NSTX Upgrade Project

STRUCTURAL CALCULATION OF THE TF FLAG KEY

NSTXU-CALC-132-08-00

October 26, 2010

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PPPL Calculation Form

Calculation # NSTXU-CALC-132-08 Revision # 00 __ WP #, 1672
(ENG-032)

Purpose of Calculation: (Define why the calculation is being performed.)

To ensure that the TF crown and the TF insulation can take the out of plane torque load and safely deliver it to the center stack lid.

References (List any source of design information including computer program titles and revision levels.)

1] NSTX-CALC-13-001-00 Rev 1 Global Model – Model Description, Mesh Generation, Results, Peter H. Titus December 2010
[2] NSTX Structural Design Criteria Document, I. Zatz
[3] NSTX Design Point June 2010
http://www.pppl.gov/~neumeyer/NSTX_CSU/Design_Point.html
[4] NSTX-CALC-13-04-00 Rev 0 DCPS Inner leg torsional shear Stress, P.H.Titus, R.Woolley

Assumptions (Identify all assumptions made as part of this calculation.)

1.) the CTD101K insulation strength values at 100C, currently being measured by the manufacturer, are close to the published room temperature values of 790 MPa for compression, and 103 MPa for shear;
2.) the 9000 lbf equivalent force per TF conductor blade due to the OOP torque.
3.)The shear strength of the epoxy used to bond the CRES insert into the G10 crown piece is close to that of the CTD101K insulation (103 MPa).

Calculation (Calculation is either documented here or attached)

Please see attached.

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

Stresses in the crown and the TF conductor are below the limits for G10 and copper. The normal stress in the epoxy filled fiberglass wrapped insulation is safely below 10 MPa.

Cognizant Engineer's printed name, signature, and date

Jim Chrzanowski Jim Chrzanowski Digitally signed by Jim Chrzanowski DN: cn=Jim Chrzanowski, o=PPPL, ou=Enginering, email=jchrzano@pppl.gov, c=US Date: 2011.01.18 14:16:17 -05'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker's printed name, signature, and date

Tom Willard Thomas Willard Digitally signed by Thomas Willard DN: cn=Thomas Willard, o=Engineering, ou=PPPL, email=twillard@pppl.gov, c=US Date: 2011.01.18 10:52:13 -05'00'

Executive Summary

The NSTX upgrade center stack TF conductors are designed to have a locking feature to engage the G-10 insulating crown and exchange the out of plane torque between the TF inner leg bundle and umbrella structure/vacuum vessel. The G-10 block and the TF conductors and insulation need to be able to withstand the forces in all working current scenarios. The TF conductors including epoxy insulation were modeled together with the G-10 block in cyclic symmetry models. Expected torques and forces were obtained from the global FEA model for the worst case out-of-plane twisting loads. The forces were exerted on the cyclic symmetry models. Initial designs of the locking mechanism involved teeth in the G-10 engaging the TF bundle and flags. Two different teeth models were studied. The first teeth model involved machining a pocket in the end of each conductor and a matching G-10 piece to engage the teeth. The second model used alternate short and tall flag pieces to engage the matched G10 crown. In both models the teeth in G-10 showed large shear stress which exceeded the G-10 inter-laminar shear limit. For this reason it was decided to design the locking mechanism using radial pins that engage the crown, the flags and the TF conductors. The calculations/simulations for this design showed lower stresses which were below the G-10 limit.

References

[1] NSTX-CALC-13-001-00 Rev 1 Global Model – Model Description, Mesh Generation, Results, Peter H. Titus December 2010
[2] NSTX Structural Design Criteria Document, I. Zatz
[3] NSTX Design Point June 2010 http://www.pppl.gov/~neumeyer/NSTX_CSU/Design_Point.html
[4] NSTX-CALC-13-04-00 Rev 0 DCPS Inner leg torsional shear Stress, P.H.Titus, R.Woolley

Objective

In the NSTX upgrade, the inner and outer legs of the TF coils interact with the fields from the poloidal field coils and the OH resulting in torsional loads and out of plane forces which are transferred through several load paths to the vessel and other machine structures (Figure 1). These load paths include the lower and upper lids, umbrella structures, bellows etc. The current in the inner legs of the TF coils which interact strongly with the OH field cause torsional loads in the TF bundle that need to be supported against by transferring them via a stiff lid to the umbrella structure. Although the TF straps are going to share in the torque transfer but they are not designed to take the out of plane loads and the torque needs to be supported mainly through transfer by the lid. To do this and maintain electrical insulation between the TF and the vessel the TF bundle needs to transfer this torque to the inner hub of the lid using a locking feature employing the G10 insulator material as a crown.

