<u>**N**ational **S**pherical **T**orus e**X**periment - **U**pgrade</u>

NSTX-U

Calculation of PF1C Upper Coil & Lead Support and Inner Bus Bar

NSTXU-CALC-131-002-0

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NSTX-U CALCULATION

Record of Changes

Rev.	Date	Description of Changes	Revised by
0	3/27/18	Initial Release	

NSTX-U Calculation Form

Purpose of Calculation:

- Verify the structural integrity of inner PF 1C upper coil leads;
- Validate the structural design of support brackets at coil terminals.

References:

[1] NSTX-U-RQMT-GRD-001-00 General Requirements Document, S. Gerhardt, December, 2017
[2] NSTX-U-RQMT-SRD-002-00 System Requirements Document Magnet Systems, S. Gerhardt, December, 2017.
[3] NSTX-U-SPEC-MAG-001-2 Specification for Inner PF coil conductor, M. Kalish, November, 2017
[4] MAG-180306-YZ-01, Material Properties for Inner PF Coil FDR, MAG-180306-YZ-01, March, 2018.
[5] NSTX-U-CALC-131-27, Inner PF Coil Thermal Analysis, Y. Zhai, March 14, 2018.
[6] NSTX-U-CALC-133-28, Summary of Loads for Inner PF Leads and Bus Bars Analysis, Y. Zhai, March 20, 2018.

Assumptions:

See NSTX-U-CALC-131-28

Calculation:

See attached Report.

Table of Contents

1. Executive Summary

This report is intended to provide the stress analysis of PF1C upper coil lead section using ANSYS Workbench. The three-dimensional PF1C upper spiral winding coil & support, lead support and bus bars assembly model have been developed. The coil lead region is interfaced with coil & coil support, terminal flag and bus bar & its support. The complexity on the structural design arises from multiple load paths. During the operation, the conductors in PF 1C coil lead sections will experience large Lorentz forces from the background 2-3 T toroidal magnetic fields. Thermal induced stresses are also significant between coil leads and bus bars when coils are pulsed. This calculation is to validate PF1C upper coil lead stresses with the lead support brackets and bus bar structure assembly.

2. Scope of The Report

This report focused on the 3D structural analysis of PF 1C upper coil lead region. The Lorentz forces on conductors are provided by Y.Zhai. Specifically, the body force density cloud data is extracted from the 3D MAXWELL Magneto-static analysis [6]. Thermal analysis of all inner PF coils prescribe the thermal condition of coil, lead & bus bar interface [5], which also covers the PF 1C upper coil. The analysis follows a procedure developed for 3D lead analysis [6].

3. 3D Solid Model

Model was imported into ANSYS geometry tool (Design Modeler & Spaceclaim) for the geometrical simplification. Bolt connections were also removed and bonded connection was assumed. Figure 1shows the geometrical presentation of PF1C upper winding coil package, simplified coil support, lead support, inner bus bar with support.

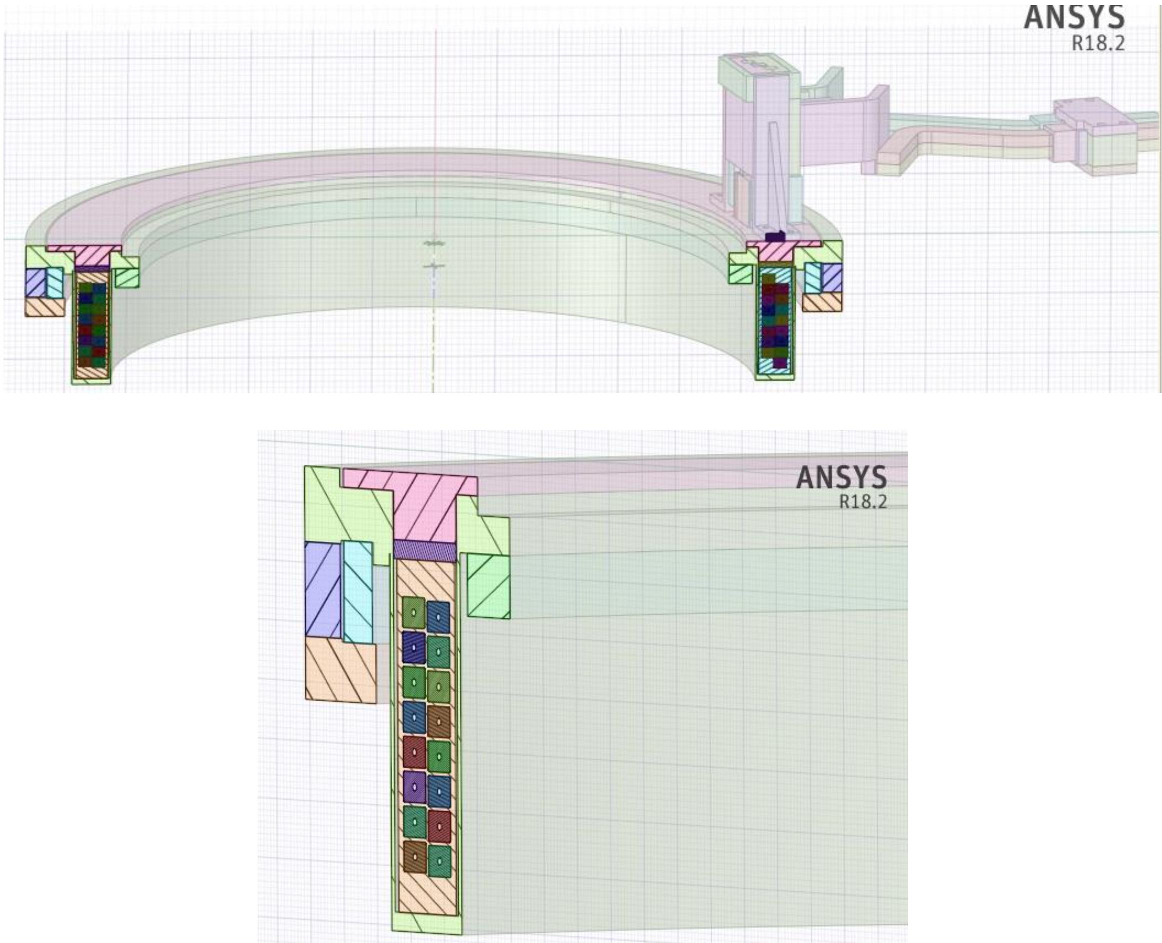

Figure 1 Solid model of the PF1C upper winding coil package, coil support, lead support, flags, inner bus bar with support.

