

National Spherical Torus eXperiment Upgrade

Vacuum Vessel (VV) Field Scope WBS 1.01.02.03

NSTX-U Recovery Project FDR – March 17-19, 2020

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Last edit: 3/10/20

Outline

1. Overview

2. Scope

3. Requirements and Interfaces

4. Analysis/Prototyping

5. Chit Closure

6. Procurement, Fabrication, Installation, and Test

7. Risk - Project Risks and Design FMECA

8. Quality, Environmental, Safety, and Health

9. Summary

Overview - WBS 1.01.02.03

WBS Title	VVIH Field Scope	WBS #	1.01.02.03
Project Cog.	Mojtaba Safabakhsh	Assoc. Proj. Man.	Bill Gattoni
Design Scope	1) Improvements to the vessel leg isolation; 2) improvements to electrical isolation of the lower umbrella lid; 3) Redrill bolt circles on main vessel flange; 4) Lock TF turnbuckles; 5) Modify vessel leg to avoid interference; 6) Remove radial restraint on PF coils and ensure uniform bolt torques; 7) Assess reusability of carbonite coated surfaces; 8) Assess/remedy broken bolt on pedestal; 9) Document as built Umbrella arch		
Technical Impact of Scope	Various technical improvements will enhance the reliability of the vessel, provides for assembly of new MCS polar region and improves coil support components		
Design Status	Final design completed over course of two reviews FDR #1 : Link and FDR # 2: link Calculations: link Drawings: link SoWs/Specs: N/A Chit reports: link		
Fabrication Status	Fabrication will start following CDE-3B ESAAB Approval		

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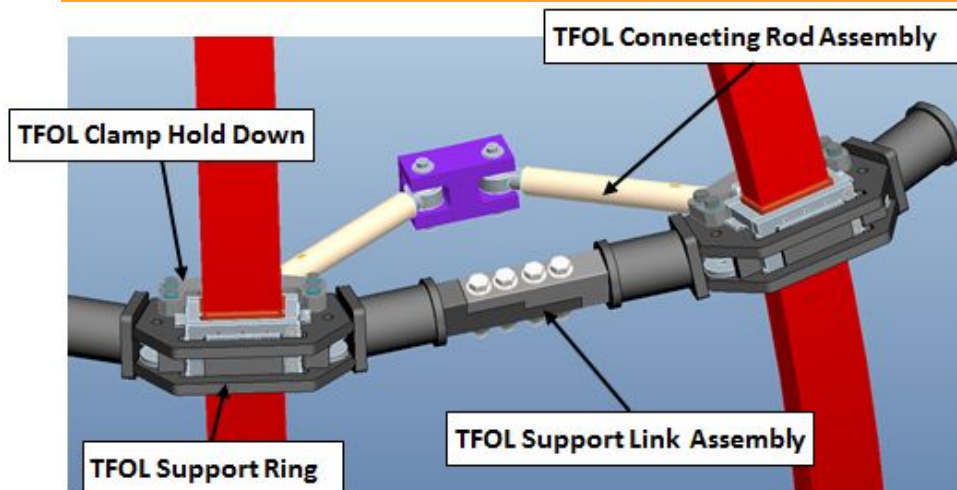
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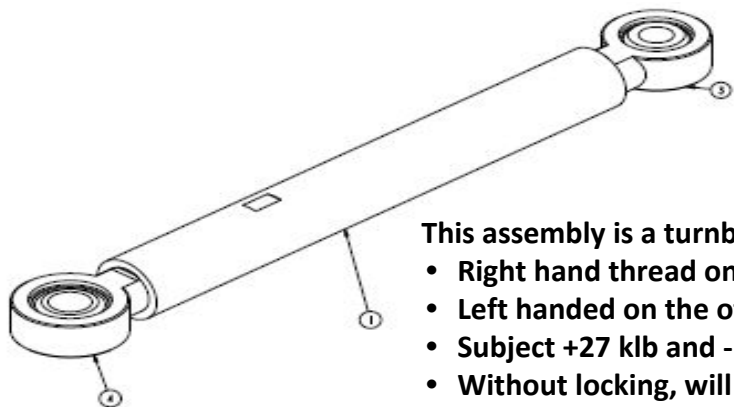
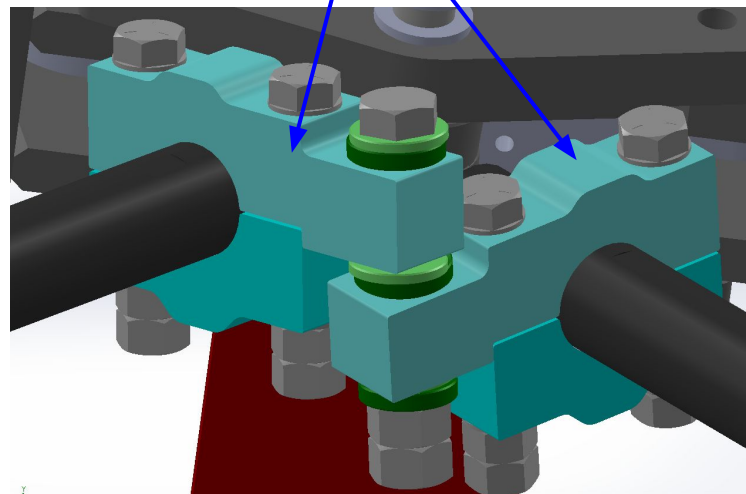
VV&IH Field Scope WBS Element Derived from DVVR Chits

