DRAFT

NSTX

Digital Coil Protection System Inputs

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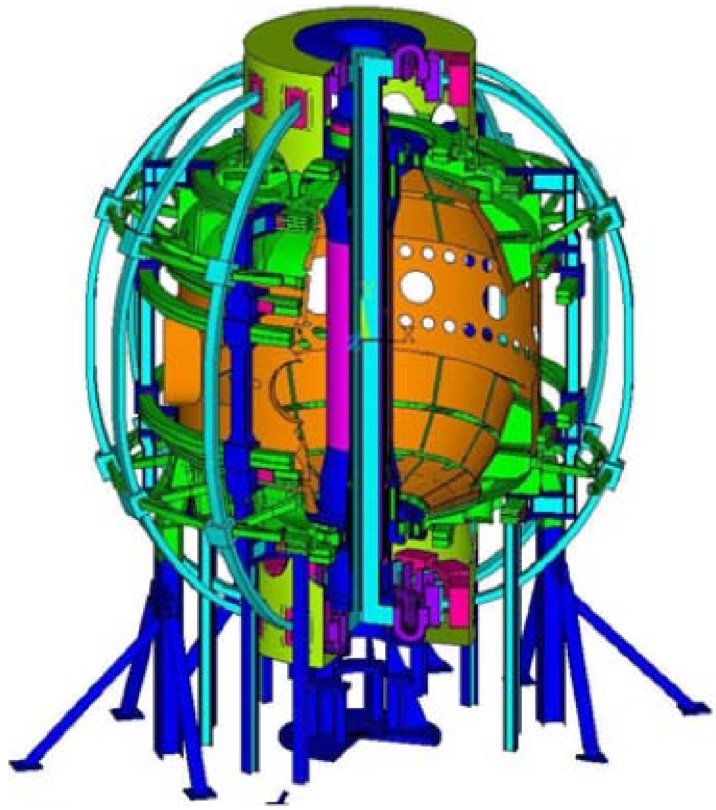
Introduction

Conceptual design, of the upgrade to NSTX, explored designs sized to accept the worst loads that power supplies could produce. Excessive structures resulted that would have been difficult to install and were much more costly than needed to meet the scenarios required for the upgrade mission, specified in the General Requirements Document (GRD). Instead the project decided to rely on a digital coil protection system (DCPS). Initial sizing was then based on the 96 scenarios in the GRD design point with some headroom to accommodate operational flexibility and uncertainty. The DCPS must control currents to limit component stresses and temperatures to acceptable levels. The digital coil protection system theory , hardware and software are described in other papers at this conference. The intention of this paper is to describe the generation of stress multipliers, and algorithms that are used to characterize the stresses at key
areas in the tokamak,



Two approaches are used to provide the needed multipliers/algorihms:

The first is to use the loads on PF coils computed by the DCPS software and apply these to local models of components.

The second approach to calculating the stress multipliers/algorithms, is to utilize the global model that simulates the whole structure and includes an adequately refined modeling of the component in question.

Unit terminal currents are applied to each coil separately, Lorentz loads are calculated, and the response of the whole tokamak and local component stress is computed. Local component stresses may then be computed in the DCPS or in a spreadsheet for the many scenarios required by the GRD. Separate calculations use this global model to compute influence coefficients for components covered by the calculation. For example:

TF Inner Leg Torsional Shear, Including Input to the DCPS" NSTXUCALC-132-07-00

Brace pad embedment forces are driven by the torque carried by the outer structures (braces and I Beam Columns) vs. the inner structures or centerstack assembly (taken by the Pedestal). This is mitigated by the spoked lid connections between the inner and outer structures. The biggest loads in the braces result from seismic and bake-out loads. From Section 12.15.1, For the 96 normal equilibria, shear loads are less than 2000N for FX and 4000N for Fz per pad or 250 lbs per Hilti anchor . Each 1/2 inch anchorhas a 1861 lb shear design capacity(based on 1/4 of the failure load). Loads for the FY or vertical component are trivial for the 96 equilibria. Each Hilti has a capacity of 1027 lbs, also based on 1/4 of the pull-put load. For normal operating loads it is not expected that the Hilti loads need to be checked in the DCPS.

Section 1 - Torus Systems

1.1 Component: Seismic Analysis

Calculation: NSTXU-CALC-10-02-00 Rev 0
Cognizant Engineer: Phil Heitzenroeder
Responsible Analyst: Peter Titus

DCPS Algorithm

No input to the DCPS is required for seismic qualification. A seismic event cannot be anticipated or mitigated by the DCPS.

Section 2 – Plasma Facing Components

2.1 Component: First Wall Final Tile Stress Analysis (ATJ Tiles)

Calculation: NSTXU-CALC-11-03-00
Cognizant Engineer: Kelsey Tresemer
Responsible Analyst: Art Brooks

DCPS Algorithm

The background maximum field values were obtained by scanning thru the 96 operating scenarios specified in the Design Point Spreadsheet "NSTX_CS_Upgrade_100504.xls" using a FORTRAN code built on the Magnetics Library routine FICOI. This was found to be in agreement with results generated by others using the OPERA code.

Requirements – Peak Background Fields

Coil	R (center)	dR	Z (center)	dZ	nR	nZ	Turns	Fill
	(cm)	(cm)	(cm)	(cm)				0.0000
OH (half-plane)	24.2083	6.9340	106.0400	212.0800	4.0	110	442	0.7013
PF1a	31.9300	5.9268	159.0600	46.3533	4.0	16	64	0.8594
PF1b	40.0380	3.3600	180.4200	18.1167	2.0	16	32	0.7938
PF1c	55.0520	3.7258	181.3600	16.6379	2.0	10	20	0.8560
PF2a	79.9998	16.2712	193.3473	6.7970	7.0	2	14	0.7409
PF2b	79.9998	16.2712	185.2600	6.7970	7.0	2	14	0.7409
PF3a	149.4460	18.6436	163.3474	6.7970	7.5	2	15	0.6928
PF3b	149.4460	18.6436	155.2600	6.7970	7.5	2	15	0.6928
PF4b	179.4612	9.1542	80.7212	6.7970	2.0	4	8	0.7525
PF4c	180.6473	11.5265	88.8086	6.7970	4.5	2	9	0.6723
PF5a	201.2798	13.5331	65.2069	6.8580	6.0	2	12	0.7733
PF5b	201.2798	13.5331	57.8002	6.8580	6.0	2	12	0.7733