4. Meshing

Meshing of the assembly model is performed in ANSYS Workbench. Fine mesh is given to the conductors, lead bracket while the coarse mesh goes to coil support, which is not the focus of this report, as shown in Figure 2 & 3 below.

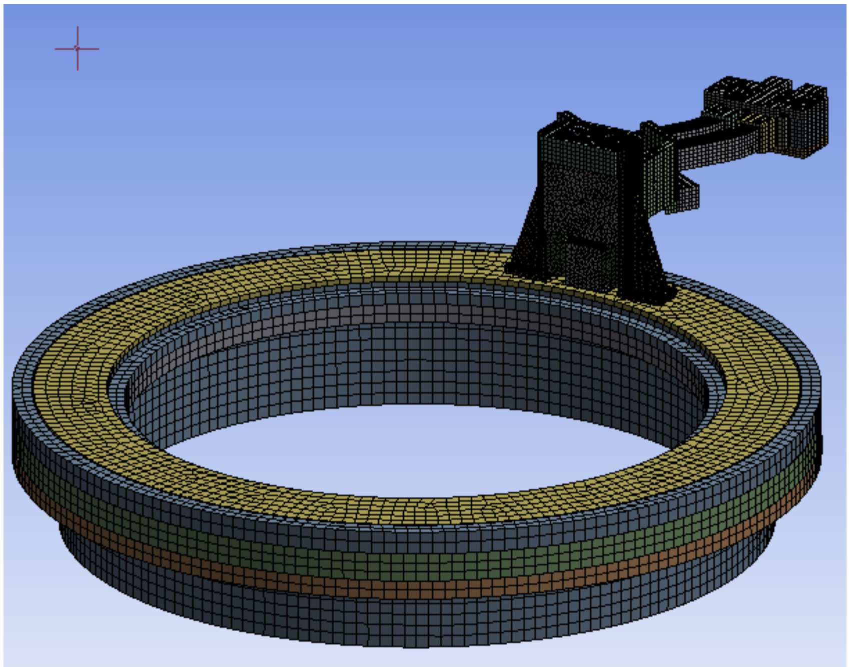

Figure 2 Mesh on PF1C upper coil interface assembly

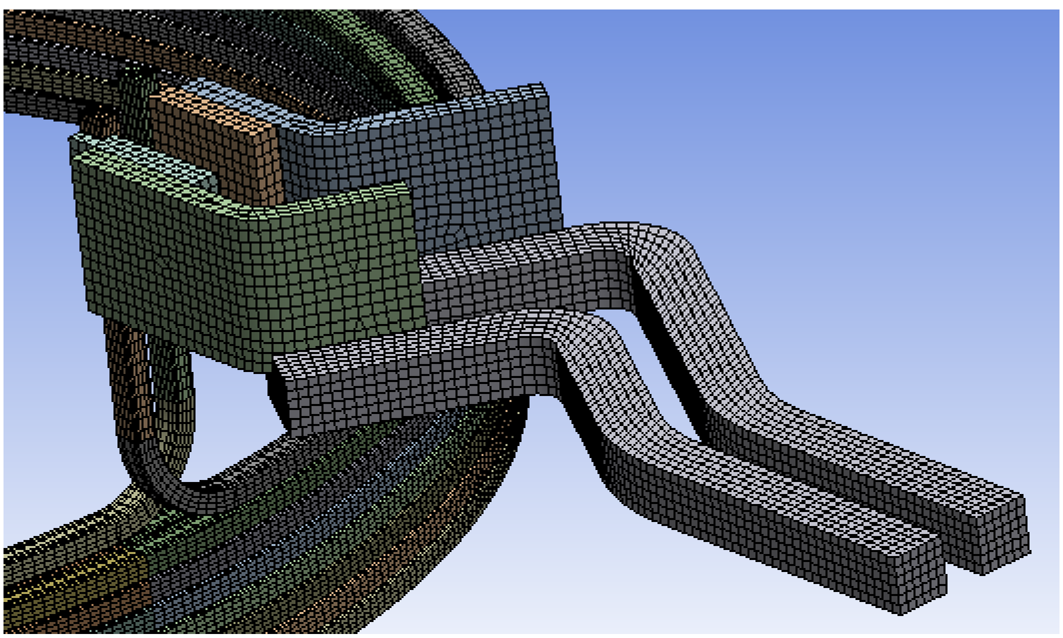

Figure 3 Fine mesh on conductors

5. Materials and Allowable

Material properties from NSTX database were used. Material allowable is presented in ref [6].

Conductors: copper.
Material is isotropic with elastic modulus of 110GPa and Poisson ratio of 0.34;
Thermal expansion coefficient is 1.8·10-5[1/K] at 293K.

Insulation: G11
Material is isotropic with elastic modulus of 11.721GPa and Poisson ratio of 0.12;
Thermal expansion coefficient is 1.49·10-5[1/K] at 293K.

Lead & bus bar support hardware (: steel.

Material is isotropic with elastic modulus of 193GPa and Poisson ratio of 0.31.
Thermal expansion coefficient is 1.7·10-5[1/K] at 293K.

Bus bar bracket inserts: low elastic modulus material
Material is isotropic with elastic modulus of 1.1GPa and Poisson ratio of 0.34.
Thermal expansion coefficient is 1.8·10-5[1/K] at 293K.

