NCSX

Design Basis Analysis

Vacuum Vessel Lateral Support Bracket Analysis

NCSX-CALC-12-008-00

20 June 2005

Prepared by:

Kevin D. Freudenberg 2005.06.22 11:39:35 -04'00'

K.D Freudenberg, ORNL

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct. I concur with analysis methodology and inputs and with the reasonableness of the results and their interpretation.

Reviewed by:

? Signature Not Verified Paul Goranson Digitally signed by Paul Goranson DN: cn=Paul Goranson, c=US Date: 2005.06.22 11:41:41 -04'00'

P. Goranson, Engineer

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I Executive Summary

The purpose of this analysis is to examine the effects of lateral loading on the vacuum vessel assembly through the neutral beam port. The overall vacuum vessel structural analysis is covered in DAC NCSX-CALC-12-007 by Fred Daulgren which covers structural and buckling analysis of the vessel and attached ports. That analysis, however, does not include the reaction loading from the lateral vacuum, seismic and magnetic loading which is transmitted to the supports on the neutral beam assembly. To that end, this study examines the neutral beam assembly (isolated from the vacuum vessel) and applies the appropriate loading to the lateral supports so that the resulting deflection and local stress can be analyzed.

II Assumptions

- Vessel & port configuration as of 10 May '05 Pro-E models. SE122-068 assembly.
- Neutral Beam port fabricated from 0.375 thick Inconel 625. E =
- Vacuum pressure loading on neutral beam transition duct is omitted.
- Lateral support bracket is far from the neutral beam port flange. Thus, the port flange is fixed in this model and only local stress/deformation effects near the bracket are analyzed.
- Magnetic and seismic disruption loads assumed are 7000 lbs lateral distributed evenly between two neutral beam ports (3500 each).
- Vacuum loading due to unbalanced atmospheric load from two 12" diameter pumping ducts on one neutral beam port is considered. This results in a load (15 psi *π*12"^2/4 = 1696 lb) applied on the neutral beam port lateral support.

III Analysis Methodology and Inputs

For this study, the maximum allowable temperature gradient is 40 C. This corresponds to the max gradient the modular coil experiences during operation and pulse.

III.a *Software and data files*

The FEA code used in this analysis was Ansys Workbench 9.0 – Windows edition. The Pro-E files listed below were the current files as of 10 May 2004. The ProE-files associated with the main assembly were then transferred directly into Ansys Workbench. From that point, the model was meshed with solid 186 and solid 187 elements. Solid 186 is a higher order 3-D 20-node structural solid element and Solid187 is a higher order 3-D, 10-node tetrahedral element. Contact elements are also created between each part in the assembly.

III.b *Drawings and models*

The following Pro/E models were used in this analysis.

SE122-068
SE122-073
SE122-077
SE122-078
SE122-075
SE122-075
SE122-093
SE122-184
SE122-090
SE122-091
SE122-092
SE122-090
SE122-091
SE122-092
SE122-090
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SE122-092

SE122-094
SE122-095
SE122-092
SE122-094
SE122-095
SE122-092
SE124-042
SE124-045
SE124-042
SE124-045
150776
150776
SJDR-NB_DIAG_PORT
SJDR-NB_DIAG_PORT
SJDR-NB_DIAG_PORT
SJDR-NB_DIAG_PORT

<u>Ansys Workbench Input file:</u>

VV_lateral_loads_5_12_05.dsdb

III.c *Material Properties*

The neutral beam port is comprised of only one material, Inconel 625. The properties used in this analysis are:

-Youngs Modulus	28.7e6 psi
-Shear Modulus	11.1e6 psi
-Poissons' Ratio	0.286
-Density	0.305 lbs/cu. in.
-Coeff. of Thermal Exp.	7.3e-6 in./in.-deg.F

From Huntington Alloys/Specialty Metals publication for Inconel 625

III.d *Model Setup*

Figure 1: Mesh of neutral beam portFigure 1 shows the mesh of the neutral beam port from two perspectives. The mesh near the support bracket (image on the right) is refined and is much more dense than areas away from the bracket.

