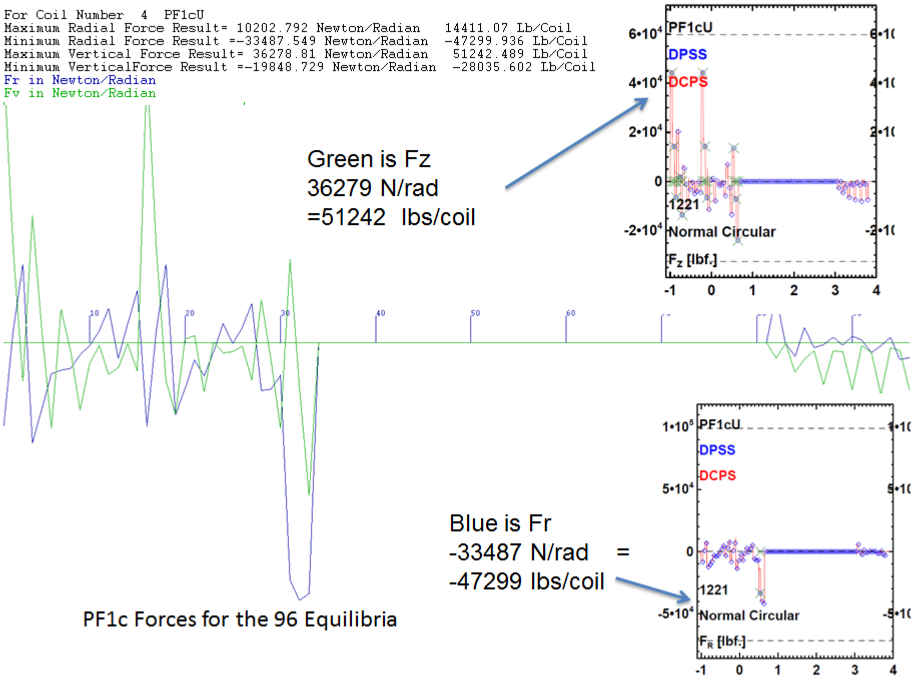
NSTX Upgrade

DRAFT

DCPS Check Calculations



```
For Coil Number  4  PF1cU
Maximum Radial Force Result= 10202.792 Newton/Radian   14411.07 Lb/Coil
Minimum Radial Force Result =-33487.549 Newton/Radian  -47299.936 Lb/Coil
Maximum Vertical Force Result= 36278.81 Newton/Radian   51242.489 Lb/Coil
Minimum VerticalForce Result =-19848.729 Newton/Radian  -28035.602 Lb/Coil
Fr in Newton/Radian
Fv in Newton/Radian
```

Green is Fz
36279 N/rad
=51242 lbs/coil

Blue is Fr
-33487 N/rad =
-47299 lbs/coil

PF1c Forces for the 96 Equilibria

NSTXU-CALC-13-07-00

December   2016

Prepared By:

Peter Titus, PPPL Mechanical Engineering

Reviewed By:

Tim Stevenson, NSTXU Cognizant Engineer

PPPL Calculation Form

Calculation # **NSTXU-CALC-13-07-00** Revision # 00 WP #, 5200 (ENG-032)

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

There are a number of places where calculations were performed to provide algorithm details for the Digital Coil Protection System. Each of the NSTXU calculation was supposed to have a section that provided guidance on the DCPS algorithm that would cover the component in the calculation. This calculation either provides pointers to the appropriate calculation or includes additional algorithm calculations here. The algorithms have been incorporated into a True Basis code that can run the algorithm evaluations for the 96 GRD design point equilibria and other provided scenarios. This can be used to check the DCPS implementation or find limiting equilibria among the provided 96.

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

Included in the body of the calculations

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

Axisymmetry of the coils

Calculation **(Calculation is either documented here or attached)**

Included in the body of the calculations

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

Moment influence coefficients have been calculated and tabulated for checking other's work or inclusion in the DCPS

Cognizant Engineer’s printed name, signature, and date

Tim Stevenson ____

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

Checker’s printed name, signature, and date

Robert Woolley ____

Table of Contents

Results

4.0 Executive Summary:

The Digital Coil Protection System (DCPS) is a combination of computer hardware and software which is intended to protect the coils from excessive loads and load combinations, and maintain resulting stresses below the stress allowable used in the design.

Prototype DCPS Computer In FCC Rack

Internal View of DCPS Computer with I/O cards installed

The DCPS effort begins with computation of loads from coil currents via influence coefficients. The structural response of NSTX-U often is based on combinations of loads on structural assemblies. One important case is the net launching load on the centerstack which carries net loads from the OH and inner PF coils, PF1a, and b upper and lower. . In this case the loads are computed, summer and compared with an allowable based on the bolting and weld details that resist the vertical tensile load. Other DCPS algorithms are based on stress based influence coefficients. An example of this is the torsional shear stress algorithm that is based on shear stress contributions from individual coil unit currents.

In all these cases, the process of structural Lorentz force calculation structural response and final implementation in the computer software needs to be checked. Checking of the Lorentz force calculations and many of the structural calculations that are input to the DCPS algorithms are found in filed calculations. Every calculations done in support of NSTX-U was supposed to have a section which provided guidance on an appropriate algorithm that would address the calculations components. Other calculations were intended to develop the algoirithms directly. Some of these are listed below:

[1] NSTX Influence Coefficients, calculation # NSTXU 13 03-00, Ron Hatcher DATE: July 9 2009
[3] NSTX Structural Design Criteria Document, NSTX_DesCrit_IZ_080103.doc I. Zatz
[4] NSTX Design Point Sep 8 2009 http://www.pppl.gov/~neumeyer/NSTX_CSU/Design_Point.html
[5] OOP PF/TF Torques on TF , R. Woolley, NSTXU CALC 132-03-00
NSTX-CSU-RD-DCPS for the National Spherical Torus Experiment Center Stack Upgrade, February 5, 2010 R. Woolley
[9] NSTX Upgrade General Requirements Document, NSTX_CSU-RQMTS-GRD Revision 5, C. Neumeyer, June 14 2012
[11] "NSTX Upgrade TF Inner Leg Torsional Shear, Including Input to the DCPS" NSTXU-CALC-132-07-01 Rev 1 November 6 2015 P Titus, Checked by R. Wooley
[12] "OH Stress and Segmented OH Influence Coefficients for the DCPS" August 2013 P. Titus, Reviewed by S. Gerhardt, Ali Zolfaghari, R. Wooley, Ron Hatcher

It is usual practice to utilize influence coefficient calculations to determine hoop and axial (vertical for tokamak's) loads from coil currents. However the centroid of the Lorentz loads may not be at the geometric center of the coils. Where there is significant offset between the Lorentz centroid and the geometric center, there will be a moment about the coil geometric center in addition to the net loads. This may be a significant contributor to the support reaction loads and to the stresses in the coils themselves. In design and analysis of coil systems, distributions of fields and forces are typically calculated for a useful structural/magnetic mesh which is typically fine enough to properly distribute the Lorentz forces and resolve any moments about the coil current centers. When influence coefficients are used in operating tokamaks to check coil stresses and support loading the effect of moments has been omitted. To the author's knowledge, this is true of Alcator C-

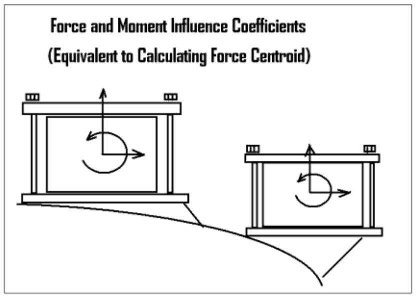
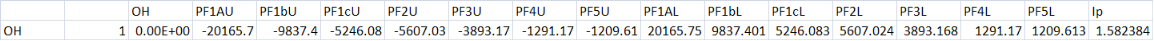


Figure 1 Moments at Current Centers.

Mod, TFTR and NSTX . Addition of the moment coefficients completes the three degrees of freedom available from the axisymmetric analysis of ring coils. For NSTX the effect of the moment coefficients is small for the compact ring coils but is interesting for the thin solenoids - the OH and PF1a,b,and c. Two plasma shapes have been investigated a rectangular cross section and a shaped plasma.

Excerpt from the Shaped Plasma Moment Influence Coecfficients



		OH	PF1AU	PF1bU	PF1cU	PF2U	PF3U	PF4U	PF5U	PF1AL	PF1bL	PF1cL	PF2L	PF3L	PF4L	PF5L	Ip
OH	1	0.00E+00	-20165.7	-9837.4	-5246.08	-5607.03	-3893.17	-1291.17	-1209.61	20165.75	9837.401	5246.083	5607.024	3893.168	1291.17	1209.613	1.582384

The largest moment influence factors are for moments on the OH from PF1aU and L currents as might be expected from the coil geometries. The effect on the outer ring coils is minimal. The results of this calculation were compared with R. Hatchers results for the 2009 coil builds and with R. Woolley's calculations for the 2011 coil builds. The comparison with Wooley's moment coefficients show results typically within 2 to 5 % with two outliers at 8% and large difference ratios when the two analyses are both calculating essentially zero factors.

Digital Coil Protection System (DCPS)

Calculations with DCPS section already included

Torus Systems

- Global Model – Description, Mesh Generation, and Results
- Seismic Analysis

Vacuum Vessel/Supports

- Disruption Analysis of VV & Passive Plates
- PF2 and PF3 Bolting, Bracket, and Weld Stress
- PF4 and PF5 Support Analysis
- Aluminum Block Analysis
- Umbrella Reinforcement Details
- Lid and Spoke Assembly, Upper and Lower
- Pedestal Analysis

General

- DCPS Moment Influence Matrix

Toroidal Field Coils

- Analysis of TF Outer Leg
- Maximum TF Torsional Shear
- TF Flag Key
- Analysis of Knuckle Clevis

Center Stack

- Center Stack Casing Disruption Inductive and Halo Current Loads
- OH Stress Analysis
- OH Fatigue and Fracture Mechanics

- OH and PF1 Electromagnetic Stability Analysis
- Model Analysis and Normal Operation Transient Load Effects

Calculations missing DCPS section

Plasma Facing Components

- First Wall Heat Balance NO
- First Wall Final Tile Stress Analysis (ATJ Tiles) YES Art brooks - maybe upper bound on PF/TF field used to qualify the tiles
- Armor NO

Vacuum Vessel/Supports

- Opera 2D Analysis No
- Redesigned Vessel Support Bracket No

General

- NSTX Force Influence Matrix Input to DCPS, [1]

Poloidal Coils Field

- Poloidal Magnetic Quantities for the May 2010 Provisional Design Input to DCPS

Toroidal Coils Field

- Out-of-Plane PF/TF Torques on TF Conductors Han Zhang YES - keyed to global torque
- TF Coupled Thermo Electromagnetic Diffusion Analysis YES maybe just temp limit
- TF Flex Joint and TF Bundle Stub YES Tom Willard TF current limit PF field limit
- TF Cool Down Using FCOOL YES -Ali Zolfaghari - Maybe just temp limit
- Ring Bolted Joint YES Pete Rogoff - Han Zhang gave him the loads
- TF Coil Inductance NO

Center Stack

- Structural Analysis of the PF1 Coils and Supports YES Ali Zolfaghari and Len Myatt
- OH Preload System and Belleville Spring Design YES Pete Rogoff
- Halo Current Analysis of Center Stack Casing NO
- OH Coolant Hole Optimization YES Ali Zolfaghari - temp limit
- OH Coax Lead Analysis YES Mike Mardenfeld PF and TF field limits
- Center Stack Casing Bellows YES Pete Rogoff

Plasma Heating and Current Drive

- Vessel Port Re-Work for NB and Thompson Scattering Port YES Neway Atnafu
- Armor Backing Plate NO
- HHFW Antenna YES Han Zhang and Bob Ellis
- Turbo Pump Magnetic Shielding Analysis NO
- Stress Analysis of Bay L and 2nd NBI Upgrade Neway Atnafu YES Keyed to global torque
- Diagnostic Review and Database YES limit of PF and TF field

Power Systems

- Modification of TF Coil Power System PSCAD Model NO
- Modification of the OH Coil Power System PSCAD Model NO
- Current Unbalance in the Eight Parallel Branches NO
- Bus Bar Analysis YES

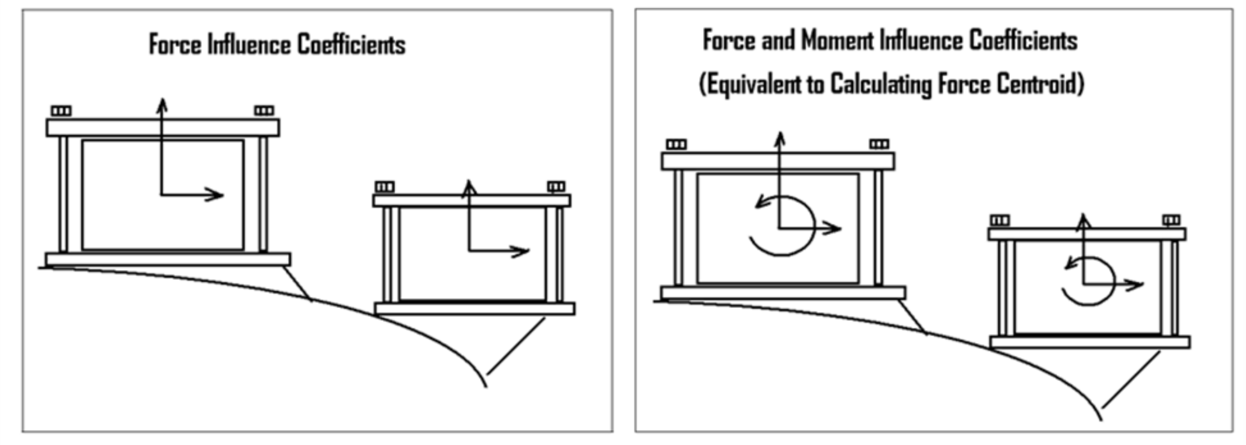
5.0 Digital Coil Protection System (DCPS) Input

The early proposal for the DCPS was described in detail in a draft requirements document by Robert Woolley ref [7]. This was subsequently simplified including elimination of certain look-aheads and measured temperature effects, being replaced with only calculated temperature effects. Force influence coefficients are included in the DCPS. Moment coefficients are also included for specific components like PF2, 3 4, and 5 clamp bolting. In the description of the DCPS, the “systems code” is the collection of algorithms 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. One examples is:

.

PF 2,3 supports, welds bolts –These were 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.

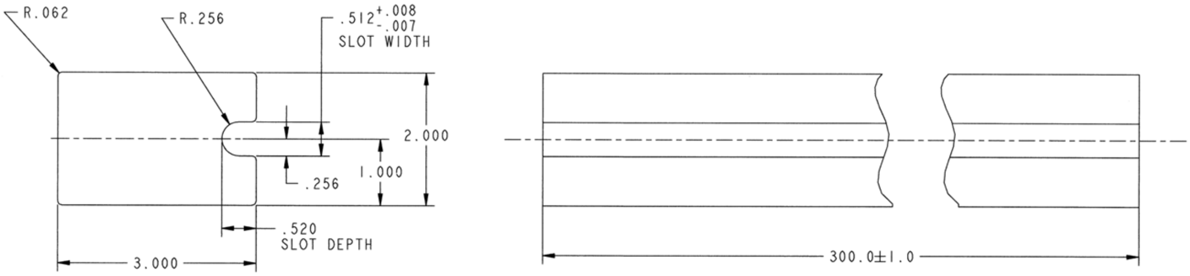
Bolt Loads are calculated from the vertical force and the moment divided by the width of the bolt pattern

6.0 Design Input

6.1 References

[1] NSTX Influence Coefficients, calculation # NSTXU 13 03-00, Ron Hatcher DATE: July 9 2009
[2] NSTX-CALC-13-001-00 Rev 1 Global Model – Model Description, Mesh Generation, Results, Peter H. Titus December 2010
[3] NSTX Structural Design Criteria Document, NSTX_DesCrit_IZ_080103.doc I. Zatz
[4] NSTX Design Point Sep 8 2009 http://www.pppl.gov/~neumeyer/NSTX_CSU/Design_Point.html
[5] OOP PF/TF Torques on TF , R. Woolley, NSTXU CALC 132-03-00
[6] "MHD and Fusion Magnets, Field and Force Design Concepts", R.J.Thome, John Tarrh, Wiley Interscience, 1982
[7] DIGITAL COIL PROTECTION SYSTEM (DCPS) REQUIREMENTS DOCUMENT (DRAFT), NSTX-CSU-RD-DCPS for the National Spherical Torus Experiment Center Stack Upgrade, February 5, 2010 R. Woolley
[8] NSTXU-CALC-132-04-00 ANALYSIS OF TF OUTER LEG, Han Zhang, August 31, 2009
[9] NSTX Upgrade General Requirements Document, NSTX_CSU-RQMTS-GRD Revision 5, C. Neumeyer, June 14 2012
[10] “Stress Analysis of the Inner PF Coils (1a,1b &1c), Center Stack Upgrade” NSTXU CALC 133-01-2 L. Myatt and A Zolfaghari
[11] “NSTX Upgrade TF Inner Leg Torsional Shear, Including Input to the DCPS” NSTXU-CALC-132-07-01 Rev 1 November 6 2015 P Titus, Checked by R. Wooley
[12] “OH Stress and Segmented OH Influence Coefficients for the DCPS” August 2013 P. Titus, Reviewed by S. Gerhardt, Ali Zolfaghari, R. Wooley, Ron Hatcher
[13] NSTX-PLAN-12-207 NSTX-U Structural Benchmark Instrumentation, December 2016, P. Titus

6.2 Drawing Excerpts

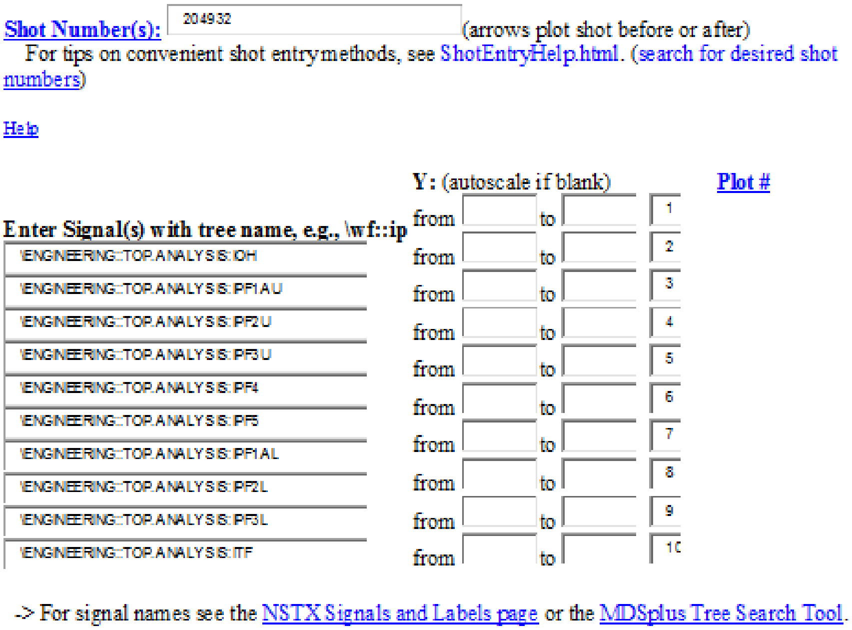


TF Outer Leg Cross Section

6.3 Input Currents

The DCPS and this evaluation is intended to address the acceptability of any set of currents. These can be the 96 equilibria specified in the design point spreadsheet [4] or actual shot currents. Stefan Gerhardt has run a number of algorithms through the 96 equilibria and the magnitude and character of the resulting response plots can be readily compared with implementation of what should be the same algorithms in the true basic code used in this calculation to produce results plots. These comparisons are included in section 8.0

In addition, actual shot currents can be extracted from early run periods in NSTX-U and these can be compared with actual DCPS output that is logged in the MDS+ data.

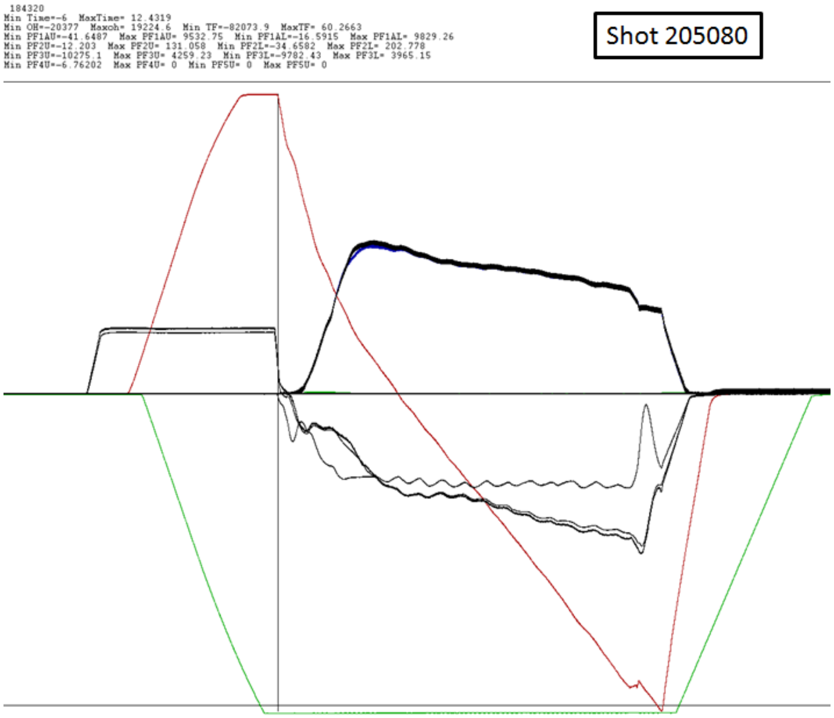


Shot Number(s): 204932 (arrows plot shot before or after)
For tips on convenient shot entrymethods, see ShotEntryHelp.html. (search for desired shot numbers)

Help

Enter Signal(s) with tree name, e.g., \wf::ip	Y: (autoscale if blank)			Plot #
\ENGINEERING::TOP.ANALYSIS:IOH	from	to		1
\ENGINEERING::TOP.ANALYSIS:IPF1AU	from	to		2
\ENGINEERING::TOP.ANALYSIS:IPF2U	from	to		3
\ENGINEERING::TOP.ANALYSIS:IPF3U	from	to		4
\ENGINEERING::TOP.ANALYSIS:IPF4	from	to		5
\ENGINEERING::TOP.ANALYSIS:IPF5	from	to		6
\ENGINEERING::TOP.ANALYSIS:IPF1AL	from	to		7
\ENGINEERING::TOP.ANALYSIS:IPF2L	from	to		8
\ENGINEERING::TOP.ANALYSIS:IPF3L	from	to		9
\ENGINEERING::TOP.ANALYSIS:ITF	from	to		10

-> For signal names see the NSTX Signals and Labels page or the MDSplus Tree Search Tool.



```
 184320
Min Time=-6  MaxTime= 12.4319
Min OH=-20377  Maxoh= 19224.6  Min TF=-82073.9  MaxTF= 60.2663
Min PF1AU=-41.6487  Max PF1AU= 9532.75  Min PF1AL=-16.5915  Max PF1AL= 9829.26
Min PF2U=-12.203  Max PF2U= 131.058  Min PF2L=-34.6582  Max PF2L= 202.778
Min PF3U=-10275.1  Max PF3U= 4259.23  Min PF3L=-9782.43  Max PF3L= 3965.15
Min PF4U=-6.76202  Max PF4U= 0  Min PF5U= 0  Max PF5U= 0
```

7.0 Analysis Codes

7.1 NTFTM

Mesh generation , calculation of the Lorentz forces, and generation of the influence coefficients is done using a code written by the author of this report. The influence coefficient subroutine is included as appendix A The mesh generation feature of the code is checked visually and within ANSYS during the PREP7 geometry check. . The authors code uses elliptic integrals for 2D field calculations, and Biot Savart solution for 3D field calculations. These are based 2D formulations, and single stick field calculations from Dick Thomes book [8] with some help from Pillsbury's FIELD3D code to catch all the coincident current vectors, and other singularities.

The code in various forms has been used for 20 years and is suitable for structural calculations. It is also being used for calculation of load files in an NSTX global model[8]. Recent checks include NSTX out-of-plane load comparisons with ANSYS [9] and MAXWELL and calculations of trim coil fields for W7X compared with Neil Pomphrey's calculations. The analysts in the first ITER EDA went through an exercise to compare loads calculated by the US (using this code), RF and by Cees Jong in ANSYS, and agreements were good. Some information on the code, named FTM (Win98) and NTFTM2 (NT,XP), is available at: http://198.125.178.188/ftm/manual.pdf). or, within PPPL: at P:\public\Snap-srv\Titus\NTFTM

Axisymmetric Analysis Model

Computation of influence coefficients is done by computing contributions of fields and forces in one element group with respect to other element groups. The element groups are identified by real constant numbers for the elements in the group. This allows coils or sections of coils to be considered in the matrix calculation. For this calculation, the element designations used by Ron Hatcher's calculation [1] have been used to allow a comparison with the force influence coefficients. Moment coefficients require the computation of the force contributions with a running summation of forces multiplied by the element force times the appropriate radial or axial lever arm with respect to the element group centroid. So computation of the moment influence coefficients also produces the force influence coefficients.

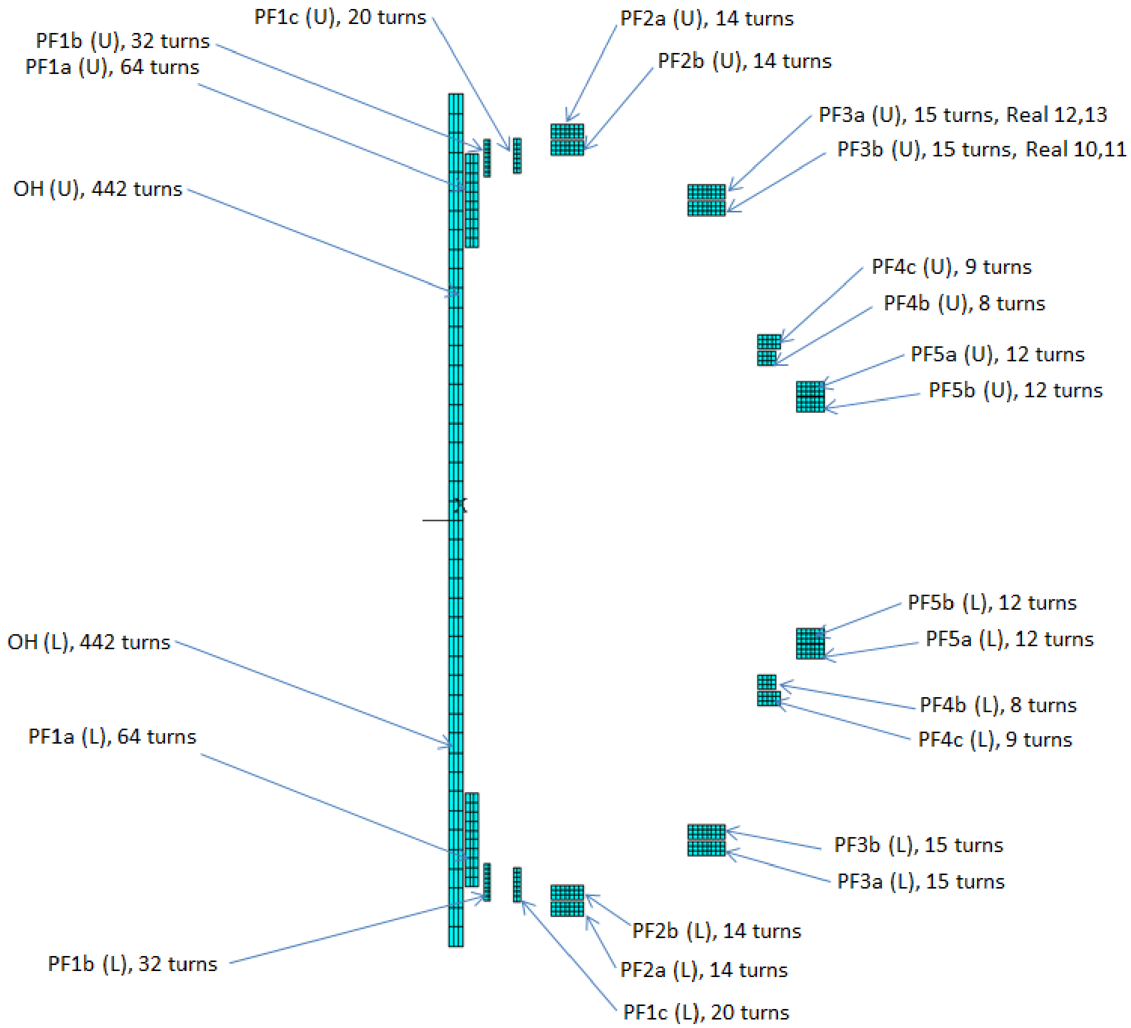
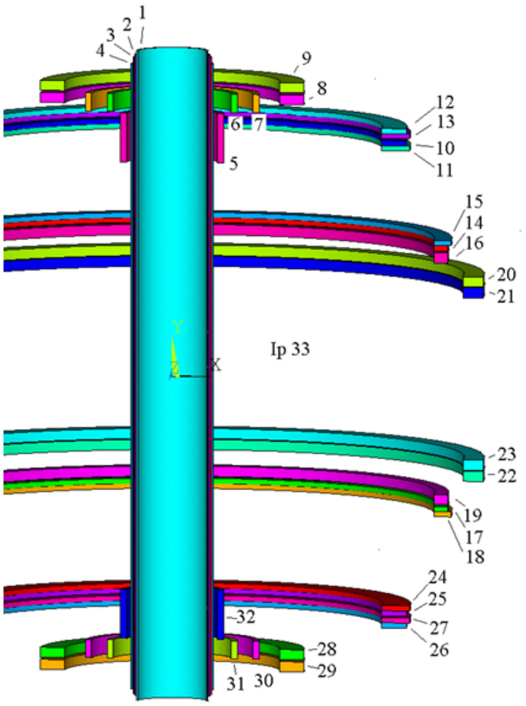
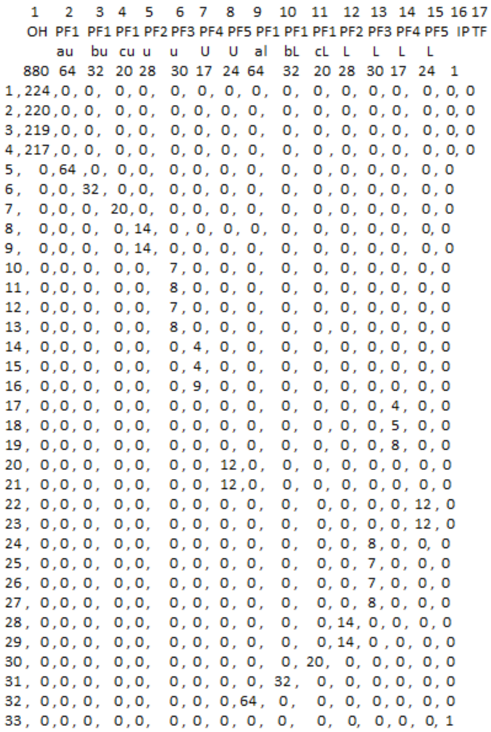