6. Loads

- ***Electromagnetic Load (EM)***

Two worst EQ scenarios (EQ 18 &33) are identified for PF 1C coil [6]. 3D magneto-static analyses of coil, coil terminals and bus bars was performed using ANSYS Maxwell. With the consideration of reversed TF current, total four scenarios are considered [6]:

- EQ#18
- EQ#18 reverse TF
- EQ#33
- EQ#33 reverse TF

Results of EM analysis were imported as a tabulated distributed force density as ANSYS workbench external data, as shown in Figure 4. The body force density data was validated using the reaction force from four scenarios, in comparison with the load summary in Ref [6]. Figure 5 illustrates the mapped vector force density on the coil, flags, bus bars for scenario 18.

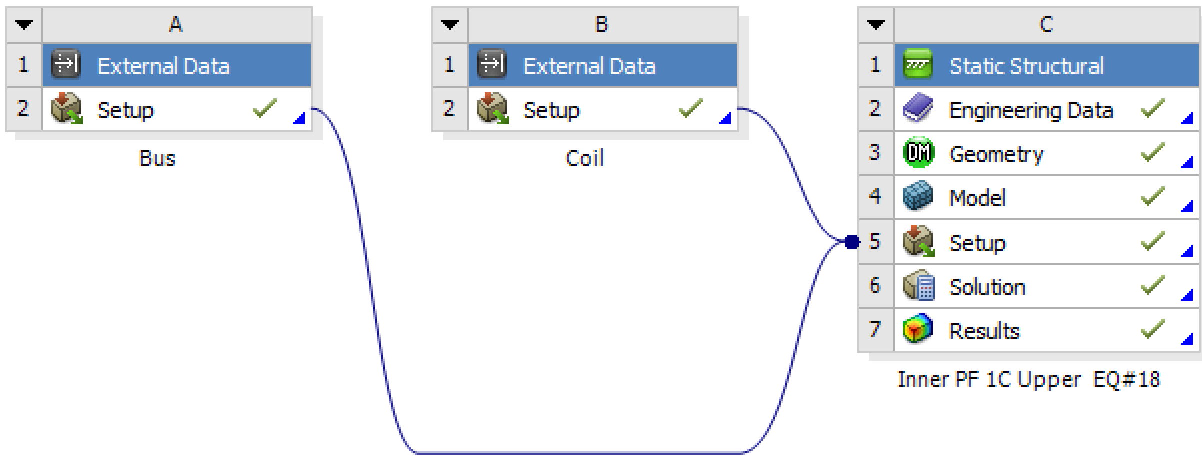

Figure 4 Illustration of element force mapped on the coil as the external data in ANSYS

