NSTX-U Vacuum Vessel Design Modification

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***Abstract*— The NSTX-U requirements will double the Toroidal Field (TF), Plasma Current (Ip), Beam Injection Power, and extend pulse length. The larger centerstack requires re-aiming of the Multi Pulse Thomson Scattering (MPTS) lasers and Vacuum Vessel (VV) modifications at Bay L. The second neutral beam requirements include larger tangency radii and thus a VV modification at Bay K and Bay J. A cap design for a new weldment was developed to achieve these larger beam trajectories without losing the utility of the Bay J port for diagnostics. Analyses of loads indicated the need for reinforcements of the vessel at the midplane. NSTX has 6 picture frame type Resistive Wall Mode (RWM) coils around the exterior circumference of the vacuum vessel; each coil surrounds pairs of ports. The modifications needed for the upgrade were intended to minimize the impact to the RWM fields at the plasma. A Pro E global model segment was used to model the vacuum vessel. ANSYS was used to apply loads and investigate reinforcement configurations. A focused effort and analysis produced a design capable of achieving the desired performance of the upgrade while maintaining utility and continuity of RWM coil physics pre- and post-upgrade physics performance. The installation of the Bay J-K and Bay L Port Caps was completed and the reinforcing weldments have been partially installed.**

Keywords*— *NSTX-U; vacuum vessel, port, reinforcement; stress; weldment

I. Introduction

The National Spherical Torus Experiment (NSTX) is the world's highest performance Spherical Torus (ST) research facility and is the centerpiece of the U.S. ST research program. Since starting operation in 1999, NSTX has established the attractiveness of the low-aspect-ratio tokomak ST concept characterized by a strong intrinsic plasma and enhancing stabilizing magnetic field line curvature [1]. The NSTX is undergoing an upgrade at a projected cost of $94 million. The purpose of the NSTX Upgrade project is to expand the NSTX operational space and thereby the physics basis for the next-step ST facilities [2]. As part of the upgrade project, a 2nd neutral beam will be added and the existing center stack will be replaced with a larger diameter [3]. The 2nd neutral beam will be installed in the Bay J-K Port. This required the existing Bay J, Bay K and Bay L Ports to be redesigned. The increased performance of the upgrade NSTX results in larger EM loads. Therefore, it was necessary to analyze the stress level in various locations of the vacuum vessel. ANSYS analysis software was used for the calculations.

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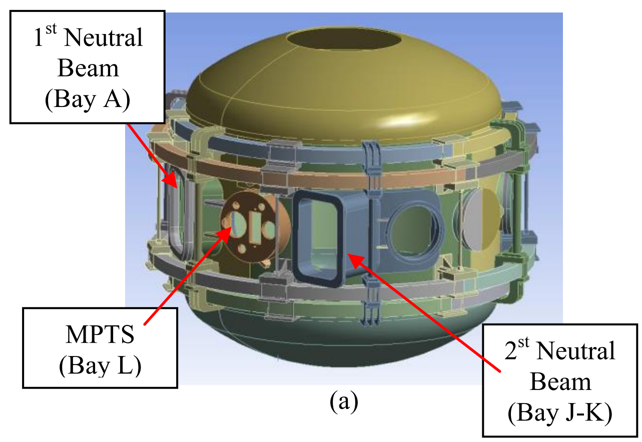
II. Design Changes

Multiple design changes were made based on results from stress iterations. The design also considered minimizing the impact on the 6 picture frame type Resistive Wall Mode (RWM) coils that are located around the exterior circumference of the NSTX vacuum vessel. The Bay J, Bay K and Bay L Ports were redesigned. Reinforcements were added in various locations on the vessel where high stresses were indicated. The Bay L t-FIDA Diagnostic Port was re-designed using thicker tube. These changes were made in a way that do not interfere with the RWM fields and that minimizes changes to the design of the RWM Coils and supports. Figure 1 shows the design changes on the vacuum vessel.



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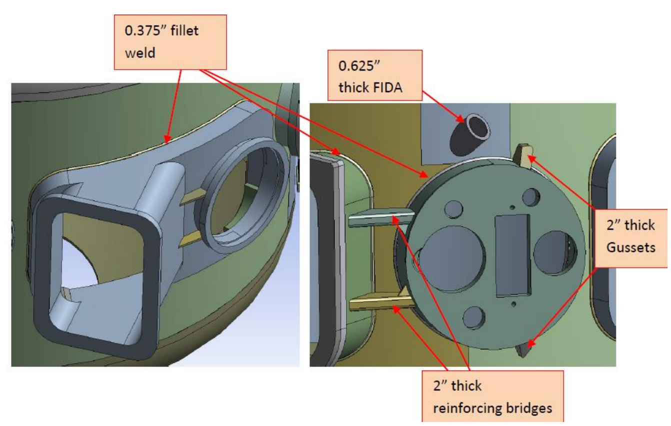