Figure 2 Axisymmetric Models



PF Coil Real Constants



```
   1    2    3   4   5    6   7   8   9   10  11   12  13  14  15 16 17
   OH  PF1  PF1 PF1 PF2 PF3 PF4 PF5 PF1 PF1 PF1 PF2 PF3 PF4 PF5  IP TF
        au   bu  cu  u   u    U   U  al  bL  cL  L    L   L   L
   880  64  32  20 28   30 17  24 64   32   20 28  30 17  24   1
1 ,224 ,0 , 0 ,  0 , 0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 , 0 ,  0 , 0, 0
2 ,220 ,0 , 0 ,  0 , 0 ,  0 , 0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 , 0 ,  0 , 0, 0
3 ,219 ,0 , 0 ,  0 , 0 ,  0 , 0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 , 0 ,  0 , 0, 0
4 ,217 ,0 , 0 ,  0 , 0 ,  0 , 0 ,  0 ,  0 ,  0 ,  0 , 0 ,  0 , 0 ,  0 , 0, 0
5 ,   0 ,64 ,0 ,  0 , 0 ,  0 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 ,  0 , 0
6 ,   0 , 0 , 32 ,  0 , 0 ,  0 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 ,  0 , 0
7 ,   0 , 0 , 0 ,  20 , 0 ,  0 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 ,  0 , 0
8 ,   0 , 0 , 0 ,  0 , 14 ,  0 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 ,  0, 0
9 ,   0 , 0 , 0 ,  0 , 14 ,  0 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 ,  0 , 0
10 ,  0 , 0 , 0 ,  0 , 0 ,   7 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 , 0 , 0
11 ,  0 , 0 , 0 ,  0 , 0 ,   8 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 , 0 , 0
12 ,  0 , 0 , 0 ,  0 , 0 ,   7 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 , 0 , 0
13 ,  0 , 0 , 0 ,  0 , 0 ,   8 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 , 0 , 0
14 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 4 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 , 0 , 0
15 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 4 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 , 0 , 0
16 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 9 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 0 , 0 , 0
17 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 4 , 0 , 0
18 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 5 , 0 , 0
19 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,  0 , 0 , 0 , 8 , 0 , 0
20 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  12 , 0 ,  0 ,  0 ,  0 , 0 , 0 , 0 , 0
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22 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,   0 , 0 , 0 , 0 , 12 , 0
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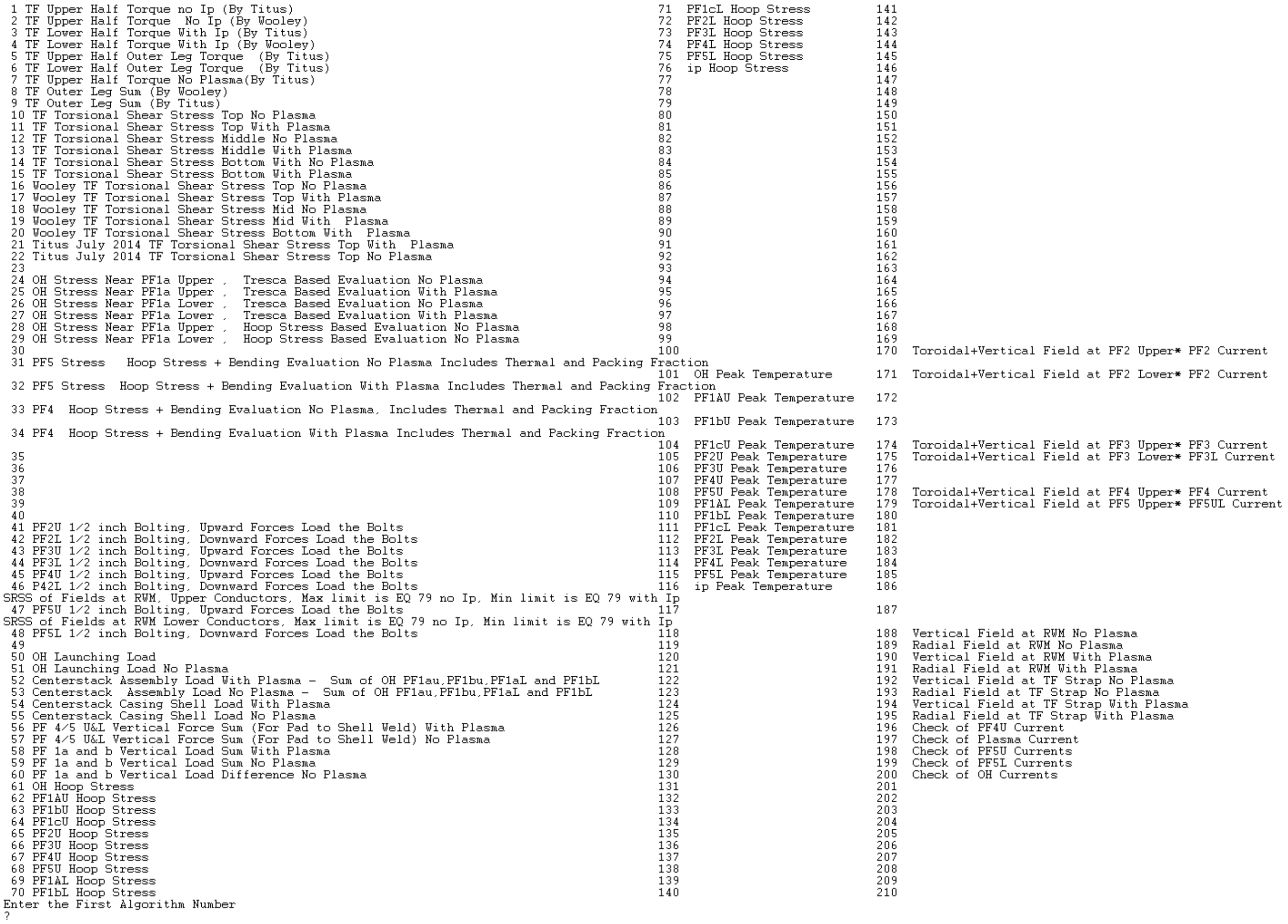
25 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,   0 , 0 , 7 , 0 , 0 , 0
26 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,   0 , 0 , 7 , 0 , 0 , 0
27 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,   0 , 0 , 8 , 0 , 0 , 0
28 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,   0 , 14 , 0 , 0 , 0 , 0
29 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,   0 , 14 , 0 , 0 , 0 , 0
30 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 , 20 ,  0 , 0 , 0 , 0 , 0
31 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 , 32 ,  0 ,  0 , 0 , 0 , 0 , 0
32 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 , 64 ,  0 ,  0 ,  0 , 0 , 0 , 0 , 0
33 ,  0 , 0 , 0 ,  0 , 0 ,   0 , 0 ,  0 ,  0 ,  0 ,   0 ,  0 , 0 , 0 , 0, 1
```

Input Geometries

Results

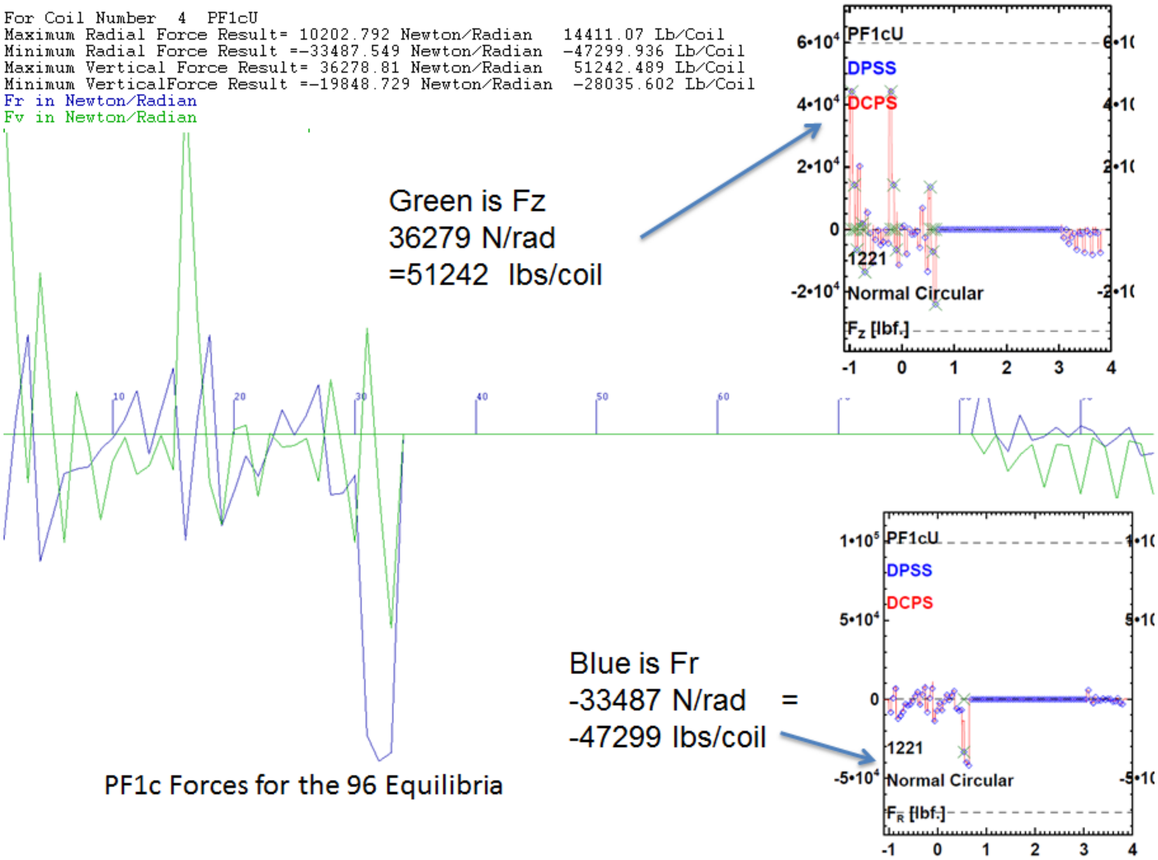
7.2 True Basic Algorithm Code TBDCPS



```
 1 TF Upper Half Torque no Ip (By Titus)                                                  71  PF1cL Hoop Stress         141
 2 TF Upper Half Torque  No Ip (By Wooley)                                                72  PF2L Hoop Stress          142
 3 TF Lower Half Torque With Ip (By Titus)                                                73  PF3L Hoop Stress          143
 4 TF Lower Half Torque With Ip (By Wooley)                                               74  PF4L Hoop Stress          144
 5 TF Upper Half Outer Leg Torque  (By Titus)                                             75  PF5L Hoop Stress          145
 6 TF Lower Half Outer Leg Torque  (By Titus)                                             76  ip Hoop Stress            146
 7 TF Upper Half Torque No Plasma(By Titus)                                               77                            147
 8 TF Outer Leg Sum (By Wooley)                                                           78                            148
 9 TF Outer Leg Sum (By Titus)                                                            79                            149
 10 TF Torsional Shear Stress Top No Plasma                                               80                            150
 11 TF Torsional Shear Stress Top With Plasma                                             81                            151
 12 TF Torsional Shear Stress Middle No Plasma                                            82                            152
 13 TF Torsional Shear Stress Middle With Plasma                                          83                            153
 14 TF Torsional Shear Stress Bottom With No Plasma                                       84                            154
 15 TF Torsional Shear Stress Bottom With Plasma                                          85                            155
 16 Wooley TF Torsional Shear Stress Top No Plasma                                        86                            156
 17 Wooley TF Torsional Shear Stress Top With Plasma                                      87                            157
 18 Wooley TF Torsional Shear Stress Mid No Plasma                                        88                            158
 19 Wooley TF Torsional Shear Stress Mid With  Plasma                                     89                            159
 20 Wooley TF Torsional Shear Stress Bottom With  Plasma                                  90                            160
 21 Titus July 2014 TF Torsional Shear Stress Top With  Plasma                            91                            161
 22 Titus July 2014 TF Torsional Shear Stress Top No Plasma                               92                            162
 23                                                                                       93                            163
 24 OH Stress Near PF1a Upper ,  Tresca Based Evaluation No Plasma                        94                            164
 25 OH Stress Near PF1a Upper ,  Tresca Based Evaluation With Plasma                      95                            165
 26 OH Stress Near PF1a Lower ,  Tresca Based Evaluation No Plasma                        96                            166
 27 OH Stress Near PF1a Lower ,  Tresca Based Evaluation With Plasma                      97                            167
 28 OH Stress Near PF1a Upper ,  Hoop Stress Based Evaluation No Plasma                   98                            168
 29 OH Stress Near PF1a Lower ,  Hoop Stress Based Evaluation No Plasma                   99                            169
 30                                                                                       100                           170  Toroidal+Vertical Field at PF2 Upper* PF2 Current
 31 PF5 Stress   Hoop Stress + Bending Evaluation No Plasma Includes Thermal and Packing Fraction
                                                                                          101  OH Peak Temperature      171  Toroidal+Vertical Field at PF2 Lower* PF2 Current
 32 PF5 Stress  Hoop Stress + Bending Evaluation With Plasma Includes Thermal and Packing Fraction
                                                                                          102  PF1AU Peak Temperature   172
 33 PF4  Hoop Stress + Bending Evaluation No Plasma, Includes Thermal and Packing Fraction
                                                                                          103  PF1bU Peak Temperature   173
 34 PF4  Hoop Stress + Bending Evaluation With Plasma Includes Thermal and Packing Fraction
                                                                                          104  PF1cU Peak Temperature   174  Toroidal+Vertical Field at PF3 Upper* PF3 Current
 35                                                                                       105  PF2U Peak Temperature    175  Toroidal+Vertical Field at PF3 Lower* PF3L Current
 36                                                                                       106  PF3U Peak Temperature    176
 37                                                                                       107  PF4U Peak Temperature    177
 38                                                                                       108  PF5U Peak Temperature    178  Toroidal+Vertical Field at PF4 Upper* PF4 Current
 39                                                                                       109  PF1AL Peak Temperature   179  Toroidal+Vertical Field at PF5 Upper* PF5UL Current
 40                                                                                       110  PF1bL Peak Temperature   180
 41 PF2U 1/2 inch Bolting, Upward Forces Load the Bolts                                   111  PF1cL Peak Temperature   181
 42 PF2L 1/2 inch Bolting, Downward Forces Load the Bolts                                 112  PF2L Peak Temperature    182
 43 PF3U 1/2 inch Bolting, Upward Forces Load the Bolts                                   113  PF3L Peak Temperature    183
 44 PF3L 1/2 inch Bolting, Downward Forces Load the Bolts                                 114  PF4L Peak Temperature    184
 45 PF4U 1/2 inch Bolting, Upward Forces Load the Bolts                                   115  PF5L Peak Temperature    185
 46 P42L 1/2 inch Bolting, Downward Forces Load the Bolts                                 116  ip Peak Temperature      186
SRSS of Fields at RWM, Upper Conductors, Max limit is EQ 79 no Ip, Min limit is EQ 79 with Ip
 47 PF5U 1/2 inch Bolting, Upward Forces Load the Bolts                                   117                           187
SRSS of Fields at RWM Lower Conductors, Max limit is EQ 79 no Ip, Min limit is EQ 79 with Ip
 48 PF5L 1/2 inch Bolting, Downward Forces Load the Bolts                                 118                           188  Vertical Field at RWM No Plasma
 49                                                                                       119                           189  Radial Field at RWM No Plasma
 50 OH Launching Load                                                                     120                           190  Vertical Field at RWM With Plasma
 51 OH Launching Load No Plasma                                                           121                           191  Radial Field at RWM With Plasma
 52 Centerstack Assembly Load With Plasma -  Sum of OH PF1au,PF1bu,PF1aL and PF1bL        122                           192  Vertical Field at TF Strap No Plasma
 53 Centerstack  Assembly Load No Plasma -  Sum of OH PF1au,PF1bu,PF1aL and PF1bL         123                           193  Radial Field at TF Strap No Plasma
 54 Centerstack Casing Shell Load With Plasma                                             124                           194  Vertical Field at TF Strap With Plasma
 55 Centerstack Casing Shell Load No Plasma                                               125                           195  Radial Field at TF Strap With Plasma
 56 PF 4/5 U&L Vertical Force Sum (For Pad to Shell Weld) With Plasma                     126                           196  Check of PF4U Current
 57 PF 4/5 U&L Vertical Force Sum (For Pad to Shell Weld) No Plasma                       127                           197  Check of Plasma Current
 58 PF 1a and b Vertical Load Sum With Plasma                                             128                           198  Check of PF5U Currents
 59 PF 1a and b Vertical Load Sum No Plasma                                               129                           199  Check of PF5L Currents
 60 PF 1a and b Vertical Load Difference No Plasma                                        130                           200  Check of OH Currents
 61 OH Hoop Stress                                                                        131                           201
 62 PF1AU Hoop Stress                                                                     132                           202
 63 PF1bU Hoop Stress                                                                     133                           203
 64 PF1cU Hoop Stress                                                                     134                           204
 65 PF2U Hoop Stress                                                                      135                           205
 66 PF3U Hoop Stress                                                                      136                           206
 67 PF4U Hoop Stress                                                                      137                           207
 68 PF5U Hoop Stress                                                                      138                           208
 69 PF1AL Hoop Stress                                                                     139                           209
 70 PF1bL Hoop Stress                                                                     140                           210
Enter the First Algorithm Number
?
```

8.0 DCPS Coding Test Cases

8.1 PF1c Upper Forces for the 96 Equilibria



```
For Coil Number  4  PF1cU
Maximum Radial Force Result= 10202.792 Newton/Radian   14411.07 Lb/Coil
Minimum Radial Force Result =-33487.549 Newton/Radian  -47299.936 Lb/Coil
Maximum Vertical Force Result= 36278.81 Newton/Radian   51242.489 Lb/Coil
Minimum VerticalForce Result =-19848.729 Newton/Radian  -28035.602 Lb/Coil
Fr in Newton/Radian
Fv in Newton/Radian
```

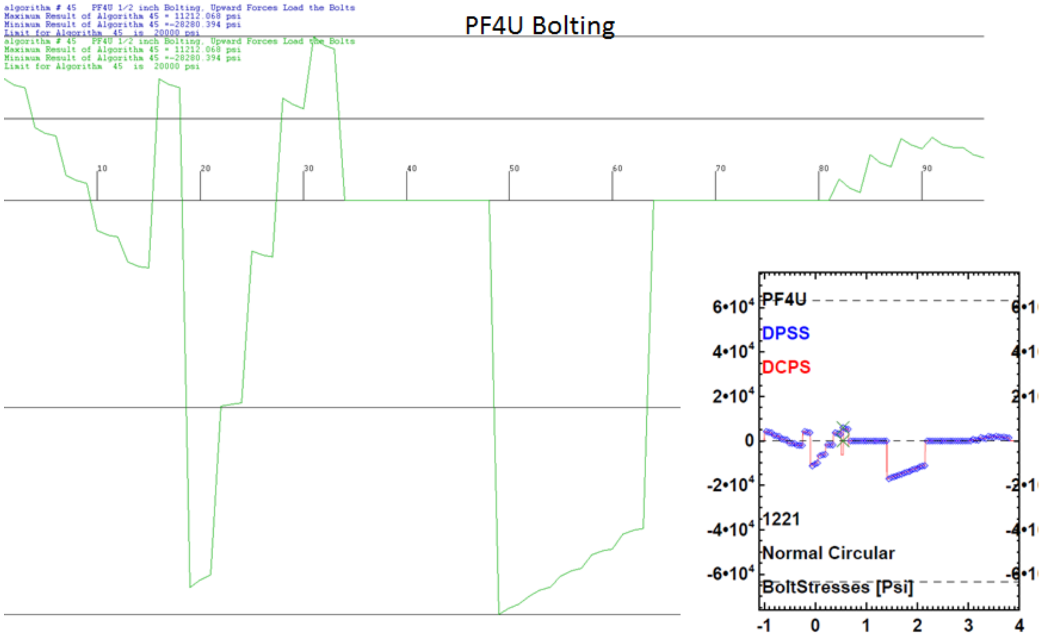
Green is Fz
36279 N/rad
=51242 lbs/coil

Blue is Fr
-33487 N/rad   =
-47299 lbs/coil

PF1c Forces for the 96 Equilibria

My (Titus) Results are in the larger plot in the middle of the figure. Stefans's results are the two smaller figures on the right. In the Titus results, the 1.1 headroom factor is applied. I am not sure if it is applied to Stefan's results. The results are qualitatively in agreement and quantitatively in agreement within the limits of reading Stefan's plots

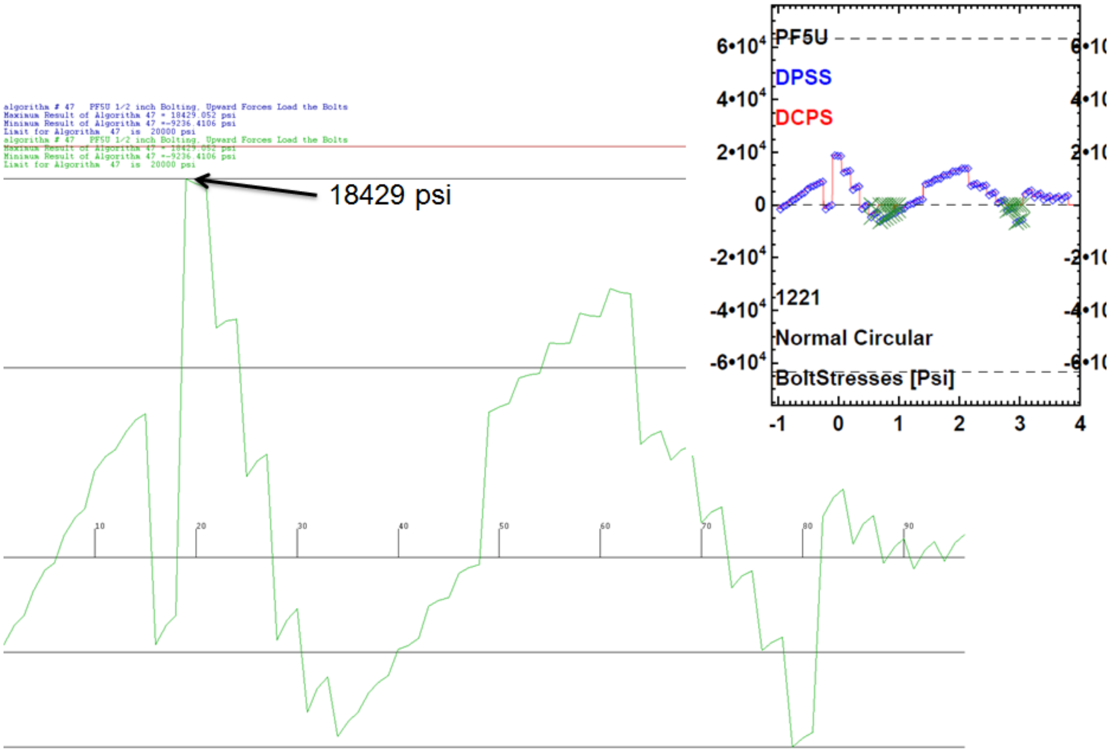
8.2 PF4Upper Bolting



PF4U Bolting

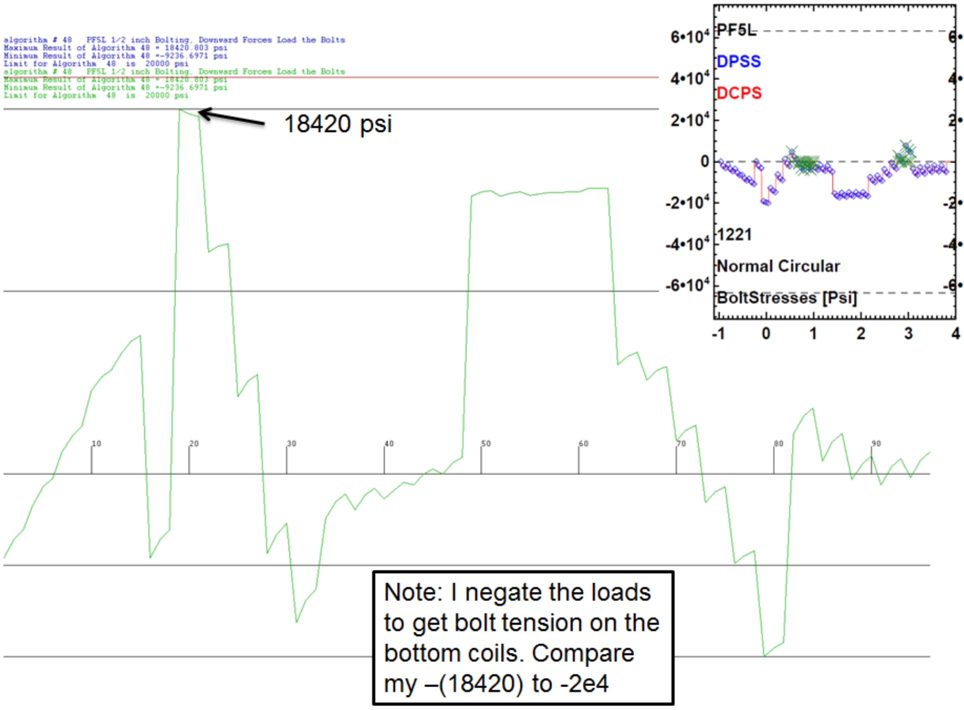
```
algorithm # 45   PF4U 1/2 inch Bolting, Upward Forces Load the Bolts
Maximum Result of Algorithm 45 = 11212.068 psi
Minimum Result of Algorithm 45 =-28280.394 psi
Limit for Algorithm  45  is  20000 psi
algorithm # 45   PF4U 1/2 inch Bolting, Upward Forces Load the Bolts
Maximum Result of Algorithm 45 = 11212.068 psi
Minimum Result of Algorithm 45 =-28280.394 psi
Limit for Algorithm  45  is  20000 psi
```

8.3 PF5U Bolting



```
algorithm # 47   PF5U 1/2 inch Bolting. Upward Forces Load the Bolts
Maximum Result of Algorithm 47 = 18429.052 psi
Minimum Result of Algorithm 47 =-9236.4106 psi
Limit for Algorithm  47  is  20000 psi
algorithm # 47   PF5U 1/2 inch Bolting. Upward Forces Load the Bolts
Maximum Result of Algorithm 47 = 18429.052 psi
Minimum Result of Algorithm 47 =-9236.4106 psi
Limit for Algorithm  47  is  20000 psi
```

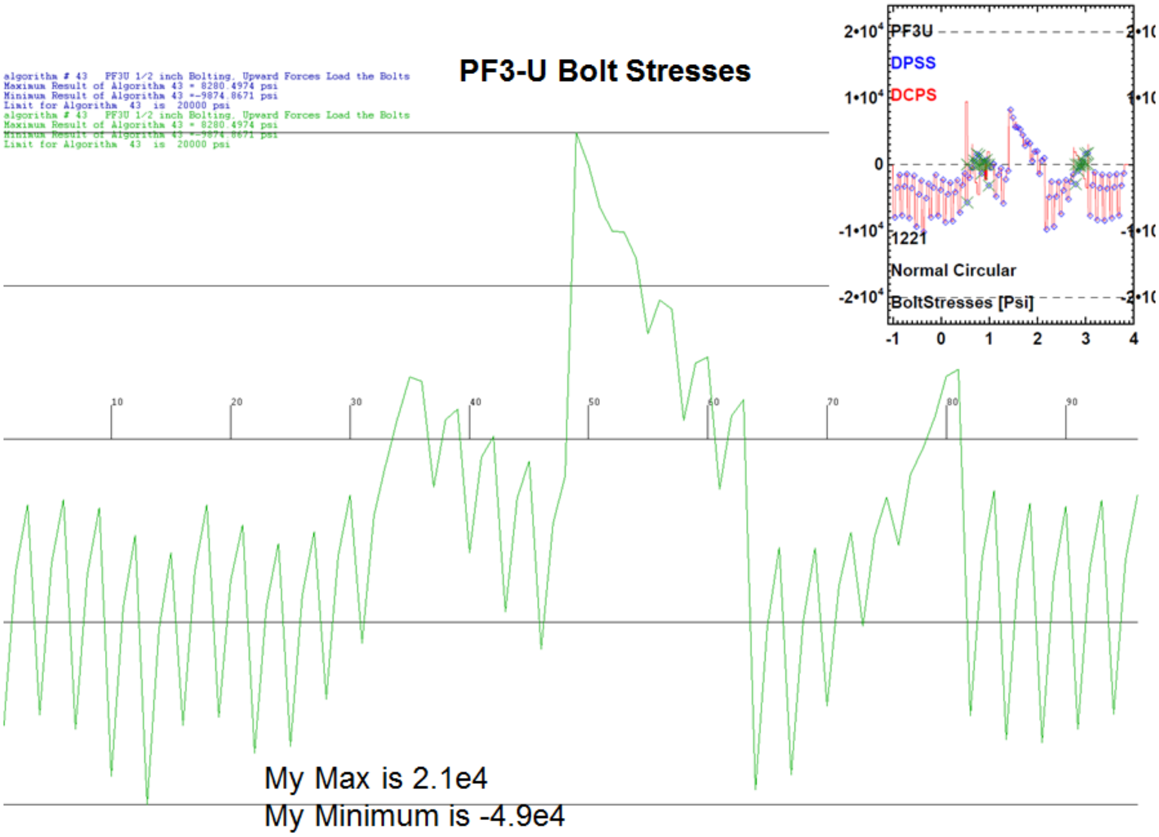
8.4 PF5L Bolting



```
algorithm # 48   PF5L 1/2 inch Bolting. Downward Forces Load the Bolts
Maximum Result of Algorithm 48 = 18420.803 psi
Minimum Result of Algorithm 48 =-9236.6971 psi
Limit for Algorithm  48  is  20000 psi
algorithm # 48   PF5L 1/2 inch Bolting. Downward Forces Load the Bolts
Maximum Result of Algorithm 48 = 18420.803 psi
Minimum Result of Algorithm 48 =-9236.6971 psi
Limit for Algorithm  48  is  20000 psi
```

Note: I negate the loads to get bolt tension on the bottom coils. Compare my –(18420) to -2e4

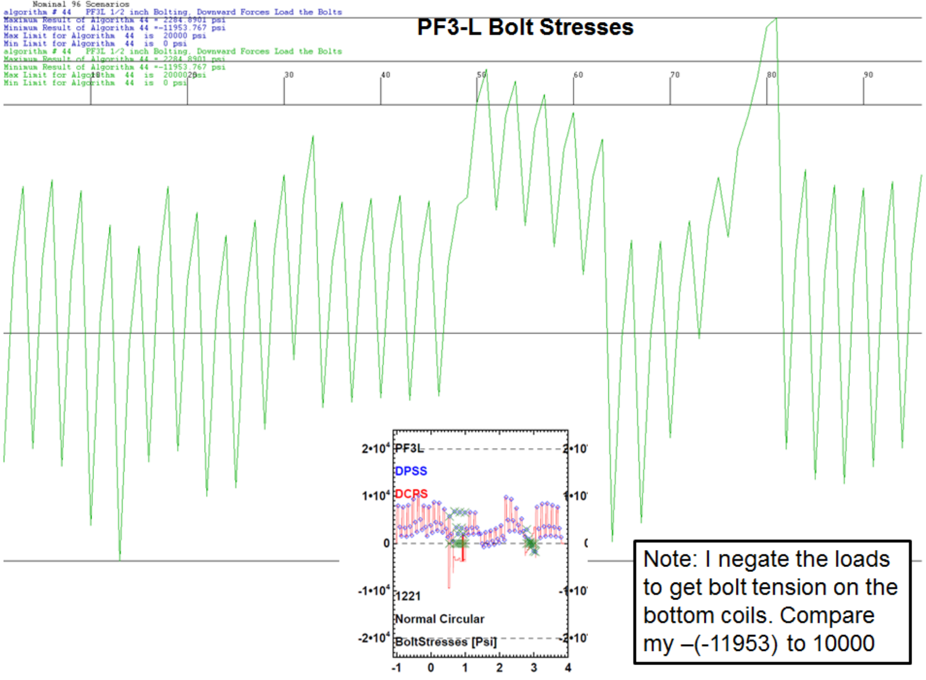
8.5 PF3U Bolting



```
algorithm # 43   PF3U 1/2 inch Bolting. Upward Forces Load the Bolts
Maximum Result of Algorithm 43 = 8280.4974 psi
Minimum Result of Algorithm 43 =-9874.8671 psi
Limit for Algorithm  43  is  20000 psi
algorithm # 43   PF3U 1/2 inch Bolting. Upward Forces Load the Bolts
Maximum Result of Algorithm 43 = 8280.4974 psi
Minimum Result of Algorithm 43 =-9874.8671 psi
Limit for Algorithm  43  is  20000 psi
```

