF cold structure is shown, illustrates the three dimensional nature of the eddy currents in the structure. The outboard insulation break (left side) is evident, since the eddy current is tangential to the edge. It suggests that the three dimensional eddy current analysis is essential for this problem.

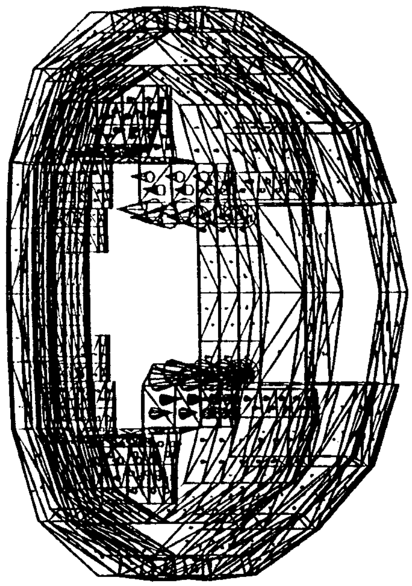

Fig. 6 Eddy Currents in the Structural Components

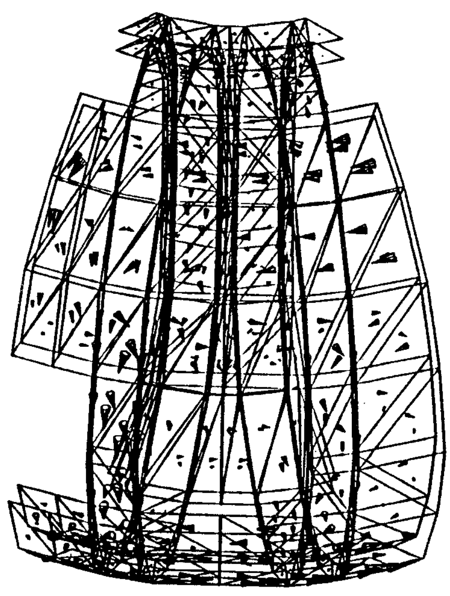

Fig. 7 Eddy Currents in the TFCS

3-D EDDY CURRENT EFFECT ON PLASMA INITIATION

To breakdown and initiate a plasma, a rapid change in the PF coil currents is needed to induce the (open) loop voltage. A significant amount of eddy current is then induced in the structures during this process. A magnetic field null within a region of circular cross section is maintained during the plasma breakdown period. This field quality is crucial to the initiation of a plasma.

An axisymmetric start-up code has been used to calculate the coil voltages and currents for plasma initiation. The axisymmetric model of the passive structure, which includes the passive plates and the vacuum vessel (no ports), is shown in Fig. 8. Eddy currents can flow only in the toroidal direction. A field null centered at R=2.5 m is desired for an outboard start-up.

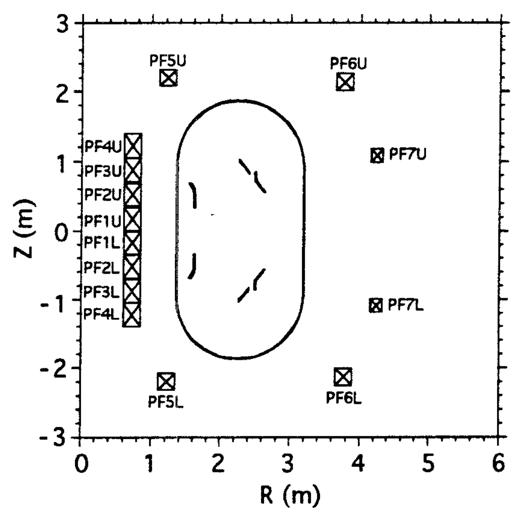

Fig. 8 Axisymmetric Start-up Model

Fig. 9 shows the vertical magnetic field versus radial positions on the equatorial plane at different times. The blip starts at t=0 s. A good field null exists from about 35 ms to 45 ms.

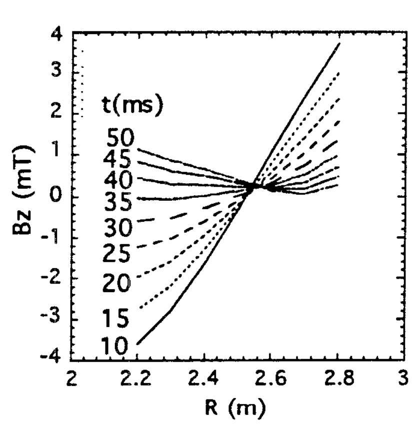

Fig. 9 Bz versus Radial Position - 2-D Calculations

To calibrate the 2-D results, a 3-D eddy current effect is calculated. The structure includes VV, PSP, and TFCS, as shown in Fig. 3. The same PF current scenario from 2-D calculation is used as the driving force. Fig. 10 shows the same vertical field plot. A similar field shape quality is obtained with an about -1.8 mT offset value. This DC offset can be adjusted by fine tuning the coil voltages.

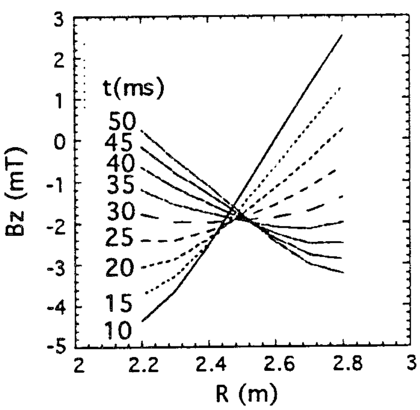

Fig. 10 Bz versus Radial Position - 3-D Calculations

Fig. 11 plots the vertical field at R=2.5 m at different toroidal angles as a function of time. This toroidal effect is from the structure physical geometry, like VV ports, insulation breaks in TFCS and gives about 0.3 mT maximum difference.

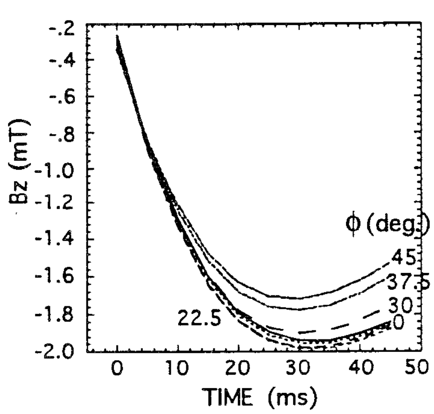

Fig. 11 Bz at R=2.5 m at Different Toroidal Positions as a Function of Time

CONCLUSIONS

The average power dissipation in the TF cold structure due to the FVPC coils is 1.39 kW. 3-D codes and finite element models including the VV and the PSP as well as the TFCS are needed for these analyses.

The 2-D start-up code calculates the coil voltages and currents that generate a good field null. The capability of fine tuning PF coils to give a DC magnetic field offset value of several milli-tesla is important. The toroidal effect, depending on the eddy current flow paths, on the plasma initiation also needs to be studied further.

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