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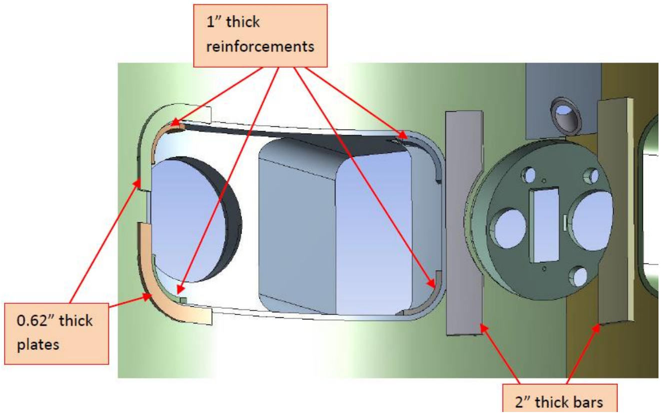

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Fig. 1. (a) Overview of the NSTX-U Vacuum Vessel and PF 4&5 Supports; (b) Reinforcements Added from Outside of the Vessel; (c) Reinforcements Added from Inside of the Vessel

III. DESIGN FACTORS

A. Materials Property

TABLE I. THE PROPERTIES OF MATERIALS USED AT ROOM TEMPERATURE (292k)

Part Name	PF 4 & 5 Coils	All other bodies
Material selection	Copper Alloy	304 Stainless Steel
Yield Strength (Ksi)	40.61	33.94
Tensile Ultimate Strength (Ksi)	62.37	92.82
Maximum Allowable Stress (Ksi)	27.07	22.63
Young's Modulus (Ksi)	1.6E+4	2.8E+4
Density (lb in^{-3})	0.3	0.28
Poisson's Ratio	0.34	0.31

B. Loading Conditions

The loading conditions for NSTX-U vacuum vessel analysis included the following:

1) Electromagnetic forces inside the PF 4 & 5 coils due to the current flow: These forces are calculated for current scenario #50 using Maxwell [2] and shown in Figure 2.

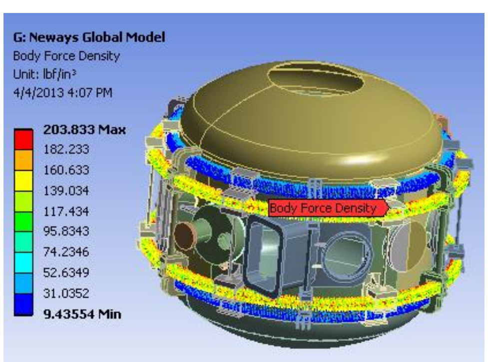


Fig. 2. Electromagnetic Forces due to Current Flow inside PF 4&5 Coils

2) Vacuum Pressure: The pressure differential between the vacuum pressure (0 psi) and the outside atmospheric pressure (14.7 psi) on the vacuum vessel has been included. Figure 3 shows the vacuum pressure.

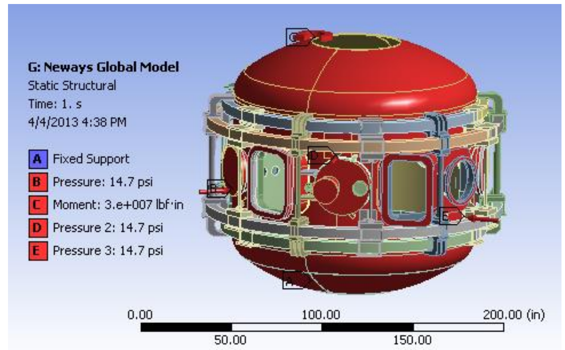


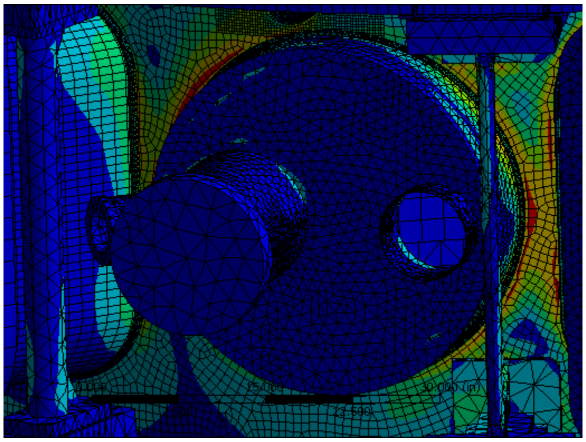
Fig. 3. The Vacuum Pressure and the OOP Load of TF Outer Coils

3) Moment: The moment created due to the Out-of-plane (OOP) load of TF outer legs was also included as shown in the Figure 3.