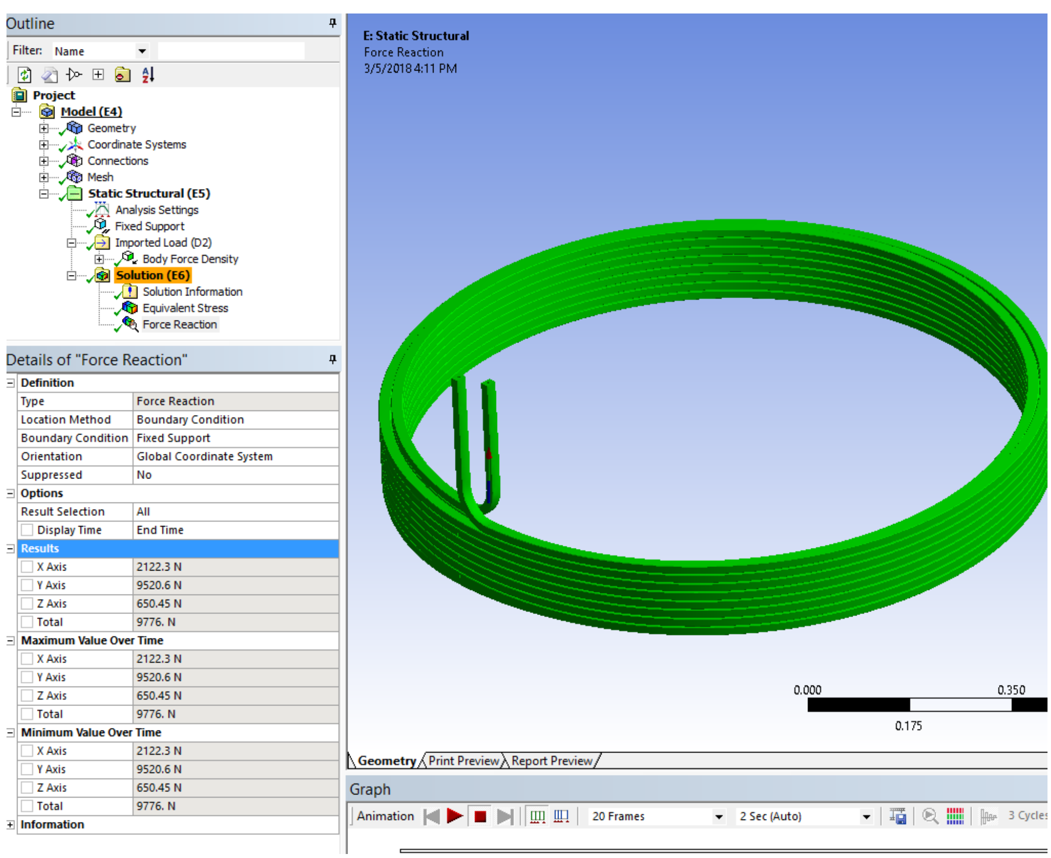

Figure 5 Checking the EM load on coil

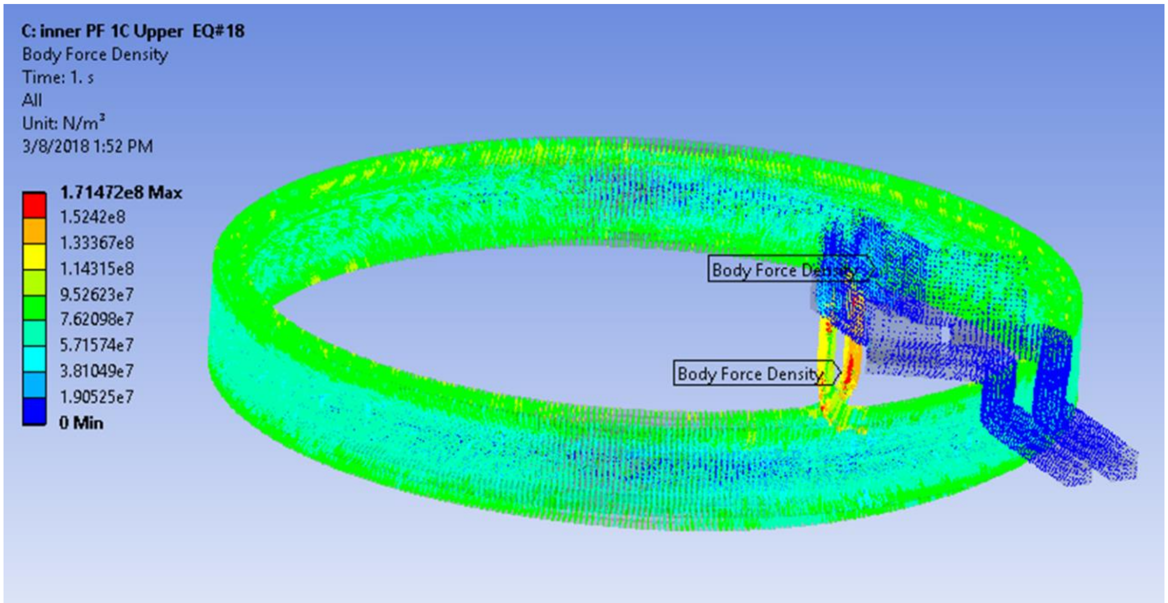

Figure 6 Element force mapped on the coil & bus assembly for scenario 18

- ***Thermal Load***

The PF1 Coils are instantaneously heated up to the maximum temperatures uniformly during the plasma operation. PF 1C upper coil temperature is set to 50ºC as a conservative assumption for the end of the pulse condition [5]. Temperature is linearly reduced to 12ºC towards the tips of the coil leads where Joule heating is absent and 12ºC coolant inlet is supplied [5]. Bus bars are not water cooled and thermally insulated from the ambient air by electrical insulation wrap. Conservative estimate 50ºC was set on the bus bars as well. Thermal load on the coil and bus bar is presented on Figure 7. This thermal gradient applied to the four scenarios for PF 1C upper coil.

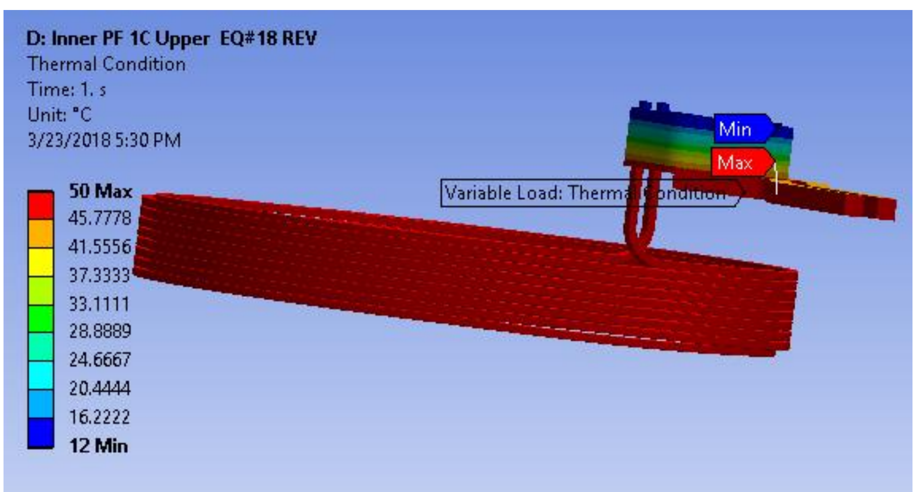

Figure 7 Thermal load for PF1C upper coil , flags and bus bar

7. Boundary & Contact Conditions

The assembly is fixed in all directions at the coil support surface and bus bar support surfaces, as shown in Figure 8. Coil lead support brackets are fixed in places of attachment to the coil support structures.