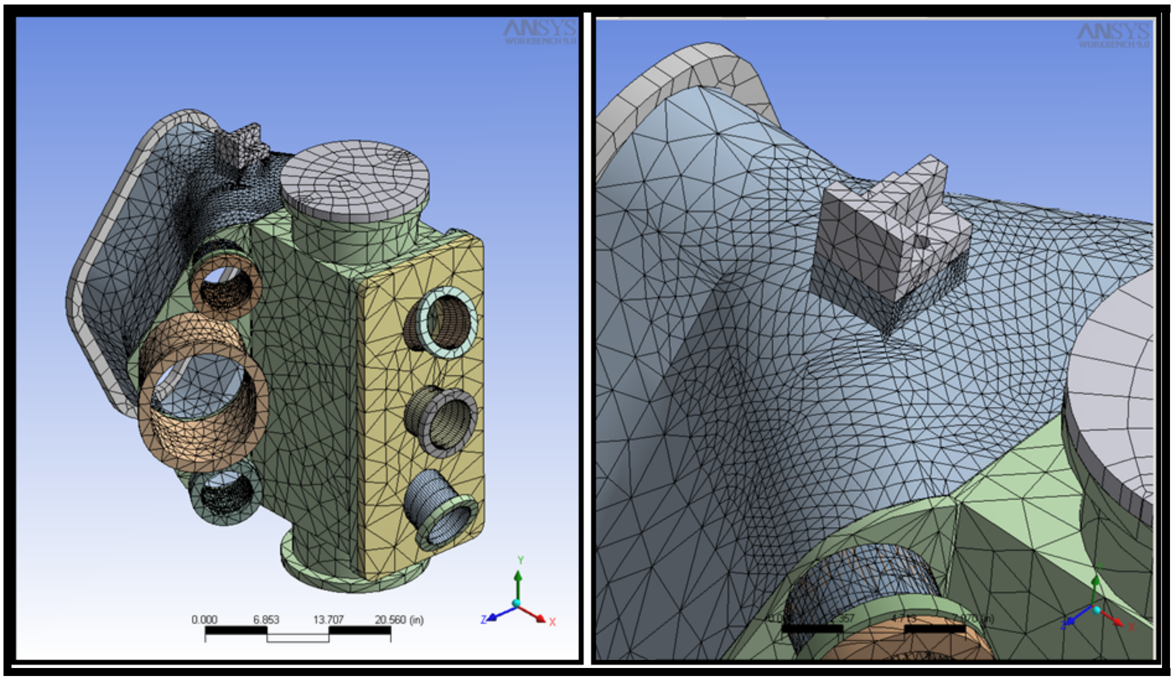

Figure 1: Mesh of neutral beam port

III.e *Loading*

The loading is shown schematically in Figure 2. The orientation depicted represents the maximum loading condition that may be encountered with two supports distributing the vacuum and magnetic loads evenly between them. This is because the support only loads normal to its face and does not supports any load perpendicular across the face.

- Fv = Vacuum vessel unbalanced atmospheric load due to bellows on the neutral beam port.
- Fl = Vacuum vessel dynamic loading due to the magnetic disruption and/or seismic loading
- Fr = Resultant load on the NBTD lateral support bracket due to Fv and Fl.