IV. RESULTS AND DISCUSSION

Stress iterations were performed using global model and sub-modeling analyses. Multiple design changes were made to support the analyses effort. The added reinforcements, as shown in Figure 4, made significant contribution in lowering the stress levels to the acceptable limit in various areas on the vacuum vessel. There are four 1" and two 5/8" thick reinforcing plates added to the Bay J-K Port from inside the vacuum vessel. These reinforcements added significant strength against the moment about the machine vertical axis created due to the OOP Load of the Outer TF Coils. The two vertical 2" thick bars added around Bay L from the inside of the vessel, the 2" outer Bay L gussets and the additional two 2" thick bridges between Bay L and Bay A Ports made significant improvements to the stress levels in the various areas of the vacuum vessel and brought it down to the acceptable stress level. The fillet welds, in addition to the full penetration welds used to mount the Bay J-K and Bay L Ports onto the vacuum vessel, played significant role in clearing some local stresses. The Bay L t-FIDA Diagnostic Port was re-designed using larger thickness tube and the stress was brought down to the allowable limit. The reinforcements discussed in this section are shown in Figure 1. Also, the stress results were verified to be in the acceptable zone in the following locations: BES Diagnostic Port at Bay B, Bay F t-FIDA and Bay F Thomson Scattering.

Since fatigue was not part of this stress analysis, periodic inspection and maintenance is requested of the welds around the BES Diagnostic Port, Bay J-K Port, Bay L Port and Bay A Port. In general, these are the regions that saw the most stress due to the nature of the loading conditions and the large cutout holes in the regions.



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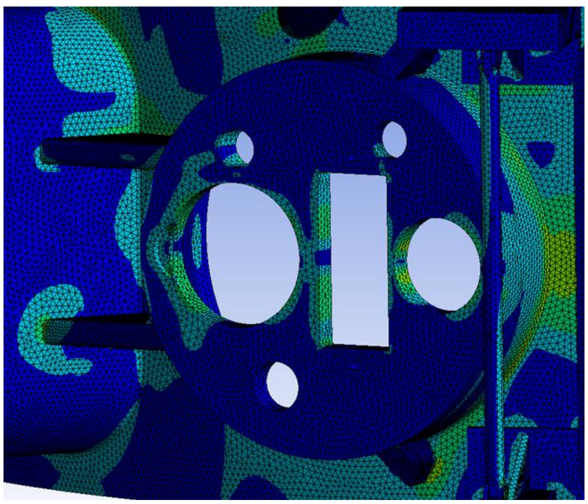

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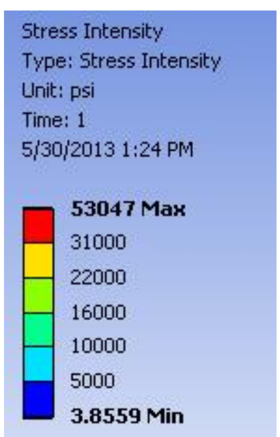

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Fig. 4. Stress Results around the Bay L Port: (a) with no reinforcement added; (b) with reinforcements; (c) the stress values

V. ACTUAL LOOK

The fabrication and installation of the new Bay J-K and Bay L ports were completed. The ports were connected to the vacuum vessel with full penetration weld and fillet welds on the outside. The exterior reinforcements for these ports were also installed. Figure 4 shows photos of the lifting and installation of the Bay J-K Port Cap, the outside look of the Bay L Port, the outside look of the Bay J-K Port after installation was completed, the exterior reinforcements and the internal view of both the Bay J-K and Bay L Ports. These photos do not show the internal reinforcements because the reinforcements were yet to be installed at the time the photos were taken.

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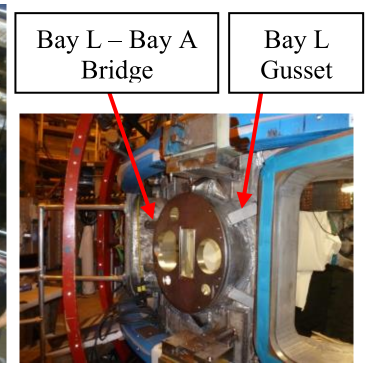

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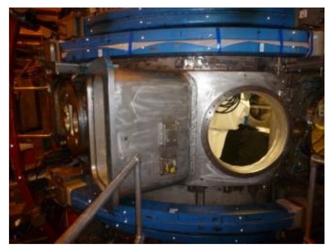

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(d)

Fig. 5. The actual look of the new Bay J-K and Bay L ports as part of the NSTX-U Vacuum Vessel: (a) The installation of the new J-K Port Cap; (b) The outside look of the installed Bay L Port and Exterior Reinforcements; (c) The outside look of the Bay J-K Port Cap; (d) The inside look of the Bay J-K and Bay L ports before the installation of the internal reinforcements.

VI. CONCLUSION

The increase in the NSTX-U forces led to design changes for the Bay J-K and Bay L Ports. The design changes were performed while minimizing the impact on the RWM coils. Analyses had showed high stresses around the newly designed ports and also other regions on the vacuum vessel. Multiple stress iterations were performed using various designs of reinforcements. Finally, the reinforcements discussed in this paper provided acceptable stress levels in all regions on the vacuum vessel. Some parts of the vacuum vessel were also scheduled for periodic inspection and maintenance. These regions include the BES Diagnostic Port, Bay J-K Port, Bay L Port and Bay A Port. Installation was completed for the Bay J-K Port, Bay L Port and the reinforcements on the outside of the vacuum vessel. The internal reinforcements are being fabricated and yet to be installed at the time this paper was written. The t-FIDA Diagnostic Port design is also in progress.

Acknowledgment

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