Btf = 1T at 0.9344m

PF Configuration from NSTX_CS_Upgrade_100504.xls
Scan of 96 scenarios in same spreadsheet used to establish max fields:

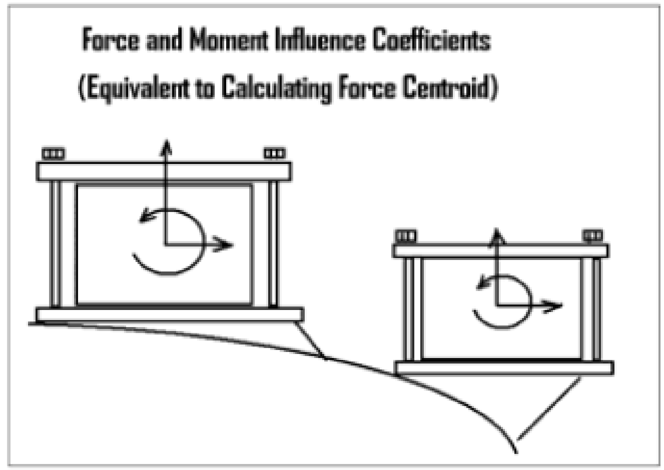
Max Br = 0.5 T
Max Bz = -0.57 T

Avg Btf ~ 2 T at IBDhs
Max Btf ~ 3 T at CS

Section 3 – Vacuum Vessel/Supports

3.1 Component: Disruption Analysis of VV and Passive Plates

Calculation: NSTXU-CALC-12-01-01 Rev 1
Cognizant Engineer: Phil Heitzenroeder
Responsible Analyst: Peter Titus



DCPS Algorithm

There is no input to the DCPS planned for disruption loading of components. The loading calculated for the vessel, passive plates and other components in this calculation is based on the maximum toroidal field.

3.2 Component: PF2 and PF3 Bolting, Bracket, and Weld Stress

Calculation: NSTXU-CALC-12-04-00 Rev 0
Cognizant Engineer: Mark Smith
Responsible Analyst: Peter Titus

DCPS Algorithm

Conceptual design of the upgrade to NSTX explored designs sized to accept the worst loads that power supplies could produce. Excessive structures resulted that would have been difficult to install and were much more costly than needed to meet the scenarios required for the upgrade mission, specified in the General Requirements Document (GRD). Instead the project decided to rely on a digital coil protection system (DCPS).
Two approaches are used to provide the needed multipliers/algorithms.
The first is to use the loads on PF coils computed by the DCPS software and apply these to local models of components. For PF 2 and 3, this translates into checking the bolt stresses for the launching loads. It is usual practice to utilize influence coefficient calculations to determine hoop and vertical loads from coil currents. However, the centroid of the Lorentz loads may not be at the geometric center of the coils, and a moment about a geometric center of the coil may be produced.

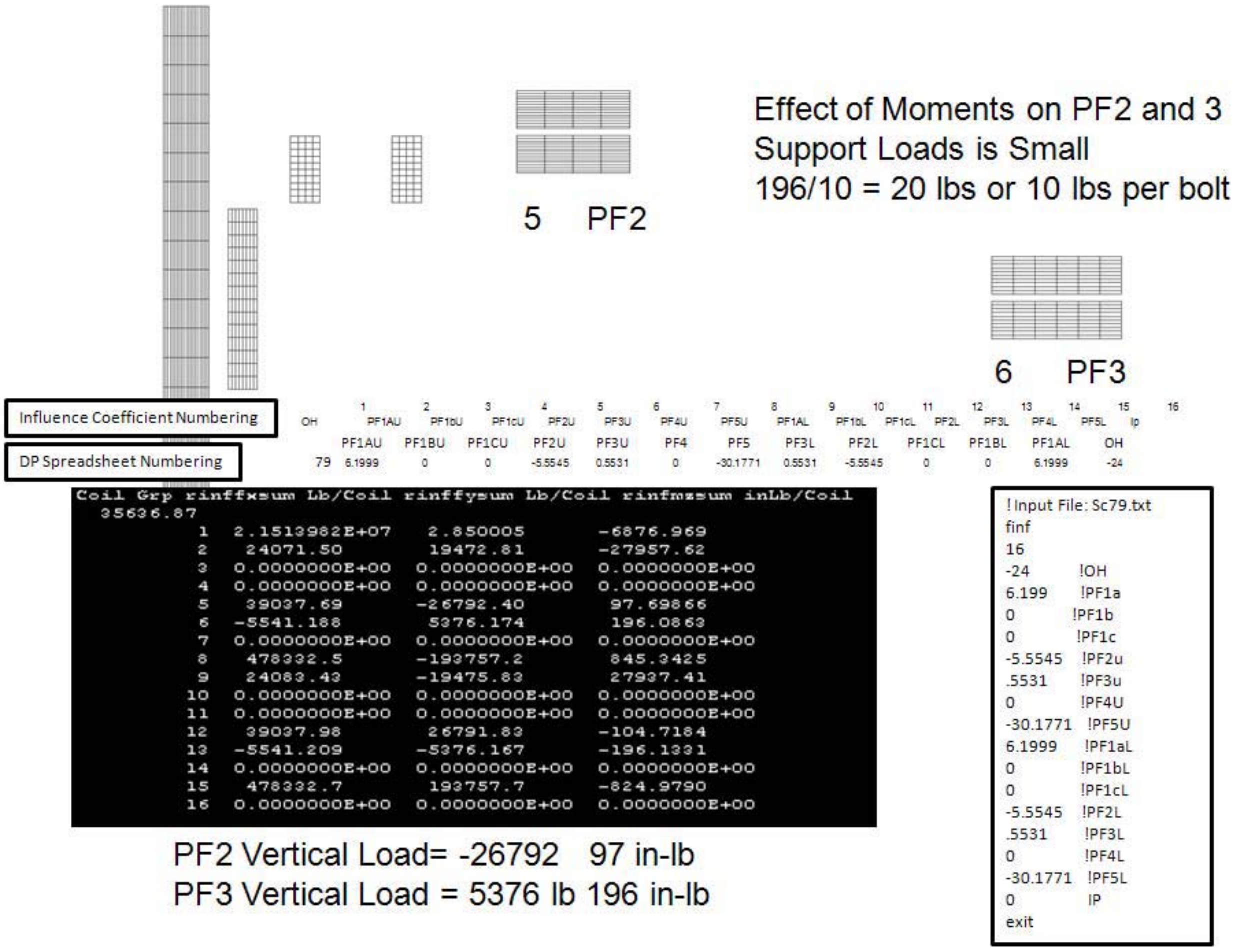


Figure 4.0-1 Results from Reference [1] NSTX Upgrad**e** Moment Influence Coefficients NSTXU-CALC-13-05-00Rev 0**,** Peter Titus, January 18 2011

Moment effects for PF2, and 3 have been found to be small and probably be neglected, but the effect is included in the DCPS multiplier table.