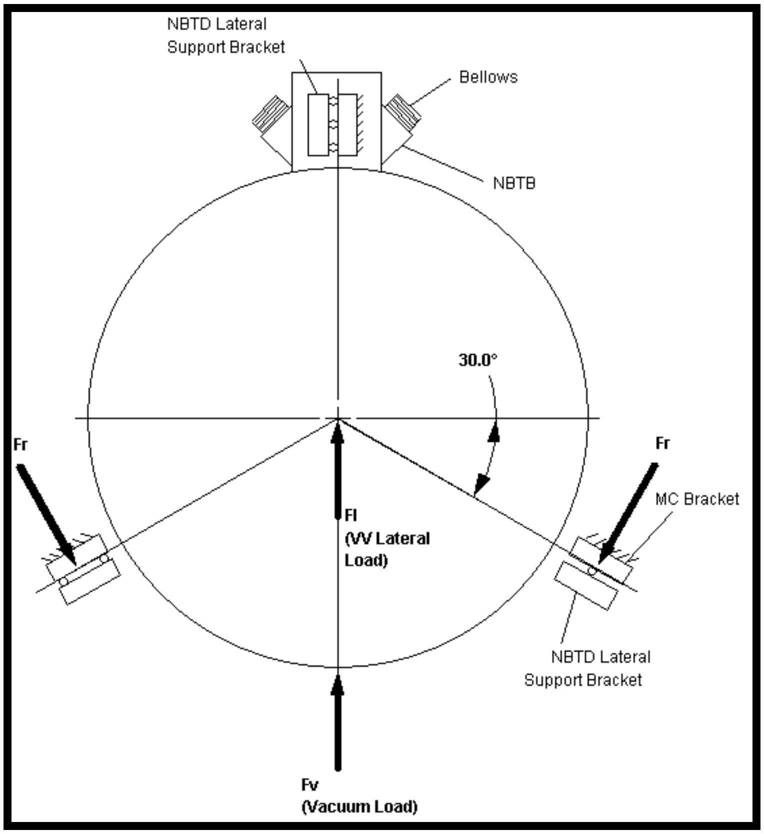

Figure 2: Loading Schematic of the overall Vacuum Vessel

The loading and restraints used in the Ansys model are shown in Figure 3. A gravitational and a combined vacuum/magnetic/seismic load are applied to the model. The model is fixed on the flange face of the neutral beam port which connects to the vacuum vessel. The vacuum unbalanced vacuum loading is derived by considering the area of the two port openings (diameter approximately 12") which act to pump the vessel down. Looking at the picture above in Figure 2, the load is applied at a 30 degree angle to the member and is calculated from the following equations.

$$F_v = N_{\#\,port\,openings} * \pi \frac{D^2}{4} * P_{atmos} = 3393\ lbs$$

$$F_{bracket\,vac} = \frac{F_v}{2} * \frac{1}{\cos 30} = 1958\ lbs$$

The combined magnetic and seismic lateral loading (F_l) is 7000 lbs but it is also applied at the same 30 degree angle to the member. Therefore, each member sees the following load:

$$F_{bracket\,lateral} = \frac{F_l}{2} * \frac{1}{\cos 30} = 4041\,lbs$$

The combined loading (F_r) seen by each bracket is: 1958 + 4041 = 6000 lbs.

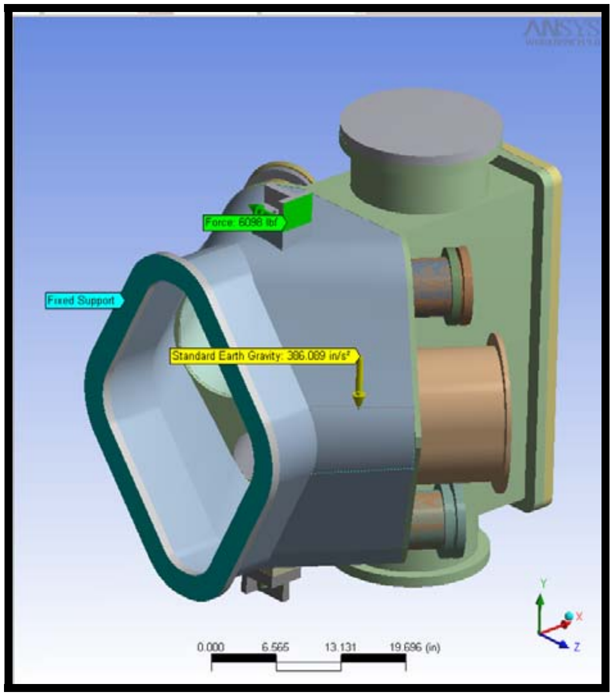

Figure 3: Loading Schematic for Ansys model

IV Results

The maximum displacement of the bracket is 0.0189 in. This occurs on the front edge of the tee structure as it is pushed slightly downward into the beam port. The deflections are shown in Figure 4 and Figure 5.

The stress intensity distribution are shown in Figure 6 and Figure 7 for the exterior and interior regions of the neutral beam port. The max stress reported is around 49 ksi and is very localized. The mean stress is around 15 ksi.