DCPS Algorithm

The load used in the analysis was based on the maximum torsional shear load being transferred through the crown to the lid, for all the 96 scenarios. This number is actually 7400 lbs (Ref 1, section 8.19). This was rounded up to 9000 lbs for design. and to allow for the 10% headroom for PF currents and to allow some headroom for halo current loads. The torsional moment at the teeth will scale with the calculated torsional shear stress in the TF coil at the turn radius. For the 96 scenarios, this is 24 MPa. (ref 4). Tooth stresses should be scaled based on the TF torsional shear stress calculated for the DCPS

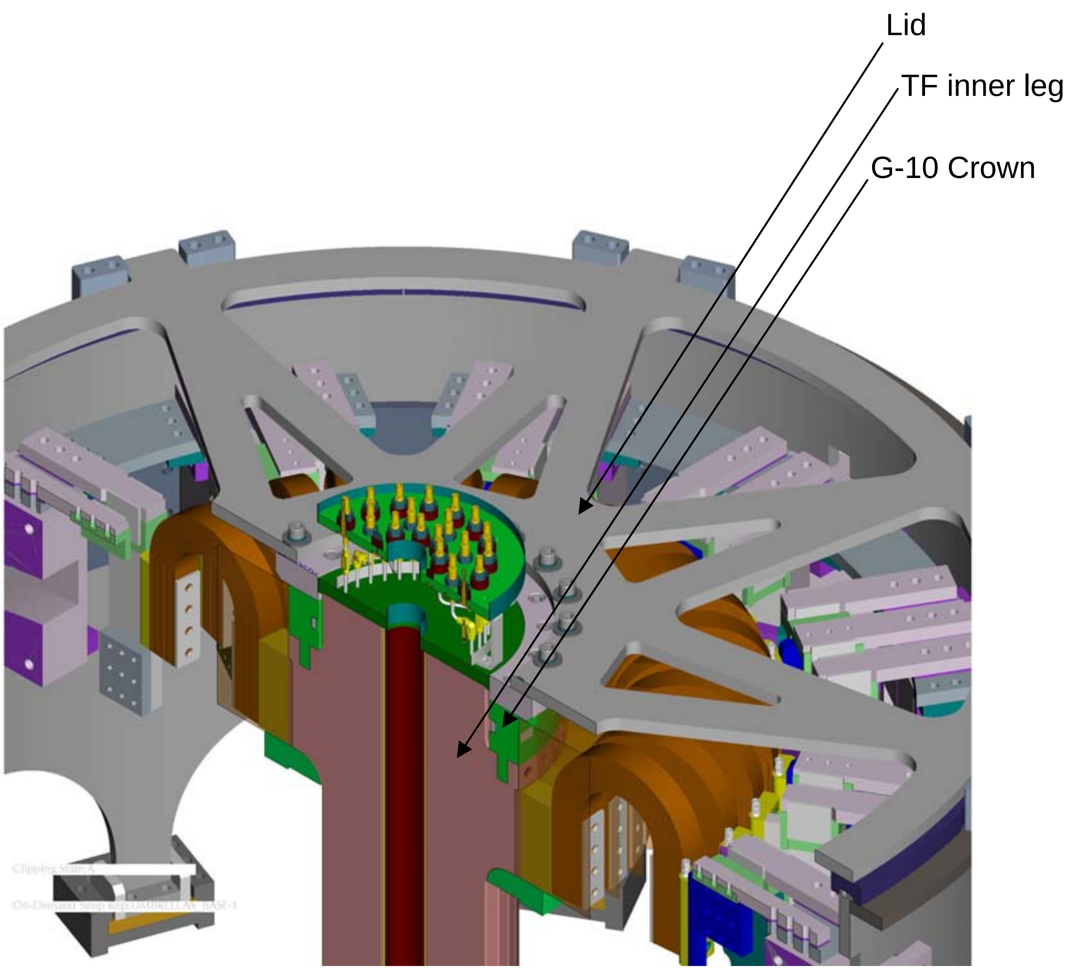

Figure 1

The mechanism for transferring the TF bundle torque was initially designed as radial teeth that locked the TF bundle to the G-10 crown. However as we'll show later in this calculation report, the stresses in the G-10 and insulation were shown to be high. For this reason a locking mechanism involving radial pins was designed (by Danny Mangra) to transfer the torque from the TF bundle to the crown and the lid. The calculation report here includes the analysis used to determine the stresses in the components of this design.