PF2/3 DCPS Multipliers

Location/Component	Stress Limit	Fvert (lbs)	Mtheta (in-lbs)
PF2 ½ in Bolts	20,000 psi*	/5.23/4/.1416	/5.23/8in/2/.1416
PF2 Plate to Rib Weld			
PF3 Lower ½ in Bolts	20,000 psi	/9/4/.1416	9/8in/2/.1416
PF3 Plate to Rib Weld			

* This is set by fatigue limits. Fatigue damage should be accumulated by the DCPS every time the bolt load exceeds 20,000 lbs. Static or infrequent limits may be as specified for replacement studs. If these are all ASTM A193 B8M Class 2 Bolts then the allowable would be the lesser of 125/3 or 2/3*100 =41.7 ksi

3.3 Component: PF4 and PF5 Support Analysis

Calculation: NSTXU-CALC-12-05-00 Rev 0
Cognizant Engineer: Mark Smith
Responsible Analyst: Peter Titus

DCPS Algorithm

The digital coil protection system algorithms are discussed in more detail in section 9. Conceptual design of the upgrade to NSTX explored designs sized to accept the worst loads that power supplies could produce. Excessive structures resulted that would have been difficult to install and were much more costly than needed to meet the scenarios required for the upgrade mission, specified in the General Requirements Document (GRD). Instead, the project decided to rely on a digital coil protection system (DCPS). Initial sizing was then based on the 96 scenarios in the GRD design point with some headroom to accommodate operational flexibility and uncertainty. The DCPS must control currents to limit component stresses and temperatures to acceptable levels.

Two approaches are used to provide the needed multipliers/algorithms.

The first is to use the loads on PF coils computed by the DCPS software and apply these to local models of components. The second approach to calculating the stress multipliers/algorithms is to utilize a global model that simulates the whole structure and includes an adequately refined modeling of the component in question. Unit terminal currents are applied to each coil separately, Lorentz loads are calculated, and the response of the whole tokamak and local component stress is computed. Local component stresses may then be computed in the DCPS or in a spreadsheet for the many scenarios required by the GRD by scaling and linear superposition of the unit results. This approach has been applied to the PF4 and 5 coil stresses.

PF4/5 DCPS Multipliers

The DCPS should calculate the upward load on the upper PF4 and 5 coils individually and assume this is split over 6 of the 12 support clamp plates which each have 4 studs. Similarly, the downward load on each of the lower PF4 and PF5 coils should be split over 6 of their 12 supports. This is a conservative but needed assumption because for most loading all 12 supports will resist the tensile loads of the coils with respect to their support brackets. Up-down asymmetry in loading may effectively load the 12 supports unequally. If the existing SS316 generic studs are replaced by ASTM A-193 B8M Class 1 bolts, the stress allowable would be 2/3*95 = 63.3 ksi, which corresponds to 8000 lbs per stud. The studs should be tensioned above this or about 10000 lbs (the NSTX Structural Design Criteria Document [3] allows 0.75*yield). With proper pre-tensioning, the alternating stress affecting fatigue will be small. Coil stress algorithms are summarized in the next two figures.

PF5 Stress Influence Coefficients

Influence Coefficients are Computed from the Global Model Stress Contour Plots
Unit Currents in the PF's are increased by a factor of 1000 to exaggerate the Stress Contours.
TF Coils are running at full Current. Units are Mpa/(Amp/1000)^2 .

OH	PF1AU	PF1BU	PF1CU	PF2U	PF3U	PF4	PF5	PF1AL	PF1BL	PF1CL	PF2L	PF3L	PF4	PF5	ip
afact	bfact	cfact	dfact	efact	ffact	gfact	hfact	ifact	jfact	kfact	lfact	mfact	nfact	ofact	pfact
2.26E+10	2.35E+1(	2.36E+10	2.51E+10	2.41E+10	2.34E+10	-3.00E+10	2.41E+10	2.40E+10	2.50E+1(	2.60E+10	2.40E+10	2.58E+10	3.57E+1(	4.21E+10	-1.92E+1(

"Smeared" Coil theta Stress (hoop and bending)=

=(B6*(afact-hfact)+C6*(bfact-hfact)+D6*(cfact-hfact)+E6*(dfact-dfact)+F6*(efact-hfact)+G6*(ffact-hfact)+H6*(gfact-hfact)+I6*(hfact-hfact)+J6*ifact+K6*(jfact-hfact)+L6*(kfact-hfact)+M6*(lfact-hfact)+N6*(mfact-hfact)+O6*(nfact-hfact)+P6*(ofact-hfact)+Q6*(pfact-hfact))/1000000/1000000*I6 +hfact*I6^2/1000000000000

The equation above includes the plasma. For "No Plasma" the p factor should be set to zero.

For Scenarios in which the absolute magnitude of PF4 currents are small (<5kA) with respect to the PF5 current, Use a stress multiplier of 1.4 and a thermal allowance of 74 Mpa.

For Scenarios in which the absolute magnitude of PF4 currents are greater then 5kA used a stress multiplier of 2.6 and the thermal allowance of 74 Mpa.

This stress must be below the static criteria of 156 Mpa and below 125 Mpa for the fatigue Criteria (See Section 6 for Stress Allowables) . Stresses Above 125 Mpa may be allowed if the DCPS Performs Cycle counting and Usage Factor Accumulation

PF4 Stress Influence Coefficients

Influence Coefficients are Computed from the Global Model Stress Contour Plots
Unit Currents in the PF's are increased by a factor of 1000 to exaggerate the Stress Contours.
TF Coils are running at full Current. Units are Mpa/(Amp/1000)^2.