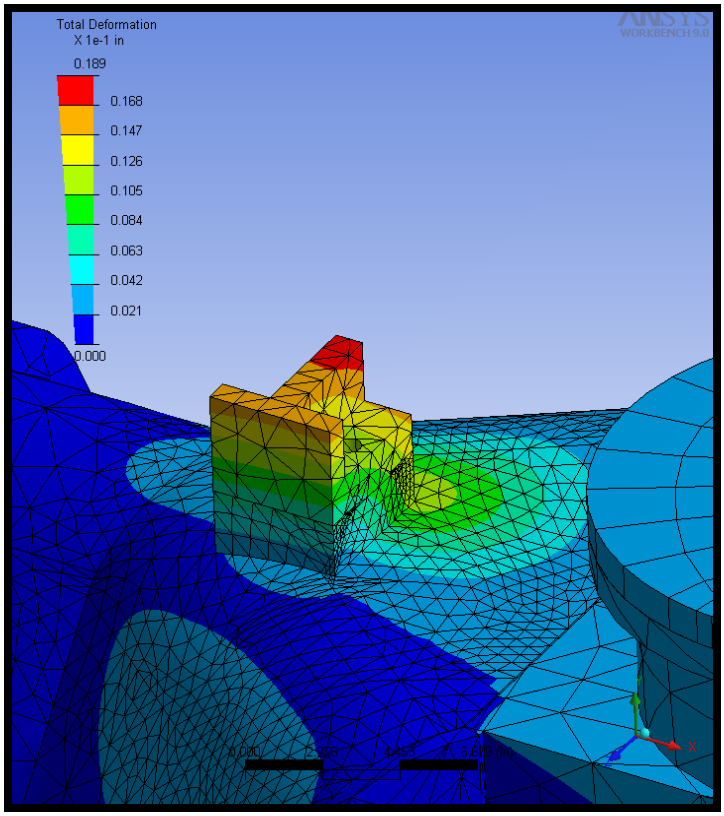

Figure 4: Deflection of the lateral support bracket (load side)

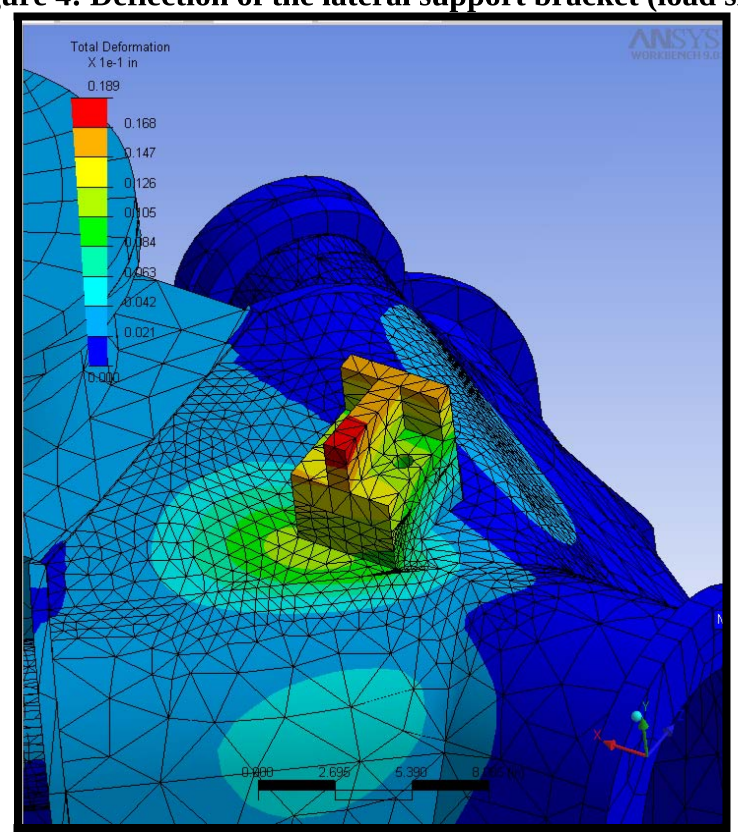

Figure 5: Deflection of the lateral support bracket (opposite side)