My Max is 2.1e4
My Minimum is -4.9e4

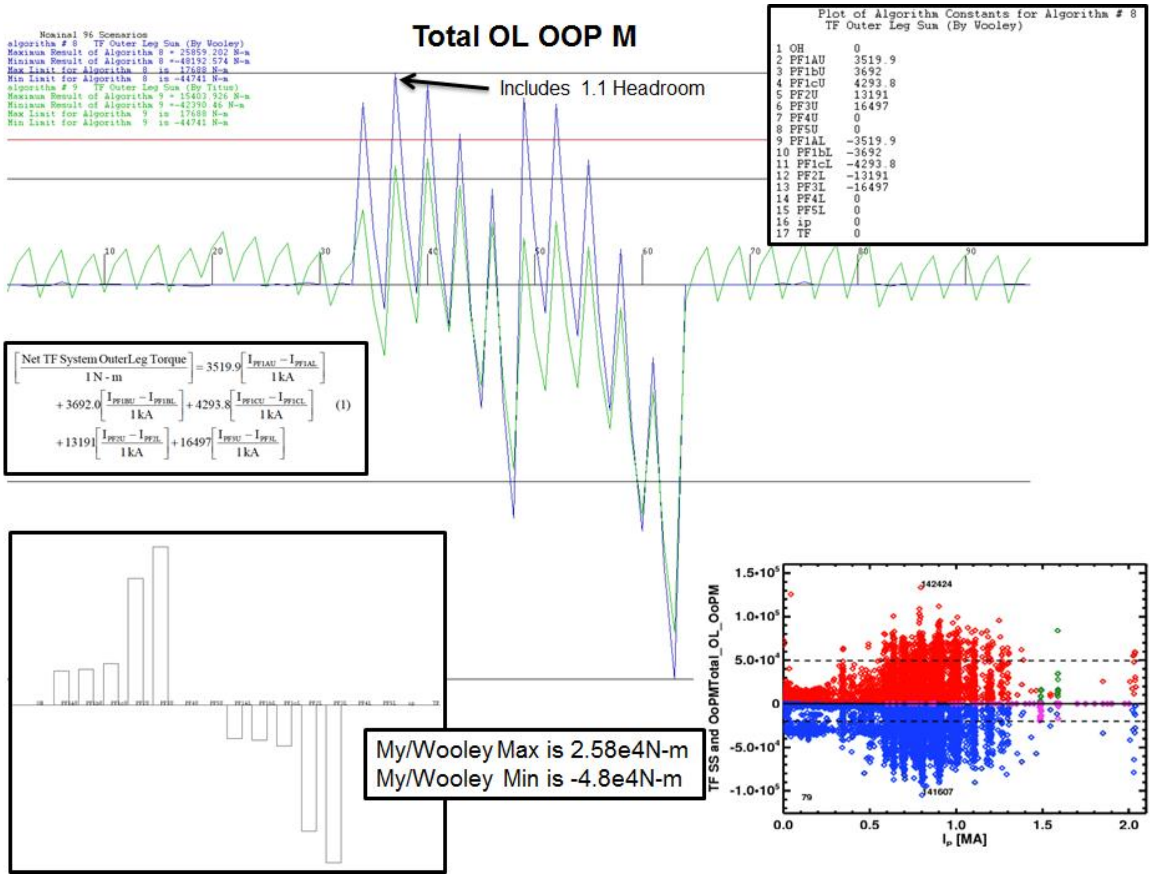
8.6 PF3L Bolting



```
      Nominal 96 Scenarios
algorithm # 44   PF3L 1/2 inch Bolting. Downward Forces Load the Bolts
Maximum Result of Algorithm 44 = 2284.8901 psi
Minimum Result of Algorithm 44 =-11953.767 psi
Max Limit for Algorithm  44  is  20000 psi
Min Limit for Algorithm  44  is  0 psi
algorithm # 44   PF3L 1/2 inch Bolting. Downward Forces Load the Bolts
Maximum Result of Algorithm 44 = 2284.8901 psi
Minimum Result of Algorithm 44 =-11953.767 psi
Max Limit for Algorithm  44  is  20000 psi
Min Limit for Algorithm  44  is  0 psi
```

Note: I negate the loads to get bolt tension on the bottom coils. Compare my –(-11953) to 10000

8.7 Total OL OOP Moment



Total OL OOP M

```
        Nominal 96 Scenarios
algorithm # 8   TF Outer Leg Sum (By Wooley)
Maximum Result of Algorithm 8 = 25859.202 N-m
Minimum Result of Algorithm 8 =-48192.574 N-m
Max Limit for Algorithm  8  is  17688 N-m
Min Limit for Algorithm  8  is -44741 N-m
algorithm # 9   TF Outer Leg Sum (By Titus)
Maximum Result of Algorithm 9 = 15403.926 N-m
Minimum Result of Algorithm 9 =-42390.46 N-m
Max Limit for Algorithm  9  is  17688 N-m
Min Limit for Algorithm  9  is -44741 N-m
```

Includes 1.1 Headroom

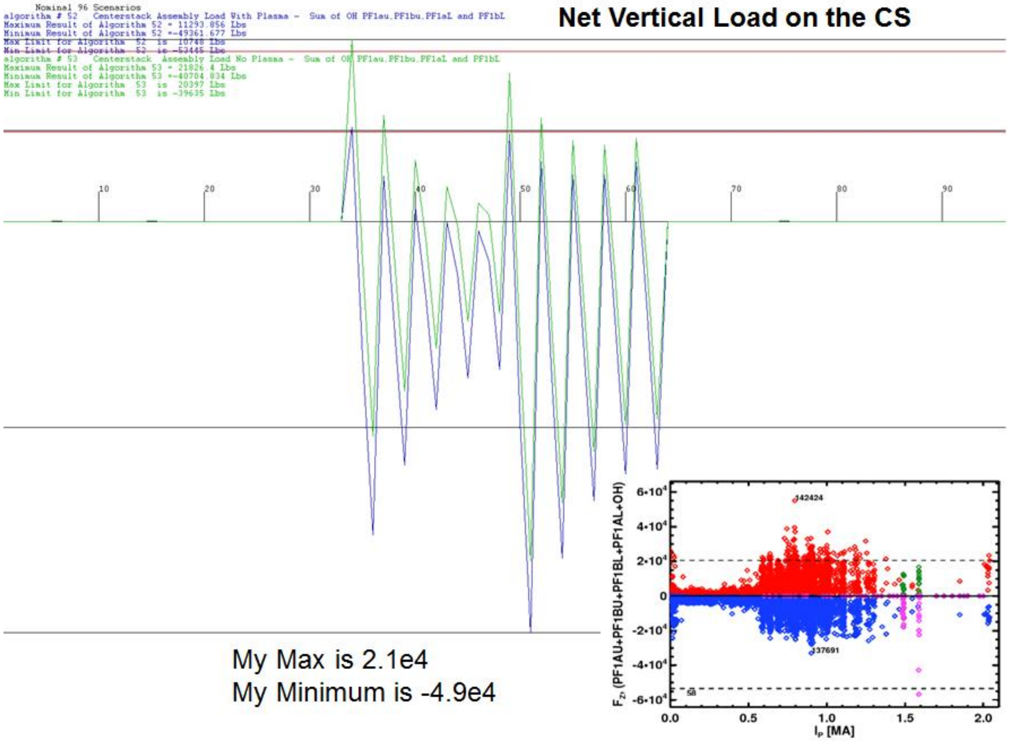
```
      Plot of Algorithm Constants for Algorithm # 8
       TF Outer Leg Sum (By Wooley)

1 OH         0
2 PF1AU      3519.9
3 PF1bU      3692
4 PF1cU      4293.8
5 PF2U       13191
6 PF3U       16497
7 PF4U       0
8 PF5U       0
9 PF1AL     -3519.9
10 PF1bL    -3692
11 PF1cL    -4293.8
12 PF2L     -13191
13 PF3L     -16497
14 PF4L      0
15 PF5L      0
16 ip        0
17 TF        0
```

$$\left[\frac{\text{Net TF System OuterLeg Torque}}{1\,\text{N-m}}\right]=3519.9\left[\frac{I_{PF1AU}-I_{PF1AL}}{1\,\text{kA}}\right]+3692.0\left[\frac{I_{PF1BU}-I_{PF1BL}}{1\,\text{kA}}\right]+4293.8\left[\frac{I_{PF1CU}-I_{PF1CL}}{1\,\text{kA}}\right]+13191\left[\frac{I_{PF2U}-I_{PF2L}}{1\,\text{kA}}\right]+16497\left[\frac{I_{PF3U}-I_{PF3L}}{1\,\text{kA}}\right] \quad (1)$$

My/Wooley Max is 2.58e4N-m
My/Wooley Min is -4.8e4N-m

8.8 Net Vertical Load on the CS



```
        Nominal 96 Scenarios
algorithm # 52   Centerstack Assembly Load With Plasma -  Sum of OH PF1au,PF1bu,PF1aL and PF1bL
Maximum Result of Algorithm 52 = 11293.856 Lbs
Minimum Result of Algorithm 52 =-49361.677 Lbs
Max Limit for Algorithm  52  is  10748 Lbs
Min Limit for Algorithm  52  is -53445 Lbs
algorithm # 53   Centerstack  Assembly Load No Plasma -  Sum of OH PF1au,PF1bu,PF1aL and PF1bL
Maximum Result of Algorithm 53 = 21826.4 Lbs
Minimum Result of Algorithm 53 =-40704.834 Lbs
Max Limit for Algorithm  53  is  20397 Lbs
Min Limit for Algorithm  53  is -39635 Lbs
```

Net Vertical Load on the CS

My Max is 2.1e4
My Minimum is -4.9e4

9.0 Coil Force Computations

9.1 Unit Current Input for Global Model

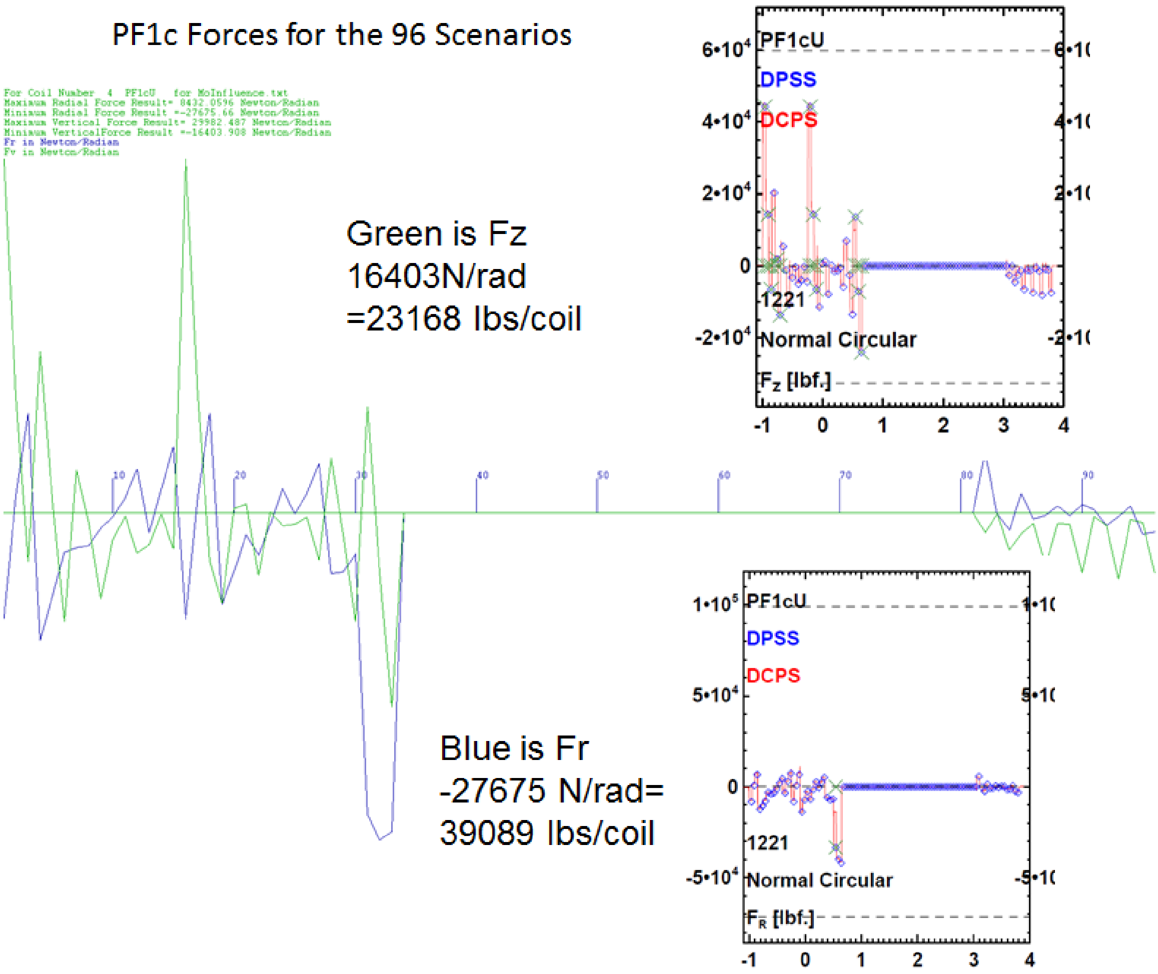
9.2 PF1c Radial and Vertical Forces

Force Influence Coefficients

Force influence coefficients are provided by Ron Hatcher

```
zero
!  Influence Coefficient Matrix
Check of Ron's Coefficients
read
ron7
divi
0,2,2,1
snal
1
merge
1,.0001
redu
    !real no.,nx , ny , nturns,
terminal current
rcoi
16
1,4,7,64,250         !PF1AU
Note that
2,2,5,32,250         !PF1bU
Current is not 1000 Amp
3,2,5,20,250         !PF1cU
But 250 Because of divi 0,2,2,1
4,4,14,28,250         !PF2U
5,3,10,30,250         !PF3U
6,1,17,17,250         !PF4U
7,4,6,24,250          !PF5U
8,4,6,24,250          !PF5L
9,1,17,17,250         !PF4L
10,3,10,30,250        !PF3L
11,4,14,28,250        !PF2L
12,2,5,20,250         !PF1cL
13,2,5,32,250         !PF1bL
14,4,7,64,250         !PF1aL
15,10,80,884,250      !OH
16,6,8,1,250          !Plasma
infl
16
copt
r
plce
pl
exit
```

PF1c Radial and Vertical Forces



PF1c Forces for the 96 Scenarios

```
For Coil Number  4  PF1cU   for MoInfluence.txt
Maximum Radial Force Result= 8432.0596 Newton/Radian
Minimum Radial Force Result =-27675.66 Newton/Radian
Maximum Vertical Force Result= 29982.487 Newton/Radian
Minimum VerticalForce Result =-16403.908 Newton/Radian
Fr in Newton/Radian
Fv in Newton/Radian
```

Green is Fz
16403N/rad
=23168 lbs/coil

Blue is Fr
-27675 N/rad=
39089 lbs/coil

Figure from a comparison with Stefan Gerhard’s implementation of the DCPS algorithms

10.0 Global Moment Sums

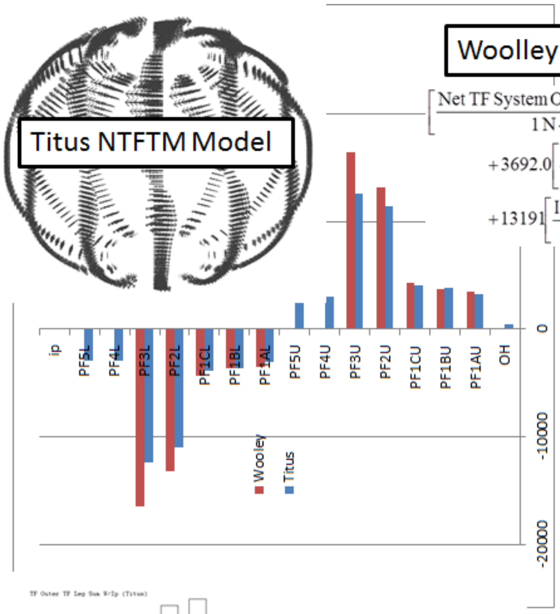
The analyses of record for these are provided by Bob Woolley. In this calculation, coefficients were derived to check Bob’s results are presented.

10.1 Upper Half Machine

10.2 Lower Half Machine

10.3 Net Outer Leg Torque

The total outer leg moment, and total upper half and total lower half moments are not ones that correlate directly to any filed calculation structural assessment.



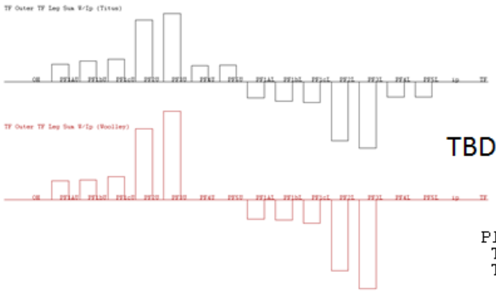
Titus NTFTM Model

Woolley Total Outer Leg Torque

$$\left[\frac{\text{Net TF System OuterLeg Torque}}{1\,\text{N-m}}\right] = 3519.9\left[\frac{I_{PF1AU} - I_{PF1AL}}{1\,\text{kA}}\right] + 3692.0\left[\frac{I_{PF1BU} - I_{PF1BL}}{1\,\text{kA}}\right] + 4293.8\left[\frac{I_{PF1CU} - I_{PF1CL}}{1\,\text{kA}}\right] + 13191\left[\frac{I_{PF2U} - I_{PF2L}}{1\,\text{kA}}\right] + 16497\left[\frac{I_{PF3U} - I_{PF3L}}{1\,\text{kA}}\right]$$

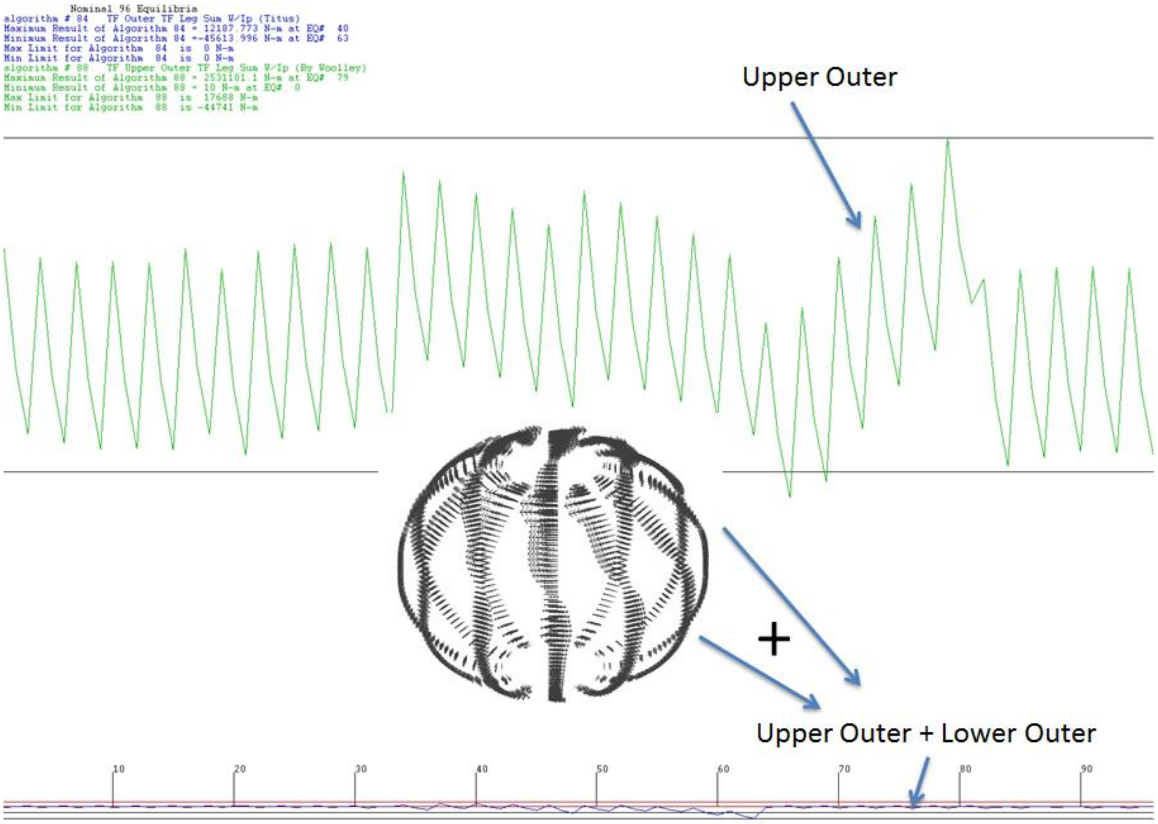
Note: To be consistent with Bob Woolley's PF4 and 5 zero coefficients, my coefficients must cancel. My IP and OH must be zero

				mx	my	mz
ts01	3.1789	119070.8	6.1093	14.0134	418904.25	27.56
ts02	-0.3904	119072.8	2.9907	2.604	3214156.5	-3.7615
ts03	-0.2504	119074.6	2.0666	-0.1401	3804323	0.4192
ts04	-0.1192	119073	3.8309	-0.8239	4118795	-0.1958
ts05	-1.6422	119072.7	-0.544	-1.4114	11449032	-1.6275
ts06	2.8188	119072.9	3.997	52.5403	12602428	-59.5076
ts07	1.5163	119072.4	1.9891	-25.4406	2973213	15.5745
ts08	7.7427	119072.4	-1.7653	-45.1223	3019350.3	4.0661
ts09	8.4465	119073.1	-3.3811	1.6016	-3068555	-1.2855
ts10	2.2689	119074.4	-1.5289	-1.9	-3630245	1.2011
ts11	-6.0004	119071.2	6.8939	-1.2549	-3931130	1.81
ts12	5.4494	119071.3	-4.4568	-3.1828	-10993174	-0.6054
ts13	-2.6436	119072	4.599	31.3316	-12361105	-71.5009
ts14	-0.7714	119073.7	-6.2398	-45.0761	-2901700	49.2506
ts15	4.4942	119075.2	6.0277	27.3054	-2910025	-22.2913
ts16	-9.2997	119071.1	-10.0801	-26.267	738048.06	1090.4331



TBDCPS Coefficient Comparison

```
Plot of Algorithm Constants for Algorithm # 84  and  85
 TF Outer TF Leg Sum W/Ip (Titus)
 TF Outer TF Leg Sum W/Ip (Woolley)
```



```
        Nominal 96 Equilibria
algorithm # 84   TF Outer TF Leg Sum W/Ip (Titus)
Maximum Result of Algorithm 84 = 12187.773 N-m at EQ#  40
Minimum Result of Algorithm 84 =-45613.996 N-m at EQ#  63
Max Limit for Algorithm  84  is  0 N-m
Min Limit for Algorithm  84  is  0 N-m
algorithm # 88   TF Upper Outer TF Leg Sum W/Ip (By Woolley)
Maximum Result of Algorithm 88 = 2531101.1 N-m at EQ#  79
Minimum Result of Algorithm 88 = 10 N-m at EQ#  0
Max Limit for Algorithm  88  is  17688 N-m
Min Limit for Algorithm  88  is -44741 N-m
```

The total outer leg moment was included in Charlie Neumeyer's spreadsheet. Early in the development of the DCPS, the limits were set based on the 96 EQ. The equilibria probably have large opposing upper and lower outer TF loading which nets to a small total torque. If you set the limit on this "canceled" torque from the 96 EQ then it is set to a non-critical value.

The upper outer and Lower Outer moment sums represent loading at the TF outer leg bending, TF trusses and aluminum blocks, also the torque carried by the vessel mid plane. The TF torsional shear is also obviously connected directly with the TF epoxy stress. If these have a comfortable margin, the criteria on the total outer leg moment, and the upper half sums and lower half sums should be relaxed. The spoked lid calculation DCPS section indicates that the spoked lid load and stress correlates with the TF torsional shear Upper Outer TF Legs

10.4 Bob Woolley's 96 EQ Max Min Upper Outer and Lower Outer TF With plasma Both at EQ 79

Upper Max: 2531101 N-m
Min: ~0 N-m
Lower Max:~0
Min: -2591595 N-m

No plasma Both at EQ 79

Upper Max: 3927760 N-m
Min: ~0 N-m
Lower Max:~0
Min: -3988254 N-m

P. Titus's 96 EQ Max Min Upper Outer and Lower Outer TF

With plasma Both at EQ 79

Upper Max: 3014979 N-m
    Min: ~0 N-m
Lower Max:~0
    Min: -2995245 N-m

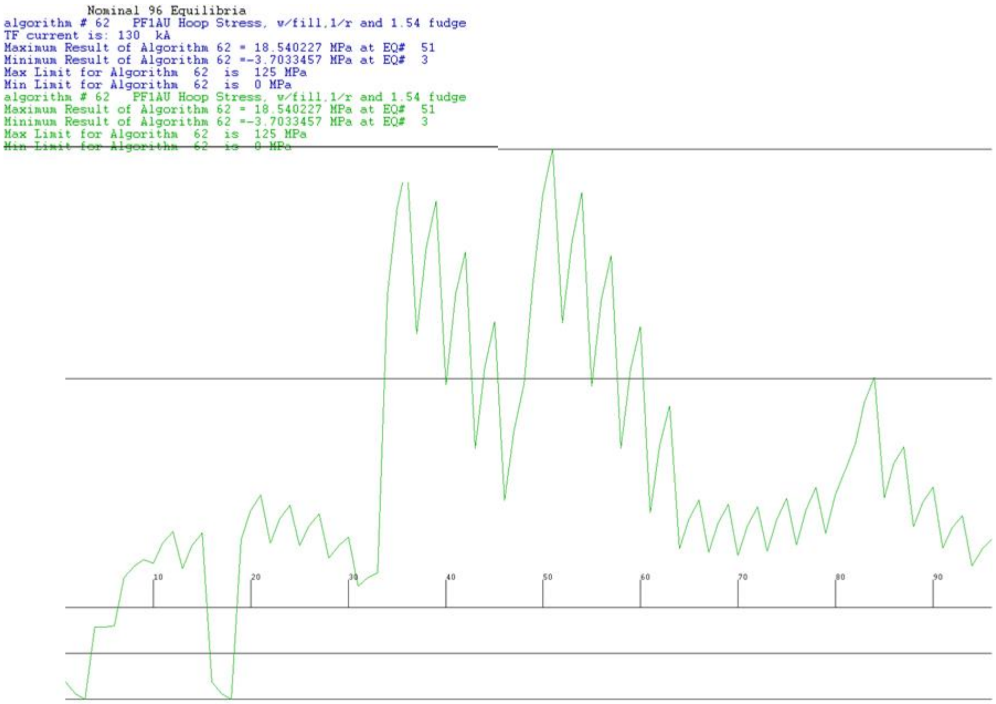
No plasma Both at EQ 79

Upper Max: 4093792.8 N-m
    Min: ~0 N-m
Lower Max:~0
    Min: -4077575 N-m

5

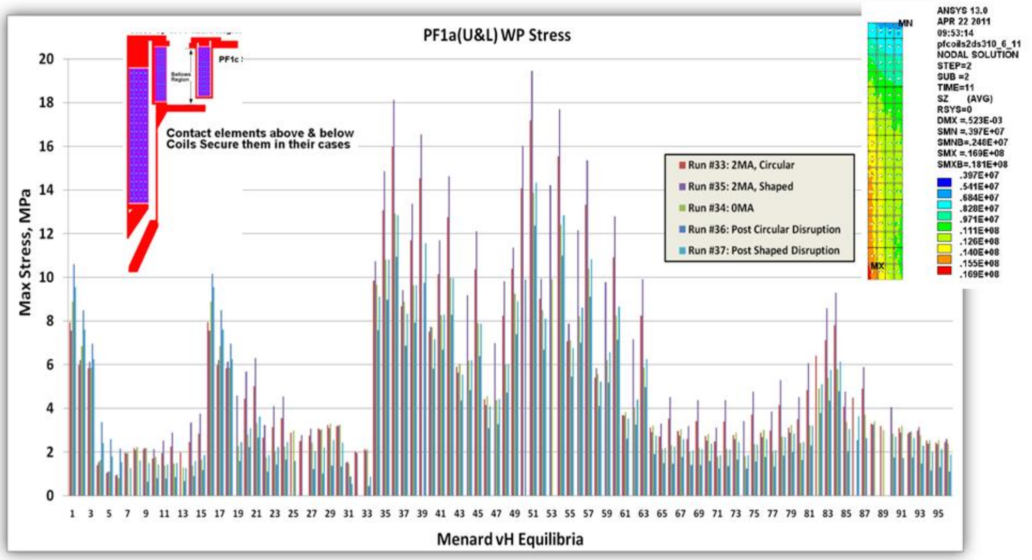
10.5 Lower Outer TF Legs

11.0 PF Hoop Stress



```
            Nominal 96 Equilibria
algorithm # 62   PF1AU Hoop Stress, w/fill,1/r and 1.54 fudge
TF current is: 130  kA
Maximum Result of Algorithm 62 = 18.540227 MPa at EQ#  51
Minimum Result of Algorithm 62 =-3.7033457 MPa at EQ#  3
Max Limit for Algorithm  62  is  125 MPa
Min Limit for Algorithm  62  is  0 MPa
algorithm # 62   PF1AU Hoop Stress, w/fill,1/r and 1.54 fudge
Maximum Result of Algorithm 62 = 18.540227 MPa at EQ#  51
Minimum Result of Algorithm 62 =-3.7033457 MPa at EQ#  3
Max Limit for Algorithm  62  is  125 MPa
Min Limit for Algorithm  62  is  0 MPa
```

Above is a result for the PF1a hoop stress from the DCPS simulator. The hoop stress is approximated with the radial load, a 1/r correction and a “fudge factor” to account for local distributions in the conductor. Below Len Myatt’s results are plotted. The results are close .

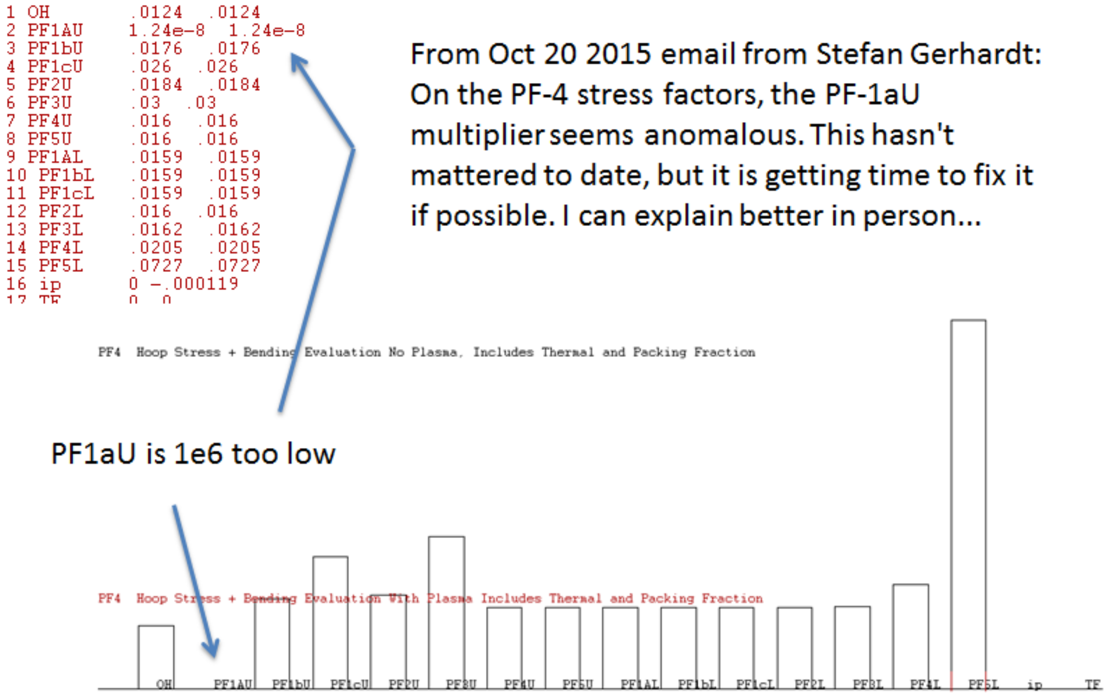


Stress Analysis of Inner PF Coils (1a, 1b & 1c),
Center Stack Upgrade
NSTXU-CALC-133-01-01, Reference [9]
October 27, 2011

NSTXU-CALC-133-01-02

Note: Biggest Winding Pac Stress is 18 Mpa with an allowable of 125 MPa

12.0 PF1aU Factor Correction



```
 1 OH        .0124   .0124
 2 PF1AU    1.24e-8  1.24e-8
 3 PF1bU     .0176   .0176
 4 PF1cU     .026   .026
 5 PF2U      .0184   .0184
 6 PF3U      .03   .03
 7 PF4U      .016   .016
 8 PF5U      .016   .016
 9 PF1AL     .0159   .0159
10 PF1bL     .0159   .0159
11 PF1cL     .0159   .0159
12 PF2L      .016   .016
13 PF3L      .0162   .0162
14 PF4L      .0205   .0205
15 PF5L      .0727   .0727
16 ip       0 -.000119
17 TF       0  0
```

From Oct 20 2015 email from Stefan Gerhardt: On the PF-4 stress factors, the PF-1aU multiplier seems anomalous. This hasn't mattered to date, but it is getting time to fix it if possible. I can explain better in person...