OH	PF1AU	PF1BU	PF1CU	PF2U	PF3U	PF4	PF5	PF1AL	PF1BL	PF1CL	PF2L	PF3L	PF4	PF5	ip
afact	bfact	cfact	dfact	efact	ffact	gfact	hfact	ifact	jfact	kfact	lfact	mfact	nfact	ofact	pfact
1.24E+10	1.24E+04	1.76E+10	2.60E+10	1.84E+10	3.00E+10	1.60E+10	1.60E+10	1.59E+10	1.59E+10	1.59E+10	1.60E+10	1.62E+10	2.05E+10	7.27E+10	-1.19E+11

"Smeared" Coil theta Stress (hoop and bending)=

=(B6*(afact-hfact)+C6*(bfact-hfact)+D6*(cfact-hfact)+E6*(dfact-dfact)+F6*(efact-hfact)+G6*(ffact-hfact)+H6*(gfact-hfact)+I6*(hfact-hfact)+J6*ifact+K6*(jfact-hfact)+L6*(kfact-hfact)+M6*(lfact-hfact)+N6*(mfact-hfact)+O6*(nfact-hfact)+P6*(ofact-hfact)+Q6*(pfact-hfact))/1000000/1000000*I6 +hfact*I6^2/1000000000000

The equation above includes the plasma. For "No Plasma" the p factor should be set to zero.

For Scenarios in which the absolute magnitude of PF4 currents are small (<5kA) with respect to the PF5 current, Use a stress multiplier of 1.4 and a thermal allowance of 74 Mpa.

For Scenarios in which the absolute magnitude of PF4 currents are greater then 5kA used a stress multiplier of 2.6 and the thermal allowance of 74 Mpa.

This stress must be below the static criteria of 156 Mpa and below 125 Mpa for the fatigue Criteria (See Section 6 for Stress Allowables) . Stresses Above 125 Mpa may be allowed if the DCPS Performs Cycle counting and Usage Factor Accumulation

PF4 and 5 Support Columns

The six new columns and the replacements for the old rods in the existing supports are modeled as 3-inch OD pipes with .3 inch wall thicknesses. In table 6.3.5, the PF4U+PF5U load sum from the design point is shown to be nearly equal and opposite to the PF4-L + PF5-L load sum. This is the column compressive load. PF4 loading contributes to a bending stress in the column. The column load divided by the column cross sectional area plus the PF4 load times its offset from the column centerline divided by the column section modulus should remain below the bending allowable for the column material. In the 96 equilibrium results, this value is 200 MPa (30ksi). A material should be selected that has yield about 35 to 70 MPa (5 to 10 ksi) above 200 MPa to provide some margin for the DCPS.

3.4 Component: Aluminum Block Analysis

Calculation: NSTXU-CALC-12-05-00 Rev 0
Cognizant Engineer: Mark Smith
Responsible Analyst: Peter Titus

DCPS Algorithm

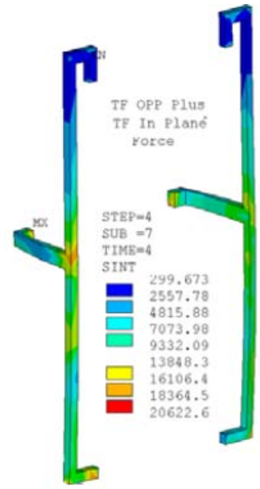


Figure 3.0-8

The out-of-plane (OOP) component of the critical stresses in the aluminum block and associated hardware will scale with the upper and lower half outer leg net moments. These are available from Bob Woolley's equations in NSTXU CALC 132-03-00 [5], and are implemented in Charlie Neumeyer's Design Point [4]. The in-plane component of the critical stress will scale with the square of the TF current.

3.5 Component: Umbrella Reinforcement Details

Calculation: NSTXU-CALC-12-07-00 Rev 0
Cognizant Engineer: Mark Smith
Responsible Analyst: Peter Titus

DCPS Algorithm

The components covered by this calculation, the umbrella arch and foot reinforcements, and the local dome details are loaded predominantly by the global torque. This is available in the digital coil protection system from torque summaries by R. Woolley [12]. The global torque on the outboard TF leg is split between the truss at the vessel knuckle, and the umbrella structure. The series of calculations that address the umbrella structure, truss and knuckle clevis, and aluminum block use conservative load distributions. The calculations are converging on about an equal split of the OOP load between the knuckle region and the umbrella structure. If based on the earlier linear models, results in this calculation indicate 180 MPa (26 ksi) in Titus's analysis and 140 MPa (20 ksi) in H. Zhang's analyses for the max OOP torque for the 96 scenarios. The umbrella leg will have a yield and a bending allowable of at least 200 MPa (30 ksi). These results can be scaled in the DCPS. Final qualification of the ribs and bridging tabs is based on the limit analysis, The rib weldments are also loaded predominantly by the OOP loads and can be scaled from the OOP torque, but the PF1c, PF2 and PF3 also loads the ribs and an assessment of their contributions will be added to the DCPS. Note that the analysis shown in Figure 6.2-2, (the local model of umbrella leg foot and dome/rib from as-builts) shows the full PF coil umbrella leg load inventory.

3.6 Component: Lid and Spoke Assembly, Upper and Lower

Calculation: NSTXU-CALC-12-08-01 Rev 1
Cognizant Engineer: Mark Smith
Responsible Analyst: Peter Titus

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 to allow for the 10% headroom for PF currents and to allow some headroom for halo current loads. The torsional moment at the TF collar teeth/pins will scale with the calculated torsional shear stress in the TF coil at the turn radius. For the 96 scenarios, this is 24 MPa [4]. Spoked lid stresses should be scaled based on the TF torsional shear stress calculated for the DCPS.

3.7 Component: Pedestal Analysis

Calculation: NSTXU-CALC-12-09-00 Rev 0
Cognizant Engineer: Mark Smith
Responsible Analyst: Peter Titus

DCPS Algorithm

Conceptual design of the upgrade to NSTX explored designs sized to accept the worst loads that power supplies could produce. Excessive structures resulted that would have been difficult to install and were much more costly than needed to meet the scenarios required for the upgrade mission, specified in the
General Requirements Document (GRD). Instead the project decided to rely on a digital coil protection system (DCPS). For the pedestal the critical loads are the vertical loads from the OH and PF1 a and b
Upper and Lower coils interacting with the rest of the PF system. For the "Vee" Pipe design torsional loads are added to the vertical loads. For the downward loads from the PF coils, both pedestal designs are adequate even for the "worst case power supply" loads.
The limit to the upward loading is the concrete anchors or Hilties. Ninety four 3/4 inch Hilties are required to resist the worst case power supply loads. It is not likely that this number will be used. Only 5
3/4 inch anchors are needed to react the normal operating net load on the centerstack. Many more than 5 are suggested. The actual number will set the limit for the DCPS.