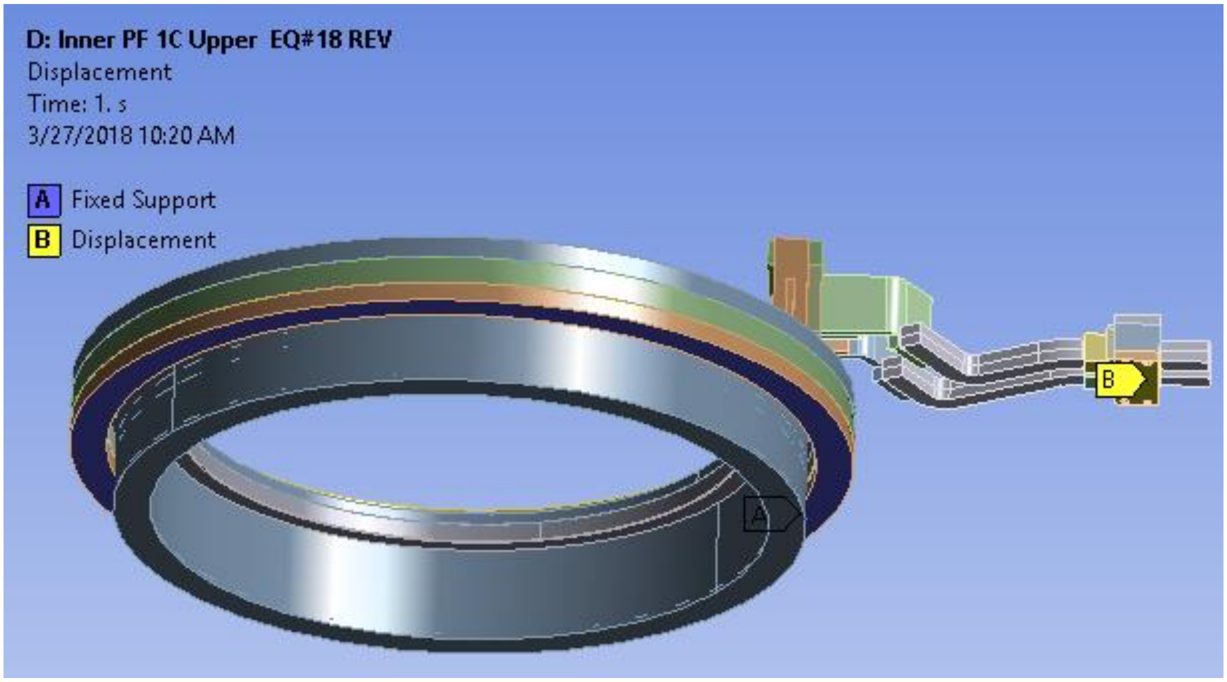

Figure 8 Boundary conditions used in the analysis

No separation conditions are imposed between smeared coil and structure and between bus bar soft inserts and support brackets, allowing thermal expansion.

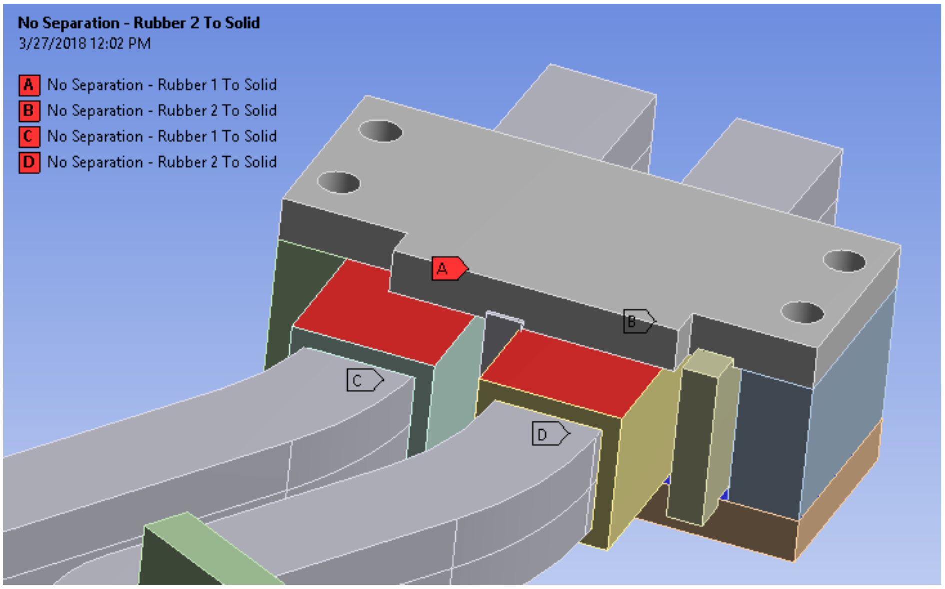

Figure 9 Contact condition at the bus bar inserts and steel support

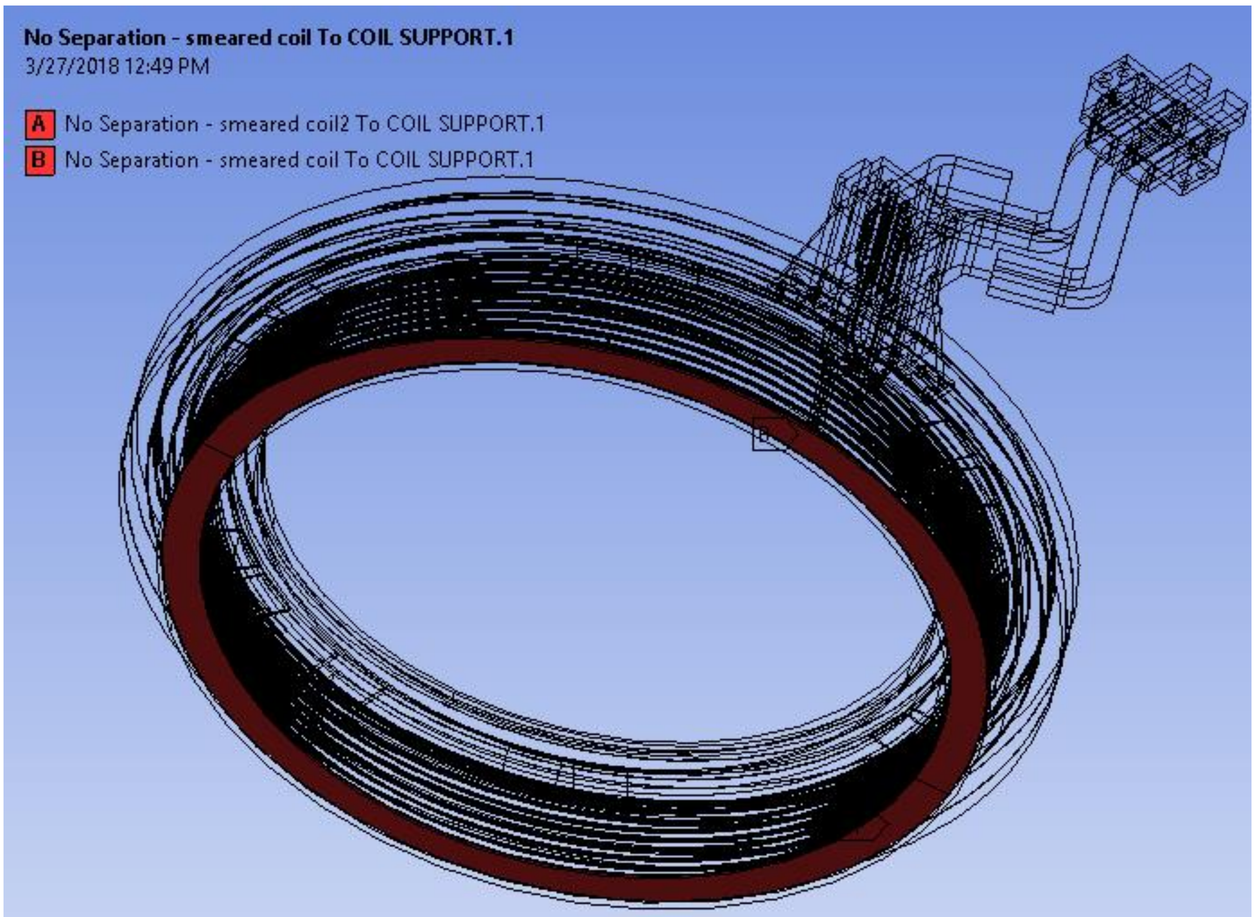

Figure 10 Contact condition at the smeared coil exterior and its support while keeping the coil centered