PF1aU is 1e6 too low

Plot of Algorithm Constants for Algorithm # 33 and 34
PF4 Hoop Stress + Bending Evaluation No Plasma, Includes Thermal and Packing Fraction

17.0 Algorithm 160,161 TF Outer Leg Stress

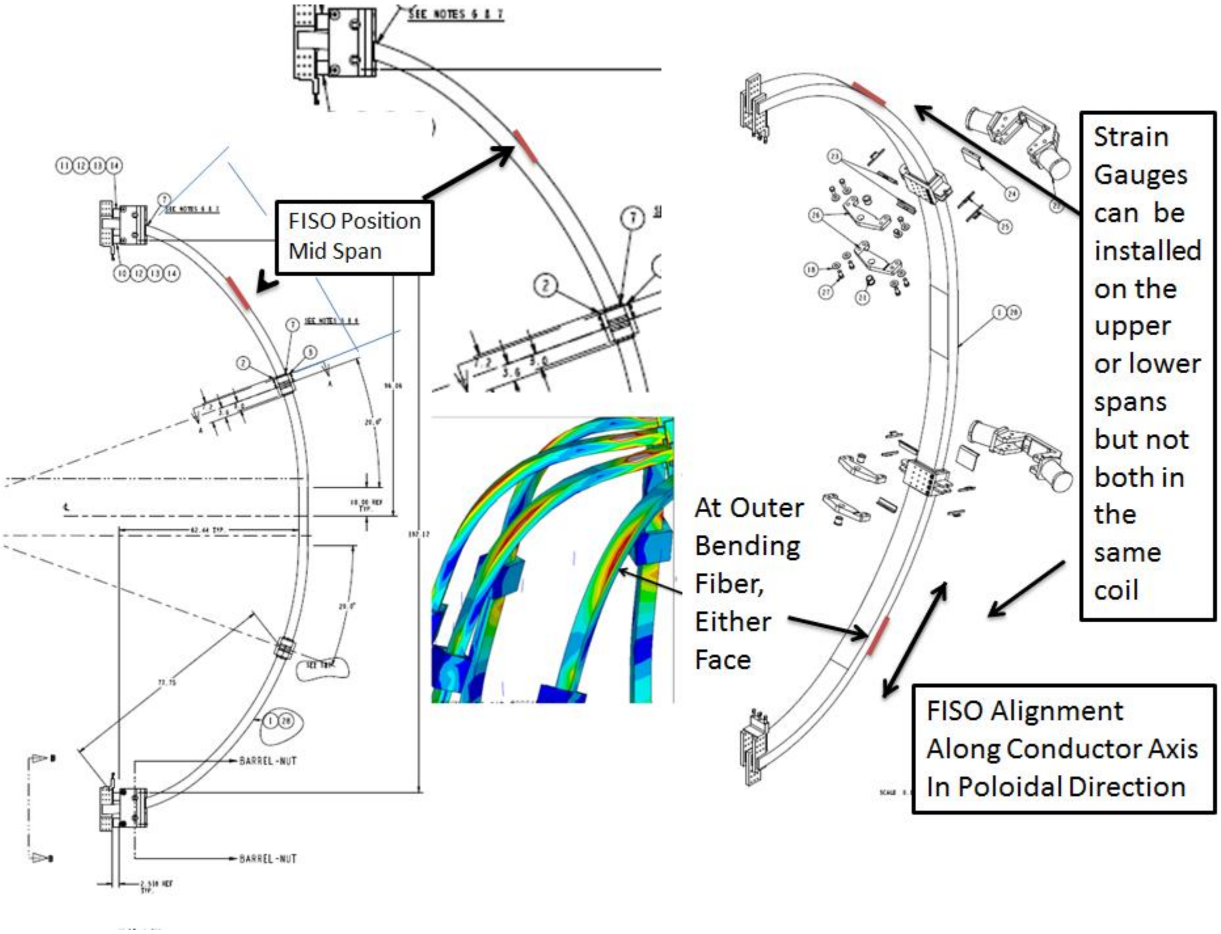


Figure 17.0-1 Installed Location of Outer Leg FISO Strain Gauges

Item	Description	Sensor Type	Range	Serial Nmbr	GageFactor
1	NE OH(BayD) Upr Pre-Load	Displacement	-390 to +390	-	8053284
2	SE OH Upr(Bay J) Pre-Load	Displacement	-390 to +390	DF10005	8053355
3	Bay E/F Upr Lid Outside	Strain	-5000 to +5000	SF05136	1001034
4	Bay E/F Upr Lid Inside	Strain	-5000 to +5000	SF05135	1001044
5	Bay E/F Lwr Lid Outside	Strain	-5000 to +5000	SF05134	1001054
6	TF COIL "A"	Strain	-5000 to +5000	SF15175	1001342
7	TF COIL "B"	Strain	-5000 to +5000	SF05133	1001036
8	TF COIL "C"	Strain	-5000 to +5000	SF15171	1001385
9	TF COIL "D"	Strain	-5000 to +5000	SF15174	1001430
10	TF COIL "E"	Strain	-5000 to +5000	SF15097	1001322
11	TF COIL "F"	Strain	-5000 to +5000	SF15098	1001371
12	TF COIL "G"	Strain	-5000 to +5000	SF15173	1001355
13	TF COIL "H"	Strain	-5000 to +5000	-	-
14	TF COIL "I"	Strain	-5000 to +5000	-	-
15	TF COIL "J"	Strain	-5000 to +5000	SF16016	1001445
16	TF COIL "K" - New	Strain	-5000 to +5000	SF15169	1001359
17	TF COIL "L" - New	Strain	-5000 to +5000	SF15177	1001466

Figure 17.0-2 FISO Strain Gauge Designations

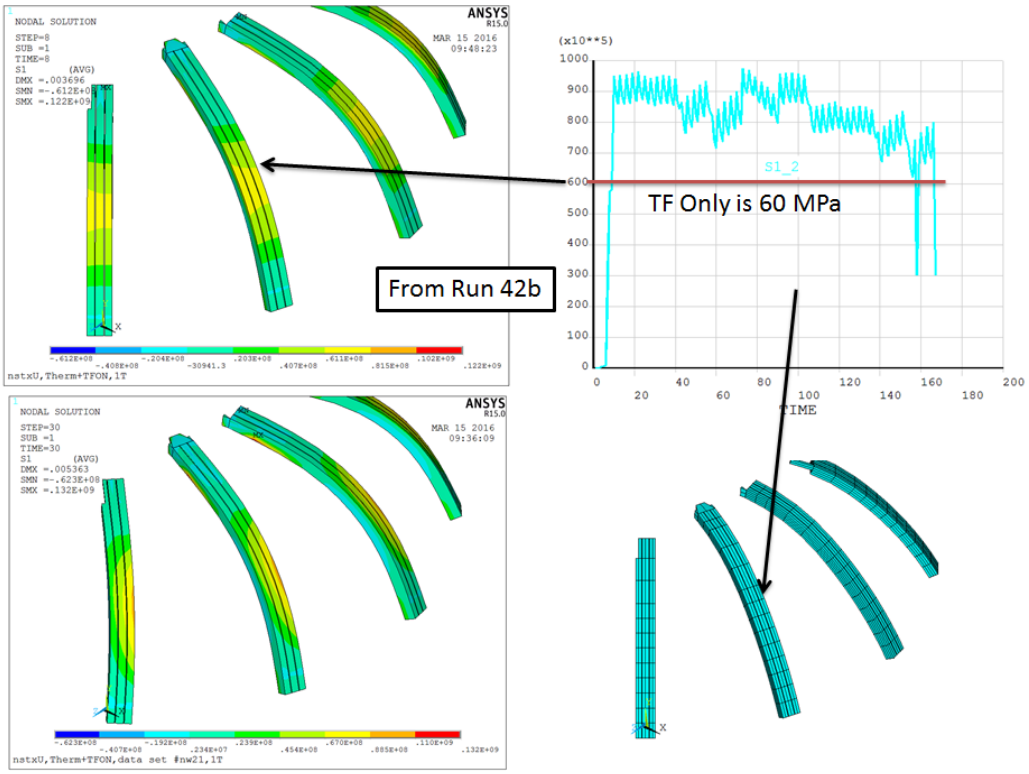


Figure 17.0-3

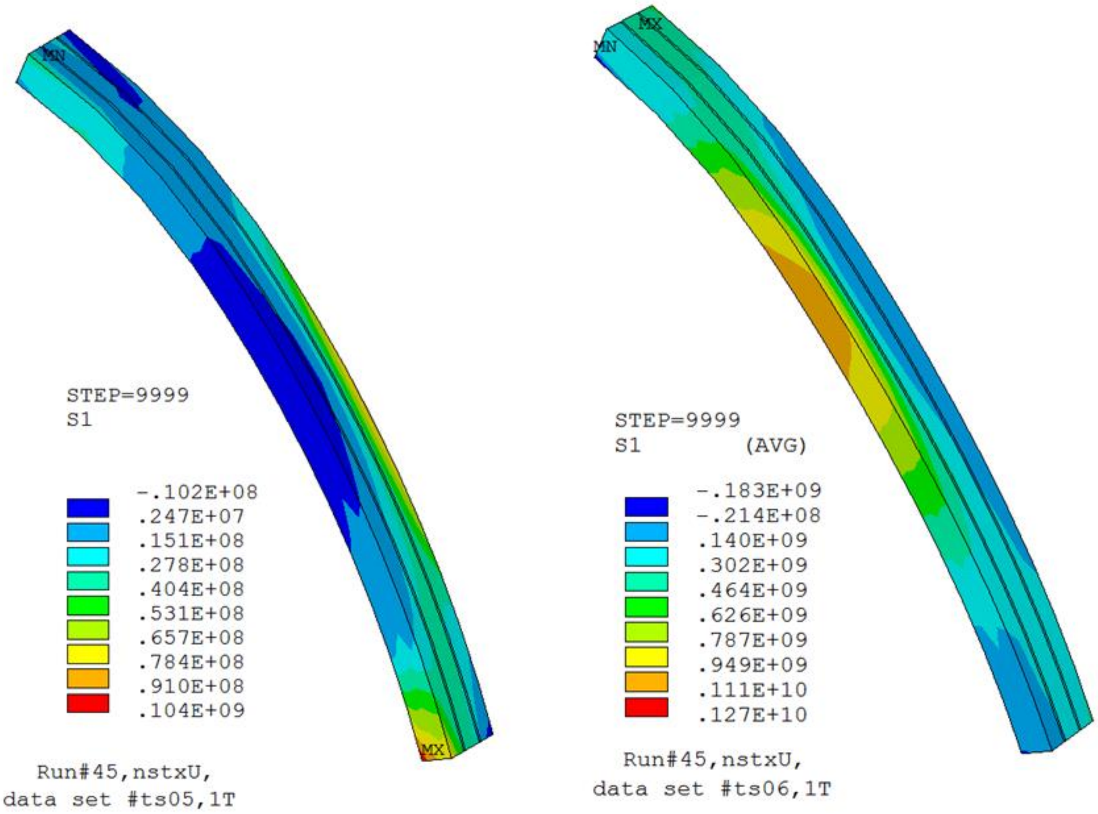
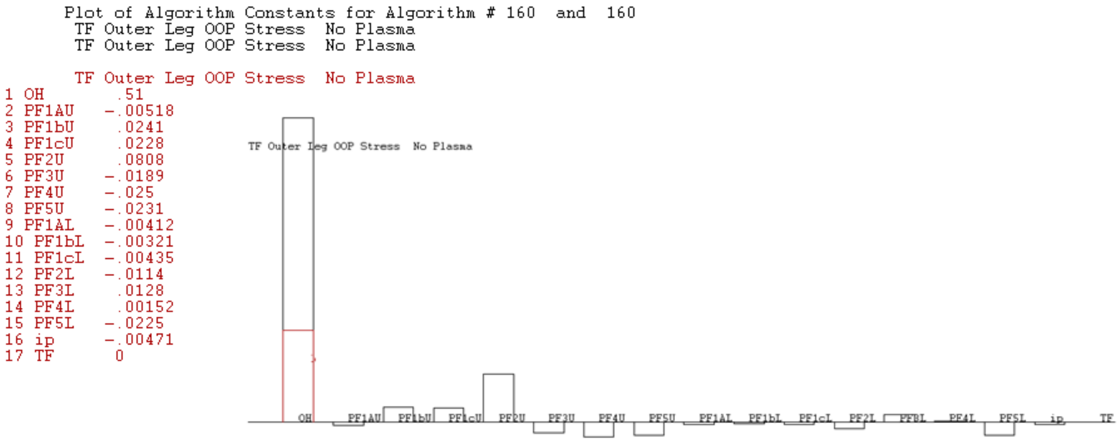


Figure 17.0-4



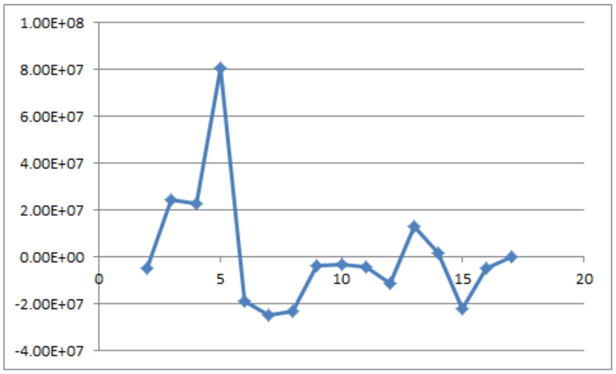
```
      Plot of Algorithm Constants for Algorithm # 160  and  160
       TF Outer Leg OOP Stress  No Plasma
       TF Outer Leg OOP Stress  No Plasma

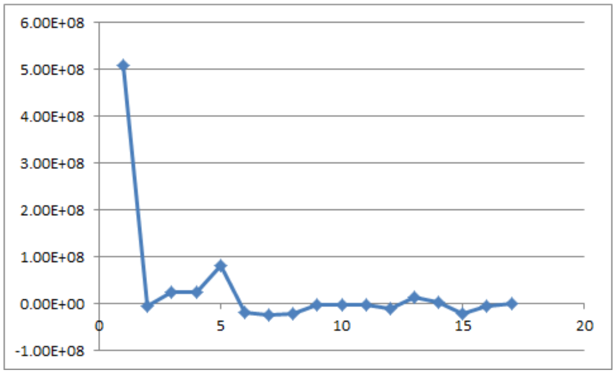
       TF Outer Leg OOP Stress  No Plasma
1 OH        .51
2 PF1AU   -.00518
3 PF1bU    .0241
4 PF1cU    .0228
5 PF2U     .0808
6 PF3U    -.0189
7 PF4U    -.025
8 PF5U    -.0231
9 PF1AL   -.00412
10 PF1bL  -.00321
11 PF1cL  -.00435
12 PF2L   -.0114
13 PF3L    .0128
14 PF4L    .00152
15 PF5L   -.0225
16 ip     -.00471
17 TF       0
```

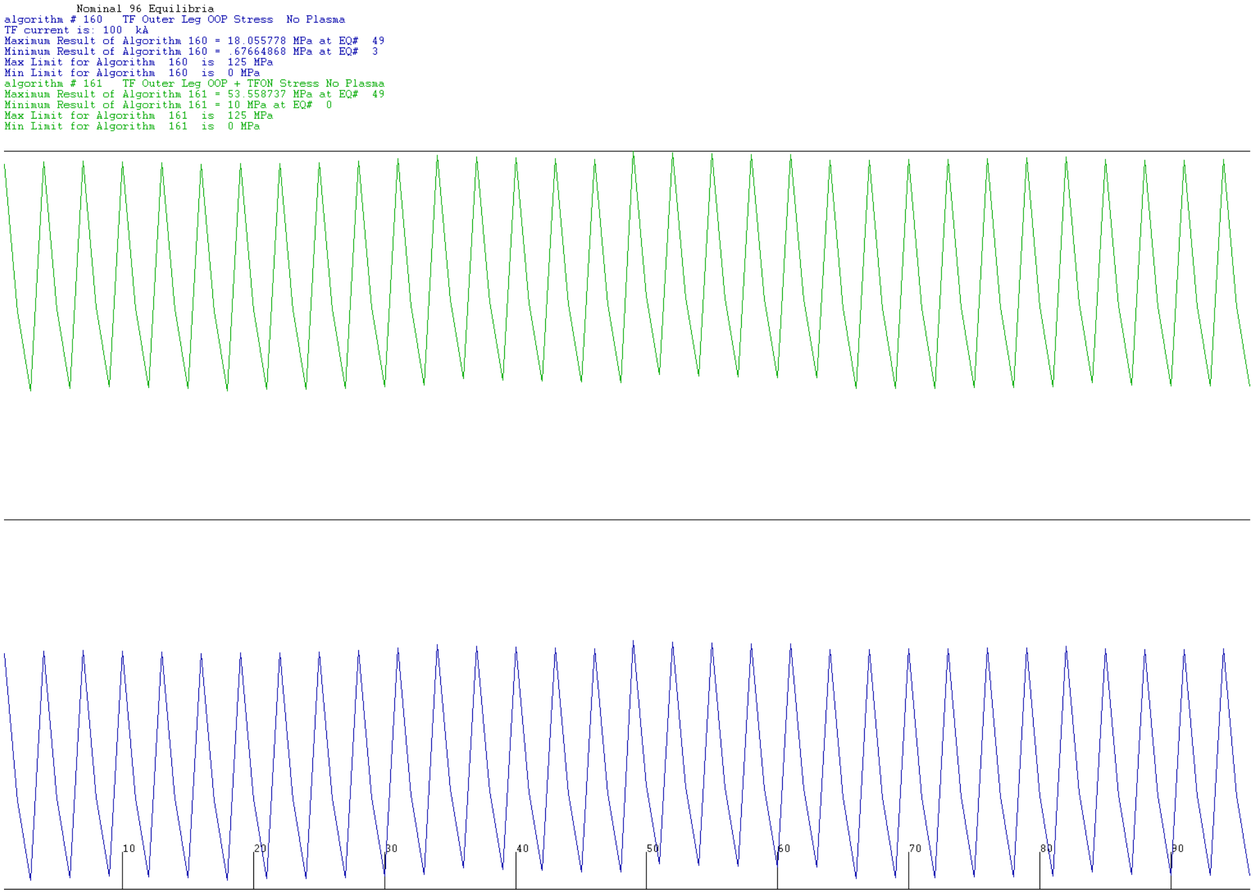
Figure 17.0-5 Outer Leg Algorithm Constants

TF Outer Leg Stress Influence Coefficients

	1	5.39E+08	2.92E+07	1	5.10E+08
	2	2.40E+07	2.92E+07	2	-5.18E+06
	3	5.33E+07	2.92E+07	3	2.41E+07
	4	5.20E+07	2.92E+07	4	2.28E+07
Pf2U	5	1.10E+08	2.92E+07	5	8.08E+07
PF3U	6	1.03E+07	2.92E+07	6	-1.89E+07
PF4U	7	4.22E+06	2.92E+07	7	-2.50E+07
PF5U	8	6.05E+06	2.92E+07	8	-2.31E+07
	9	2.51E+07	2.92E+07	9	-4.12E+06
	10	2.60E+07	2.92E+07	10	-3.21E+06
	11	2.48E+07	2.92E+07	11	-4.35E+06
	12	1.78E+07	2.92E+07	12	-1.14E+07
	13	4.20E+07	2.92E+07	13	1.28E+07
	14	3.07E+07	2.92E+07	14	1.52E+06
	15	6.69E+06	2.92E+07	15	-2.25E+07
	16	2.45E+07	2.92E+07	16	-4.71E+06
	17	2.92E+07	2.92E+07	17	0.00E+00





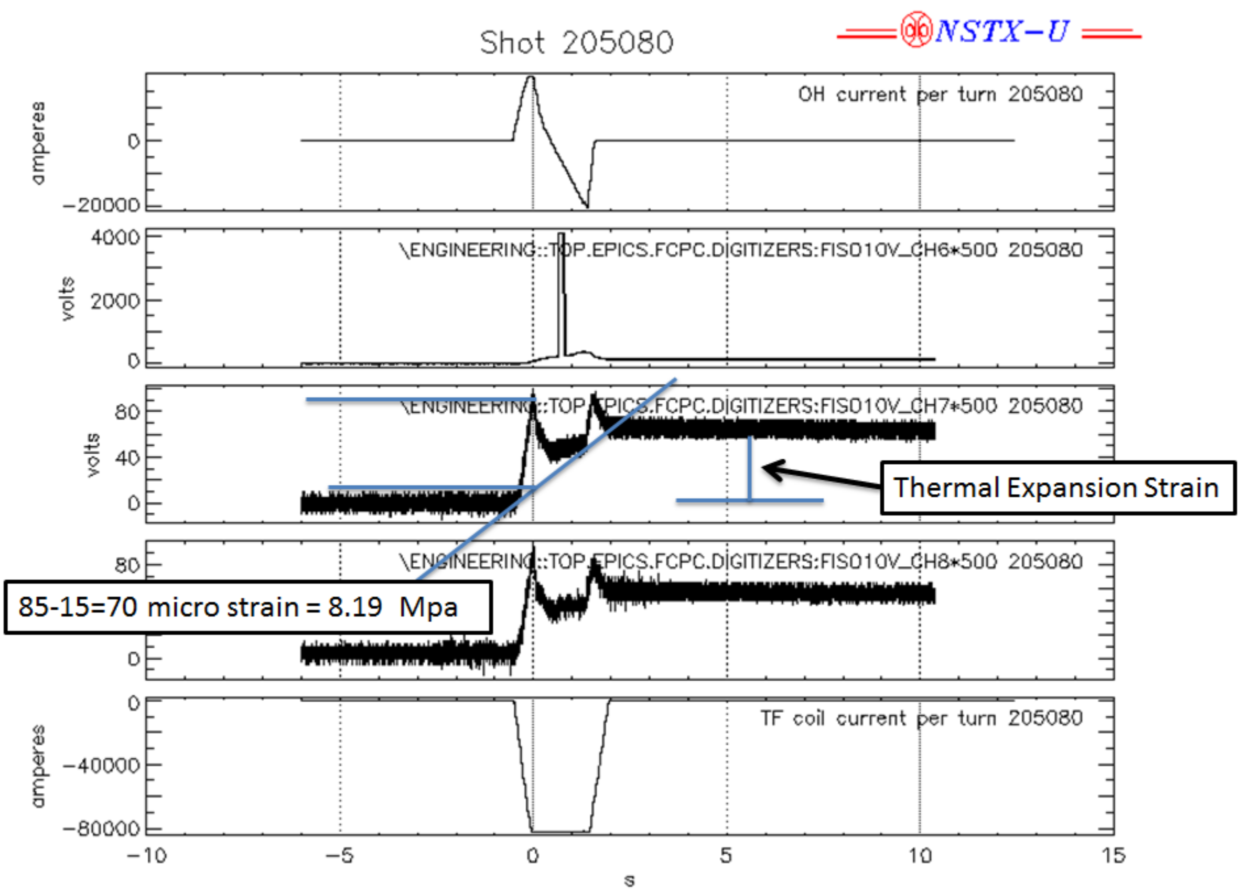


```
           Nominal 96 Equilibria
algorithm # 160   TF Outer Leg OOP Stress  No Plasma
TF current is: 100  kA
Maximum Result of Algorithm 160 = 18.055778 MPa at EQ#  49
Minimum Result of Algorithm 160 = .67664868 MPa at EQ#  3
Max Limit for Algorithm  160  is  125 MPa
Min Limit for Algorithm  160  is  0 MPa
algorithm # 161   TF Outer Leg OOP + TFON Stress No Plasma
Maximum Result of Algorithm 161 = 53.558737 MPa at EQ#  49
Minimum Result of Algorithm 161 = 10 MPa at EQ#  0
Max Limit for Algorithm  161  is  125 MPa
Min Limit for Algorithm  161  is  0 MPa
```

Figure 17.0-6

The aim of the FISO Outer Leg Strain measurements and the new Fiber Bragg Grating system is ultimately to monitor the insulation shear bonds between the 3 conductors of the TF outer legs. The shear stress in these bonded layers is proportional to the TF outer-leg out-of-plane bending. The strain gauges measure the sum of the effects of TF in-plane loading, Thermal expansion due to heat-up, and TF outer leg out-of-plane bending.

The figure below shows the MDS+ plot output for three of the installed FISO TF outer leg strain gauges. The data shown is for shot 205080 which was a clean shot done prior to the PF1a failure. The FISO gauges measure all the sources of strain including in-plane “bursting” load on the TF, out-of–plane bending from the interaction with the PF field, and the thermal strain due to expansion of the warming TF.



Thermal Expansion Strain

85-15=70 micro strain = 8.19 Mpa

Figure 17.0-7 MDS-+ Plots from the FISO Strain Gauges

The upper plot (number 1) in figure 4.5-1 is the OH current which is one contributor to the out-of-plane loading. The bottom plot (number 5 is the TF current that is a measure of the in-plane tensile loading. Plots 2,3,and 4 are the total bending strain in three different upper outer legs. The shift in strain before and after the shot shown in plots 3 and 4 is a measure of the thermal strain that results from the expansion of the TF outer leg. To evaluate just the bending due to the out-of-plane loading, in-plane and thermal strains must be subtracted out of the total strain. This will be true of the FBG system. An appropriate scale factor to be applied to the TF current will be needed for the in-plane strain and the TF end temperature will be needed to quantify the thermal strain. Then ideally these should be subtracted out of the total strain and these values summarized and presented in trending evaluations and COE summary page.

Scale Factors

With TF Only Loading, and 130 kA terminal current, the stress in the upper outer leg is 30.6 MPa or 261 micro strain. This will scale with the square of the current so for 80 kA the expected stress is 11.5 MPa or a strain for in-plane loading is 99 micro strain. In figure 3.5-1 the total stress is about MPa for the upper outer TF leg. Thus the out-of-plane stress is MPa.

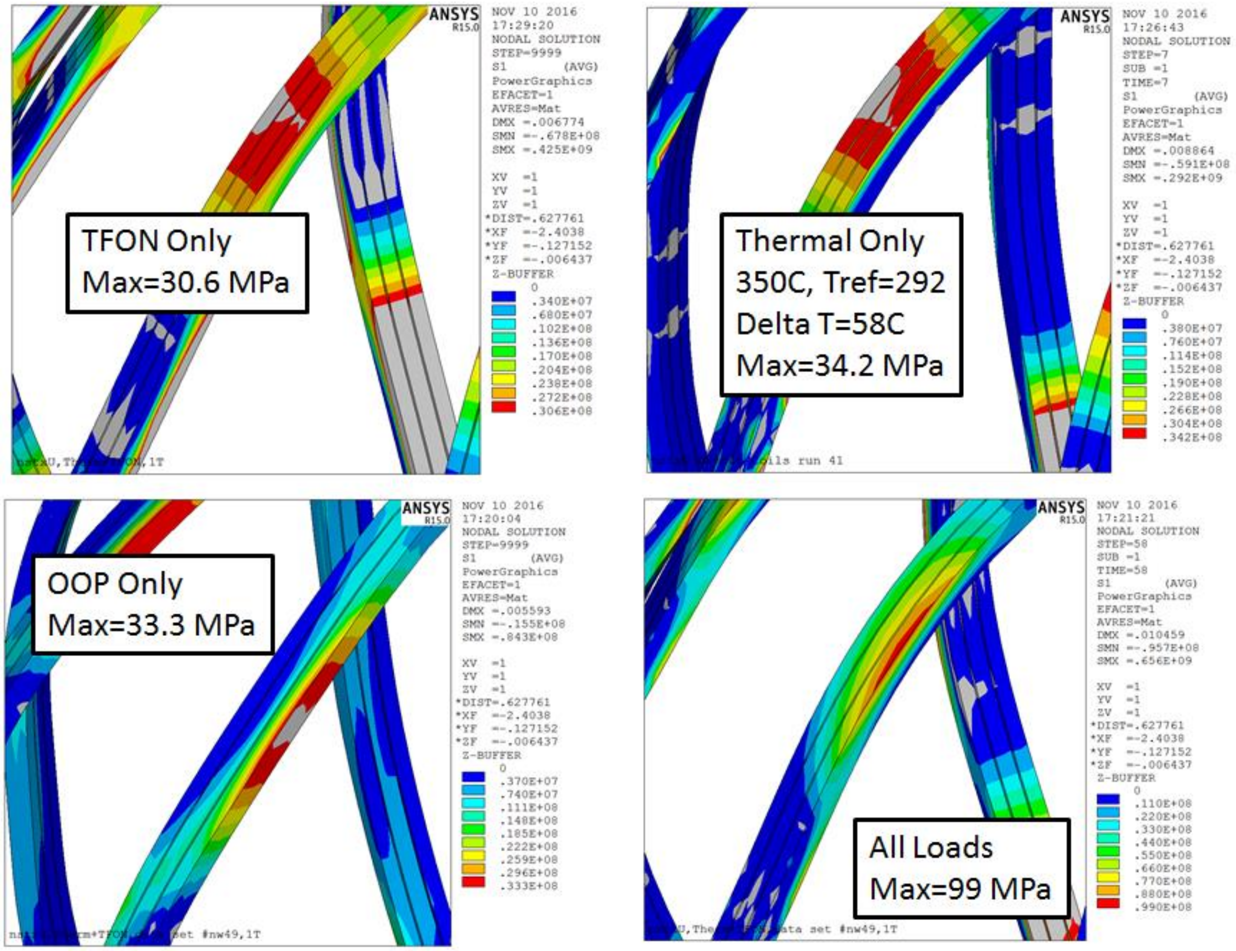
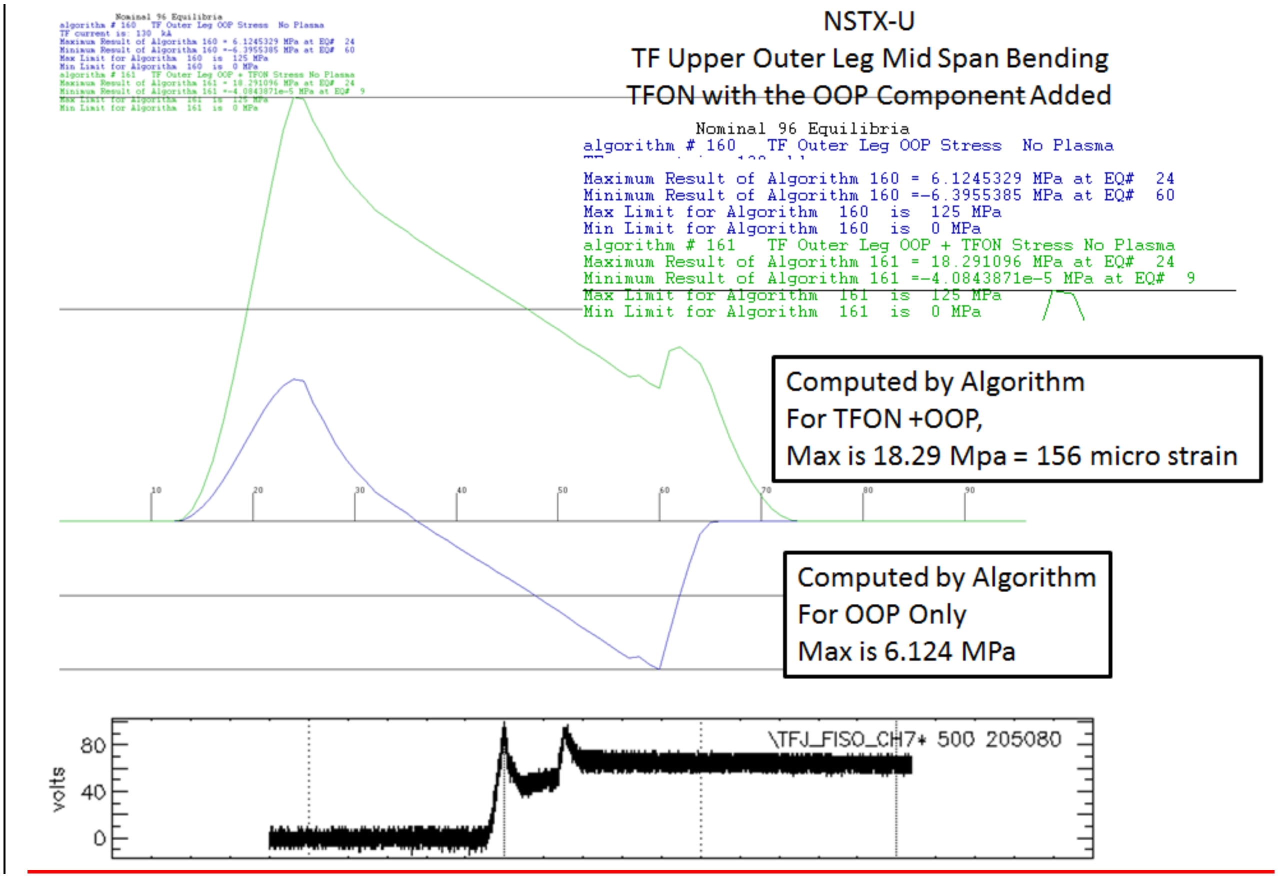