Section 4 – General

4.1 Component: DCPS Moment Influence Coefficients

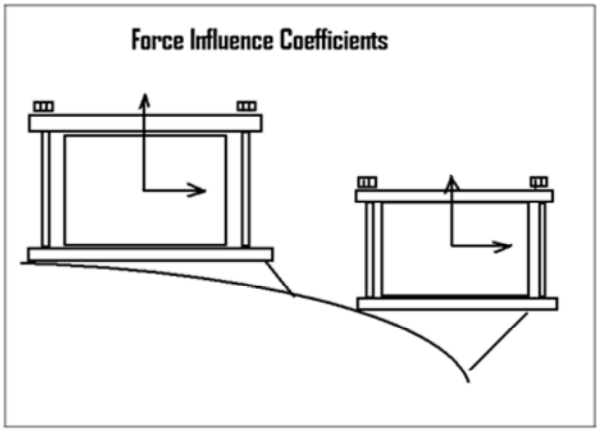
Calculation: NSTXU-CALC-13-05-00 Rev 0
Cognizant Engineer: Ron Hatcher
Responsible Analyst: Peter Titus

DCPS Algorithm

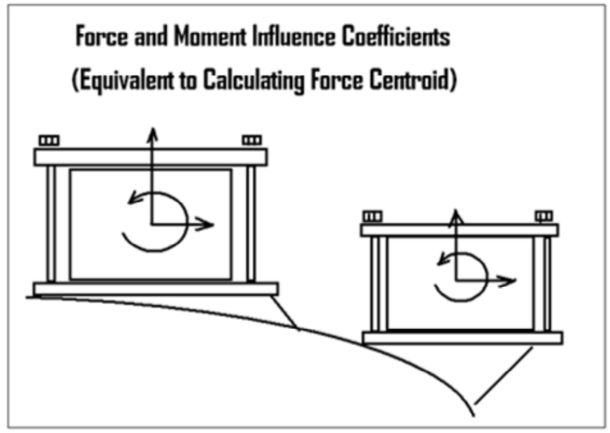
The proposed DCPS is described in detail in a draft requirements document by Robert Woolley ref [7].
Force influence coefficients are already included in plans for the DCPS. Inclusion of these moment coefficients is proposed, depending on their usefulness in quantifying stresses for specific components. In the description of the DCPS, the “systems code” will actually be the analyses described in the filed structural calculations. There is a global model which is the closest thing we have to a single systems code, but this is augmented in many ways by separate calculations to address specific stress locations and components and support hardware. During the final design activity, Each preparer of a calculation will be assigned the development of “mini algorithms” These may make use of moment influence coefficients. One example is:

.
PF 2,3 supports, welds bolts – At this stage, these are just calculated from influence coefficient matrix loads divided by weld or bolt area. Addition of moment influence coefficients adds overturning moments to the calculation of the bolt loads .

Addition of Moment Influence Coefficients to DCPS



Bolt Loads are calculated only from the vertical force.



Bolt Loads are calculated from the vertical force and the moment divided by the width of the bolt pattern.

Section 5 - Toroidal Field Coils

5.1 Component: Analysis of TF Outer Leg

Calculation: NSTXU-CALC-132-09-00 Rev 1
Cognizant Engineer: Mark Smith
Responsible Analyst: Peter Titus

DCPS Algorithm

The DCPS algorithms will be supplied in the calculation for the outer TF support structures, ref [1]. A simplified approach would be to scale the loads from the OOP torque computed in the design point spreadsheet. This is the upper half outer leg torque from spreadsheet - based on the equation in ref [6]. The shear load limit at this writing is 37,000 lbs. Derived from Scenario #79. The reported stresses can be scaled by the calculated torque for the currents being checked by the DCPS divided by the torque for equilibrium # 79.

5.2 Component: Maximum TF Torsional Shear

Calculation: NSTXU-CALC-132-07-00 Rev 0
Cognizant Engineer: Jim Chrzanowski
Responsible Analyst: Peter Titus

DCPS Algorithm

The out-of-plane (OOP) component of the critical stresses in the inner leg will approximately scale with the upper and lower half outer leg net moments. These are available from Bob Woolley's equations NSTXU CALC 132-03-00 [6], and are implemented in Charlie Neumeyer's Design Point [4, 5] . The moment summation of the upper half vs lower half of the tokamak is not completely useful because the stiffness of the structure will determine how much torque goes to the central column and how much goes to the outer TF and vessel structures, and the local distribution of OOP loads is important compared with the global torque.

A more detailed calculation of the inner leg shear stress relies on the elastic response of the entire tokamak and the Lorentz Loads from the poloidal field distribution crossing the inner leg currents. The global model was run with full TF current and 1000kA of current in each PF coil. The torsional shear in the upper and lower inner leg radii were then determined from each of the 16 load cases that resulted.

TF Inner Leg Upper Corner Torsional Shear Stress Influence Coefficients

Influence Coefficients are Computed from the Global Model Stress Contour Plots
Unit Currents in the PFs are increased by a factor of 1000 to exaggerate the Stress Contours
TF Coils are running at Full Current

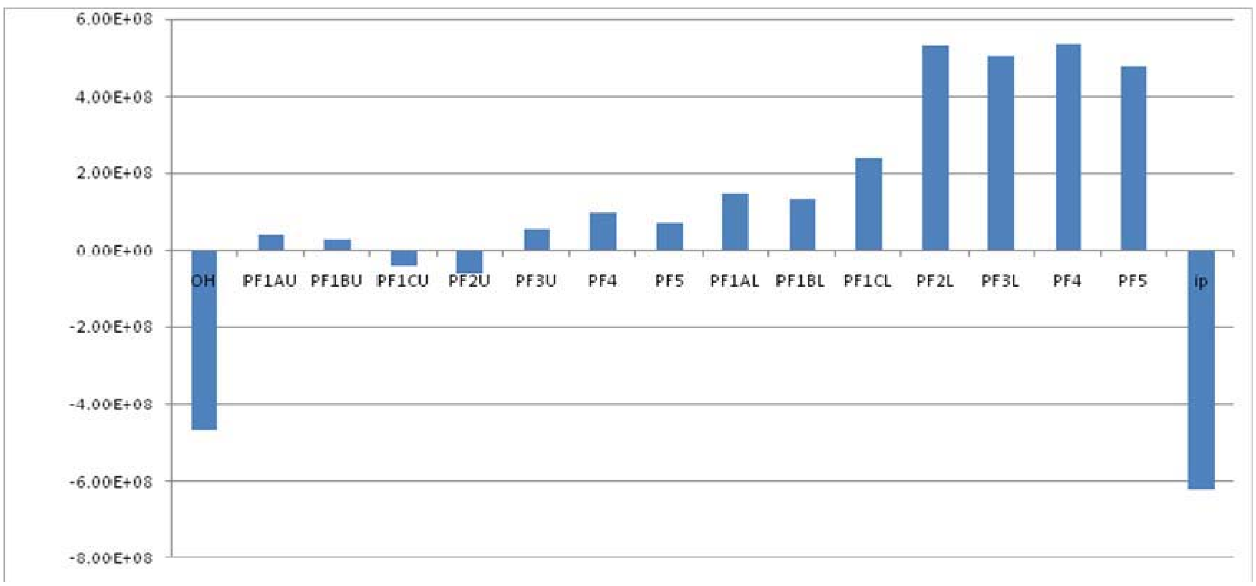


Figure 4 Influence Coefficients Calculated from the Global Model.