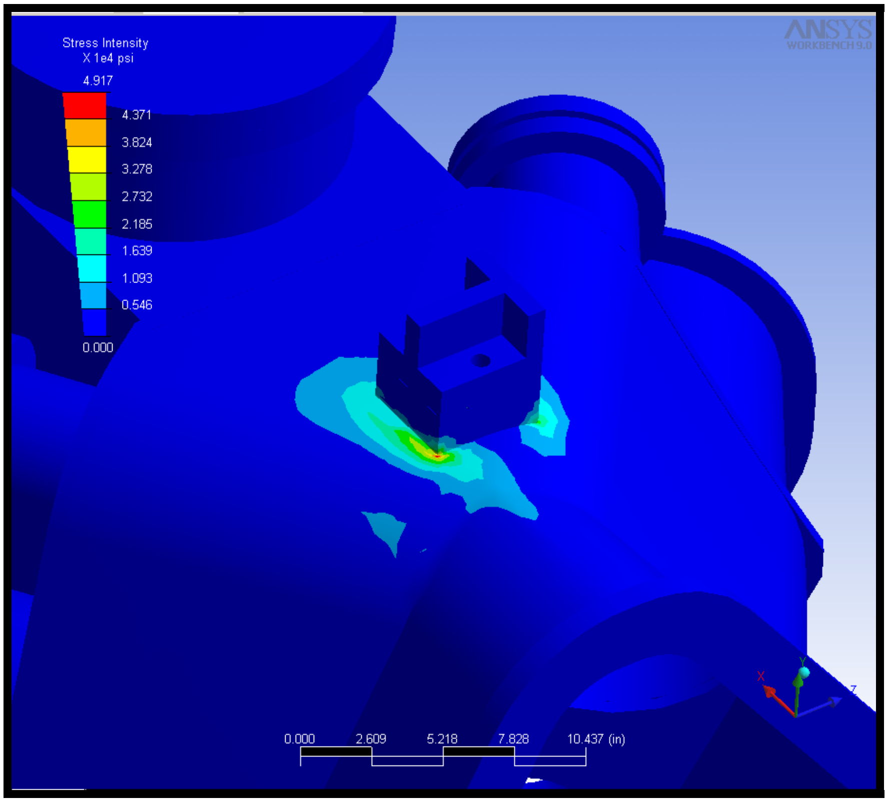

Figure 6: Stress Intensity (Tresca) for the exterior of the neutral beam port

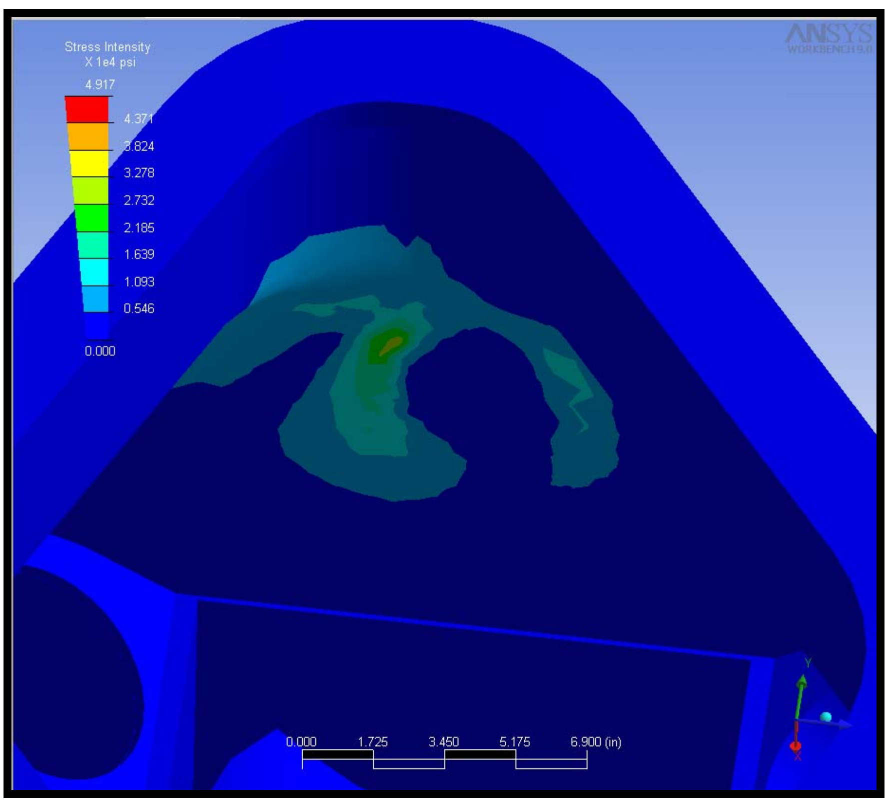

Figure 7: Stress intensity (Interior View)

V Summary and Recommendations

The ASME Pressure Vessel Code Criteria is summarized below:

Table 2B – Section II of the ASME BPVC indicates a design stress intensity (S**m**) of 30.4 ksi at the maximum operating temperature of 750 deg.F (~400 deg.C).
For normal operations the maximum operating temperature will be 400 deg.F (~200 deg.C), for which S**m** is 33.4 ksi.
Appendix 4, Section VIII – Division 2 the general stress criteria and categories for vessel design based on stress analysis:

Category	Description	Not to exceed
P**m**	Primary membrane Stress (Average across solid section, produced only by body forces and mechanical loads).	1.0k x S**m**
P**L**	Local Primary membrane Stress (Average stress across solid section, includes discontinuities but not Stress concentrations).	1.5k x S**m***
P**b**	Primary bending stress (Stresses proportional to the distance from the centroid of a solid section – excludes discontinuities & str.conc.).	1.5k x S**m***
Q	Secondary Membrane + bending stresses, self equilibrating, due to thermal or mechanical loads, or discontinuities (excludes local stress concentrations.	3.0k x S**m****
F	Incremental stress added by stress concentrations (notch), thermal stresses producing thermal fatigue.	na

* Pl or Pl + Pb < 1.5k x Sm, (k typically = 1.0),