8. Results

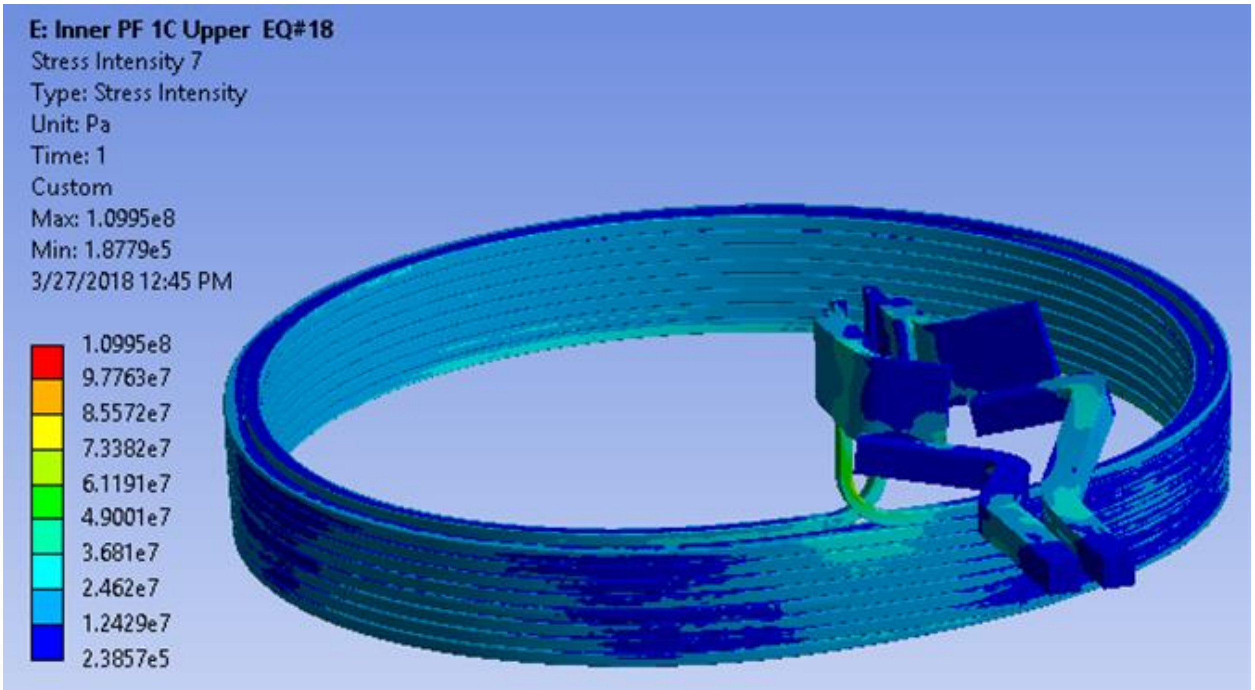

Figure 11 Stress intensity on coil, terminal flag and bus (EQ #18)

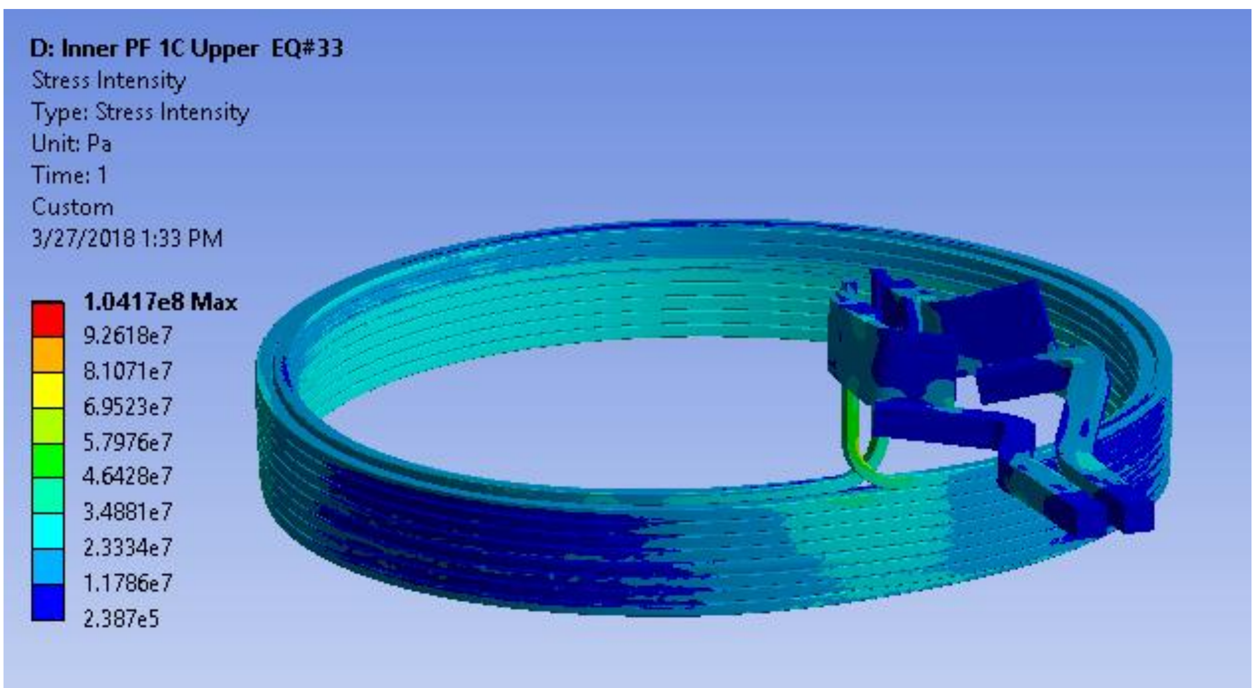

Figure 12 Stress intensity on coil, terminal flag and bus (EQ #33)