The methodology employed here has some history in the original NSTX. The coil protection calculator exercised a model of the TF system with unit PF currents and calculated stress multipliers. This is described in Irv Zatz's memo [12]. Much of the initial work on coil protection was done in support of TFTR operation. The theory is also described in Bob Woolley's DCPS system description document [1]. In Woolley's document he describes a system code which predicts elastic responses of the entire tokamak based on unit coil currents. The global model employed here is essentially this systems code. The inner leg torsional shear is a single stress component, and lends itself to the linear superposition methodology that Woolley describes. Other coil and structure performance evaluations will be based on equivalent stresses or combinations with thermal effects, that will make simple application of linear superposition less tractable.

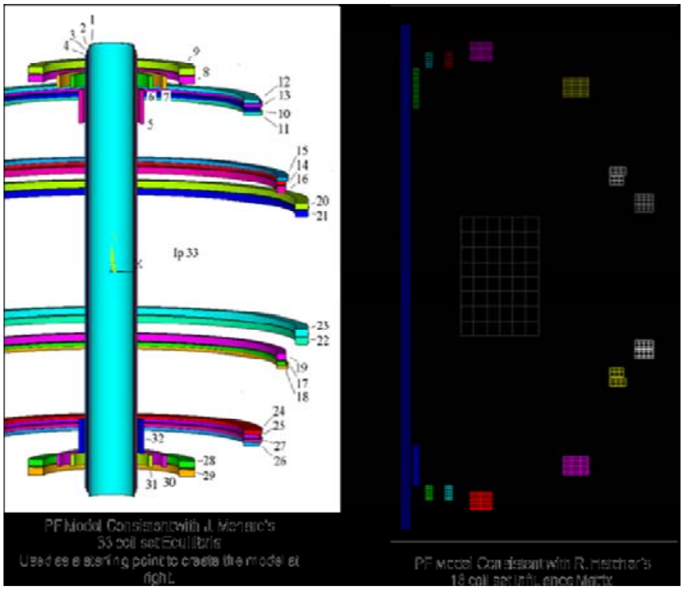


Figure 5 Coil Builds Used in the FEA analyses and the DCPS

The global model Lorentz Forces are computed for a coil set that includes all individual coil pancakes. To be consistent with the influence coefficients used in the DCPS, a regrouping of the coils is necessary.

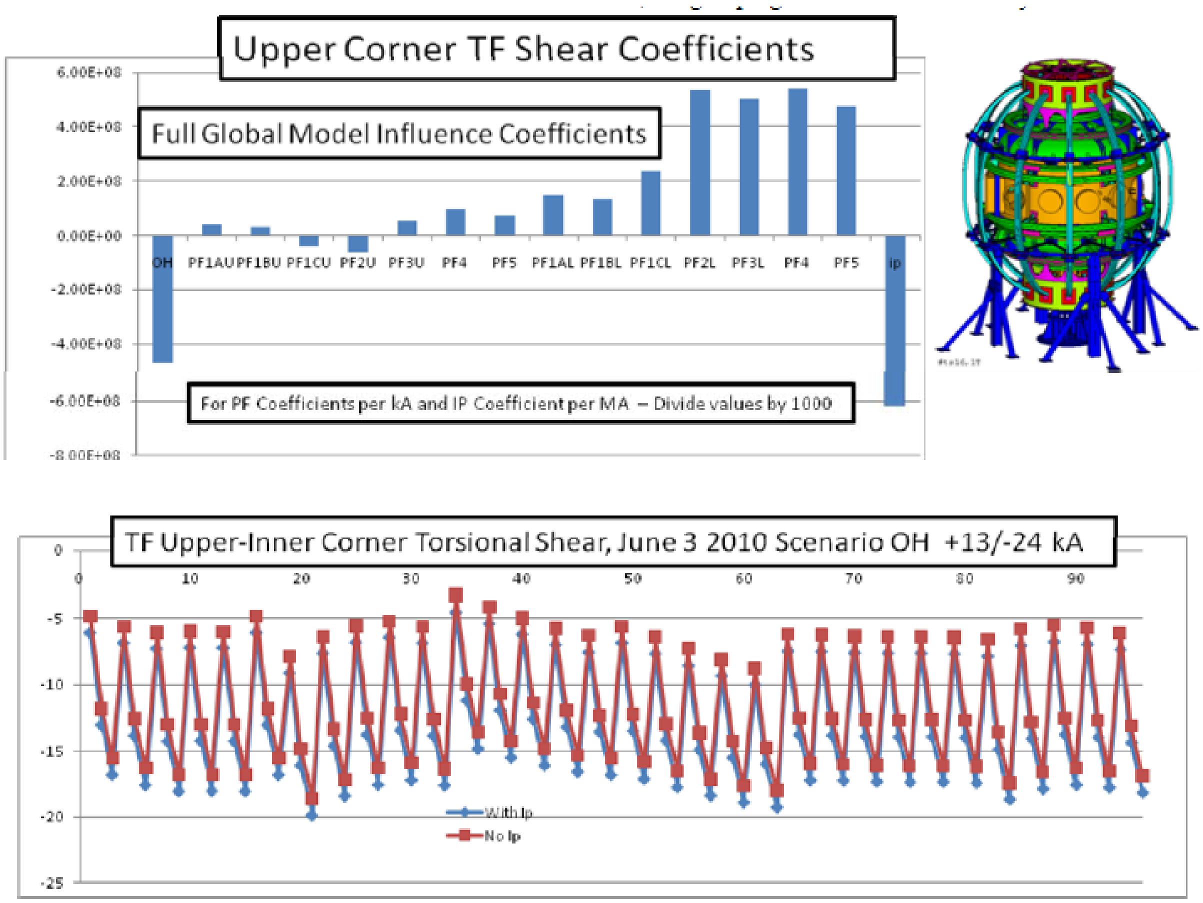


Figure 6 Torsional Shear Stresses from the influence coefficients multiplied by the Design Point Scenarios

If the fixity supplied by the crown connections, at the upper and lower ends of the inner leg, is sufficient, then only a model of the inner leg is needed. This would allow a simpler modeling of the inner leg shear, but calculations of the influence coefficients for the global model and a simpler TF model with fixity at the umbrella structures showed that there were large contributions from the outer PF coils that were suppressed by artificially fixing the umbrella structure.