Calculation and modeling techniques:

Ansys software was used to analyze the structure. Due to the cyclic symmetry of the geometry analysis was performed on 1/36 of the problem geometry (or one TF blade and flag, Figure 2). Ansys was instructed to match mesh and impose symmetry conditions on the symmetry planes. The geometry also included the TF conductor epoxy insulation bonded to the conductor. The design of the crown included stainless steel inserts to be used as nuts for bolting the lid to the upper portion of the crown. The actual fabrication and assembly of the structure involves using glass fiber and epoxy during or after the wet wrap process to secure these inserts. For this reason we have used a “bonded” contact type for the analysis of the contact area involving the insert and the G-10 crown.
The amount of torque expected to be exerted on the locking assembly was obtained from the global FEA model maintained by P. Titus (Ref 1, Section 8.19). The worst case out of plane twist load from the global model corresponded to 360,000 N.m of torque on the crown to TF bundle interface which results in approximately 9000 lbs force per blade/flag. The load was put on the top surface of the G-10 crown piece in the model analyzed (Figure 3). The model was held fixed on the bottom.

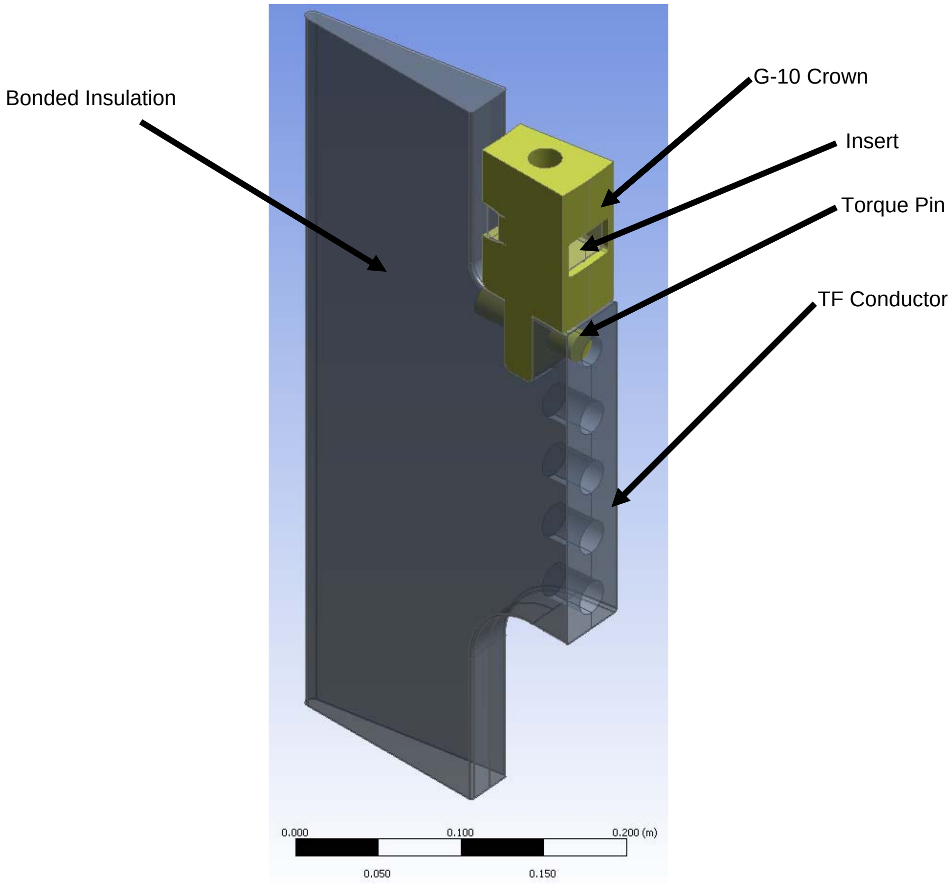

Figure 2

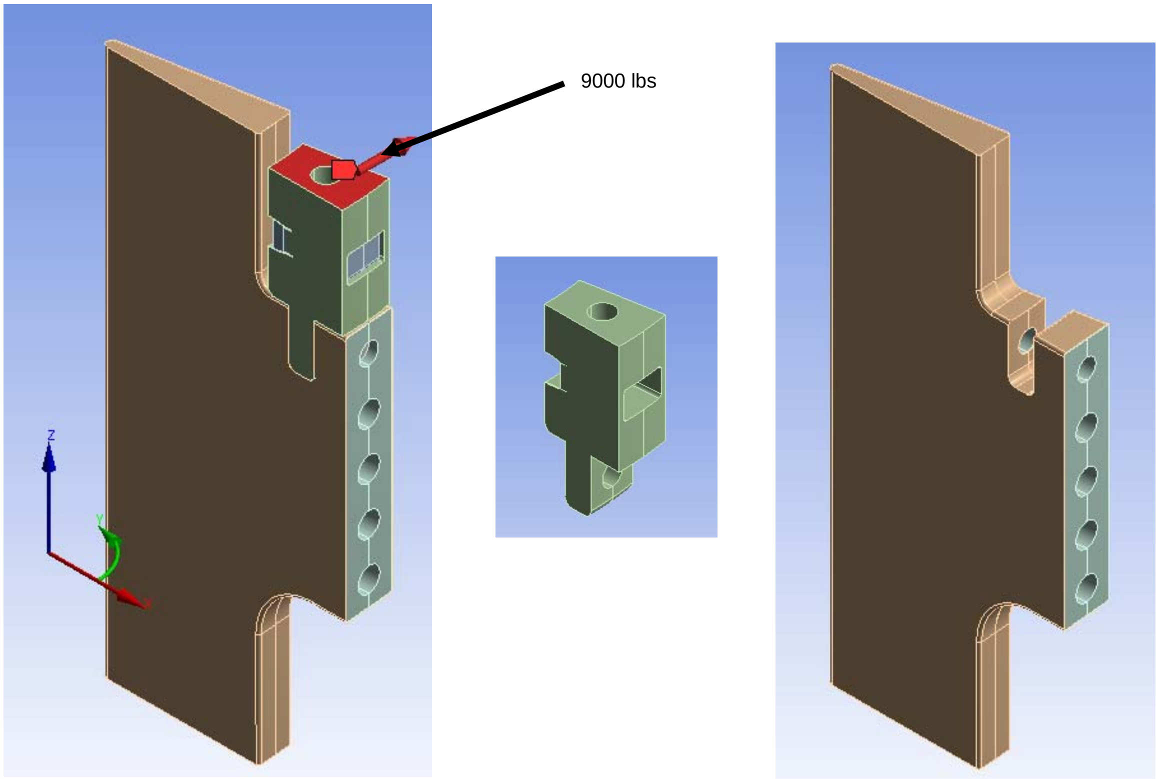

Figure 3

Results:

The results of the FEA analysis for this design are shown in Figure 4-7. Figure 4 is a contour plot of equivalent stress on the components of the model. Figure 5 is the equivalent stress in the G-10 crown section. As can be seen from these plots the stresses are below the manageable limits for copper, epoxy, and G-10. The shear stress in the insulation shown in Figure 6 is also below the (Cyanate Ester) bond strength which is *** MPa. Figure 7 is the normal stress in the epoxy filled fiberglass wrapped insulation. As can be seen the normal stress in the insulation is safely below 10 MPa.