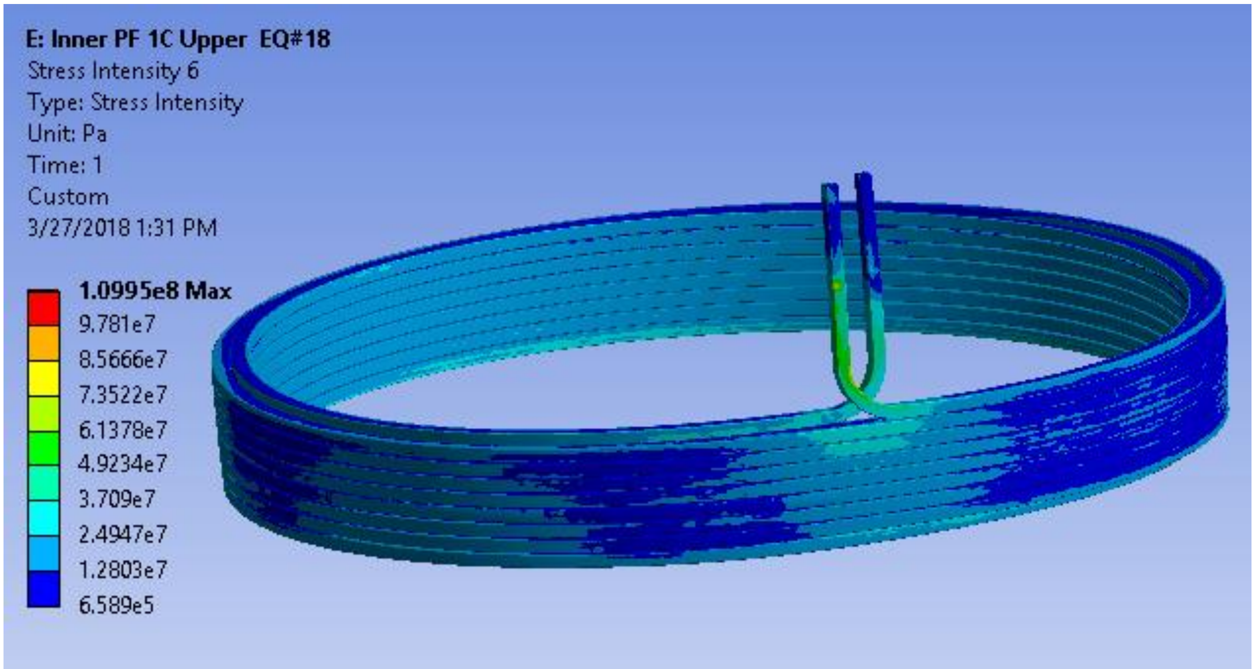

Figure 13 Stress intensity on coil terminals (EQ #18)

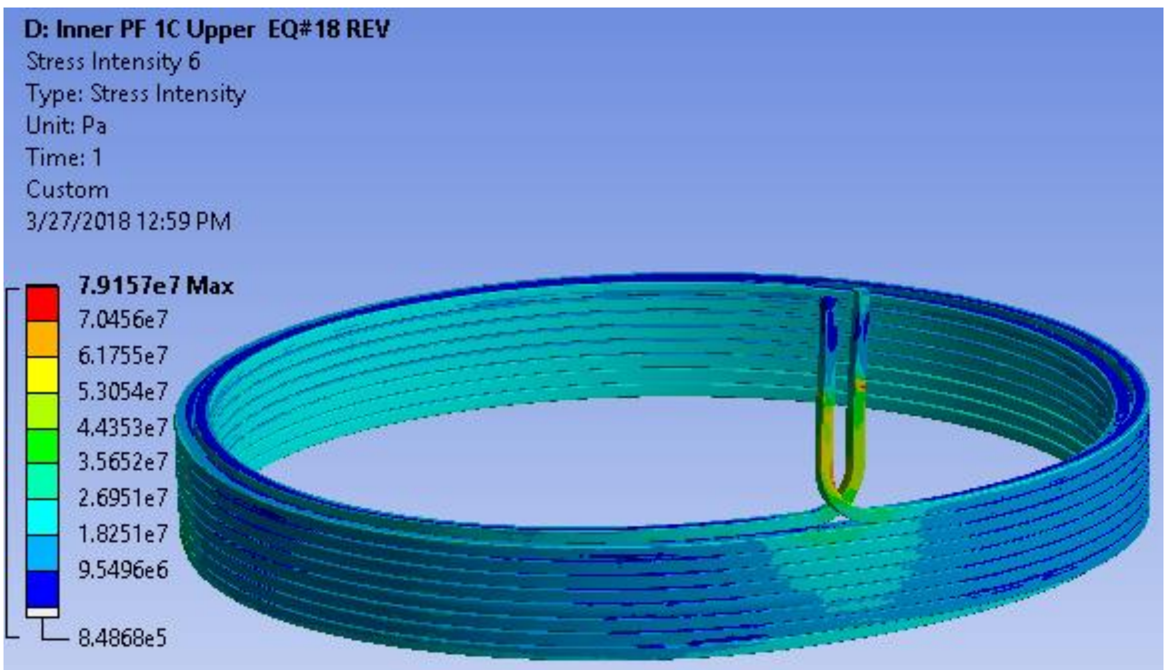

Figure 14 Stress intensity on coil terminals (EQ #18 with the reversed TF current)

