

**NSTX-U**

Redesigned Vacuum Vessel Support Bracket

**NSTXU-CALC-12-10-01**

**Rev 1**

**February 2013**

**Prepared By:**

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**PPPL Calculation Form**

Calculation # **NSTXU-CALC-12-10-01** Revision #**01** WP # **1677**

 (ENG-032)

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

 The NSTX Vacuum Vessel (VV) main support structure consists of a specially designed “Chair” which is welded at four locations ninety degrees apart along the surface of the Vessel. However, the clevis assemblies are required at thirty degree intervals to provide connectivity between the lower TF coil ring/clamp assembly and the VV. This mechanism provides better structural support for total NSTX-U device. The original device (the NSTX) had a completely different support structure which permitted a symmetric “Chair” design. Because of the introduction of the heavy link member (see, NSTX-U-CALC-132-12-00), the existing structure had to be redesigned eliminating part of the assembly. This new geometry and the FEA model simulation are provided in the enclosed power point presentation. Therefore, a complete set of analyses to check the integrity of the redesign were required for various new loads and VV temperature conditions.

 The original calculations (March 2012) , were done using the most ideal VV – Support Chair connectivity assumptions. The weld size of 3/8 inch was assumed and simulated only in most accessible locations. However, upon the NSTX further disassembly, it become clear and necessary to implement a more representative welding scenario and replace some chair members to assure a better total device assembly effort. To check and justify new changed parts and increase of the welds to 5/8 inch, the As-Built justification became necessary. This initiated Revision 1.

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

 A complete set of FEA simulation runs were performed utilizing the “FEA 2010.1r.2, NASTRAN

code”. Applied forces and boundary conditions were extracted from various ANSYS code Global Models simulations. Results are presented in the best possible graphics format clearly marking maximum stress and/or strain values and locations.

 For Revision 1, an additional FEA calculation was performed (Run#5-MOD1-106NL-fea) using the same code and modified weld geometry (see below, the new power point file ‘VV-Support-Chair-as-Built.ppt)

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

 For this analysis the following assumptions are important: The ninety degree VV sector is simulated to provide the complete symmetry representation in the vicinity of the chair/support structure. This provides sufficient simulation for the boundary conditions to permit the critical location stress/strain values predictions. NASTRAN MPC conditions are utilized to simulate the VV symmetry condition. Loads are

applied as pressure on the vertical open VV surface as demonstrated in the power point slides. The vertical support beam is fully fixed at the location where angled brackets connect it to the test cell floor. This is expressed with the NASTRAN SPCs application set to zero for three principal coordinates. (Note: since the used solid elements require only translational (X ,Y, Z) degrees of freedom). The assumption is that at this location, the complete support structure remains in a steady state condition because of the angled floor brackets.

Calculation (Calculation is either documented here or attached

All the existing calculations are provided and explained by the following Power Point file:

Vessel-Suppot-Chair.ppt (original calculations – March 2012)

 This presentation describes the complete set of the NASTRAN simulation of the VV Chair- Support structure. This file presents simulations inputs as well as the outputs for the six individual runs as follows below:

 RUN #1 – Static (Solution 101) with extreme boundary conditions that react the entire load through the four bolts in the vacuum vessel support - total vessel load of 160,000 lbs, but, scaled to 40,000.lbs for a ninety degree sector. This simulation was used to investigate the maximum possible stresses on the VV/Chair welded locations. This case is considered overly conservative.

 RUN #2 – Static simulation with relaxed boundary condition, spreading the support loads through the pad and not just the bolts, using the same SPCs, MPCs, and loads as in the RUN #1. With this simulation additional information was demonstrated for the maximum expected calculations.

 RUN #3 – Static simulation with final and complete model with RBE2(rigid link) elements instead of GAPs. SPCs are changed to the vertical beam location where angled floor brackets connect to it. MPCs and applied load pressures are as in the prior runs. This run correctly simulates the overall intended analyses approach.

 RUN #4 – Non linear run (Solution 106) where RBE2s were replaced with the proper GAP elements which are aligned to Coordinate #2 with element X-direction in the negative vertical direction. Elements slide (with a coefficient of friction assumed to be 0.3) in the element Y and Z direction. The obtained results are very similar to the data from RUN #3. The reason for this is that there is not much global radial motion without the thermal effects on the Vacuum Vessel.

 RUN #5 – Non linear run with the addition of the 37,000. Lbs. link/clevis load as shear parallel to the vacuum vessel surface. All other loads and boundary conditions are identical to RUN #4. Obtained results values for this case increase since an addition load was added. Locations for the maximum values are relocated but remain reasonable for the material allowable. This simulation is most representative of the standard device operating environment since it includes the ring/clamp vacuum vessel clevis forces.

 RUN #6 – Non linear “BAKEOUT” simulation. This is a special run which includes the combination of the mechanical loads due to the vacuum vessel weight and the possible worst case thermal differences during the “BAKEOUT” event as the structure reaches a steady state condition after 1,200 minutes of temperature application. Same scenario was used to predict this condition for the PF 4 and 5 support brackets where temperature profile was measured and recorded during the actual “BAKEOUT” operation.