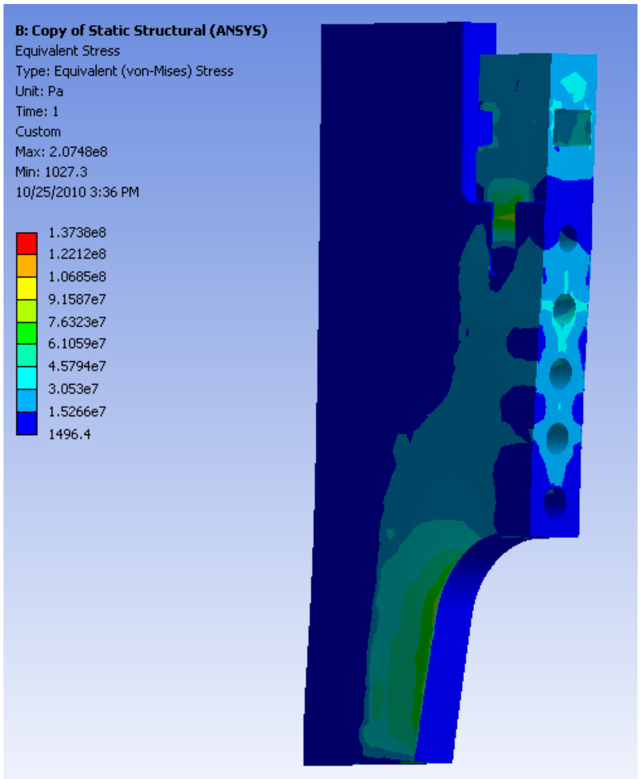

Figure 4

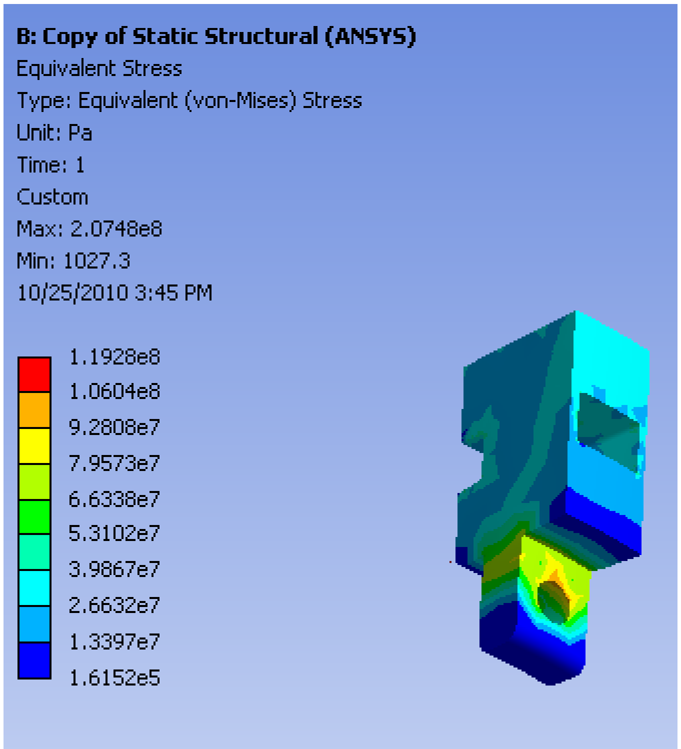

Figure 5

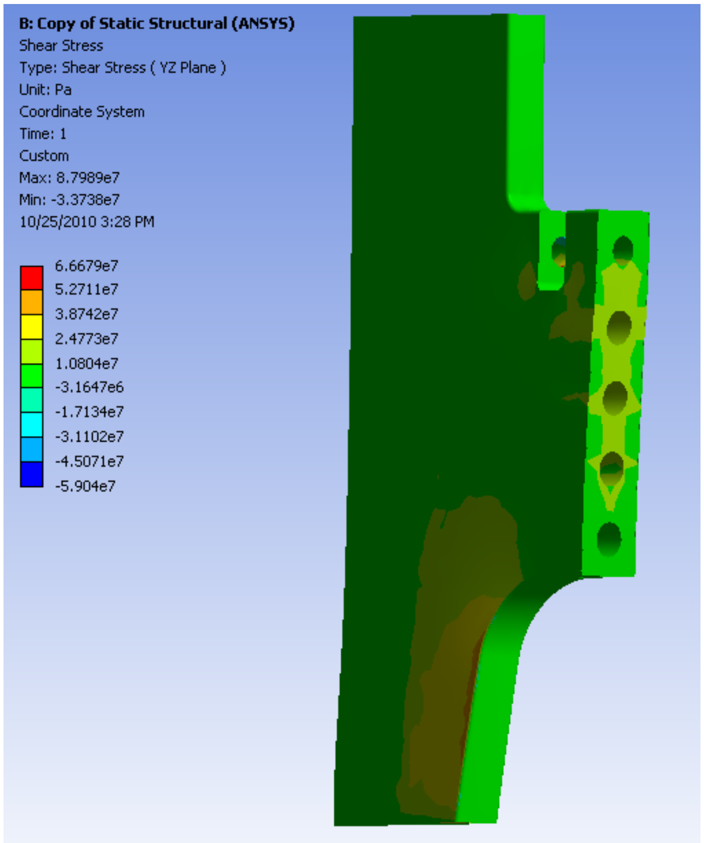
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Figure 6