5.3 Component: TF Flag Key

Calculation: NSTXU-CALC-132-07-00 Rev 0
Cognizant Engineer: James Chrzanowski
Responsible Analyst: Ali Zolfaghari

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

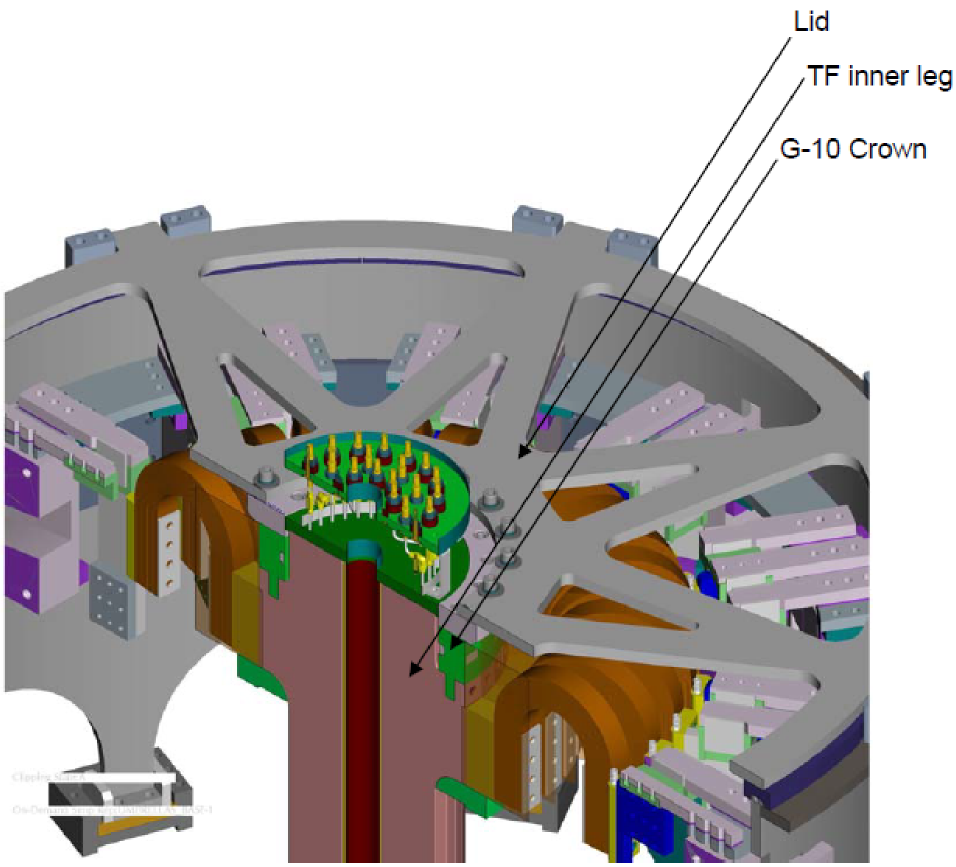


Figure 1

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.

5.4 Component: Analysis of Knuckle Clevis

Calculation: NSTXU-CALC-132-09-00 Rev 1
Cognizant Engineer: Mark Smith
Responsible Analyst: Peter Titus

DCPS Algorithm

As required for input to the machine simulator described in the DCPS Requirements Document [9], The DCPS algorithms will be supplied for loading in the calculation for the outer TF support structures, ref [1]. A simplified approach for the clevis would be to scale the loads from the OOP torque computed in the design point spreadsheet. This is the upper half outer leg torque from spreadsheet - based on the equation in ref [6]. The shear load limit at this writing is 37,000 lbs. Derived from Scenario #79. The reported stresses can be scaled by the calculated torque for the currents being checked by the DCPS divided by the torque for equilibrium # 79 Charlie's revision or new version of the DCPS requirements document[12] has some important changes. The planned disruption and shut-down look-aheads, have been removed, and the effect of passive structures has been ignored. I talked with Charlie about the TF outer leg summations in the spreadsheet. As of March 7 2012, Charlie had not updated the TF torque sums for the disruption currents. He provided the new torque values in March 7 2012. The disruption torque is lower than the normal outer leg torque. -See the discussion in Appendix G, Ref [11]. The DCPS stress multipliers may remain scaled based on the TF outer leg upper half torque divided by the EQ 79 torque. There is no fatigue margin in the clevis pin, so the OOP torque must be maintained below the EQ 79 value - or fatigue cycle counting must be implemented.

5.5 Component: Out-of-Plane PF/TF Torques on Conductors

Calculation: NSTXU-CALC-132-03-00
Cognizant Engineer: Peter Titus
Responsible Analyst: R. Woolley

DCPS Algorithm

5.6 Component: TF Coupled Thermo Electromagnetic Diffusion Analysis

Calculation: NSTXU-CALC-132-05-01
Cognizant Engineer: J. Chrzanowski
Responsible Analyst: Han Zhang

DCPS Algorithm

5.7 Component: TF Flex Joint and TF Bundle Stub

Calculation: NSTXU-CALC-132-06-01
Cognizant Engineer: Ali Zolfaghari
Responsible Analyst: Tom Willard

DCPS Algorithm

5.8 Component: TF Cool Down Using FCOOL

Calculation: NSTXU-CALC-132-10-00
Cognizant Engineer: Jim Chrzanowski
Responsible Analyst: Ali Zolfaghari

DCPS Algorithm

5.9 Component: Ring Bolted Joint

Calculation: NSTXU-CALC-132-11
Cognizant Engineer: Mark Smith
Responsible Analyst: Pete Rogoff

DCPS Algorithm

Section 6 - Center Stack

6.0 Component: Center Stack Casing Disruption Inductive and Halo Current Loads

Calculation: NSTXU-CALC-133-03-00
Cognizant Engineer: Irving Zatz
Responsible Analyst: Peter Titus

