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Three Dimensional Calculation of Misalignment Forces for the TPX Vacuum Vessel

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ABSTRACT

During a plasma disruption eddy currents are induced in all the conducting structures surrounding a tokamak plasma. There is a very real possibility that large structures, such as a tokamak vacuum vessel, are either (1) imperfectly formed and are not bodies of revolution or (2) not perfectly aligned with the plasma, TF coils and PF coils. Previous work in this field has dealt with these concerns by calculating forces and currents on sets of displaced circular filaments. We have performed several studies on this subject using the computer code SPARK. The SPARK code [1] models arbitrary surfaces in three dimensions and gives results frequently different from the simple filament calculations. This paper summarizes several types of perturbation from perfect geometry and summarizes the trends observed.

INTRODUCTION

The plan of this paper is to examine net force and moment calculations in an idealized toroidal shell produced by a simple plasma disruption. These net forces and moments are zero for a perfect shell which has been placed perfectly in the ideal toroidal and poloidal field typical of a tokamak. When this shell is displaced by a radial motion or a rotation about a radial axis the disruption forces and moments in the shell sum to non zero values. We start off by describing the trends for a simple thin ring and then present results for both poloidal and toroidal flux changes in a perturbed toroidal shell.

In the following several simplifying assumptions have been made. We concentrate our attention on flux preserving calculations for poloidal and toroidal flux changes. This gives a single force and moment for each geometry perturbation instead of a transient. The toroidal shell considered here has a single wall instead of the double walled TPX geometry. We have ignored details of the geometry such as radial and vertical ports. Such penetrations are very important when calculating disruption induced forces and the result is dependent on details of their shape and the detailed geometry of the PF and TF coil systems.

We have also ignored all the internal hardware and stabilizing structures that are extremely important for TPX operation. Most of the toroidal eddy currents are expected to flow in the internal stabilizing structure. This paper is limited to the racetrack shape toroidal shell chosen for TPX.

II. THIN RING CALCULATIONS

Prior work on this topic has exclusively modeled toroidal shells as a set of coaxial filaments. The set of inductively coupled filaments is subjected to a poloidal flux

change and the force and moment calculation is then done. The trends predicted by such an analysis differ only in detail from the results one gets from a single thin ring. We have summarized such an analysis for the single thin ring in figure 1.

Figure 1 Single Thin Ring

The dimensions of this ring were chosen to place it at the outer mid plane of the TPX vacuum vessel. We have placed the ring in the x-y plane and its axis coincides with the z-axis. The ring is centered at the origin of coordinates. This ring is in a magnetic environment similar to TPX, i.e., an axisymmetric TF field with 4.0 Tesla at 2.25 m and a PF field [2] appropriate for an 'end of burn'. A 2.0 MA plasma was simulated by a uniform current density, circular cross section conductor $(R,a) = (2.25,0.8)$ (m) and a poloidal flux preserving calculation was done. The following plots summarize the net force and moment on this structure as it is either displaced along the x axis or rotated in a positive direction about the x axis.

Figure 2 Thin Ring X Force Vs X Displacement

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Figure 3 Thin Ring X Moment Vs X Displacement

Figure 4 Thin Ring Net X Force Vs X Rotation

Figure 5 Thin Ring X Moment Vs X Rotation

In these calculations the toroidal field effects dominate the moment resulting from displacement and the force resulting from rotation. The poloidal field effects dominate the force resulting from displacement and the moment resulting from rotation.

III. TOROIDAL SHELL CALCULATIONS

The toroidal shell used in the misalignment

calculations is illustrated in figure 6. The plasma poloidal and toroidal flux components of a plasma disruption are considered separately. The same poloidal flux source was used as in the thin ring studies. Toroidal flux was examined by considering a 0.1 Weber toroidal field created by an interior set of circular coils arranged into a toroidal set.

Figure 6 Ideal Toroidal Shell for TPX

Perturbations in location, either displacement or rotation, made no change in the picture of the current streamlines for a flux conserving calculation of toroidal flux. This is reasonable since the toroidal shell is ideally a region of zero magnetic field (the toroidal field is perfectly contained within the shell). Figure 7 illustrates these streamline patterns.

Figure 7 Current Streamlines for Toroidal Flux

The following four figures (8 thru 11) illustrate the dependence of net force and net moment on x displacement and rotation about the x axis. Since the eddy current pattern for toroidal flux conservation is unchanged with our geometric displacements the dependencies illustrated in these figures are completely determined by the local field changes caused by our perturbations.

When we consider this pattern of eddy currents, toroidal field effects dominate the net force resulting

from translation and the net moment resulting from rotation. The poloidal field effects dominate the net moment resulting from translation and net force resulting from a translation.

Figure 8 Toroidal Shell for Toroidal Flux
X force Vs X displacement

Figure 9 Toroidal Shell for Toroidal Flux
X Moment Vs X Displacement

Figure 10 Toroidal Shell for Toroidal Flux
X Force Vs X Rotation

Figure 11 Toroidal Shell for Toroidal Flux
X Moment from X Rotation

When we consider perturbations in location and a poloidal flux conserving calculation the situation becomes more interesting. In this situation the pattern in which the toroidal shell intersects the poloidal field lines changes with the type of perturbation. For a perfectly aligned structure the current streamlines are concentric with the vertical axis of the shell. Figure 12 illustrates the eddy current streamlines for a x displacement of 0.05 m.

Figure 12 Eddy Current Streamlines for
Poloidal Flux Conservation with the Vacuum Vessel
Displaced 0.05 m in x direction.

Examination of Figure 12 shows that the eddy current streamlines are not concentric with the axis of the shell. The induced eddy currents have components in the vertical direction. This is a phenomena that is fundamentally different from the solution that would be obtained from a set of concentric filaments. Similar type current streamlines also occur when the toroidal shell is rotated. The displacement illustrated in Figure 12 is extreme and would probably never occur in practice. However the phenomena is present at any scale of displacement and the details of the results are dependent on the shape of the toroidal vacuum vessel.

Figures 13 thru 16 illustrate the dependence of net force and net moment on x displacement and x rotation.

Figure 13 Toroidal Shell for Poloidal Flux
X Force Vs X Displacement

Figure 14 Toroidal Shell for Poloidal Flux
X Moment Vs X Displacement

Figure 15 Toroidal Shell for Poloidal Flux
X Force Vs X Rotation

Figure 16 Toroidal Shell for Poloidal Flux
X Moment Vs X Rotation

When we consider the eddy current pattern defined by poloidal flux conservation we find that toroidal field effects dominate the net moment resulting from a translation and the net force resulting from a rotation. The poloidal field effects dominate the net force resulting from a translation and the net moment resulting from a rotation.

CONCLUSIONS

A detailed analysis of the eddy currents in a structure often gives results different from a simple axisymmetric (filament) analysis. Experience with similar calculations has shown that details of the structure, currents, and fields often leads to surprising results.

ACKNOWLEDGMENT

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REFERENCES

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- [2] Bulmer, R. private communication

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