Figure 17.0-8 Stress Components from The Global Model Run

Table 4.5-1 Stresses for TF Upper Outer Leg Midspan

	Thermal (MPa)	TFON Only	TFON +Thermal	Total TFON OOP +Therm	OOP Only From Components	OOP (ANSYS Load Case Subtraction)
Base Load	Delta=58 C	130 kA				
Load Step	7		8	58		
Upper Outer TF	34.2	30.6	65.7	99	99-65.7=33.3	33.3



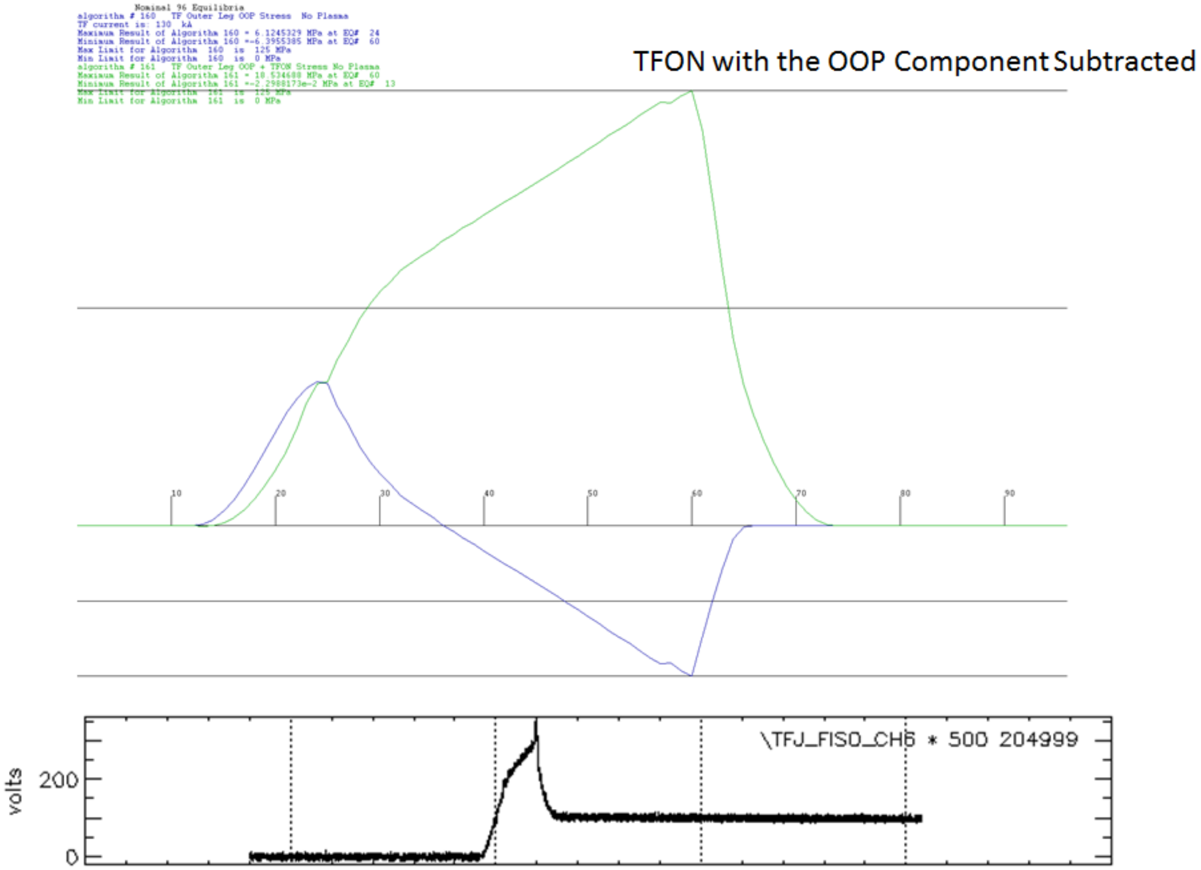
```
               Nominal 96 Equilibria
algorithm # 160   TF Outer Leg OOP Stress  No Plasma

Maximum Result of Algorithm 160 = 6.1245329 MPa at EQ#  24
Minimum Result of Algorithm 160 =-6.3955385 MPa at EQ#  60
Max Limit for Algorithm  160  is  125 MPa
Min Limit for Algorithm  160  is  0 MPa
algorithm # 161   TF Outer Leg OOP + TFON Stress No Plasma
Maximum Result of Algorithm 161 = 18.291096 MPa at EQ#  24
Minimum Result of Algorithm 161 =-4.0843871e-5 MPa at EQ#  9
Max Limit for Algorithm  161  is  125 MPa
Min Limit for Algorithm  161  is  0 MPa
```

Figure 17.0-9 Computed and Measured TF Outer Leg Stress and Strain – OOP Adds.

About 70 micro strain TF Heat-up Strain . In figure 17.0-9, the outer-upper TF leg bending stress has been computed from influence coefficients for the sum of TFON+OOP, and for the OOP load only. A two peak plot is produced, for the TFON +OOP case, similar to the plot measured by the FISO strain gauges. In the FISO measurement, the thermal strain is included and this shifts the before and after strain. The measured strain is 90 micro strain and the predicted is 156. This can be a calibration error with the FISO gauges (John Dong provided the factor of 500), or the installed gauges may not be at the same location as was used to compute the stresses from the global model -Or the analysis needs improving. For the monitoring of the results, consistency from coil to coil, and shot to shot will be important.

One additional point is that the results vary depending on which side the strain gauges are mounted on. This determines if the OOP component adds to or subtracts from the TFON and thermal strains.

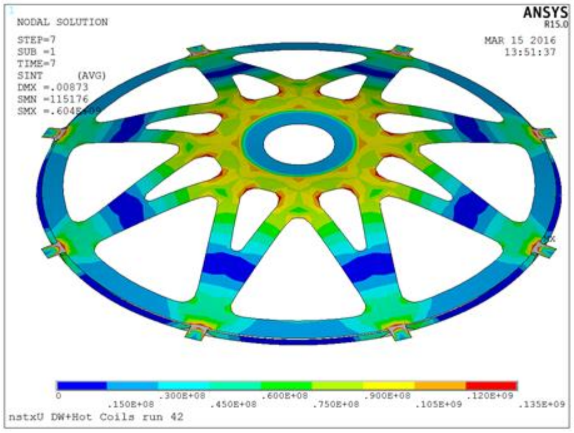


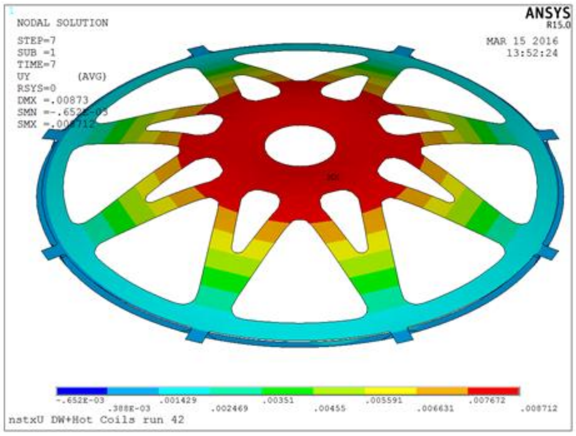
```
            Nominal 96 Equilibria
algorithm # 160   TF Outer Leg OOP Stress  No Plasma
TF current is: 130  kA
Maximum Result of Algorithm 160 = 6.1245329 MPa at EQ#  24
Minimum Result of Algorithm 160 =-6.3955385 MPa at EQ#  60
Max Limit for Algorithm  160  is  125 MPa
Min Limit for Algorithm  160  is  0 MPa
algorithm # 161   TF Outer Leg OOP + TFON Stress No Plasma
Maximum Result of Algorithm 161 = 10.534688 MPa at EQ#  60
Minimum Result of Algorithm 161 =-2.2988173e-2 MPa at EQ#  13
Max Limit for Algorithm  161  is  125 MPa
Min Limit for Algorithm  161  is  0 MPa
```

Figure 4.5-4 Computed and Measured TF Outer Leg Stress and Strain – OOP Subtracts

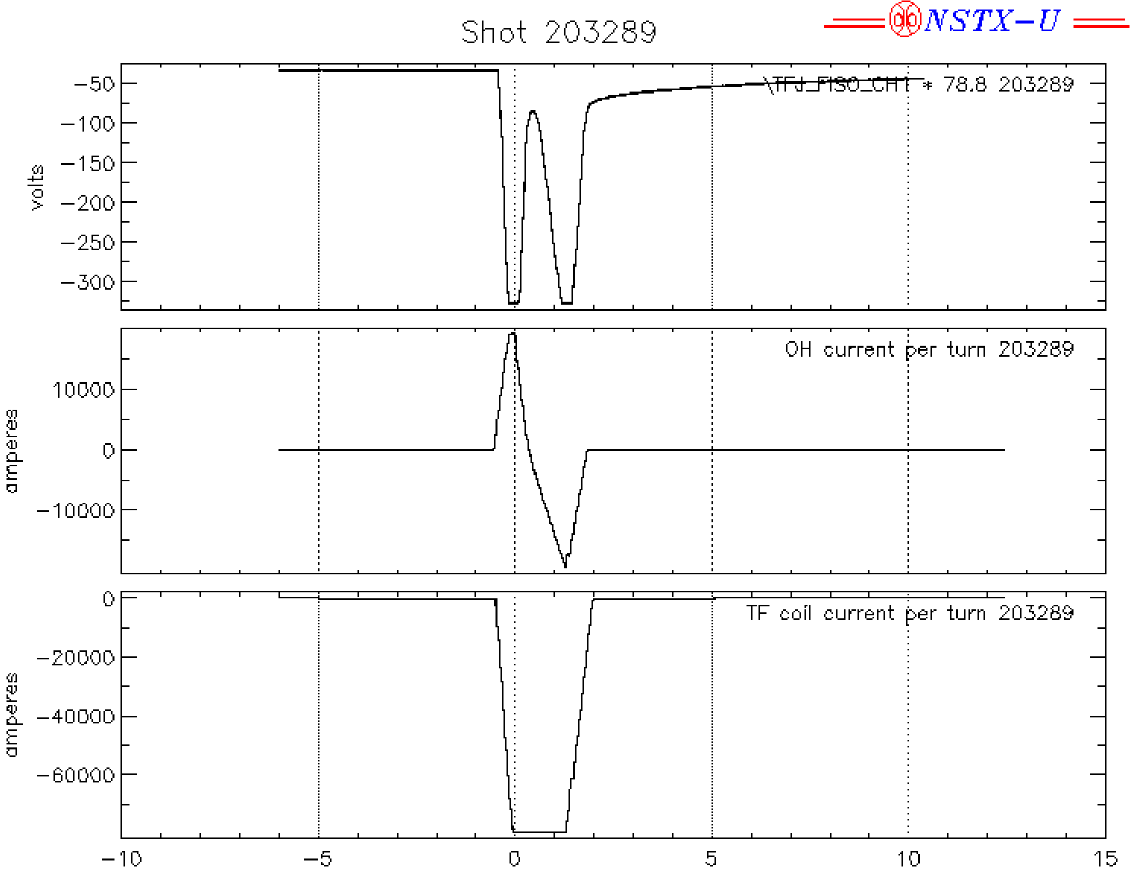
Figure 4.4-4 is for the case where the strain gauge is on the opposite edge of the coil from the situation plotted in figure 4.4-3. The shape of the curves of the computed total and FISO measurement are similar – These are for two different shots, because John Dong swapped the input to the FISO box. Once installed, we will be able to determine whether the OOP part should be additive or subtractive. If we want to subtract out the before and after shot thermal strain we will either need a measured TF temperature or do a j^2t calculation on the TF current profile.

18.0 Algorithm 165,166 Upper Spoked Lid



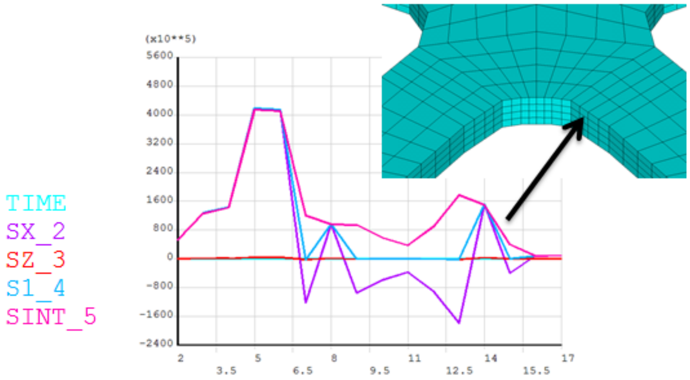


Spoked lid stress is a function of the twisting moment and the vertical motion of the OH as it is heated and as it contracts under its self loads. As measured by the FISO LVDT, the OH contracts about 325 mils for 20 kA In the figure above, the stress is 135MPa/8mm = 16.875 MPa/mm or 428.6 MPa per inch.
So the spoked lid stress is 428.6 *.325/20^2 *Ioh^2 =.348*Ioh^2 with Ioh in kA



Algorithm 165

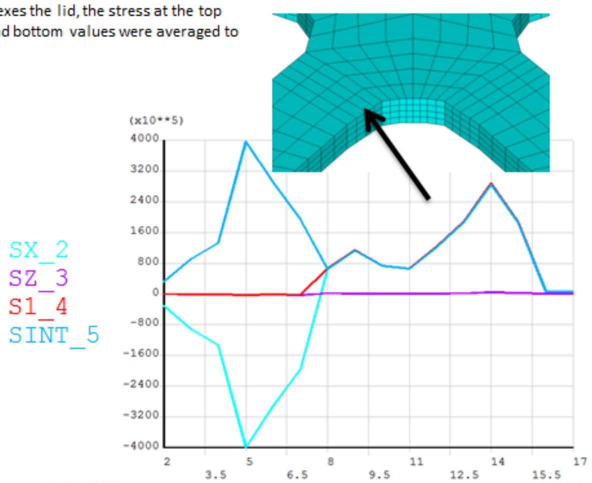
```
***** ANSYS POST26 VARIABLE LISTING *****
 TIME       1 TIME   ANSO S  X   ANSO S  Z   ANSO S  1   ANSO S  INT
            TIME      SX_2       SZ_3       S1_4       SINT_5
1.00000   -0.105615E+11 -0.160167E+09 -0.160133E+09 0.104116E+11
2.00000    0.535902E+08  523669.    0.535992E+08 0.530762E+08
3.00000    0.127679E+09 0.126686E+07 0.127713E+09 0.126446E+09
4.00000    0.143819E+09 0.132840E+07 0.143848E+09 0.142520E+09
5.00000    0.418624E+09 0.383669E+07 0.418700E+09 0.414863E+09
6.00000    0.414534E+09 0.353970E+07 0.414558E+09 0.411062E+09
7.00000   -0.122076E+09 -0.245802E+07 -0.243546E+07 0.120226E+09
8.00000    0.965855E+08 0.101328E+07 0.969103E+08 0.961205E+08
9.00000   -0.950221E+08 -815151.   -814883.    0.942234E+08
10.0000   -0.592438E+08 -509225.   -508901.    0.587427E+08
11.0000   -0.372372E+08 -258752.   -258512.    0.369804E+08
12.0000   -0.904854E+08 -744951.   -744415.    0.897536E+08
13.0000   -0.179122E+09 -0.165532E+07 -0.165410E+07 0.177528E+09
14.0000    0.151820E+09 0.275241E+07 0.151960E+09 0.149212E+09
15.0000   -0.396057E+08  23431.0    31884.9    0.396486E+08
16.0000    0.813733E+07  121124.    0.815141E+07 0.803033E+07
17.0000    0.856795E+07  125880.    0.858516E+07 0.845944E+07
```

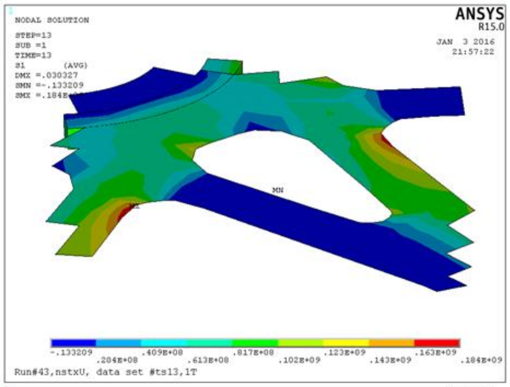


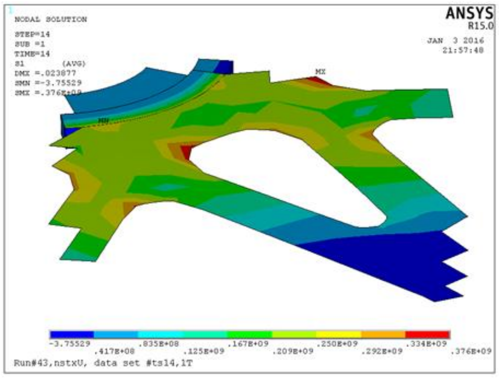
Because the OH vertical contraction under the centering self load flexes the lid, the stress at the top and the bottom of the lid spoke is substantially different. The top and bottom values were averaged to obtain the OH coefficient.

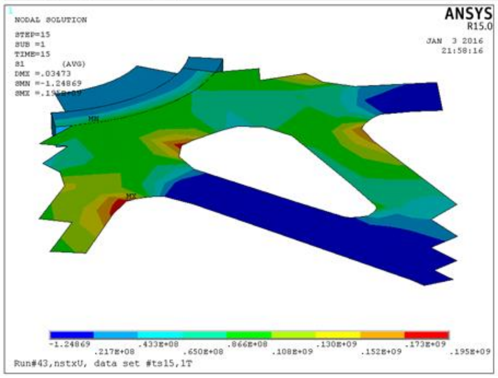
Algorithm 166

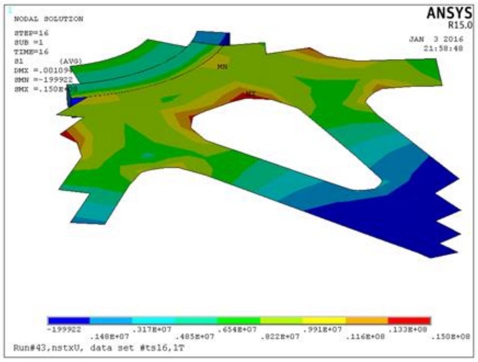
```
***** ANSYS POST26 VARIABLE LISTING *****
TIME      ANSO S  X   ANSO S  Z   ANSO S  1   ANSO S  INT
          SX_2       SZ_3       S1_4       SINT_5
1.0000    -0.891473E+10-0.144470E+09-0.144425E+09 0.879863E+10
2.0000    -0.315708E+08 -182472.   -180569.    0.314093E+08
3.0000    -0.921504E+08 -720118.   -719733.    0.915754E+08
4.0000    -0.134482E+09-0.119220E+07-0.119185E+07 0.133528E+09
5.0000    -0.398775E+09-0.355674E+07-0.355551E+07 0.395945E+09
6.0000    -0.291338E+09-0.164674E+07-0.157660E+07 0.289931E+09
7.0000    -0.196256E+09-0.252197E+07-0.250502E+07 0.194067E+09
8.0000     0.647098E+08 0.148444E+07 0.661778E+08 0.647734E+08
9.0000     0.113267E+09 0.111401E+07 0.113568E+09 0.112455E+09
10.000     0.739247E+08  742938.    0.740947E+08 0.733524E+08
11.000     0.657170E+08  707568.    0.658818E+08 0.651747E+08
12.000     0.123163E+09 0.126455E+07 0.123453E+09 0.122190E+09
13.000     0.188342E+09 0.180519E+07 0.188764E+09 0.186961E+09
14.000     0.287458E+09 0.409476E+07 0.288291E+09 0.284198E+09
15.000     0.186389E+09 0.224332E+07 0.186714E+09 0.184473E+09
16.000     0.699679E+07  114908.    0.703439E+07 0.691962E+07
17.000     0.592009E+07  100284.    0.595282E+07 0.585261E+07
```





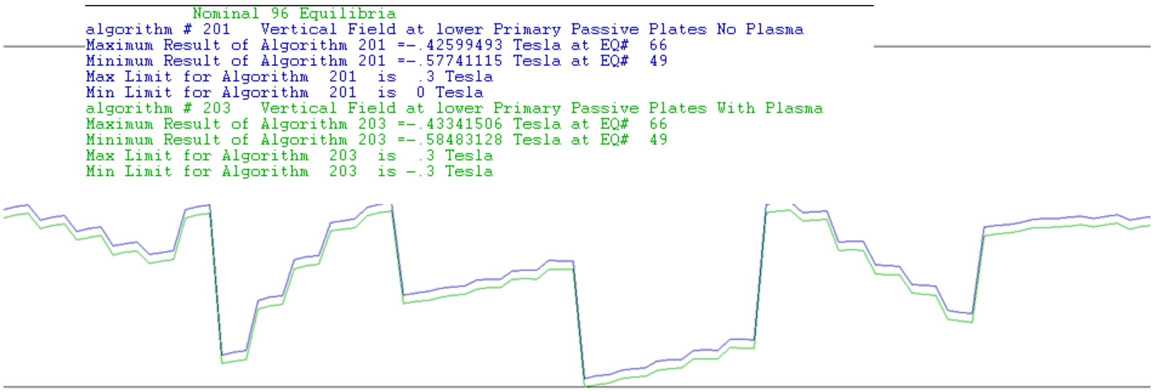




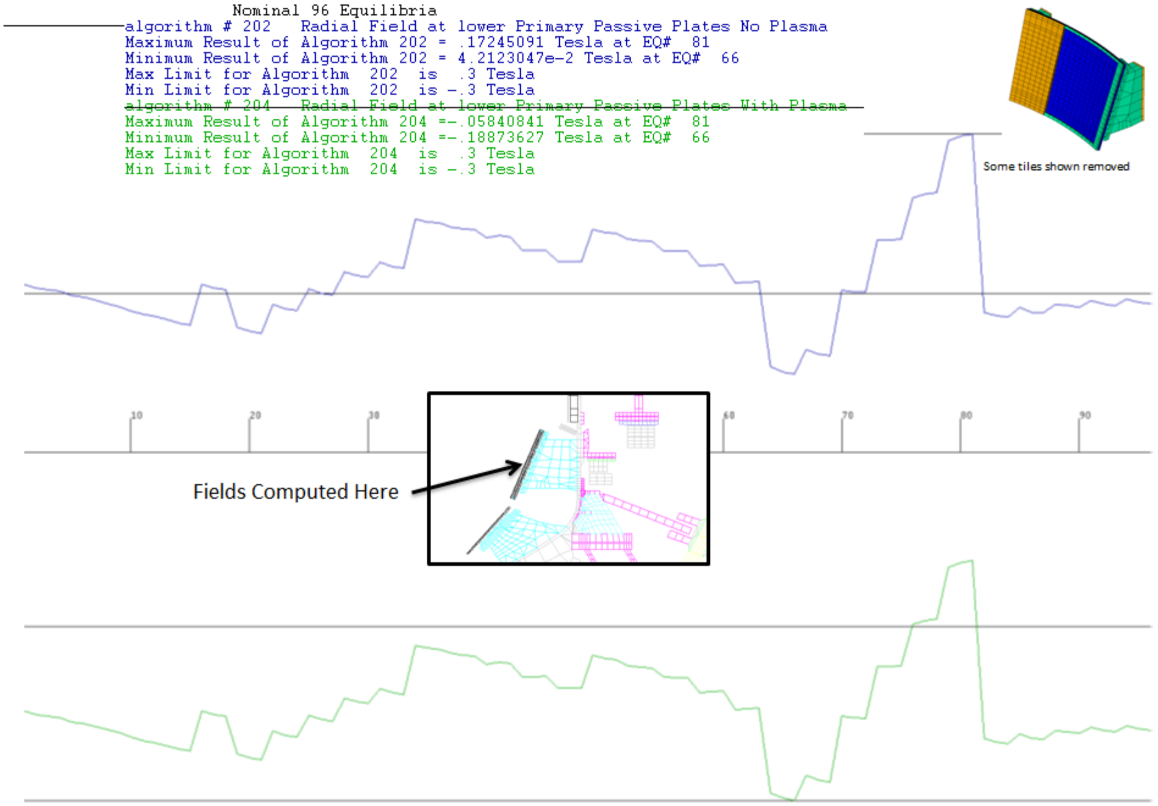


19.0 Fields at Specific Locations in the Machine

19.1 Algorithm 201 Passive Plate Fields



```
           Nominal 96 Equilibria
algorithm # 201   Vertical Field at lower Primary Passive Plates No Plasma
Maximum Result of Algorithm 201 =-.42599493 Tesla at EQ#  66
Minimum Result of Algorithm 201 =-.57741115 Tesla at EQ#  49
Max Limit for Algorithm  201  is  .3 Tesla
Min Limit for Algorithm  201  is  0 Tesla
algorithm # 203   Vertical Field at lower Primary Passive Plates With Plasma
Maximum Result of Algorithm 203 =-.43341506 Tesla at EQ#  66
Minimum Result of Algorithm 203 =-.58483128 Tesla at EQ#  49
Max Limit for Algorithm  203  is  .3 Tesla
Min Limit for Algorithm  203  is -.3 Tesla
```



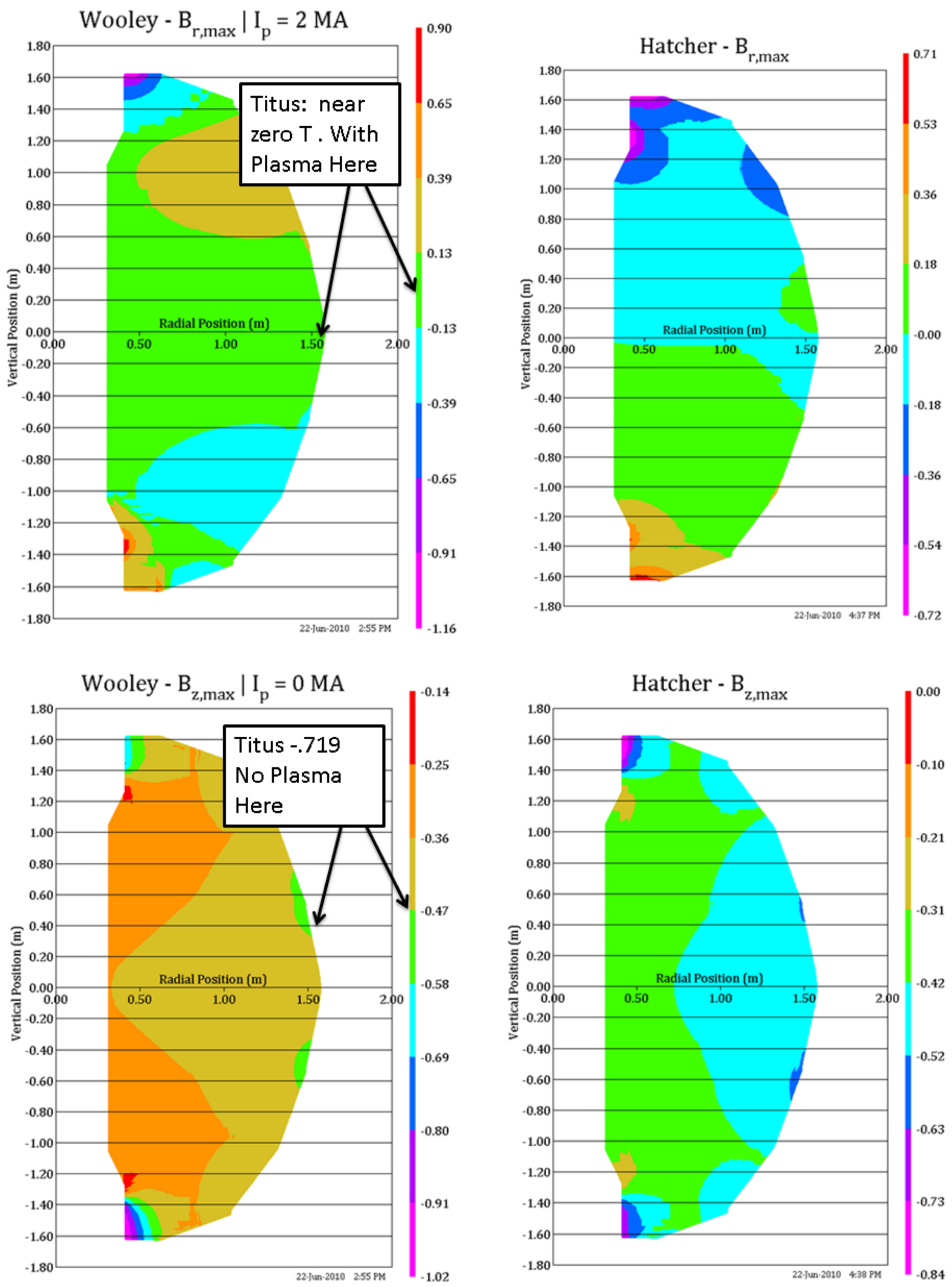
```
           Nominal 96 Equilibria
algorithm # 202   Radial Field at lower Primary Passive Plates No Plasma
Maximum Result of Algorithm 202 = .17245091 Tesla at EQ#  81
Minimum Result of Algorithm 202 = 4.2123047e-2 Tesla at EQ#  66
Max Limit for Algorithm  202  is  .3 Tesla
Min Limit for Algorithm  202  is -.3 Tesla
algorithm # 204   Radial Field at lower Primary Passive Plates With Plasma
Maximum Result of Algorithm 204 =-.05840841 Tesla at EQ#  81
Minimum Result of Algorithm 204 =-.18873627 Tesla at EQ#  66
Max Limit for Algorithm  204  is  .3 Tesla
Min Limit for Algorithm  204  is -.3 Tesla
```