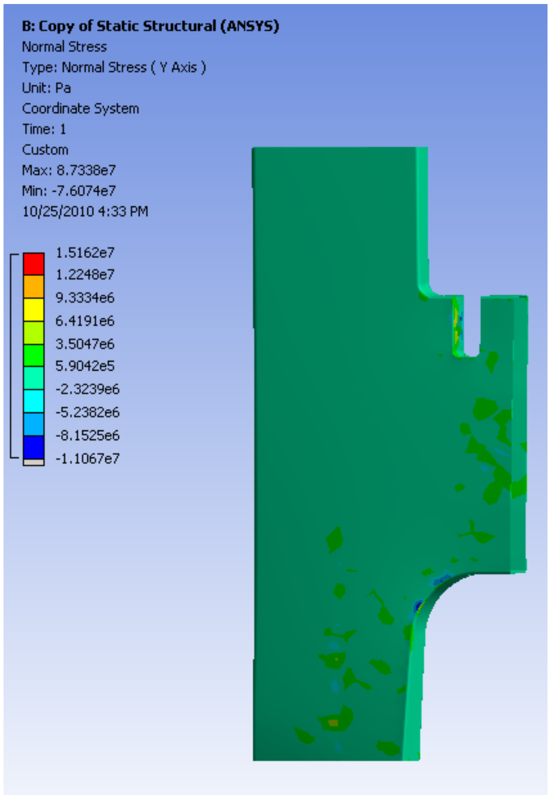


Figure 7

Initial (Teeth) Designs:

The initial designs of the torque transfer mechanism included sets of teeth arranged in the toroidal direction to engage the G-10 insulating crown and exchange the out of plane torque between the TF inner leg bundle and umbrella structure/vacuum vessel. The teeth in the G-10 block, the TF conductors, and the insulation need to be able to withstand the loads in all working current scenarios. To evaluate these designs, TF conductors including epoxy insulation were modeled together with the G-10 block in 1/18 and 1/36 cyclic symmetry models. Expected torques and forces were obtained from the global FEA model for the worst case out-of-plane twisting loads. The forces were exerted on the cyclic symmetry models. Figure 8 shows sections of the two different teeth models studied. The first teeth model used alternate short and tall flag pieces to engage the G-10. The second model involved machining a pocket in the end of each conductor and a matching G-10 piece to engage the teeth.