** PL + Pb + Q < 3.0k x Sm (stress intensity range)

A review of the vessel stress analysis indicates the following:

- For normal operating conditions the worst case loading will produce a stress intensity of 49.2 ksi located at the edge of the vertical support bracket. This stress is a combination of P**L** and P**b** indicated above and thus the peak stress is allowable.

$$\mathbf{S_{Peak\ Tresca}} = 49.2 < 1.5k\mathbf{S_m} = 50.1 \text{ ksi}$$

Since this stress intensity includes primary + secondary stresses the code permits a value of 3kS_m for the total range of stress intensity. The rational for this is the assumption that some localized plastic deformation in ductile materials is permissible during shakedown as long as the subsequent stress range in the locally yielded regions will remain in the elastic range.

In conclusion, the lateral loads from the vacuum vessel (magnetic, vacuum and seismic) are reacted by the lateral support bracket and the stresses lie in the allowable range. The vacuum vessel can support the lateral loads through the neutral bema port.

VI Notes and Appendix

- A comprehensive analysis of the entire neutral beam port is outside the scope of the current WBS.
- With more effort, the deflections from the global model of the vacuum vessel can be mapped onto the connecting flange on the neutral beam port.
- However, it would be challenging to place an actual neutral beam on the global model as currently constructed since it is split down the middle of the neutral beam port and cyclic symmetry is used to form the 3 period model (see Figure 8).