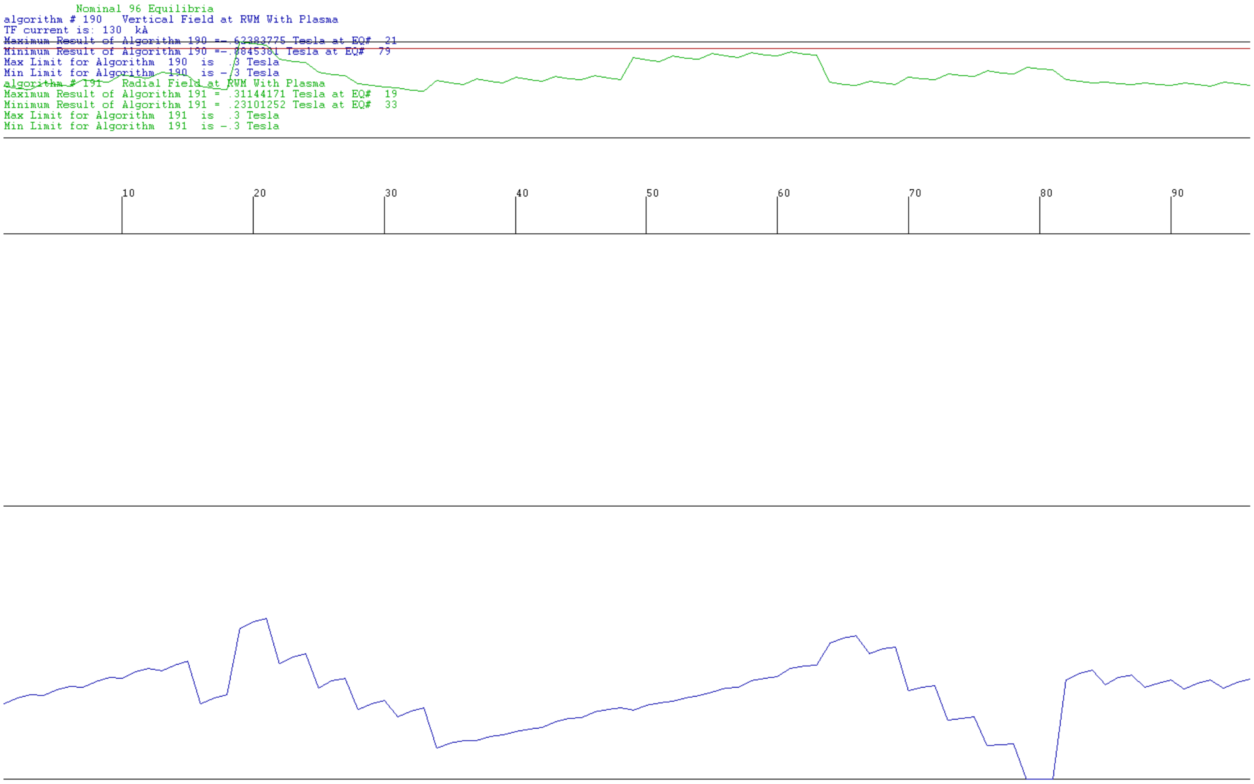
Some tiles shown removed

Fields Computed Here

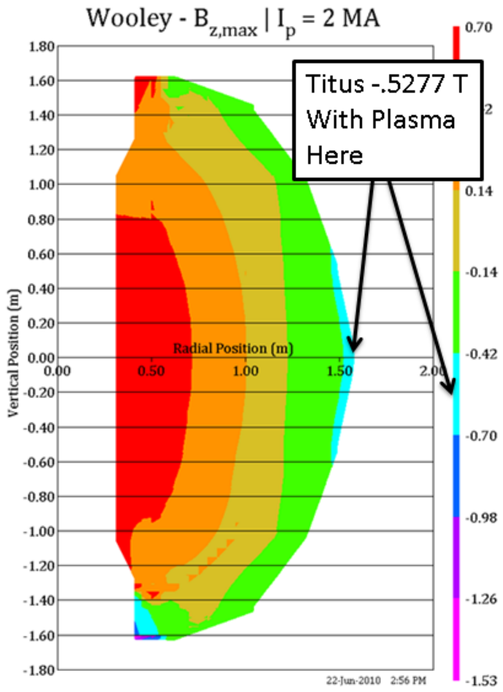
19.2 Fields at the Resistive Bolometer

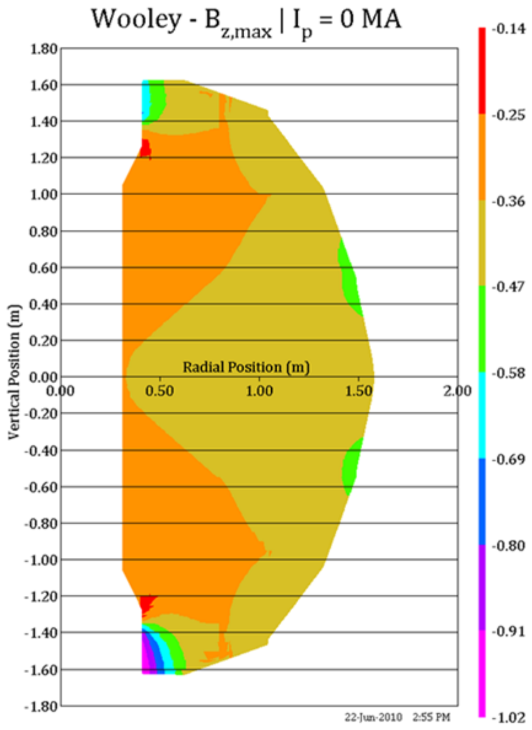
Radial Fields from Wooley and Hatcher



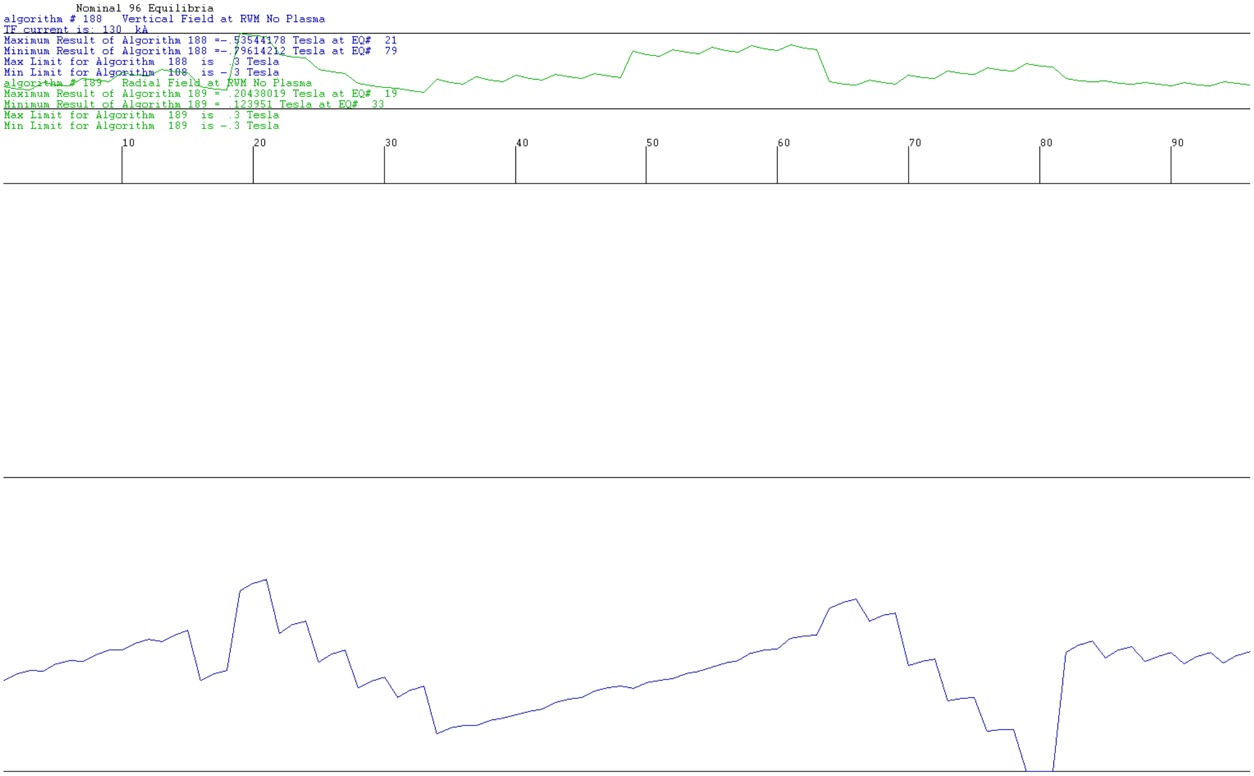


```
        Nominal 96 Equilibria
algorithm # 190   Vertical Field at RWM With Plasma
TF current is: 130  kA
Maximum Result of Algorithm 190 =-.62383775 Tesla at EQ#  21
Minimum Result of Algorithm 190 =-.8845381 Tesla at EQ#  79
Max Limit for Algorithm  190  is  .3 Tesla
Min Limit for Algorithm  190  is -.3 Tesla
algorithm # 191   Radial Field at RWM With Plasma
Maximum Result of Algorithm 191 = .31144171 Tesla at EQ#  19
Minimum Result of Algorithm 191 = .23101252 Tesla at EQ#  33
Max Limit for Algorithm  191  is  .3 Tesla
Min Limit for Algorithm  191  is -.3 Tesla
```





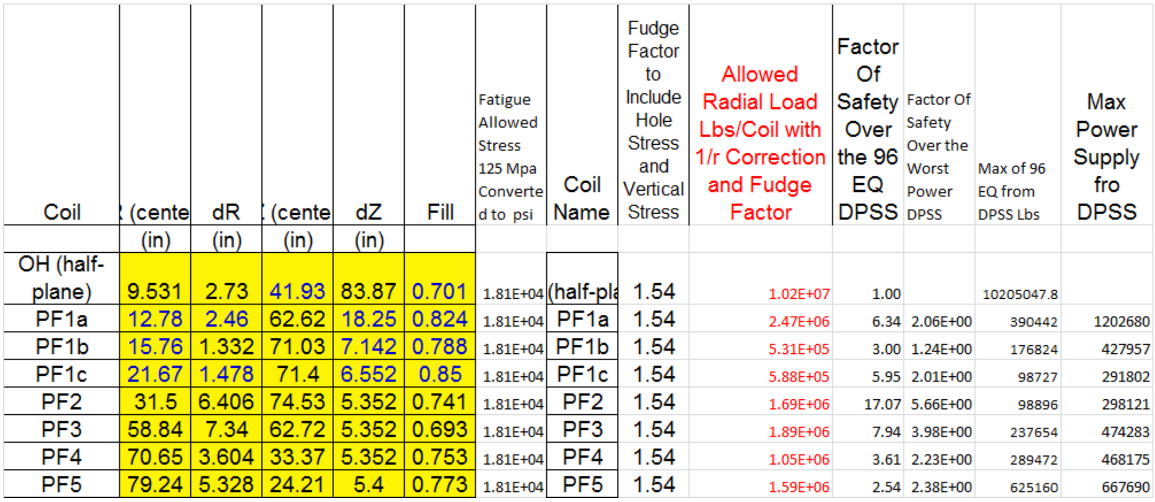
19.3 Background fields at the RWM coils



```
             Nominal 96 Equilibria
algorithm # 188   Vertical Field at RWM No Plasma
TF current is: 130  kA
Maximum Result of Algorithm 188 =-.53544178 Tesla at EQ#  21
Minimum Result of Algorithm 188 =-.79614212 Tesla at EQ#  79
Max Limit for Algorithm  188  is  .3 Tesla
Min Limit for Algorithm  188  is -.3 Tesla
algorithm # 189   Radial Field at RWM No Plasma
Maximum Result of Algorithm 189 = .20438019 Tesla at EQ#  19
Minimum Result of Algorithm 189 = .123951 Tesla at EQ#  33
Max Limit for Algorithm  189  is  .3 Tesla
Min Limit for Algorithm  189  is -.3 Tesla
```

20.0 Radial Force Limits based on Hoop Stress Limits

The radial forces were previously limited to the 96EQ maxima. This is overly conservative. Vertical forces were found to be much more significant than radial force effects. In fact inNSTX, the radial forces were not set to some limit in the coil protection system, only vertical forces. To get more operating space, the radial force limits were calculated based on an allowed hoop stress based on fatigue of 125 MPa.



Coil	(cente	dR	(cente	dZ	Fill	Fatigue Allowed Stress 125 Mpa Converted to psi	Coil Name	Fudge Factor to Include Hole Stress and Vertical Stress	Allowed Radial Load Lbs/Coil with 1/r Correction and Fudge Factor	Factor Of Safety Over the 96 EQ DPSS	Factor Of Safety Over the Worst Power DPSS	Max of 96 EQ from DPSS Lbs	Max Power Supply fro DPSS
	(in)	(in)	(in)	(in)									
OH (half-plane)	9.531	2.73	41.93	83.87	0.701	1.81E+04	(half-pla	1.54	1.02E+07	1.00		10205047.8	
PF1a	12.78	2.46	62.62	18.25	0.824	1.81E+04	PF1a	1.54	2.47E+06	6.34	2.06E+00	390442	1202680
PF1b	15.76	1.332	71.03	7.142	0.788	1.81E+04	PF1b	1.54	5.31E+05	3.00	1.24E+00	176824	427957
PF1c	21.67	1.478	71.4	6.552	0.85	1.81E+04	PF1c	1.54	5.88E+05	5.95	2.01E+00	98727	291802
PF2	31.5	6.406	74.53	5.352	0.741	1.81E+04	PF2	1.54	1.69E+06	17.07	5.66E+00	98896	298121
PF3	58.84	7.34	62.72	5.352	0.693	1.81E+04	PF3	1.54	1.89E+06	7.94	3.98E+00	237654	474283
PF4	70.65	3.604	33.37	5.352	0.753	1.81E+04	PF4	1.54	1.05E+06	3.61	2.23E+00	289472	468175
PF5	79.24	5.328	24.21	5.4	0.773	1.81E+04	PF5	1.54	1.59E+06	2.54	2.38E+00	625160	667690

The hoop stress computations were implemented in the True Basic DCPS code. These were then checked against the factor of safety reported above for the 96 EQ and they agreed.

```
!      PF Hoop Stresses
!When I gave Stefan the radial force limits it was based on 125 MPa fatigue
!1.54 fudge factor for hole vertical stress, hoop fill factor is also included
for i=1 to 16
let algor$(60+i)=myname$(i)&" Hoop Stress, incl fill and 1/r and 1.54 fudge"
let AlgAccept(60+i)=125
let algunits$(60+i)="MPa"
for j=1 to curnum
let algresults(60+i,j)= (Fr(j,i)/pfdr(i)/pfdz(i))/1e6*1.54*pfr(i)/(pfr(i)-pfdr(i))/fill(i)
next j
next i
```

21.0 Evaluation of force sums

FZ, PF1aU+PF1bU   Maybe important for the case connection to the centerstack - Will quantify
FZ, PF1aU-PF1bU   Probably not important - will quantify anyway
FZ, PF1aL+PF1bL   Probably could be deleted in favor of the last one below.
FZ, PF1aL-PF1bL   Probably not important
FZ, PF3U+PF4U+PF5U+PF4L+PF5L   Meaningless - can be deleted
FZ, (PF1AU+PF1BU+PF1BL+PF1AL+OH)   This is the centerstack launching load - Upward is limited by the capacity of the bolting in the casing and PF1a,b mandrel structure - This will include some headroom in the bolt stress to take the possibility of halo loads - will quantify. Downward will be much higher.

		OH	PF1AU	PF1bU	PF1cU	PF2U	PF3U	PF4U	PF5U	PF1AL	PF1bL	PF1cL	PF2L	PF3L	PF4L	PF5L	Ip
FX		Influence	Matrix	N/rad													
OH	1	25230.3	3806.061	1708.908	967.1191	1134.092	1209.182	776.9004	1080.26	3806.043	1708.914	967.123	1134.096	1209.203	776.8887	1080.252	58.04883
PF1AU	2	-140.673	856.7656	804.679	402.8212	385.0967	267.9286	97.79694	113.873	2.693542	1.662048	1.908569	5.065918	19.87793	25.48993	46.92737	1.891357
PF1bU	3	-111.435	-147.157	344.059	462.4921	333.3344	164.4536	52.2583	60.96289	1.346069	0.843353	0.970917	2.600311	10.30087	13.1109	24.38876	0.834534
PF1cU	4	-49.8817	-66.3434	-186.161	152.8504	363.0069	147.4613	44.34793	51.61908	1.111908	0.69957	0.805283	2.161407	8.583679	10.90804	20.36479	0.65506
PF2U	5	-31.1968	-44.1531	-82.4588	-136.834	292.1378	317.2212	81.96744	95.94821	1.96759	1.253113	1.443481	3.899963	15.58963	19.65652	37.01328	1.009399
PF3U	6	-21.5523	-26.2723	-19.4406	-24.8062	-74.7123	400.619	163.52	198.7234	3.382355	2.227905	2.566162	7.052979	28.73105	35.6076	68.99472	0.94574
PF4U	7	-14.8351	-3.98004	-1.31325	-1.43192	-0.89291	16.79922	150.6147	444.4194	2.456009	1.717377	1.986237	5.62558	23.96396	30.02812	62.74477	-0.35266
PF5U	8	-20.3084	-2.72794	-0.53848	-0.5621	1.093414	15.20554	-199.776	300.6638	2.999451	2.246582	2.606537	7.632538	33.50699	39.08331	86.71771	-1.09036
PF1AL	9	-140.673	2.693604	1.662109	1.908752	5.066101	19.87787	25.4903	46.92773	856.7654	804.6786	402.821	385.0972	267.929	97.79706	113.8729	1.891724
PF1bL	10	-111.435	1.3461	0.843353	0.970947	2.600433	10.30093	13.11102	24.38889	-147.157	344.0589	462.4922	333.3345	164.4537	52.25842	60.96298	0.834717
PF1cL	11	-49.8816	1.111908	0.699554	0.805328	2.161484	8.583694	10.90807	20.36481	-66.3433	-186.161	152.8504	363.007	147.4612	44.34799	51.61909	0.655121
PF2L	12	-31.1969	1.96756	1.253174	1.443481	3.900024	15.58957	19.65646	37.01309	-44.1531	-82.459	-136.834	292.1379	317.2212	81.9675	95.9483	1.00943
PF3L	13	-21.5522	3.382446	2.227753	2.566376	7.05304	28.73096	35.6077	68.99469	-26.2725	-19.4405	-24.8061	-74.7123	400.6189	163.5198	198.7233	0.945801
PF4L	14	-14.8352	2.456024	1.717377	1.986221	5.625595	23.96391	30.02812	62.74481	-3.97992	-1.31326	-1.43192	-0.89294	16.79919	150.6147	444.4194	-0.35263
PF5L	15	-20.3084	2.999481	2.246521	2.606598	7.632538	33.50702	39.0834	86.7178	-2.72781	-0.53839	-0.56195	1.093506	15.20557	-199.776	300.6637	-1.09033
Ip	16	-0.65479	0.39844	0.250672	0.287969	0.757769	2.9888	4.106287	6.647198	0.39844	0.250672	0.287969	0.757769	2.9888	4.106287	6.647198	0.205512

FY		Influence	Matrix	N/rad													
OH	1	0.00E+00	101.6216	132.1296	87.8682	115.5602	56.18751	13.25849	12.59733	-101.621	-132.129	-87.8677	-115.56	-56.1874	-13.2583	-12.5974	1.15E-04
PF1AU	2	-101.118	0.00E+00	384.1478	118.9599	77.54909	0.139336	-8.96284	-10.4976	-0.15052	-9.56E-02	-0.14978	-0.4568	-2.08736	-2.97952	-5.23168	-0.41885
PF1bU	3	-131.409	-386.426	0.00E+00	13.84991	35.47831	-9.61017	-7.17572	-7.91616	-9.66E-02	-6.30E-02	-9.43E-02	-0.28422	-1.29785	-1.85637	-3.34522	-0.21371
PF1cU	4	-87.757	-119.389	-13.8709	0.00E+00	67.80286	-13.4356	-8.80649	-9.60769	-0.14898	-9.25E-02	-0.12476	-0.35941	-1.56134	-2.19689	-3.96695	-0.23739
PF2U	5	-115.714	-77.7934	-35.61	-68.2043	0.00E+00	-69.1412	-26.9411	-28.6129	-0.45662	-0.28304	-0.36006	-1.00674	-4.25728	-5.93188	-10.8552	-0.55093
PF3U	6	-56.2119	-0.1395	9.6224	13.45625	69.21666	0.00E+00	-157.733	-149.975	-2.08676	-1.29659	-1.56193	-4.25708	-17.5993	-24.5514	-46.0942	-1.64419
PF4U	7	-13.2569	8.966514	7.175429	8.808064	26.94148	157.7714	0.00E+00	-368.7	-0.83501	0.288889	-5.35E-02	-3.78803	-22.4096	-33.9093	-67.3666	0.65353
PF5U	8	-12.5961	10.50075	7.915802	9.609217	28.61358	149.9904	371.0913	0.00E+00	-5.23136	-3.34403	-3.96774	-10.8557	-46.0978	-69.5098	-140.886	-1.53568
PF1AL	9	101.1179	0.150541	9.56E-02	0.149777	0.456797	2.08738	2.979534	5.231685	0.00E+00	-384.148	-118.96	-77.5491	-0.13934	8.962835	10.49761	0.418849
PF1bL	10	131.4086	9.55E-02	6.19E-02	9.32E-02	0.283148	1.296791	1.855291	3.344139	386.4264	0.00E+00	-13.8499	-35.4783	9.61014	7.175722	7.916151	0.213699
PF1cL	11	87.75694	0.149756	9.33E-02	0.125511	0.360171	1.562139	2.197661	3.967718	119.3888	13.87093	0.00E+00	-67.8029	13.43558	8.80649	9.607681	0.23738
PF2L	12	115.7142	0.456672	0.283127	0.360149	1.00679	4.257355	5.931921	10.85529	77.79339	35.61006	68.20438	0.00E+00	69.14127	26.94106	28.61289	0.550955
PF3L	13	56.21167	2.086667	1.296516	1.561787	4.257044	17.59918	24.55125	46.09405	0.139395	-9.62249	-13.4564	-69.2168	0.00E+00	157.7327	149.9749	1.644278
PF4L	14	13.25691	2.97919	1.855294	2.19768	5.932143	24.55371	36.0535	69.51076	-8.96656	-7.17546	-8.80807	-26.9415	-157.772	0.00E+00	368.6999	-0.65354
PF5L	15	12.59614	5.231288	3.343943	3.967732	10.85565	46.09769	69.50972	140.8862	-10.5008	-7.91585	-9.60928	-28.6136	-149.991	-371.092	0.00E+00	1.535666
Ip	16	-1.55E-08	0.419172	0.212848	0.238377	0.551498	1.645014	1.489633	1.53422	-0.41917	-0.21285	-0.23838	-0.5515	-1.64501	-1.48963	-1.53422	0.00E+00

Moment Influence Coefficients

		OH	PF1AU	PF1bU	PF1cU	PF2U	PF3U	PF4U	PF5U	PF1AL	PF1bL	PF1cL	PF2L	PF3L	PF4L	PF5L	Ip
MZ		Influence	Matrix	N-m/rad													
OH	1	0.00E+00	-5784.29	-2838.07	-1513.56	-1616.71	-1121.45	-371.817	-348.327	5784.292	2838.077	1513.561	1616.714	1121.453	371.8189	348.3287	1.54E-03
PF1AU	2	7.152492	0.00E+00	-73.6636	-20.0842	-10.7058	-1.67E-02	1.050949	1.221679	4.40E-02	2.56E-02	2.81E-02	7.11E-02	0.266337	0.352855	0.613915	4.54E-02
PF1bU	3	0.450232	-6.49832	0.00E+00	-0.48198	-0.75231	0.146579	0.101039	0.110743	3.10E-03	1.88E-03	2.03E-03	5.06E-03	1.95E-02	2.64E-02	4.72E-02	2.47E-03
PF1cU	4	-4.01E-02	-1.14453	-0.29893	0.00E+00	-1.36518	0.137595	7.59E-02	8.12E-02	2.03E-03	1.17E-03	1.35E-03	3.36E-03	1.35E-02	1.80E-02	3.27E-02	1.64E-03
PF2U	5	3.73E-02	3.25E-02	8.51E-03	-3.28E-02	0.00E+00	-2.93E-02	-9.37E-03	-9.36E-03	1.93E-04	4.89E-04	-2.55E-04	-2.66E-05	-5.84E-04	-1.09E-03	-2.90E-03	-5.31E-05
PF3U	6	3.28E-02	-8.45E-05	-1.69E-02	-2.42E-02	-0.13652	0.00E+00	-0.19286	-0.17624	-1.35E-03	-6.15E-04	-1.23E-03	-2.31E-03	-1.18E-02	-1.78E-02	-3.60E-02	1.01E-05
PF4U	7	1.81E-03	1.45E-02	1.02E-02	1.26E-02	3.48E-02	0.208274	0.00E+00	1.686089	-8.70E-02	-8.69E-02	-8.68E-02	-8.67E-02	-8.36E-02	-7.60E-02	-5.52E-02	-8.88E-02
PF5U	8	6.00E-04	2.37E-03	1.34E-03	1.66E-03	4.70E-03	2.13E-02	0.34347	0.00E+00	3.96E-04	9.27E-05	2.31E-04	5.87E-04	4.05E-03	4.44E-03	1.63E-02	-6.30E-04
PF1AL	9	-7.15235	-4.34E-02	-2.57E-02	-2.80E-02	-7.17E-02	-0.2658	-0.35305	-0.61401	0.00E+00	73.66515	20.08523	10.70527	1.58E-02	-1.05117	-1.22179	-4.59E-02
PF1bL	10	-0.45037	-3.05E-03	-1.71E-03	-1.99E-03	-5.31E-03	-1.96E-02	-2.65E-02	-4.71E-02	6.498307	0.00E+00	0.482262	0.752478	-0.14651	-0.1009	-0.11069	-2.63E-03
PF1cL	11	3.99E-02	-1.98E-03	-1.10E-03	-1.35E-03	-3.52E-03	-1.34E-02	-1.81E-02	-3.26E-02	1.14442	0.298811	0.00E+00	1.365146	-0.13729	-7.59E-02	-8.14E-02	-1.71E-03
PF2L	12	-3.69E-02	-3.48E-04	-3.97E-04	4.51E-05	-2.21E-04	4.78E-04	1.18E-03	2.56E-03	-3.21E-02	-7.84E-03	3.30E-02	0.00E+00	2.88E-02	9.07E-03	8.70E-03	-2.28E-04
PF3L	13	-3.30E-02	1.25E-03	9.91E-04	1.05E-03	2.59E-03	1.25E-02	1.79E-02	3.62E-02	3.17E-04	1.61E-02	2.39E-02	0.136112	0.00E+00	0.193252	0.176294	5.08E-05
PF4L	14	-1.84E-03	-1.38E-04	-1.84E-04	-1.52E-04	-3.86E-04	-3.46E-03	-1.12E-02	-3.20E-02	-0.01459	-1.02E-02	-1.27E-02	-3.48E-02	-0.20831	0.00E+00	-1.68622	8.86E-02
PF5L	15	-5.71E-04	-3.25E-04	-9.78E-05	-4.88E-04	-9.94E-04	-3.86E-03	-4.33E-03	-1.58E-02	-2.34E-03	-1.28E-03	-1.46E-03	-4.74E-03	-2.13E-02	-0.34239	0.00E+00	5.13E-04
Ip	16	-4.60E-10	-1.95E-02	-1.32E-02	-1.53E-02	-4.05E-02	-0.16181	-0.22447	-0.26779	1.95E-02	1.32E-02	1.53E-02	4.05E-02	0.161809	0.224468	0.267794	0.00E+00

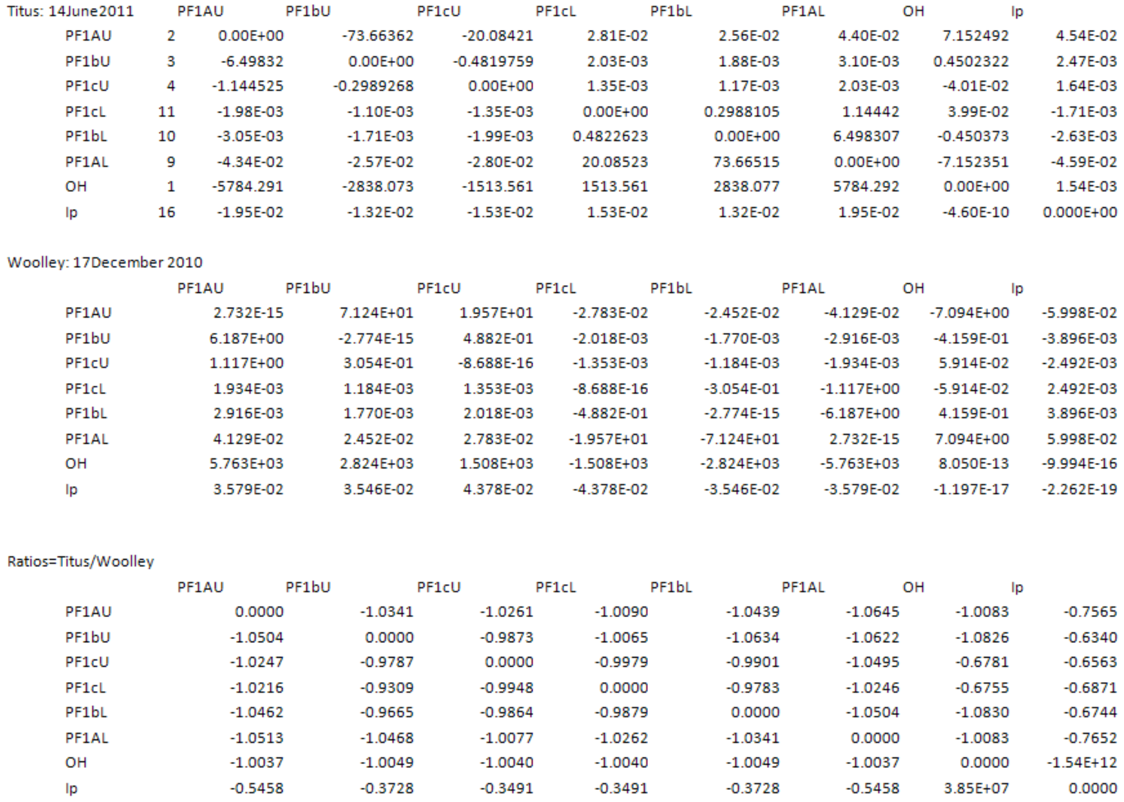
			OH	PF1AU	PF1bU	PF1cU	PF2U	PF3U	PF4U	PF5U	PF1AL	PF1bL	PF1cL	PF2L	PF3L	PF4L	PF5L	Ip
	FX		Influence	Matrix	lb/coil													
OH		1	35636.87	5375.921	2413.77	1366.02	1601.863	1707.925	1097.343	1525.827	5375.896	2413.779	1366.026	1601.869	1707.955	1097.327	1525.816	81.99184
PF1AU		2	-198.695	1210.15	1136.58	568.9702	543.9351	378.4394	138.1346	160.8414	3.80453	2.347582	2.695784	7.155424	28.07685	36.00359	66.28319	2.671473
PF1bU		3	-157.398	-207.854	485.9707	653.2532	470.8225	232.2846	73.81293	86.10785	1.901274	1.191206	1.371384	3.672844	14.54961	18.51867	34.44823	1.178748
PF1cU		4	-70.456	-93.7076	-262.946	215.8956	512.7339	208.2837	62.63983	72.91006	1.570529	0.988117	1.137432	3.052909	12.12413	15.4072	28.76452	0.925248
PF2U		5	-44.0644	-62.3646	-116.47	-193.273	412.634	448.0633	115.776	135.5233	2.779149	1.769976	2.038865	5.508555	22.01978	27.76412	52.2799	1.42574
PF3U		6	-30.4419	-37.1087	-27.4592	-35.0379	-105.528	565.8596	230.966	280.6895	4.777452	3.146835	3.62461	9.962073	40.58155	50.29444	97.45251	1.335823
PF4U		7	-20.9541	-5.62166	-1.85491	-2.02253	-1.26121	23.72829	212.7378	627.7261	3.469023	2.425732	2.805486	7.945925	33.84821	42.41362	88.62468	-0.49812
PF5U		8	-28.6848	-3.85311	-0.76059	-0.79395	1.544408	21.47726	-282.177	424.6766	4.236614	3.173215	3.681638	10.78068	47.32739	55.20375	122.4856	-1.5401
PF1AL		9	-198.695	3.804616	2.347669	2.696043	7.155682	28.07676	36.00411	66.28371	1210.15	1136.579	568.9698	543.9357	378.4399	138.1348	160.8412	2.67199
PF1bL		10	-157.397	1.901317	1.191206	1.371427	3.673017	14.54969	18.51884	34.44841	-207.854	485.9706	653.2534	470.8228	232.2848	73.81311	86.10798	1.179007
PF1cL		11	-70.456	1.570529	0.988095	1.137497	3.053017	12.12415	15.40724	28.76454	-93.7075	-262.946	215.8956	512.7341	208.2836	62.63991	72.91008	0.925334
PF2L		12	-44.0644	2.779106	1.770062	2.038865	5.508642	22.0197	27.76403	52.27964	-62.3647	-116.47	-193.273	412.6341	448.0633	115.7761	135.5235	1.425783
PF3L		13	-30.4417	4.777581	3.146619	3.624912	9.96216	40.58142	50.29457	97.45247	-37.109	-27.459	-35.0377	-105.528	565.8595	230.9658	280.6894	1.335909
PF4L		14	-20.9542	3.469044	2.425732	2.805465	7.945947	33.84815	42.41362	88.62475	-5.62149	-1.85494	-2.02253	-1.26125	23.72825	212.7378	627.7261	-0.49808
PF5L		15	-28.6848	4.236657	3.173129	3.681724	10.78068	47.32743	55.20388	122.4857	-3.85294	-0.76046	-0.79373	1.544537	21.4773	-282.177	424.6765	-1.54005
Ip		16	-0.92487	0.562782	0.354065	0.406746	1.07032	4.22157	5.799981	9.388924	0.562782	0.354065	0.406746	1.07032	4.22157	5.79998	9.388924	0.290278