For RUN #6, previous data was converted from degrees C to F and distributed accordingly on the complete simulation using element groups as described in the appropriate powerpoint slides. It is assumed that this is the best possible representation for this RUN #6 case. (please see the complete set of these attached powerpoint slides).

 VV-Support-Chair-as-Built.ppt (update February 2013)

 This presentation describes the As-Built VV Support Chair configuration. After inspecting the photos provided by the NSTXU assembly team, the actual chair assembly appeared well connected to the vacuum vessel. These photos show that, the every contact edge between the chair and the vessel is welded using

5/8 inch welds. The welds in the original simulations were modeled on the outside connecting edges only and are sized at 3/8 inch. However, the team reported, that the chair support plate may not be completely welded to the vessel in the upper location. It is difficult to visually inspect because certain coil assemblies are obstructing the view. This initiated a modification of the Run #5 simulation by removing the upper weld elements (see the reported slides for the exact location). The results from this modified simulation show the absolute maximum stress concentration for 3/8 inch welds (appropriate slides).

 Therefore, the obtained maximum Von Misses stress = 22,100 psi, (upper right corner). By converting 3/8 inch to 5/8 inch weld areas, the maximum stress for a 5/8 inch weld decreases to 7,840 psi. This clearly demonstrates the superiority of the As-Built configuration and no further FEA analyses are

necessary.

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

Based on the above described simulation the following final list shows important findings for the Redesigned Vessel Support Bracket assembly and the connecting structure. Also, please see the summary slide in the power point file. Conclusions are as follows:

* Calculated stresses and strains are well within the material allowable,
* Maximum stresses for the welded locations are equal to 16,200 psi
* Maximum strains for the welded locations are equal to .00047
* Maximum stresses for the VV-chair location are equal to 21,500 psi
* Maximum strains for the VV-chair location are equal .00062

* Based on the total set of simulations done earlier, the As-Built visual examination and weld size comparison, it is concluded that the present connection between the Vessel and existing supports are acceptable during maximum load application. Stresses in the chair structure, its sliding cradle surfaces and newly implemented 5/8 inch welds are well within the material allowable.

Previous calculations demonstrated the historical simulations to understand the general behavior of the entire system. The As-Built results describe the justification for the present

weld size and configuration.

 Note: All the maximum weld stress values are calculated by RUN #6 which includes the “BAKEOUT” temperature scenario. The results obtained in RUN #5 are slightly smaller but important peak stress locations are different.

Strong Recommendation: to carefully weld the assembly connecting corners since all maximum strains and stresses are concentrated in these locations. These additional welds should decrease the peak values making the design stronger! Please see slide #30.

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 Preparing Engineer’s printed name, signature, and date

Peter Rogoff 2/14/2013

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

Checker’s printed name, signature, and date

 Irving Zatz \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**References**

*Reference for 37000 lbs: VV-Clevis applied load. (see power point slides/data) – [Added by P. Rogoff]*

[1] Analysis of TF Outer Leg, Han Zhang, Calculation Number NSTXU-CALC-132-04,

*Reference for standard brackets/chairs and chair loads:*

[2] NSTX-CALC-13-001-00 Rev 1 Global Model – Model Description, Mesh Generation, Results, Peter H. Titus

*Reference for PF4/5*

[3] Analysis of Existing and Upgrade PF4/5 Coils and Supports – With Alternating Columns. NSTX-CALC-12-05-00 Rev 0 P. Titus March 2011

*Reference for Criteria:*

[4] NSTX Structural Design Criteria Document, NSTX\_DesCrit\_IZ\_080103.doc I. Zatz

[5] NSTX Design Point Sept 8 2009 [http://www.pppl.gov/~neumeyer/NSTX\_CSU/Design\_Point.html](https://mail.pppl.gov/exchweb/bin/redir.asp?URL=http://www.pppl.gov/~neumeyer/NSTX_CSU/Design_Point.html)

[6] Fusion Engineering and Design 54 (2001) 275–319, Engineering design of the National Spherical Torus, Experiment, C. Neumeyer et.al, Page 286 quotes 100,000 lbs for the total vacuum vessel weight

DCPS Input:

 In deriving the net loads on the vertical columns, it is assumed that all the magnetic loads sum to zero, and that the centerstack load inventory - PF1 a,b, upper and lower, and the OH, is supported by the pedestal, and an equal and opposite load is imposed on the vessel legs. The net load from the coils is 53445 lbs [5], rounded up to 60,000 lbs The tokamak is assumed to weigh 100,000 lbs [6]. The net dead load is 160,000 lbs or 40,000 lbs per column, or 177935 N per column. An initial setting for the DCPS would be to limit the sum of PF1a,b, U&L, and OH Upward vertical loading to 60,000 lbs. Upward vertical loading of the inner PF coils supported by the pedestal implies an additional downward loading on the vessel support columns of an equal magnitude.

The total mechanical load applied to all simulation runs is 40,000 lbs for the 90 degree VV sector. This is based on the Ref (5) and (6) requirements. [Added by P. Rogoff]