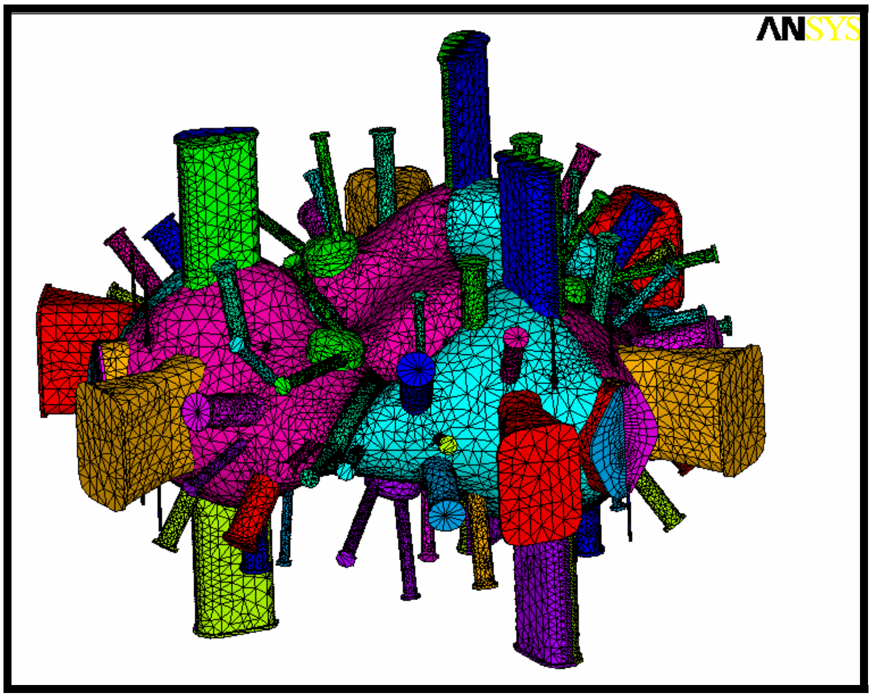

Figure 8: Ansys 3d view of vacuum vessel (split at neutral beam port)

The vacuum crush loading was applied to the structure and the preliminary results are shown below. The peak deflection no longer occurs on the bracket but instead occurs on the large vertical wall of the central beam port. The magnitude is 0.026 in. However, the peak stress does still occur near the bracket but has only increased marginally in magnitude from 43 ksi to 45 ksi. The bulk of the structure has stress under 20 ksi even with the crush loading applied. The preliminary analysis of the neutral beam port shows that it can withstand not only the lateral loading but the combined static vacuum, gravitational and magnetic loading. Still, a more comprehensive examination of the neutral beam port with cover plates and deflections mapped from the vacuum vessel analysis is needed to fully validate the assembly. The purpose of this study was to determine the suitability of the lateral support bracket's ability to handle the lateral loading, which has been shown that it indeed, can support.