	FY		Influence	Matrix	lb/coil													
OH		1	0.00E+00	143.5368	186.6282	124.1106	163.2246	79.3628	18.72713	17.79327	-143.536	-186.628	-124.11	-163.224	-79.3626	-18.7268	-17.7933	1.63E-04
PF1AU		2	-142.825	0.00E+00	542.5947	168.0264	109.5352	0.196807	-12.6597	-14.8275	-0.21261	-0.13498	-0.21157	-0.64521	-2.94831	-4.20846	-7.38955	-0.59161
PF1bU		3	-185.61	-545.813	0.00E+00	19.56249	50.1118	-13.574	-10.1355	-11.1813	-0.13644	-8.89E-02	-0.13317	-0.40145	-1.83317	-2.62205	-4.725	-0.30186
PF1cU		4	-123.954	-168.632	-19.5922	0.00E+00	95.76905	-18.9773	-12.4388	-13.5705	-0.21043	-0.13065	-0.17622	-0.50765	-2.20534	-3.10303	-5.60317	-0.3353
PF2U		5	-163.442	-109.88	-50.2978	-96.336	0.00E+00	-97.6594	-38.0533	-40.4146	-0.64495	-0.39979	-0.50857	-1.42198	-6.01325	-8.37857	-15.3326	-0.77818
PF3U		6	-79.3972	-0.19704	13.59129	19.00645	97.76599	0.00E+00	-222.792	-211.834	-2.94748	-1.83139	-2.20618	-6.01297	-24.8583	-34.6779	-65.1063	-2.32235
PF4U		7	-18.7248	12.66487	10.13503	12.44107	38.05385	222.8463	0.00E+00	-520.775	-1.17943	0.408045	-7.56E-02	-5.35045	-31.6527	-47.8957	-95.1529	0.923087
PF5U		8	-17.7915	14.83193	11.18078	13.57267	40.41563	211.856	524.1528	0.00E+00	-7.38911	-4.72331	-5.60429	-15.3333	-65.1114	-98.18	-198.997	-2.16909
PF1AL		9	142.8253	0.212634	0.134995	0.211554	0.645209	2.948348	4.208483	7.389563	0.00E+00	-542.595	-168.026	-109.535	-0.19681	12.65968	14.82749	0.591609
PF1bL		10	185.6099	0.134959	8.74E-02	0.131672	0.399936	1.83167	2.620531	4.723474	545.8131	0.00E+00	-19.5625	-50.1118	13.57397	10.13544	11.18127	0.301843
PF1cL		11	123.9535	0.211524	0.131741	0.17728	0.508729	2.206463	3.104116	5.604257	168.6322	19.59218	0.00E+00	-95.7691	18.97726	12.43884	13.5705	0.335291
PF2L		12	163.4421	0.645032	0.399907	0.508697	1.422053	6.013358	8.378621	15.3327	109.8803	50.2979	96.33618	0.00E+00	97.6595	38.05326	40.41466	0.778203
PF3L		13	79.39692	2.94734	1.831281	2.205967	6.012919	24.8582	34.67775	65.10616	0.19689	-13.5914	-19.0066	-97.7662	0.00E+00	222.7916	211.8341	2.322483
PF4L		14	18.7249	4.207996	2.620535	3.104143	8.378935	34.68122	50.92426	98.1814	-12.6649	-10.1351	-12.4411	-38.0539	-222.846	0.00E+00	520.775	-0.9231
PF5L		15	17.79158	7.389003	4.723197	5.604276	15.33321	65.1113	98.17993	198.9966	-14.832	-11.1809	-13.5728	-40.4157	-211.856	-524.153	0.00E+00	2.169071
Ip		16	-2.20E-08	0.592064	0.30064	0.336698	0.778971	2.323522	2.104052	2.16703	-0.59206	-0.30064	-0.3367	-0.77897	-2.32352	-2.10405	-2.16703	0.00E+00

Moment Influence Coefficients

			OH	PF1AU	PF1bU	PF1cU	PF2U	PF3U	PF4U	PF5U	PF1AL	PF1bL	PF1cL	PF2L	PF3L	PF4L	PF5L	Ip
	MZ		Influence	Matrix	in-lb/coil													
OH		1	0.00E+00	-321657	-157822	-84167.1	-89903.2	-62362.4	-20676.2	-19370	321656.8	157821.7	84167.15	89903.32	62362.52	20676.36	19370.1	8.54E-02
PF1AU		2	397.7406	0.00E+00	-4096.34	-1116.86	-595.338	-0.92864	58.44186	67.93596	2.444199	1.423487	1.561501	3.951034	14.81066	19.62181	34.139	2.523012
PF1bU		3	25.03682	-361.363	0.00E+00	-26.802	-41.8351	8.151034	5.618644	6.158261	0.172254	0.10466	0.112964	0.281341	1.082232	1.468651	2.622284	0.137351
PF1cU		4	-2.22988	-63.6455	-16.6229	0.00E+00	-75.916	7.651491	4.222968	4.517146	0.112876	6.52E-02	7.51E-02	0.186888	0.749204	1.003491	1.818811	9.10E-02
PF2U		5	2.072851	1.806785	0.473095	-1.82446	0.00E+00	-1.62928	-0.52132	-0.5205	1.08E-02	2.72E-02	-1.42E-02	-1.48E-03	-3.24E-02	-6.05E-02	-0.16128	-2.96E-03
PF3U		6	1.826376	-4.70E-03	-0.94109	-1.34819	-7.59144	0.00E+00	-10.7248	-9.80047	-7.53E-02	-3.42E-02	-6.82E-02	-0.1283	-0.65777	-0.98787	-2.00319	5.60E-04
PF4U		7	0.100596	0.807841	0.565928	0.700303	1.934912	11.58186	0.00E+00	93.76116	-4.84022	-4.83304	-4.82831	-4.82088	-4.64866	-4.22488	-3.06851	-4.93602
PF5U		8	3.33E-02	0.132045	7.43E-02	9.26E-02	0.261356	1.182083	19.09991	0.00E+00	2.20E-02	5.15E-03	1.29E-02	3.26E-02	0.225394	0.246646	0.908687	-3.50E-02
PF1AL		9	-397.733	-2.41395	-1.4274	-1.55944	-3.98945	-14.781	-19.6325	-34.1442	0.00E+00	4096.422	1116.913	595.3058	0.876383	-58.4543	-67.9422	-2.55193
PF1bL		10	-25.0447	-0.16964	-9.51E-02	-0.1107	-0.29508	-1.08845	-1.47231	-2.62085	361.3623	0.00E+00	26.81797	41.84433	-8.14722	-5.61095	-6.15559	-0.14611
PF1cL		11	2.22138	-0.10987	-6.13E-02	-7.48E-02	-0.1958	-0.74686	-1.00631	-1.8136	63.63967	16.61646	0.00E+00	75.91399	-7.63428	-4.22323	-4.52402	-9.52E-02
PF2L		12	-2.05474	-1.93E-02	-2.21E-02	2.51E-03	-1.23E-02	2.66E-02	6.56E-02	0.142118	-1.78606	-0.4361	1.835042	0.00E+00	1.602775	0.504313	0.483915	-1.27E-02
PF3L		13	-1.83614	6.95E-02	5.51E-02	5.81E-02	0.144168	0.694368	0.993703	2.012362	1.76E-02	0.894526	1.327448	7.569005	0.00E+00	10.74651	9.803458	2.82E-03
PF4L		14	-0.10234	-7.69E-03	-1.02E-02	-8.44E-03	-2.15E-02	-0.19217	-0.62038	-1.77811	-0.81144	-0.5678	-0.70574	-1.93624	-11.5836	0.00E+00	-93.7685	4.92904
PF5L		15	-3.17E-02	-1.81E-02	-5.44E-03	-2.72E-02	-5.53E-02	-0.21444	-0.24078	-0.879	-0.12985	-7.13E-02	-8.10E-02	-0.26365	-1.1841	-19.0401	0.00E+00	2.85E-02
Ip		16	-2.56E-08	-1.08623	-0.73522	-0.84979	-2.25193	-8.99796	-12.4824	-14.8917	1.086227	0.735221	0.849789	2.251943	8.997968	12.48235	14.89168	0.00E+00

Comparison with Bob Woolley's Moment Influence Coefficients (2011 Coil Build)



Titus: 14June2011		PF1AU	PF1bU	PF1cU	PF1cL	PF1bL	PF1AL	OH	Ip
PF1AU	2	0.00E+00	-73.66362	-20.08421	2.81E-02	2.56E-02	4.40E-02	7.152492	4.54E-02
PF1bU	3	-6.49832	0.00E+00	-0.4819759	2.03E-03	1.88E-03	3.10E-03	0.4502322	2.47E-03
PF1cU	4	-1.144525	-0.2989268	0.00E+00	1.35E-03	1.17E-03	2.03E-03	-4.01E-02	1.64E-03
PF1cL	11	-1.98E-03	-1.10E-03	-1.35E-03	0.00E+00	0.2988105	1.14442	3.99E-02	-1.71E-03
PF1bL	10	-3.05E-03	-1.71E-03	-1.99E-03	0.4822623	0.00E+00	6.498307	-0.450373	-2.63E-03
PF1AL	9	-4.34E-02	-2.57E-02	-2.80E-02	20.08523	73.66515	0.00E+00	-7.152351	-4.59E-02
OH	1	-5784.291	-2838.073	-1513.561	1513.561	2838.077	5784.292	0.00E+00	1.54E-03
Ip	16	-1.95E-02	-1.32E-02	-1.53E-02	1.53E-02	1.32E-02	1.95E-02	-4.60E-10	0.000E+00

Woolley: 17December 2010

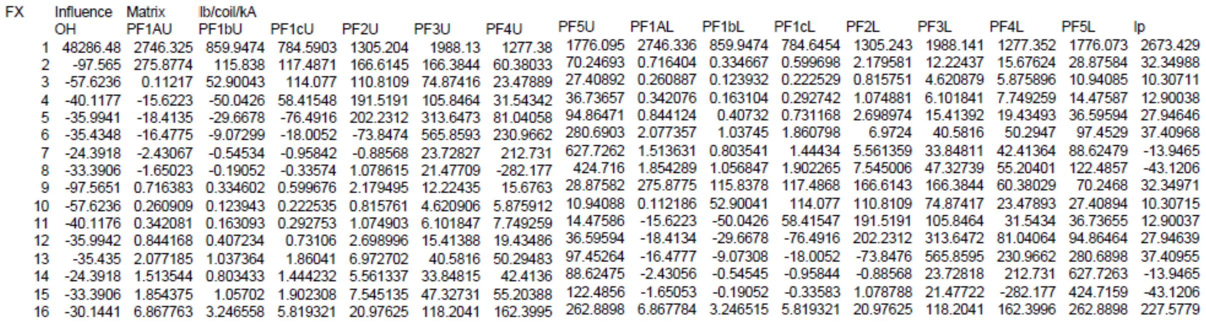
	PF1AU	PF1bU	PF1cU	PF1cL	PF1bL	PF1AL	OH	Ip
PF1AU	2.732E-15	7.124E+01	1.957E+01	-2.783E-02	-2.452E-02	-4.129E-02	-7.094E+00	-5.998E-02
PF1bU	6.187E+00	-2.774E-15	4.882E-01	-2.018E-03	-1.770E-03	-2.916E-03	-4.159E-01	-3.896E-03
PF1cU	1.117E+00	3.054E-01	-8.688E-16	-1.353E-03	-1.184E-03	-1.934E-03	5.914E-02	-2.492E-03
PF1cL	1.934E-03	1.184E-03	1.353E-03	-8.688E-16	-3.054E-01	-1.117E+00	-5.914E-02	2.492E-03
PF1bL	2.916E-03	1.770E-03	2.018E-03	-4.882E-01	-2.774E-15	-6.187E+00	4.159E-01	3.896E-03
PF1AL	4.129E-02	2.452E-02	2.783E-02	-1.957E+01	-7.124E+01	2.732E-15	7.094E+00	5.998E-02
OH	5.763E+03	2.824E+03	1.508E+03	-1.508E+03	-2.824E+03	-5.763E+03	8.050E-13	-9.994E-16
Ip	3.579E-02	3.546E-02	4.378E-02	-4.378E-02	-3.546E-02	-3.579E-02	-1.197E-17	-2.262E-19

Ratios=Titus/Woolley

	PF1AU	PF1bU	PF1cU	PF1cL	PF1bL	PF1AL	OH	Ip
PF1AU	0.0000	-1.0341	-1.0261	-1.0090	-1.0439	-1.0645	-1.0083	-0.7565
PF1bU	-1.0504	0.0000	-0.9873	-1.0065	-1.0634	-1.0622	-1.0826	-0.6340
PF1cU	-1.0247	-0.9787	0.0000	-0.9979	-0.9901	-1.0495	-0.6781	-0.6563
PF1cL	-1.0216	-0.9309	-0.9948	0.0000	-0.9783	-1.0246	-0.6755	-0.6871
PF1bL	-1.0462	-0.9665	-0.9864	-0.9879	0.0000	-1.0504	-1.0830	-0.6744
PF1AL	-1.0513	-1.0468	-1.0077	-1.0262	-1.0341	0.0000	-1.0083	-0.7652
OH	-1.0037	-1.0049	-1.0040	-1.0040	-1.0049	-1.0037	0.0000	-1.54E+12
Ip	-0.5458	-0.3728	-0.3491	-0.3491	-0.3728	-0.5458	3.85E+07	0.0000

Comparison with Ron Hatcher's Radial Influence Coefficients (2010 Coil Build)

(Titus)

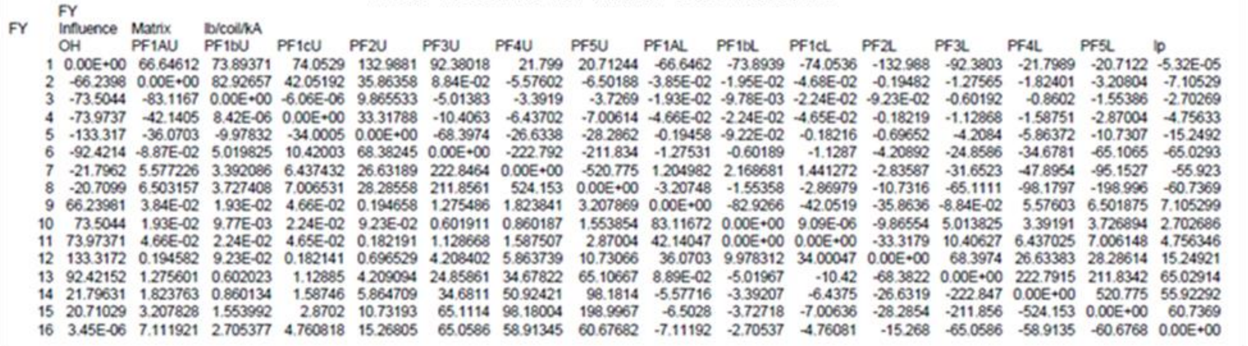


FX	Influence	Matrix	lb/coil/kA													
	OH	PF1AU	PF1bU	PF1cU	PF2U	PF3U	PF4U	PF5U	PF1AL	PF1bL	PF1cL	PF2L	PF3L	PF4L	PF5L	Ip
1	48286.48	2746.325	859.9474	784.5903	1305.204	1988.13	1277.38	1776.095	2746.336	859.9474	784.6454	1305.243	1988.141	1277.352	1776.073	2673.429
2	-97.565	275.8774	115.838	117.4871	166.6145	166.3844	60.38033	70.24693	0.716404	0.334667	0.599698	2.179581	12.22437	15.67624	28.87584	32.34988
3	-57.6236	0.11217	52.90043	114.077	110.8109	74.87416	23.47889	27.40892	0.260887	0.123932	0.222529	0.815751	4.620879	5.875896	10.94085	10.30711
4	-40.1177	-15.6223	-50.0426	58.41548	191.5191	105.8464	31.54342	36.73657	0.342076	0.163104	0.292742	1.074881	6.101841	7.749259	14.47587	12.90038
5	-35.9941	-18.4135	-29.6678	-76.4916	202.2312	313.6473	81.04058	94.86471	0.844124	0.40732	0.731168	2.698974	15.41392	19.43493	36.59594	27.94646
6	-35.4348	-16.4775	-9.07299	-18.0052	-73.8474	565.8593	230.9662	280.6903	2.077357	1.03745	1.860798	6.9724	40.5816	50.2947	97.4529	37.40968
7	-24.3918	-2.43067	-0.54534	-0.95842	-0.88568	23.72827	212.731	627.7262	1.513631	0.803541	1.44434	5.561359	33.84811	42.41364	88.62479	-13.9465
8	-33.3906	-1.65023	-0.19052	-0.33574	1.078615	21.47709	-282.177	424.716	1.854289	1.056847	1.902265	7.545006	47.32739	55.20401	122.4857	-43.1206
9	-97.5651	0.716383	0.334602	0.599676	2.179495	12.22435	15.6763	28.87582	275.8775	115.8378	117.4868	166.6143	166.3844	60.38029	70.2468	32.34971
10	-57.6236	0.260909	0.123943	0.222535	0.815761	4.620906	5.875912	10.94088	0.112186	52.90041	114.077	110.8109	74.87417	23.47893	27.40894	10.30715
11	-40.1176	0.342081	0.163093	0.292753	1.074903	6.101847	7.749259	14.47586	-15.6223	-50.0426	58.41547	191.5191	105.8464	31.5434	36.73655	12.90037
12	-35.9942	0.844168	0.407234	0.73106	2.698996	15.41388	19.43486	36.59594	-18.4134	-29.6678	-76.4916	202.2312	313.6472	81.04064	94.86464	27.94639
13	-35.435	2.077185	1.037364	1.86041	6.972702	40.5816	50.29483	97.45264	-16.4777	-9.07308	-18.0052	-73.8476	565.8595	230.9662	280.6898	37.40955
14	-24.3918	1.513544	0.803433	1.444232	5.561337	33.84815	42.4136	88.62475	-2.43056	-0.54545	-0.95844	-0.88568	23.72818	212.731	627.7263	-13.9465
15	-33.3906	1.854375	1.05702	1.902308	7.545135	47.32731	55.20388	122.4856	-1.65053	-0.19052	-0.33583	1.078788	21.47722	-282.177	424.7159	-43.1206
16	-30.1441	6.867763	3.246558	5.819321	20.97625	118.2041	162.3995	262.8898	6.867784	3.246515	5.819321	20.97625	118.2041	162.3996	262.8898	227.5779

(Hatcher ref [1])

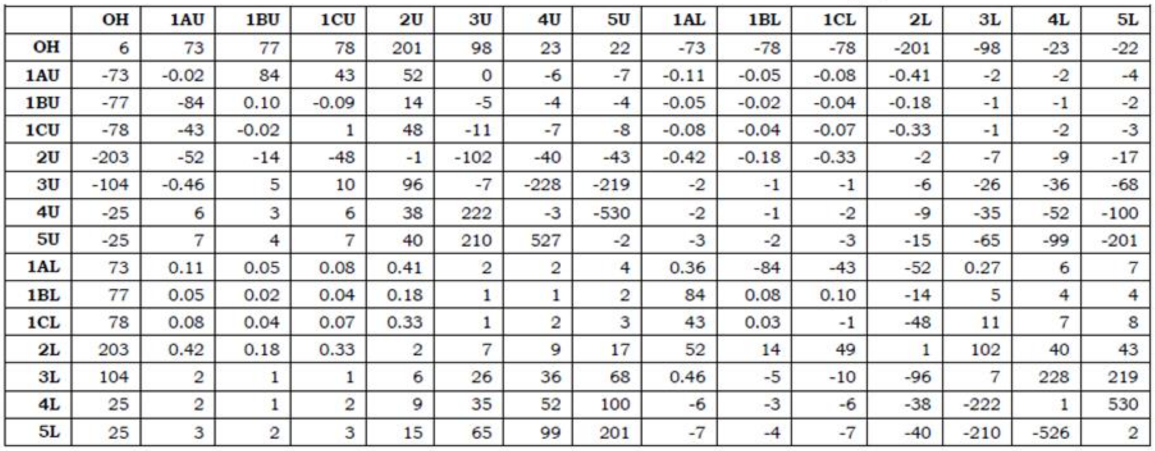
	OH	1AU	1BU	1CU	2U	3U	4U	5U	1AL	1BL	1CL	2L	3L	4L	5L
OH	47683	2736	856	780	1839	1909	1225	1690	2736	856	780	1839	1909	1225	1690
1AU	-134	266	115	117	236	162	58	66	1	0.28	1	3	10	14	26
1BU	-68	-2	49	114	158	73	22	25	0.22	0.10	0.18	1	4	5	10
1CU	-50	-17	-52	54	273	103	30	34	0.28	0.13	0.24	1	5	7	13
2U	-78	-29	-44	-112	380	436	109	125	1	0.45	1	4	18	24	45
3U	-67	-19	-10	-20	-116	495	219	263	2	1	1	7	32	43	84
4U	-44	-3	-1	-2	-5	12	179	617	1	1	1	6	27	37	80
5U	-61	-3	-1	-1	-3	6	-300	353	1	1	1	8	37	47	108
1AL	-134	1	0.28	1	3	10	14	26	266	115	117	236	162	58	66
1BL	-68	0.22	0.10	0.18	1	4	5	10	-2	49	114	158	73	22	25
1CL	-50	0.28	0.13	0.24	1	5	7	13	-17	-52	53	273	103	30	34
2L	-78	1	0.45	1	4	18	24	45	-29	-44	-113	382	436	109	125
3L	-67	2	1	1	7	32	43	84	-19	-10	-20	-116	495	219	263
4L	-44	1	1	1	6	27	37	80	-3	-1	-2	-5	12	178	617
5L	-61	1	1	1	8	37	47	108	-3	-1	-1	-3	6	-300	354

Titus Results for Axial Coefficients



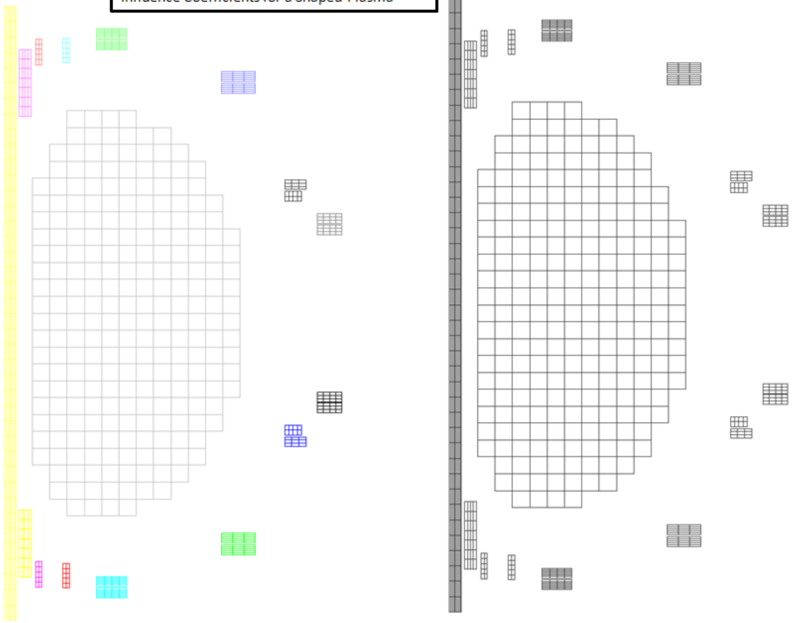
	FY															
FY	Influence	Matrix	lb/coil/kA													
	OH	PF1AU	PF1bU	PF1cU	PF2U	PF3U	PF4U	PF5U	PF1AL	PF1bL	PF1cL	PF2L	PF3L	PF4L	PF5L	Ip
1	0.00E+00	66.64612	73.89371	74.0529	132.9881	92.38018	21.799	20.71244	-66.6462	-73.8939	-74.0536	-132.988	-92.3803	-21.7989	-20.7122	-5.32E-05
2	-66.2398	0.00E+00	82.92657	42.05192	35.86358	8.84E-02	-5.57602	-6.50188	-3.85E-02	-1.95E-02	-4.68E-02	-0.19482	-1.27565	-1.82401	-3.20804	-7.10529
3	-73.5044	-83.1167	0.00E+00	-6.06E-06	9.865533	-5.01383	-3.3919	-3.7269	-1.93E-02	-9.78E-03	-2.24E-02	-9.23E-02	-0.60192	-0.8602	-1.55386	-2.70269
4	-73.9737	-42.1405	8.42E-06	0.00E+00	33.31788	-10.4063	-6.43702	-7.00614	-4.66E-02	-2.24E-02	-4.65E-02	-0.18219	-1.12868	-1.58751	-2.87004	-4.75633
5	-133.317	-36.0703	-9.97832	-34.0005	0.00E+00	-68.3974	-26.6338	-28.2862	-0.19458	-9.22E-02	-0.18216	-0.69652	-4.2084	-5.86372	-10.7307	-15.2492
6	-92.4214	-8.87E-02	5.019825	10.42003	68.38245	0.00E+00	-222.792	-211.834	-1.27531	-0.60189	-1.1287	-4.20892	-24.8586	-34.6781	-65.1065	-65.0293
7	-21.7962	5.577226	3.392086	6.437432	26.63189	222.8464	0.00E+00	-520.775	1.204982	2.168681	1.441272	-2.83587	-31.6523	-47.8954	-95.1527	-55.923
8	-20.7099	6.503157	3.727408	7.006531	28.28558	211.8561	524.153	0.00E+00	-3.20748	-1.55358	-2.86979	-10.7316	-65.1111	-98.1797	-198.996	-60.7369
9	66.23981	3.84E-02	1.93E-02	4.66E-02	0.194658	1.275486	1.823841	3.207869	0.00E+00	-82.9266	-42.0519	-35.8636	-8.84E-02	5.57603	6.501875	7.105299
10	73.5044	1.93E-02	9.77E-03	2.24E-02	9.23E-02	0.601911	0.860187	1.553854	83.11672	0.00E+00	9.09E-06	-9.86554	5.013825	3.39191	3.726894	2.702686
11	73.97371	4.66E-02	2.24E-02	4.65E-02	0.182191	1.128668	1.587507	2.87004	42.14047	0.00E+00	0.00E+00	-33.3179	10.40627	6.437025	7.006148	4.756346
12	133.3172	0.194582	9.23E-02	0.182141	0.696529	4.208402	5.863739	10.73066	36.0703	9.978312	34.00047	0.00E+00	68.3974	26.63383	28.28614	15.24921
13	92.42152	1.275601	0.602023	1.12885	4.209094	24.85861	34.67822	65.10667	8.89E-02	-5.01967	-10.42	-68.3822	0.00E+00	222.7915	211.8342	65.02914
14	21.79631	1.823763	0.860134	1.58746	5.864709	34.6811	50.92421	98.1814	-5.57716	-3.39207	-6.4375	-26.6319	-222.847	0.00E+00	520.775	55.92292
15	20.71029	3.207828	1.553992	2.8702	10.73193	65.1114	98.18004	198.9967	-6.5028	-3.72718	-7.00636	-28.2854	-211.856	-524.153	0.00E+00	60.7369
16	3.45E-06	7.111921	2.705377	4.760818	15.26805	65.0586	58.91345	60.67682	-7.11192	-2.70537	-4.76081	-15.268	-65.0586	-58.9135	-60.6768	0.00E+00

Hatcher Results for Axial Coefficients [1]



	OH	1AU	1BU	1CU	2U	3U	4U	5U	1AL	1BL	1CL	2L	3L	4L	5L
OH	6	73	77	78	201	98	23	22	-73	-78	-78	-201	-98	-23	-22
1AU	-73	-0.02	84	43	52	0	-6	-7	-0.11	-0.05	-0.08	-0.41	-2	-2	-4
1BU	-77	-84	0.10	-0.09	14	-5	-4	-4	-0.05	-0.02	-0.04	-0.18	-1	-1	-2
1CU	-78	-43	-0.02	1	48	-11	-7	-8	-0.08	-0.04	-0.07	-0.33	-1	-2	-3
2U	-203	-52	-14	-48	-1	-102	-40	-43	-0.42	-0.18	-0.33	-2	-7	-9	-17
3U	-104	-0.46	5	10	96	-7	-228	-219	-2	-1	-1	-6	-26	-36	-68
4U	-25	6	3	6	38	222	-3	-530	-2	-1	-2	-9	-35	-52	-100
5U	-25	7	4	7	40	210	527	-2	-3	-2	-3	-15	-65	-99	-201
1AL	73	0.11	0.05	0.08	0.41	2	2	4	0.36	-84	-43	-52	0.27	6	7
1BL	77	0.05	0.02	0.04	0.18	1	1	2	84	0.08	0.10	-14	5	4	4
1CL	78	0.08	0.04	0.07	0.33	1	2	3	43	0.03	-1	-48	11	7	8
2L	203	0.42	0.18	0.33	2	7	9	17	52	14	49	1	102	40	43
3L	104	2	1	1	6	26	36	68	0.46	-5	-10	-96	7	228	219
4L	25	2	1	2	9	35	52	100	-6	-3	-6	-38	-222	1	530
5L	25	3	2	3	15	65	99	201	-7	-4	-7	-40	-210	-526	2

Influence Coefficients for a Shaped Plasma



FX Influence Matrix lb/coil

1	2184.633	337.0884	150.602	85.25023	100.0352	106.7215	68.57568	95.35145	337.088	150.6022	85.24972	100.0361	106.7212	68.57516	95.35179	4.36636
2	-13.0325	74.58116	70.85085	35.52862	33.98438	23.64041	8.633018	10.05266	0.237816	0.146751	0.168535	0.4473	1.75518	2.250726	4.143437	0.220924
3	-9.86305	-13.0077	30.02943	40.7569	29.4003	14.51467	4.613392	5.381883	0.118819	7.44E-02	8.57E-02	0.229553	0.909404	1.157479	2.153139	9.16E-02
4	-4.42417	-5.86005	-16.4218	13.3616	31.99938	13.01482	3.915083	4.557014	9.81E-02	6.18E-02	7.11E-02	0.1908	0.757789	0.96299	1.797866	6.94E-02
5	-2.77526	-3.89755	-7.30427	-12.1373	25.79114	28.00179	7.23583	8.470176	0.173665	0.110615	0.127421	0.344258	1.376226	1.735252	3.267518	9.54E-02
6	-1.90668	-2.32413	-1.71882	-2.19336	-6.60047	35.25877	14.42838	17.53952	0.298596	0.196661	0.226562	0.622616	2.536441	3.143634	6.091092	4.55E-02
7	-1.30992	-0.35125	-0.11587	-0.12634	-7.89E-02	1.478745	13.28975	39.2435	0.216831	0.151606	0.175344	0.496588	2.11547	2.651024	5.539451	-4.06E-02
8	-1.793	-0.24064	-4.75E-02	-4.95E-02	9.65E-02	1.340241	-17.6072	26.26867	0.264815	0.198318	0.230105	0.673736	2.957825	3.450646	7.656071	-7.45E-02
9	-13.0325	0.237816	0.146751	0.168535	0.4473	1.75518	2.25072	4.143432	74.58116	70.85085	35.52862	33.98436	23.64041	8.633013	10.05265	0.226263
10	-9.86304	0.118822	7.45E-02	8.57E-02	0.229556	0.90941	1.157487	2.153144	-13.0077	30.02942	40.7569	29.40031	14.51467	4.6134	5.381889	9.28E-02
11	-4.42417	9.81E-02	6.18E-02	7.11E-02	0.190799	0.757788	0.962989	1.797865	-5.86005	-16.4218	13.3616	31.99938	13.01482	3.915082	4.557014	7.01E-02
12	-2.77527	0.173656	0.110615	0.127424	0.34425	1.376226	1.735249	3.26752	-3.89755	-7.30427	-12.1373	25.79114	28.00179	7.235833	8.470171	9.58E-02
13	-1.90666	0.298596	0.196664	0.226562	0.622622	2.536449	3.143647	6.091086	-2.32414	-1.71882	-2.19335	-6.60048	35.25877	14.42838	17.53951	4.50E-02
14	-1.30992	0.216826	0.1516	0.175342	0.496584	2.115465	2.651018	5.539452	-0.35126	-0.11587	-0.12634	-7.89E-02	1.478737	13.28975	39.2435	-4.08E-02
15	-1.793	0.26481	0.198318	0.230105	0.673736	2.957825	3.450652	7.656082	-0.24064	-4.75E-02	-4.95E-02	9.65E-02	1.340244	-17.6072	26.26867	-7.47E-02
16	-5.88E-02	2.04E-02	1.94E-02	2.41E-02	6.99E-02	0.274461	0.306199	0.453967	2.14E-02	2.02E-02	2.50E-02	7.18E-02	0.277376	0.307423	0.455098	7.49E-03