DCPS Algorithm

Casing Stress:
Most of the loading on the casing is either thermal or disruption loading. The DCPS typically is concerned mainly with coil Lorentz force derived stresses. Table 3.0-1 lists the Lorentz Force derived stress as 45 MPa. It occurs at the intersection of the straight section and flare. This comes from L.
Myatt's calculation of the casing stresses from the inner PF coils, ref [2]. The
45 MPa will scale based on the net vertical load from PF1a and b upper. Myatt used the worst of the 96 scenarios, which corresponds to the 67939 lbs
from the design point spreadsheet - excerpt at right. The DCPS should

Fz(lbf)	PF1aU+PF1bU
Min w/o Plasma	-29865
Min w/Plasma	-67939
Min Post-Disrupt	-35071
Min	-67939
Worst Case Min	-182214
Max w/o Plasma	55989
Max w/Plasma	48336
Max Post-Disrupt	46450
Max	55989
Worst Case Max	257587

compute the casing Lorentz Stress from:

(Sum of PF1a and b Vertical loading in lbs) * 45MPa /67939lbs = Lorentz Stress

The max stress in the casing is 200 MPa for 96 equilibria, plus thermal and disruption loads. With the Lorentz portion of the stress at 45 MPa, the "headroom" needed for Non-Lorentz Loads is 155 MPa. The static allowable is 450 MPa so the Lorentz stress could go to 300 MPa, and still pass the static allowable. The worst case Max load is 257587lbs - this would produce a casing stress of 257587/67939*45 = 170 MPa - so there is only marginally a possibility that currents in their worst configuration could cause an unacceptable stress - but the bolting in the lower flange will fail before this stress could be reached.

Lower Casing Support Bolts
Because they are sized to the worst halo loads, there isn't much margin to take anything more than the total PF 1a,b upper and lower Lorentz launching load that was used in section 17 to qualify the bolts. This is 25161 lbs from Table 5.2-1. Maintaining the net PF1a,b upper and lower summation below this value will protect the bolting from halo loads during a disruption. If more margin is needed to allow a better operating window, the halo loads on the bolts will have to be re-visited.

6.1 Component: OH Stress Analysis

Calculation: NSTXU-CALC-133-08-00
Cognizant Engineer: James Chrzanowski
Responsible Analyst: Ali Zolfaghari

DCPS Algorithm

Input to the DCPS will be developed based on the OH stress calculations as done in the NSTX Upgrade design point spreadsheet (worksheet “Base”) [2]. The advantage of this method is that OH stresses can be calculated algebraically based on current, coil dimensions. The max principal stress (i.e. hoop stress, see figure 2) in the conductor must be kept below 125 MPa and in the insulation below 10MPa.

6.2 Component: OH Fatigue and Fracture Mechanics

Calculation: NSTXU-CALC-133-09-00
Cognizant Engineer: Jim Chrzanowski
Responsible Analyst: Peter Titus

DCPS Algorithm

Input to the DCPS will be developed in the OH stress calculation, and in other calculations using similar copper conductors such as the coax cable calculation . The max principal stress in the conductor must be kept below 125 MPa.

6.3 Component: OH and PF1 Electromagnetic Stability Analysis

Calculation: NSTXU-CALC-133-11-00 Rev 0
Cognizant Engineer: Jim Chrzanowski
Responsible Analyst: Peter Titus

DCPS Algorithm

This establishes an Magnetic "stiffness". This is then compared with a structural stiffness. The structural stiffness must exceed the magnetic stiffness for the coils to be stable. The magnetic stiffness was calculated to be .637 MN/m and the structural stiffness was calculated to be 425 MN/m This calculation demonstrates a large stability margin between the inner PF coils and the OH coil, with peak coil currents applied. No interface with the DCPS is required. Stress evaluations of the more significant loads on the centerstack casing are included in ref [7].

6.4 Component: Model Analysis and Normal Operation Transient Load Effects

Calculation: NSTXU-CALC-133-13-00
Cognizant Engineer: Phil Heitzenroeder
Responsible Analyst: Peter Titus

DCPS Algorithm

While a sharp transient could be evaluated in the DCPS, no input to the DCPS is planned based on this analysis. The nominal dynamic effects are small and are not required to be mitigated by the DCPS.

6.5 Component: Structural Analysis of the PF1 Coils and Supports

Calculation: NSTXU-CALC-133-11-01
Cognizant Engineer: Jim Chrzanowski
Responsible Analyst: Leonard Myatt

DCPS Algorithm

6.6 Component: OH Preload System and Belleville Spring Design

Calculation: NSTXU-CALC-133-04-00
Cognizant Engineer: Peter Titus
Responsible Analyst: Pete Rogoff

DCPS Algorithm

6.7 OH Coolant Hole Optimization

Calculation: NSTXU-CALC-133-06-00
Cognizant Engineer: James Chrzanowski
Responsible Analyst: Ali Zolfaghari

DCPS Algorithm

6.8 Component: OH Coax Lead Analysis

Calculation: NSTXU-CALC-133-07-00
Cognizant Engineer: Jim Chrzanowski
Responsible Analyst: Michael Mardenfeld

DCPS Algorithm

6.9 Component: Center Stack Casing Bellows

Calculation: NSTXU-CALC-133-10
Cognizant Engineer: Peter Titus
Responsible Analyst: Pete Rogoff

DCPS Algorithm

Section 7 - Plasma Heating and Current Drive

7.1 Component: Vessel Port Re-Work for NB and Thompson Scattering Port

Calculation: NSTXU-CALC-24-01-00 Rev 0
Cognizant Engineer: Mark Smith
Responsible Analyst: Tom Willard

DCPS Algorithm

7.2 Component: HHFW Antenna

Calculation: NSTXU-CALC-24-03-01
Cognizant Engineer: Robert Ellis
Responsible Analyst: Han Zhang

DCPS Algorithm

7.3 Component: Stress Analysis of Bay L and 2nd NBI Upgrade

Calculation: NSTXU-CALC-24-05-00
Cognizant Engineer: Mark Smith
Responsible Analyst: Neway Atnafu

DCPS Algorithm

7.4 Component: Diagnostic Review and Database

Calculation: NSTXU-CALC-40-01-00
Cognizant Engineer: Robert Kaita
Responsible Analyst: Peter Titus

DCPS Algorithm

Section 8 - Power Systems

8.1 Component: Bus Bar Analysis

Calculation: NSTXU-CALC-55-01-00
Cognizant Engineer: Mark Smith
Responsible Analyst: Andrei Khodak

DCPS Algorithm