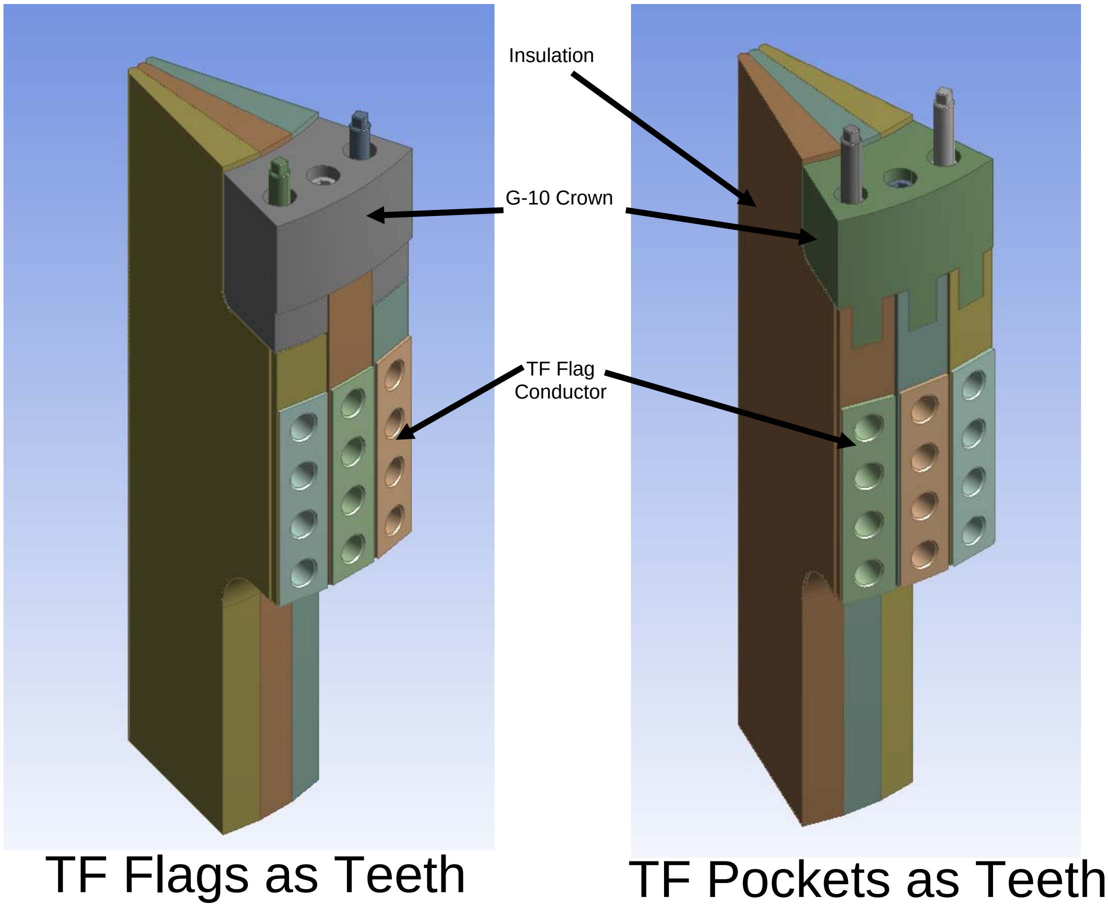
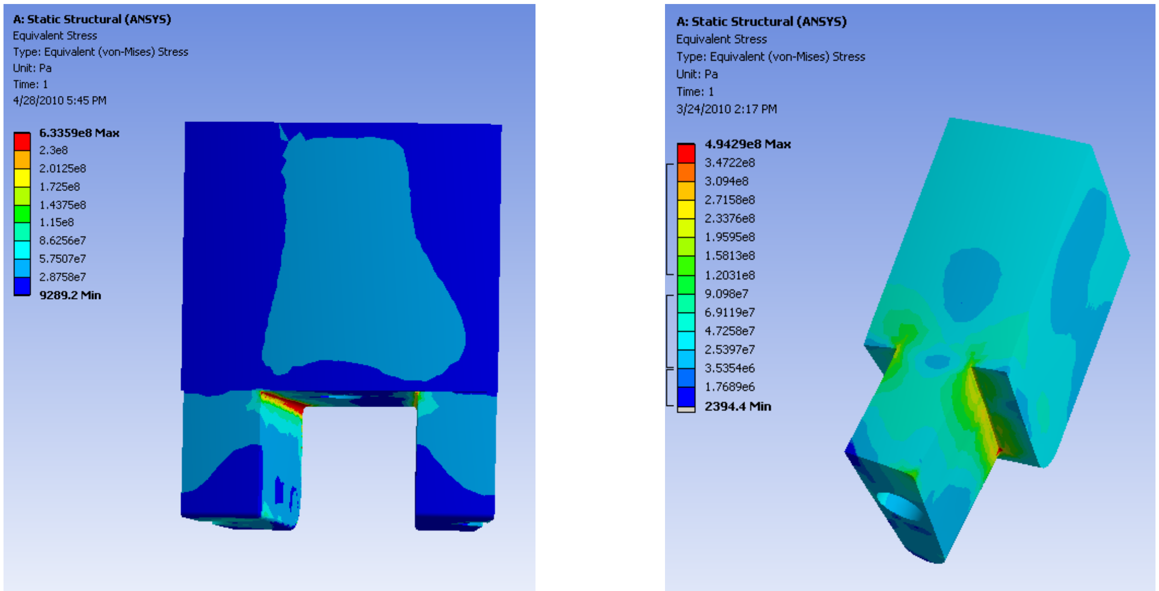


Figure 8

Cyclic symmetry FEA analyses similar to the one described above were performed for these two design. Figure 9 is the contour plot of equivalent stress in the G-10 crown. The teeth in G-10 showed large shear stress which exceeded the G-10 inter-laminar shear limit. In order for these designs to work it would be necessary to put a secondary G-10 crown ring to increase the teeth surface area in the radial direction in the upper and lower centerstack TF keys. Alternatively, a new insulating 3D orthogonal woven composite material with substantially higher lateral shear strength can be used for the crown.

Due to the nature of the first design, the bonded epoxy insulation between the TF conductors is heavily stressed. Figure 10 shows the normal stress in the insulation in the toroidal direction. The stress in the insulation exceeds the 10MPa limit causing localized delamination (albeit benign) of the TF conductor insulation.

Figure 11 is a contour plot of the shear stress at the epoxy copper bond in both designs.