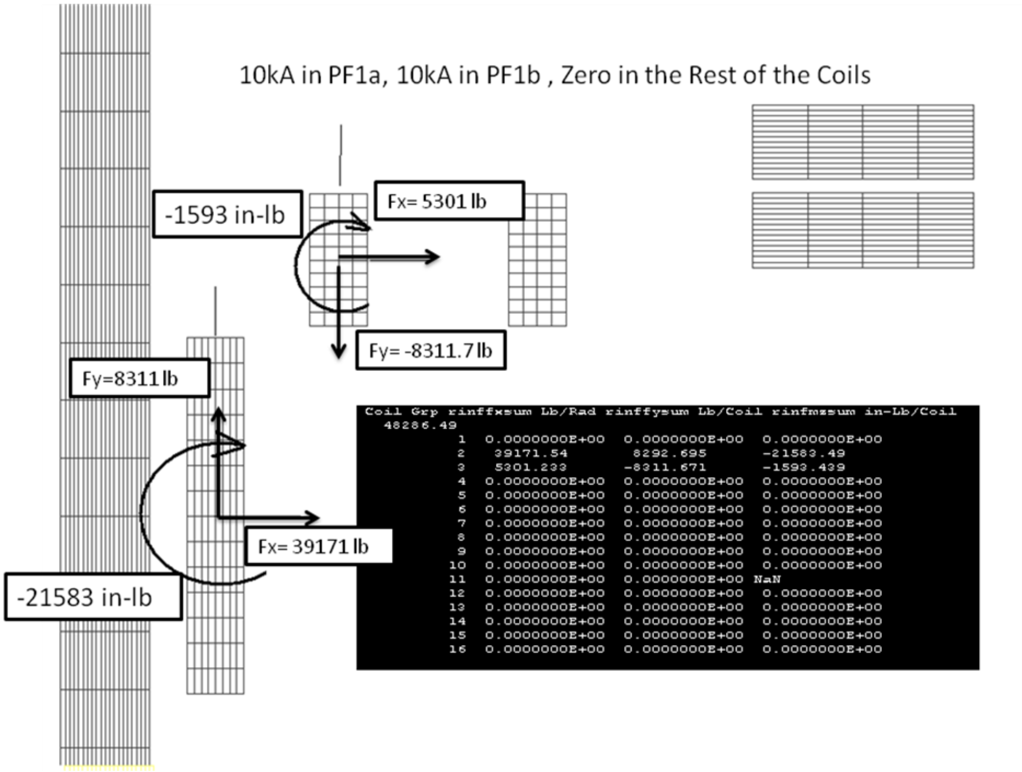
FY Influence Matrix lb/coil

1	0.00E+00	9.084172	11.79914	7.778748	10.1807	4.957735	1.170719	1.1123	-9.08418	-11.7992	-7.77876	-10.1807	-4.95773	-1.17074	-1.11231	-3.35E-04
2	-8.90795	0.00E+00	33.41848	10.41854	6.813034	1.23E-02	-0.79055	-0.92614	-1.33E-02	-8.43E-03	-1.32E-02	-4.03E-02	-0.18431	-0.26305	-0.46184	-5.35E-02
3	-11.5449	-34.244	0.00E+00	1.215617	3.118256	-0.84721	-0.63327	-0.69865	-8.48E-03	-5.51E-03	-8.28E-03	-2.50E-02	-0.11453	-0.16382	-0.29525	-2.86E-02
4	-7.73862	-10.5711	-1.22274	0.00E+00	5.944123	-1.18458	-0.77738	-0.84813	-1.32E-02	-8.24E-03	-1.11E-02	-3.18E-02	-0.13792	-0.19402	-0.35027	-3.18E-02
5	-10.2351	-6.89944	-3.16445	-6.0861	0.00E+00	-6.10059	-2.37802	-2.52554	-4.03E-02	-2.50E-02	-3.18E-02	-8.88E-02	-0.37576	-0.52355	-0.9581	-6.78E-02
6	-4.96639	-1.24E-02	0.851848	1.191608	6.127147	0.00E+00	-13.9167	-13.2359	-0.18414	-0.11443	-0.13786	-0.37572	-1.5534	-2.16692	-4.06834	-0.14459
7	-1.17017	0.791866	0.633507	0.777671	2.378207	13.93041	0.00E+00	-31.9479	0.498561	0.597741	0.56751	0.237863	-1.40619	-2.42129	-5.37498	0.683196
8	-1.11185	0.927222	0.698843	0.84838	2.525815	13.24138	32.79659	0.00E+00	-0.46171	-0.29517	-0.35023	-0.95821	-4.06954	-6.13612	-12.4371	-7.34E-02
9	8.907958	1.33E-02	8.44E-03	1.32E-02	4.03E-02	0.184313	0.263052	0.461845	0.00E+00	-33.4185	-10.4185	-6.81304	-1.23E-02	0.790547	0.926145	5.66E-02
10	11.54489	8.43E-03	5.46E-03	8.23E-03	2.50E-02	0.114481	0.163774	0.295201	34.24399	0.00E+00	-1.21562	-3.11826	0.847207	0.633268	0.698649	2.95E-02
11	7.738616	1.32E-02	8.23E-03	1.11E-02	3.18E-02	0.137909	0.194005	0.350258	10.5711	1.222739	0.00E+00	-5.94412	1.184575	0.777384	0.848128	3.26E-02
12	10.23509	4.03E-02	2.50E-02	3.18E-02	8.88E-02	0.375764	0.523551	0.958107	6.899436	3.164451	6.086101	0.00E+00	6.100593	2.37802	2.525542	6.88E-02
13	4.966392	0.184122	0.11442	0.137849	0.375706	1.553401	2.166912	4.068331	1.24E-02	-0.85185	-1.1916	-6.12715	0.00E+00	13.9167	13.23593	0.144982
14	1.170164	0.262943	0.163759	0.193992	0.523643	2.167689	3.182792	6.136477	-0.79186	-0.63351	-0.77767	-2.3782	-13.9304	0.00E+00	31.94787	-0.6834
15	1.111855	0.461736	0.295182	0.350249	0.958232	4.06956	6.136151	12.43711	-0.92722	-0.69884	-0.84838	-2.5258	-13.2414	-32.7966	0.00E+00	7.30E-02
16	3.36E-04	5.38E-02	2.87E-02	3.19E-02	6.82E-02	0.144496	7.82E-02	7.32E-02	-5.69E-02	-2.96E-02	-3.27E-02	-6.91E-02	-0.14488	-7.79E-02	-7.29E-02	0.00E+00

MZ Influence Matrix in-lb/coil

1	0.00E+00	-20165.7	-9837.4	-5246.08	-5607.03	-3893.17	-1291.17	-1209.61	20165.75	9837.401	5246.083	5607.024	3893.168	1291.17	1209.613	1.582384
2	24.48505	0.00E+00	-249.019	-68.2512	-36.4968	-5.93E-02	3.597156	4.181828	0.150695	8.74E-02	9.74E-02	0.246144	0.910378	1.21158	2.102748	0.238253
3	1.561877	-22.3793	0.00E+00	-1.62305	-2.53606	0.495806	0.342246	0.375138	1.03E-02	5.81E-03	7.06E-03	1.78E-02	6.64E-02	8.90E-02	0.159802	1.40E-02
4	-0.12537	-3.91461	-1.01542	0.00E+00	-4.59226	0.466528	0.258501	0.276698	6.85E-03	4.21E-03	4.69E-03	1.18E-02	4.58E-02	6.13E-02	0.110545	8.91E-03
5	8.86E-02	3.45E-02	-3.11E-02	-0.27883	0.00E+00	-1.14E-02	-8.58E-03	-7.34E-03	1.60E-03	7.40E-04	2.57E-04	1.01E-03	1.01E-03	-6.79E-06	-3.68E-04	-2.33E-04
6	9.00E-02	1.22E-03	-3.92E-02	-5.83E-02	-0.33361	0.00E+00	-0.4789	-0.43358	-1.60E-03	-1.95E-03	-2.38E-03	-5.77E-03	-2.91E-02	-4.36E-02	-8.77E-02	2.63E-03
7	2.45E-02	5.89E-02	3.93E-02	4.80E-02	0.129275	0.739098	0.00E+00	4.723598	-0.79548	-0.79455	-0.79473	-0.7995	-0.81921	-0.80366	-0.78433	-0.79449
8	2.84E-03	1.01E-02	6.44E-03	7.02E-03	1.74E-02	8.83E-02	1.399876	0.00E+00	1.08E-03	1.20E-03	2.08E-03	3.77E-03	1.58E-02	1.76E-02	6.35E-02	-1.16E-03
9	-24.4851	-0.15059	-8.70E-02	-9.73E-02	-0.2457	-0.90958	-1.21081	-2.10158	0.00E+00	249.0188	68.25115	36.49831	5.93E-02	-3.59795	-4.18141	-0.25066
10	-1.56241	-1.08E-02	-6.81E-03	-7.76E-03	-1.83E-02	-6.74E-02	-9.01E-02	-0.16021	22.37927	0.00E+00	1.623067	2.536109	-0.49601	-0.34273	-0.37514	-1.42E-02
11	0.125455	-6.82E-03	-4.15E-03	-4.44E-03	-1.19E-02	-4.57E-02	-6.13E-02	-0.11049	3.914487	1.015485	0.00E+00	4.592257	-0.46678	-0.25859	-0.27669	-8.80E-03
12	-8.81E-02	-1.24E-03	-5.91E-04	-8.94E-04	-9.79E-04	-1.72E-03	-1.09E-04	4.62E-05	-3.37E-02	3.17E-02	0.279924	0.00E+00	1.05E-02	8.16E-03	7.37E-03	-3.99E-05
13	-8.99E-02	9.69E-04	9.41E-04	2.02E-03	4.21E-03	2.79E-02	4.14E-02	8.62E-02	-1.28E-03	3.94E-02	5.73E-02	0.333646	0.00E+00	0.479147	0.433768	-3.37E-03
14	-2.47E-02	3.76E-03	2.97E-03	2.90E-03	7.61E-03	2.75E-02	1.17E-02	-7.64E-03	-5.89E-02	-3.94E-02	-4.82E-02	-0.12919	-0.73952	0.00E+00	-4.72365	0.794663
15	-3.01E-03	-2.25E-03	-1.54E-03	-2.56E-03	-5.34E-03	-1.63E-02	-1.85E-02	-6.40E-02	-1.05E-02	-6.80E-03	-8.08E-03	-1.85E-02	-8.90E-02	-1.40106	0.00E+00	6.94E-04
16	-9.10E-03	-3.99E-02	-0.28514	-0.3971	-1.25175	-4.40203	-3.21643	-3.18252	0.120331	0.328038	0.440437	1.313949	4.390471	3.108759	3.006638	0.00E+00

Test Cases



10kA in PF1a, 10kA in PF1b , Zero in the Rest of the Coils

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   48286.49
             1  0.0000000E+00  0.0000000E+00  0.0000000E+00
             2   39171.54       8292.695      -21583.49
             3   5301.233      -8311.671      -1593.439
             4  0.0000000E+00  0.0000000E+00  0.0000000E+00
             5  0.0000000E+00  0.0000000E+00  0.0000000E+00
             6  0.0000000E+00  0.0000000E+00  0.0000000E+00
             7  0.0000000E+00  0.0000000E+00  0.0000000E+00
             8  0.0000000E+00  0.0000000E+00  0.0000000E+00
             9  0.0000000E+00  0.0000000E+00  0.0000000E+00
            10  0.0000000E+00  0.0000000E+00  0.0000000E+00
            11  0.0000000E+00  0.0000000E+00 NaN
            12  0.0000000E+00  0.0000000E+00  0.0000000E+00
            13  0.0000000E+00  0.0000000E+00  0.0000000E+00
            14  0.0000000E+00  0.0000000E+00  0.0000000E+00
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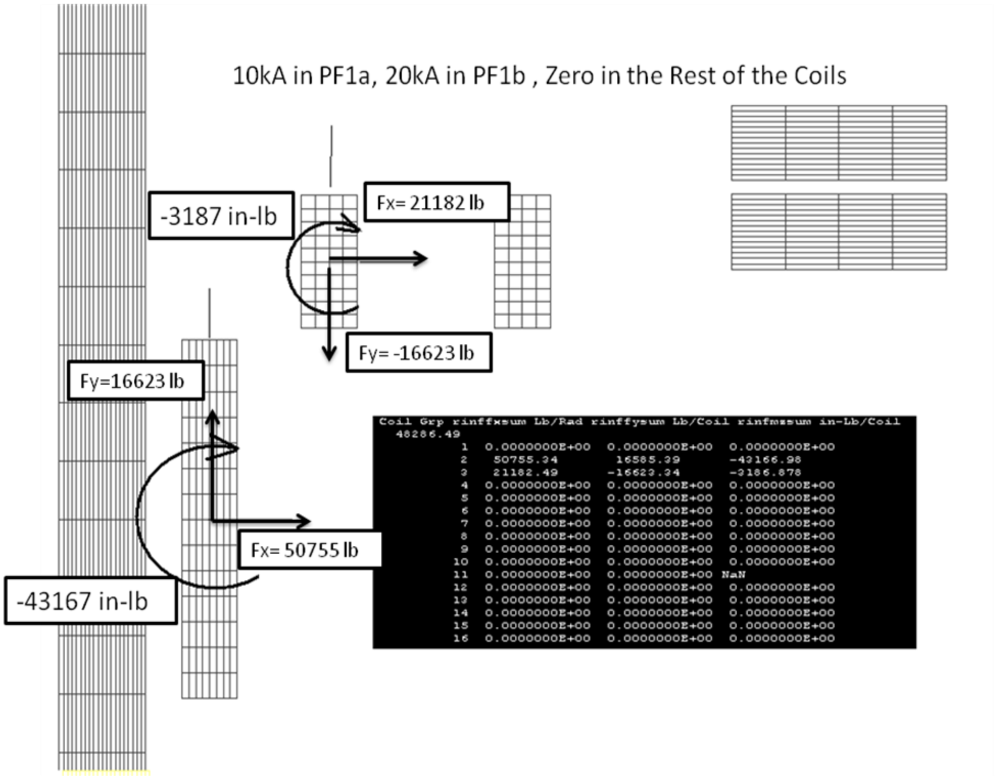

10kA in PF1a, 20kA in PF1b , Zero in the Rest of the Coils

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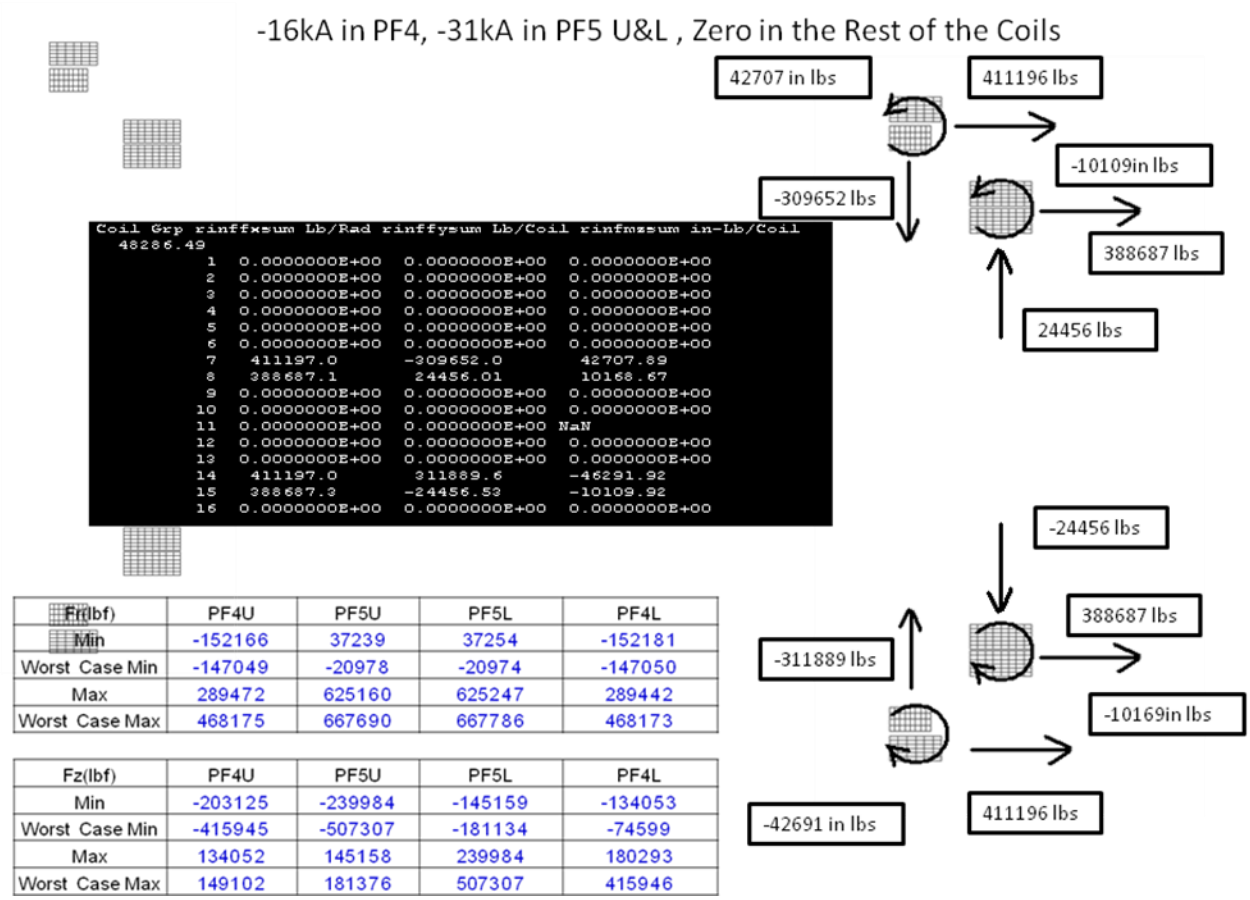
             1  0.0000000E+00  0.0000000E+00  0.0000000E+00
             2   50755.34       16585.39      -43166.98
             3   21182.49      -16623.34      -3186.878
             4  0.0000000E+00  0.0000000E+00  0.0000000E+00
             5  0.0000000E+00  0.0000000E+00  0.0000000E+00
             6  0.0000000E+00  0.0000000E+00  0.0000000E+00
             7  0.0000000E+00  0.0000000E+00  0.0000000E+00
             8  0.0000000E+00  0.0000000E+00  0.0000000E+00
             9  0.0000000E+00  0.0000000E+00  0.0000000E+00
            10  0.0000000E+00  0.0000000E+00  0.0000000E+00
            11  0.0000000E+00  0.0000000E+00 NaN
            12  0.0000000E+00  0.0000000E+00  0.0000000E+00
            13  0.0000000E+00  0.0000000E+00  0.0000000E+00
            14  0.0000000E+00  0.0000000E+00  0.0000000E+00
            15  0.0000000E+00  0.0000000E+00  0.0000000E+00
            16  0.0000000E+00  0.0000000E+00  0.0000000E+00
```



-16kA in PF4, -31kA in PF5 U&L , Zero in the Rest of the Coils

```
Coil Grp rinffxsum Lb/Rad rinffysum Lb/Coil rinfmzsum in-Lb/Coil
  48286.49
            1  0.0000000E+00  0.0000000E+00  0.0000000E+00
            2  0.0000000E+00  0.0000000E+00  0.0000000E+00
            3  0.0000000E+00  0.0000000E+00  0.0000000E+00
            4  0.0000000E+00  0.0000000E+00  0.0000000E+00
            5  0.0000000E+00  0.0000000E+00  0.0000000E+00
            6  0.0000000E+00  0.0000000E+00  0.0000000E+00
            7   411197.0      -309652.0        42707.89
            8   388687.1       24456.01        10168.67
            9  0.0000000E+00  0.0000000E+00  0.0000000E+00
           10  0.0000000E+00  0.0000000E+00  0.0000000E+00
           11  0.0000000E+00  0.0000000E+00 NaN
           12  0.0000000E+00  0.0000000E+00  0.0000000E+00
           13  0.0000000E+00  0.0000000E+00  0.0000000E+00
           14   411197.0       311889.6      -46291.92
           15   388687.3      -24456.53      -10109.92
           16  0.0000000E+00  0.0000000E+00  0.0000000E+00
```

Fr(lbf)	PF4U	PF5U	PF5L	PF4L
Min	-152166	37239	37254	-152181
Worst Case Min	-147049	-20978	-20974	-147050
Max	289472	625160	625247	289442
Worst Case Max	468175	667690	667786	468173

Fz(lbf)	PF4U	PF5U	PF5L	PF4L
Min	-203125	-239984	-145159	-134053
Worst Case Min	-415945	-507307	-181134	-74599
Max	134052	145158	239984	180293
Worst Case Max	149102	181376	507307	415946

PF 4 and 5 Moment Study

Attachment A TBDCPS Source Listing

Attachment A Influence Coefficient Subroutine

```
Subroutine Influence(numcoils)
      include 'scommon.blk'
      DIMENSION rinffx(50,50)
      DIMENSION rinffy(50,50)
      DIMENSION rinfmz(50,50)
       do 9 i=1,50
       do 9 j=1,50
       rinffx(i,j)=0
       rinffy(i,j)=0
       rinfmz(i,j)=0
  9   Continue
       do 10 i=1,numcoils
       do 10 j=1,numcoils
       call snal(0)
       call seal(0)
       ia1=1
       ia2=2
       ia3=3
       ia4=4
       ib1=0
       ib2=0
       ib3=0
       ib4=0
      CALL Sreal(i,i)
       CALL Sreal(j,i)
       call SNELEM(i,i)
      typekeydum=typekey
       typekey=7
       egrpkeydum=egrpkey
       egrpkey=7
      r=0.0
c                                         Creating Current Elements from Quad Elements
      call CCUR(R,i,ia1,ia2,ia3,ia4,ib1,ib2,ib3,ib4)
      call stype(7,70)
       call snelem(70,70)
      call sfield(i)
       call snal(0)
       call seal(0)
      call stype(7,70)
       call gerase(70)
       call reduce
       CALL Sreal(i,i)
      call SNELEM(i,i)
       CALL Sreal(j,j)
      call SNELEM(j,j)
      call mfor(i,ia1,ia2,ia3,ia4,ib1,ib2,ib3,ib4)
       call mfsum(i,i,fxsum,fysum,xmzsum)
       rinffx(i,j)=fxsum
       rinffy(i,j)=fysum
       rinfmz(i,j)=xmzsum
       bxs=0.0
       bys=0.0
       byz=0.0
      call bscale(i,bxs,bys,bzs)
      call fscale(i,bxs,bys,bzs)
      call bscale(j,bxs,bys,bzs)
      call fscale(j,bxs,bys,bzs)

 10   CONTINUE
 54   CONTINUE
       do 15 i=1,numcoils
       do 15 j=1,numcoils
       if (i.ne.j) rinffx(i,j)=rinffx(i,j)-rinffx(i,i)
       rinffy(i,j)=rinffy(i,j)-rinffy(i,i)
       rinfmz(i,j)=rinfmz(i,j)-rinfmz(i,i)
 15   Continue

      write(7,*) 'FX Influence Matrix N/rad'
       do 11 i=1,numcoils
      write(7,*) i,rinffx(i,1),rinffx(i,2),rinffx(i,3),rinffx(i,4),
     c rinffx(i,5),rinffx(i,6),rinffx(i,7),rinffx(i,8),rinffx(i,9),
     c rinffx(i,10),rinffx(i,11),rinffx(i,12),rinffx(i,13),rinffx(i,14),
```

```
     c rinffx(i,15),rinffx(i,16),rinffx(i,17),rinffx(i,18),rinffx(i,19)
 11   continue
      write(7,*) 'FY Influence Matrix N/rad'
       do 12 i=1,numcoils
      write(7,*) i,rinffy(i,1),rinffy(i,2),rinffy(i,3),rinffy(i,4),
     c rinffy(i,5),rinffy(i,6),rinffy(i,7),rinffy(i,8),rinffy(i,9),
     c rinffy(i,10),rinffy(i,11),rinffy(i,12),rinffy(i,13),rinffy(i,14),
     c rinffy(i,15),rinffy(i,16),rinffy(i,17),rinffy(i,18),rinffy(i,19)
 12   continue
      write(7,*) 'MZ Influence Matrix N-m/rad'
       do 13 i=1,numcoils
      write(7,*) i,rinfmz(i,1),rinfmz(i,2),rinfmz(i,3),rinfmz(i,4),
     c rinfmz(i,5),rinfmz(i,6),rinfmz(i,7),rinfmz(i,8),rinfmz(i,9),
     c rinfmz(i,10),rinfmz(i,11),rinfmz(i,12),rinfmz(i,13),rinfmz(i,14),
     c rinfmz(i,15),rinfmz(i,16),rinfmz(i,17),rinfmz(i,18),rinfmz(i,19)
 13   continue

       do 16 i=1,numcoils
       do 16 j=1,numcoils
       rinffx(i,j)=rinffx(i,j)*.2248*2*3.1416
       rinffy(i,j)=rinffy(i,j)*.2248*2*3.1416
       rinfmz(i,j)=rinfmz(i,j)*.2248*2*3.1416*39.37
 16   Continue
      write(7,*) 'FX Influence Matrix lb/coil'
       do 17 i=1,numcoils
      write(7,*) i,rinffx(i,1),rinffx(i,2),rinffx(i,3),rinffx(i,4),
     c rinffx(i,5),rinffx(i,6),rinffx(i,7),rinffx(i,8),rinffx(i,9),
     c rinffx(i,10),rinffx(i,11),rinffx(i,12),rinffx(i,13),rinffx(i,14),
     c rinffx(i,15),rinffx(i,16),rinffx(i,17),rinffx(i,18),rinffx(i,19)
 17   continue
      write(7,*) 'FY Influence Matrix lb/coil'
       do 18 i=1,numcoils
      write(7,*) i,rinffy(i,1),rinffy(i,2),rinffy(i,3),rinffy(i,4),
     c rinffy(i,5),rinffy(i,6),rinffy(i,7),rinffy(i,8),rinffy(i,9),
     c rinffy(i,10),rinffy(i,11),rinffy(i,12),rinffy(i,13),rinffy(i,14),
     c rinffy(i,15),rinffy(i,16),rinffy(i,17),rinffy(i,18),rinffy(i,19)
 18   continue
      write(7,*) 'MZ Influence Matrix in-lb/coil'
       do 19 i=1,numcoils
      write(7,*) i,rinfmz(i,1),rinfmz(i,2),rinfmz(i,3),rinfmz(i,4),
     c rinfmz(i,5),rinfmz(i,6),rinfmz(i,7),rinfmz(i,8),rinfmz(i,9),
     c rinfmz(i,10),rinfmz(i,11),rinfmz(i,12),rinfmz(i,13),rinfmz(i,14),
     c rinfmz(i,15),rinfmz(i,16),rinfmz(i,17),rinfmz(i,18),rinfmz(i,19)
 19   continue

      typekey=typekeydum
       egrpkey=egrpkeydum
      return
      end


      SUBROUTINE mFSUM(IGRPs,igrpe,fxsum,fysum,xmzsum)
      include 'scommon.blk'
      do 13 igrp=igrps,igrpe
       numn=0
       centx=0
       centy=0
      FxSUM=0.
      FYSUM=0.
       xmzsum=0
      ymzsum=0
!      FZSUM=0.
      DO 12  I=1 , N
      IF(NGROUP(I).EQ.IGRP)  THEN
       numn=numn+1
       centx=centx+x(i)
       centy=centy+y(i)
      FXSUM=FXSUM+FX(I)
      FYSUM=FYSUM+FY(I)
!     FZSUM=FZSUM+FZ(I)
       xMZSUM=xMZSUM-FX(I)*Y(I)
      yMZSUM=yMZSUM+FY(I)*X(I)
      end if
 12   CONTINUE
      centx=centx/numn
       centy=centy/numn
       ymom= -xmzsum/fxsum
       xmom=ymzsum/fysum
      xMZSUM=-fxsum*(ymom-centy)+fysum*(xmom-centx)
      print*,igrp,fxsum,fysum,xmzsum
      write(7,*) igrp,',',fxsum,',',fysum,',',fzsum,',',
```

```
     cxmxsum,',',xmysum,',',xmzsum
 13   CONTINUE
      RETURN
      END
```

Some of the subroutines in this subroutine may be called in scripts, the script commands are described below:

mfsu	Prompts for the start and end node group Calculates the x force sum, y force sum and moment sum about the centroid of nodes defined by node groups starting at igrps and ending at ,igrpe
mfor	Calculates Lorentz forces on a brick or quad element from fields corner nodes, currents specified as real constants, and current directions specified by inputting an element nodal sequence that defines the brick element start and end face. For an axisymmetric analysis using, the connectivity specification is 1,2,3,4,0,0,0,0. Forces computed for an axisymmetric analysis are per radian. For ANSYS analyses these loads need to be multiplied by 2*pi.
sfie	Computes 2D fields using Elliptic Integrals from loops defined by type 7 elements.

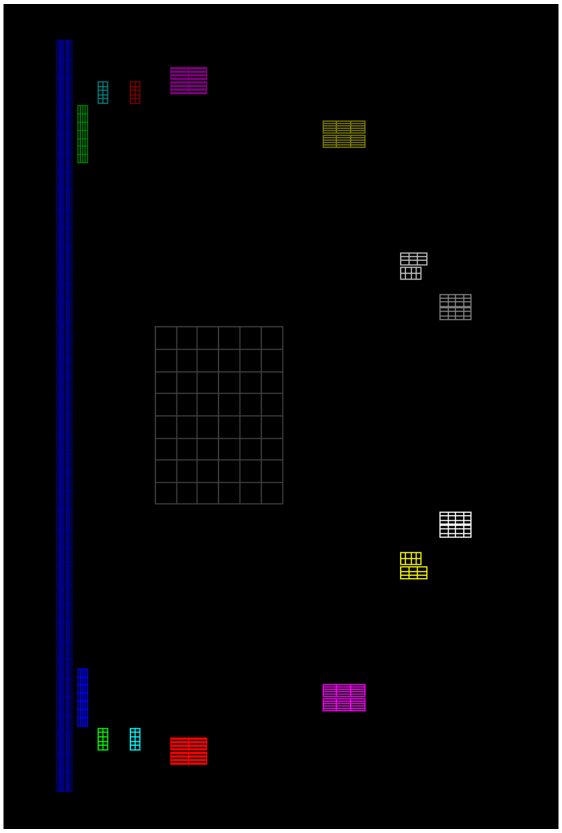
Attachment B
Influence Coefficient Matrix Script

```
zero
!  Influence Coefficient Matrix Test
read
ron2
divi
0,2,2,1
snal
1
merge
1,.0001
redu

rcoi
16
1,10,80,1029,250
2,4,7,28,250
3,2,5,10,250
4,2,5,10,250
5,4,10,28,250
6,3,10,30,250
7,1,17,17,250
8,4,6,24,250
9,4,7,28,250
10,2,5,10,250
11,2,5,10,250
12,4,10,28,250
13,3,10,30,250
14,1,17,17,250
15,4,6,24,250
16,6,8,28,250

infl
16

copt
r
plce
```



Node and Element File ron2.dat
plotted with copt,r

```
pl

exit
```