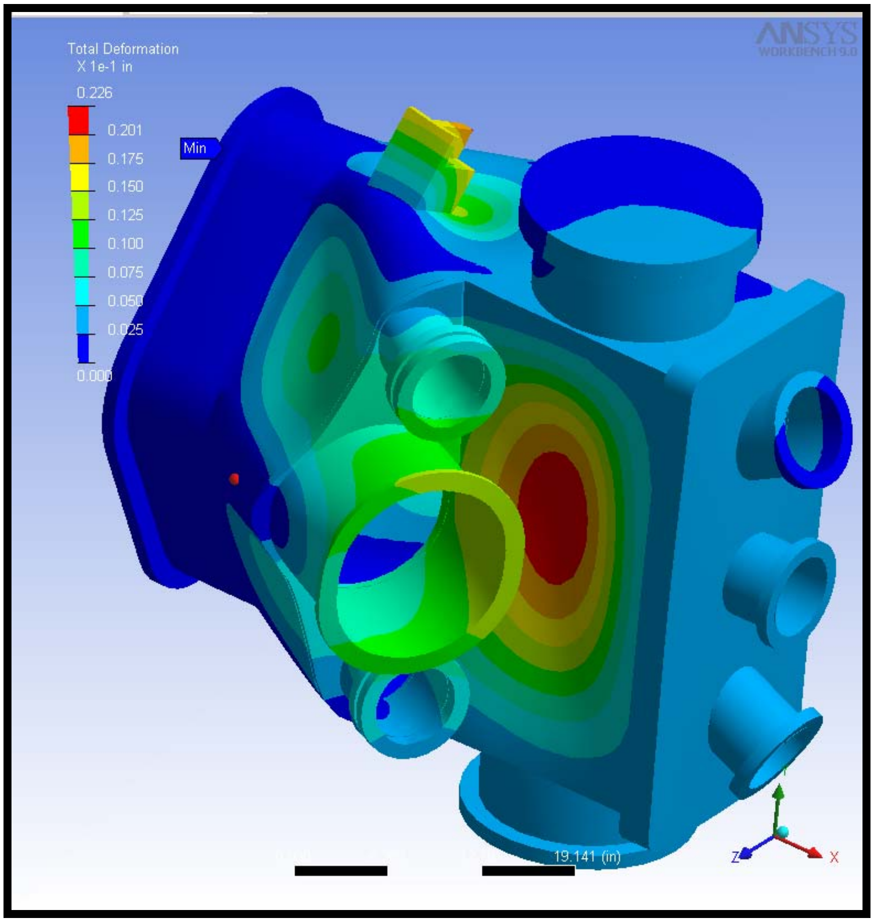

Figure 9: Deflection of neutral beam port (with vacuum pressure)

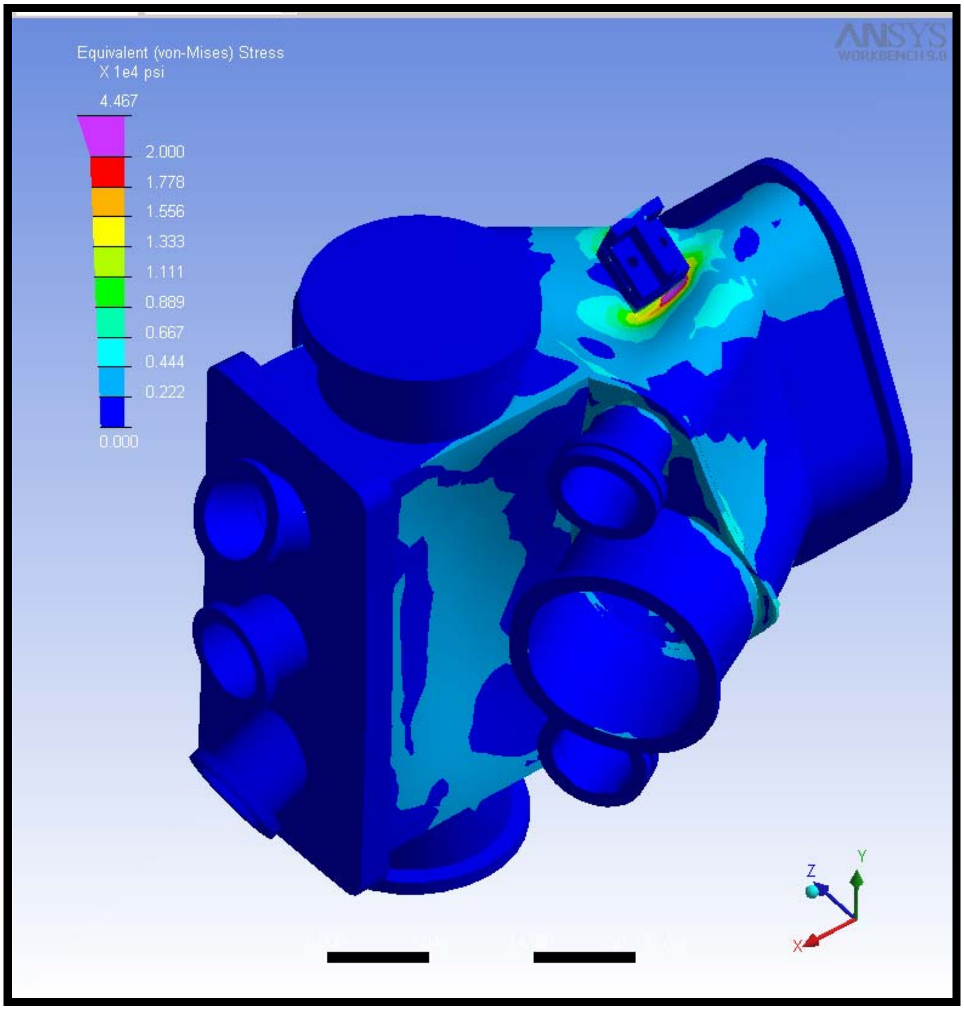

Figure 10: Von Mises Stress (with vacuum pressure)