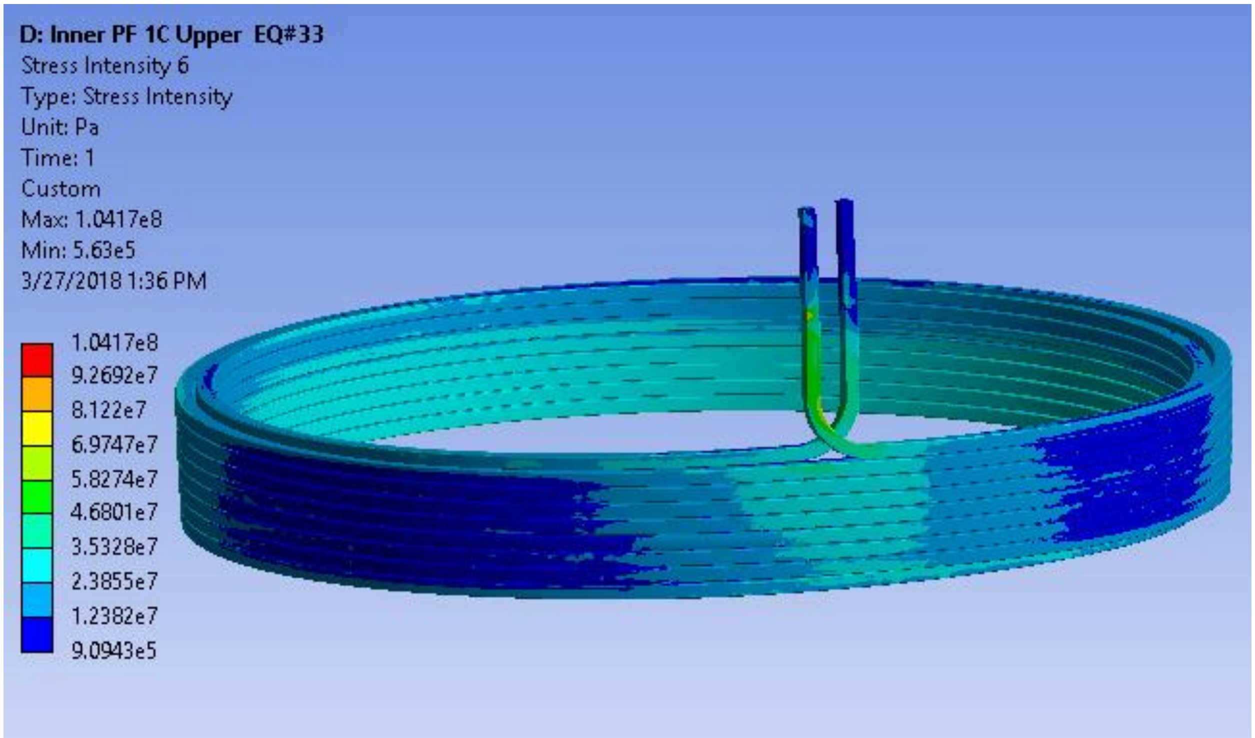

Figure 15 Stress intensity on coil terminals (EQ #33)

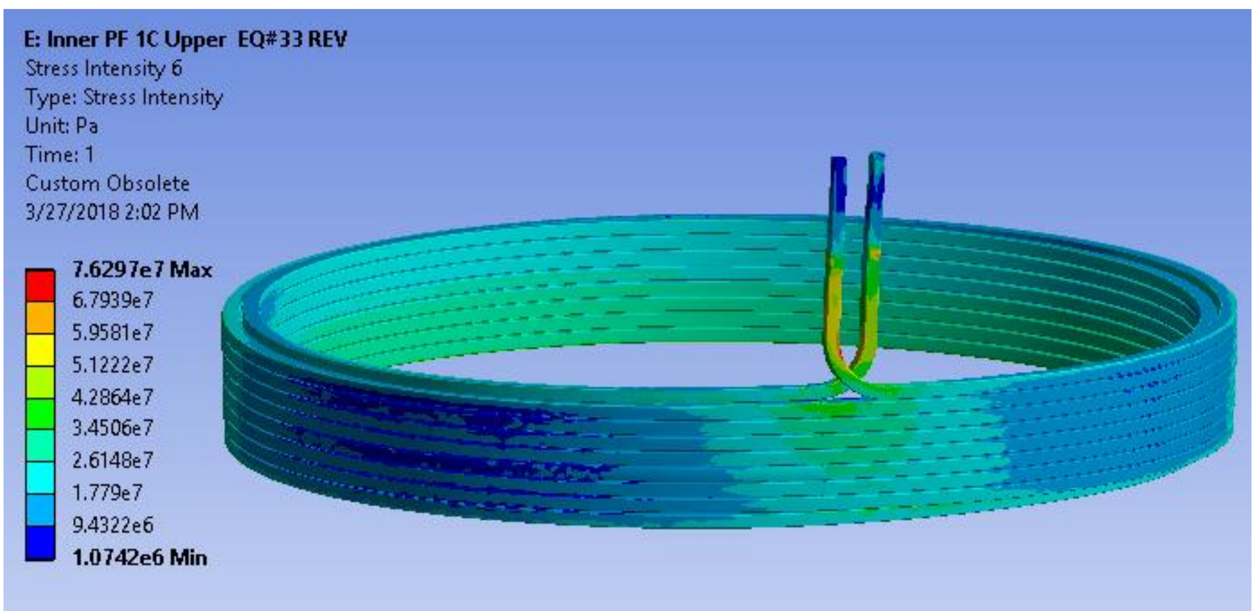

Figure 16 Stress intensity on coil terminals (EQ #33 REV TF)

Figure 11-16 shows the stress results from four load cases.

9. Summary

Maximum stress intensity on PF1C upper coil, terminal flags and bus bars is summarized below for four scenarios. To conclude, the local peak stress on the inner PF 1C upper coils is within the 125 MPa fatigue design allowable.

Scenario	Max Stress Intensity [MPA]
18 direct TF current	110
18 reverse TF current	79
33 direct TF current	104
33 reverse TF current	76

In summary, the structural analysis for PF 1C upper coil lead region is performed. The coil leads experience large values of local stresses due to magnetic forces and thermal expansion. The local high stress intensity occurs at the coil lead section and break out region for four load cases considered, but PF 1C upper coil conductors are well within the fatigue design limit allowable.