G10 teeth engaging TF Flag

G10 tooth engaging TF pocket

Figure 9

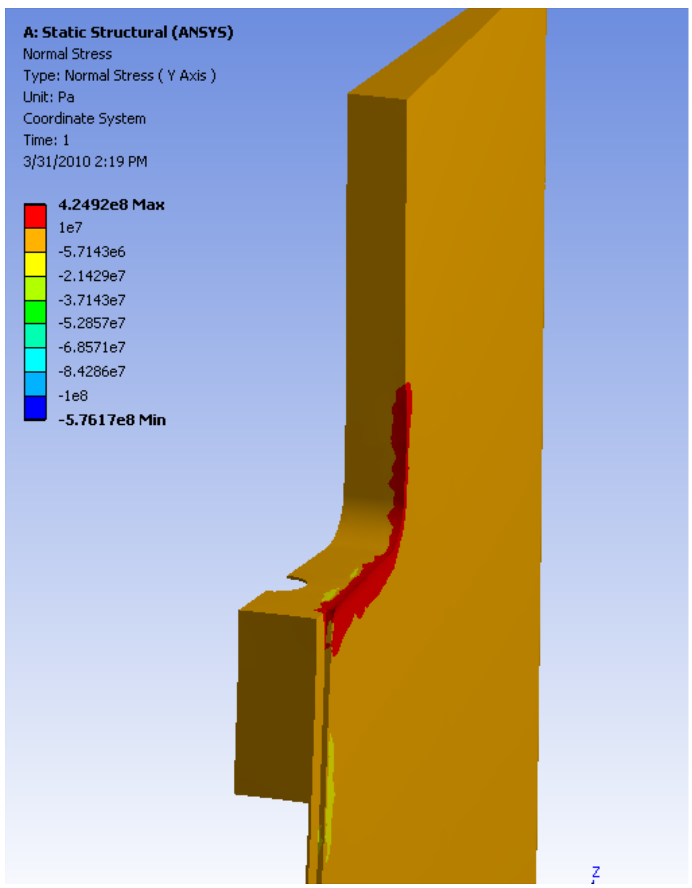


Figure 10

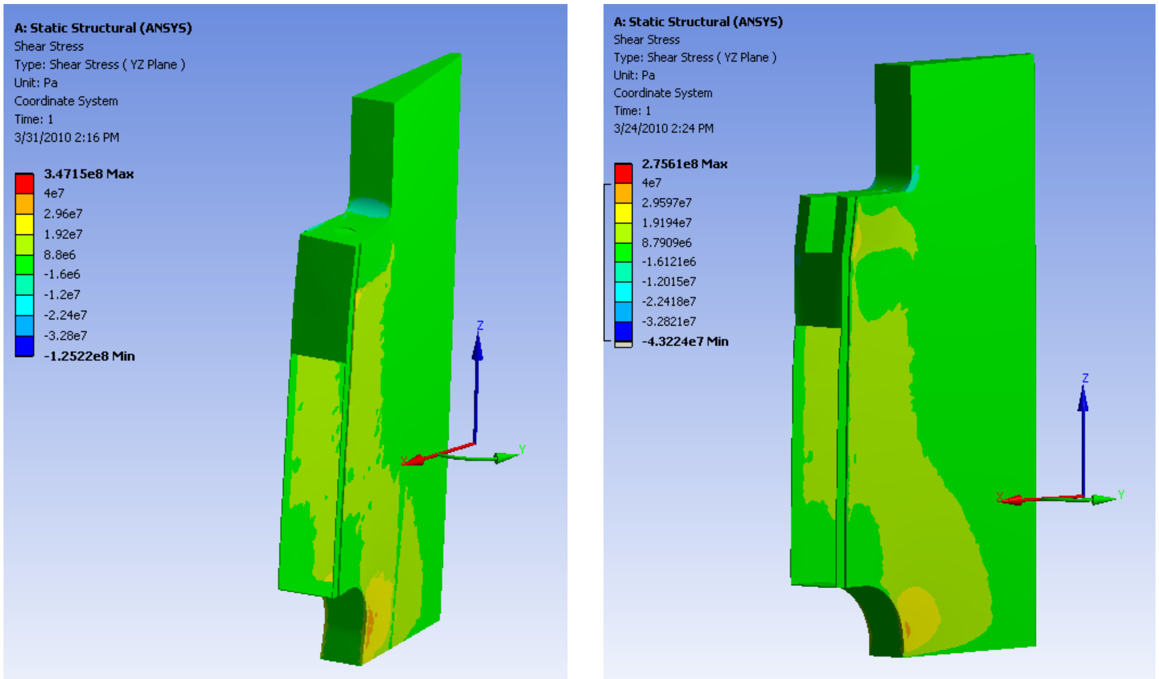

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Figure 11