- Vacuum Vessel and Internal Hardware (VVIH) Design Verification and Validation Review (DVVR) identified various issues associated with the vacuum vessel, outer-PF supports, and outer-TF supports.
- The key issues were included in the Extent of Condition plan and the Project scope.
- Some issues resolved by inspection/calculation or are related only to documentation, and not further addressed here:
 - Radial restrain bolts on outer-PF coils ([NSTXU 1-1-3-1-4 CALC 100](#))
 - Umbrella arch documentation ([drawing](#))
 - Assess reusability of parts in contact with Carbonite: [link](#)
 - Coil support grounding ([NSTXU 1-1-3 CALC 100](#))
 - Broken pedestal bolt ([NSTXU 1-1-3-3 CALC 113](#))
- These not addressed in this presentation; will only discuss to-go scope

Turnbuckles will Be Restrained Against Turning



New mechanically coupled clamps prevent any one turnbuckle from loosening by locking it to the other clamp.

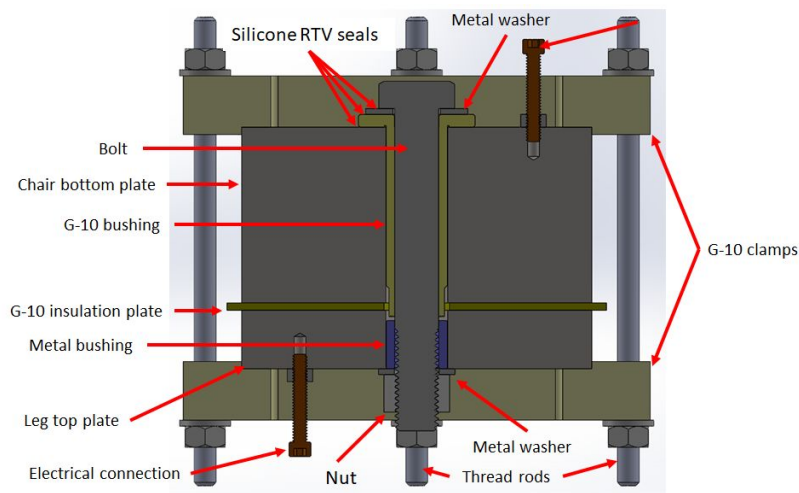
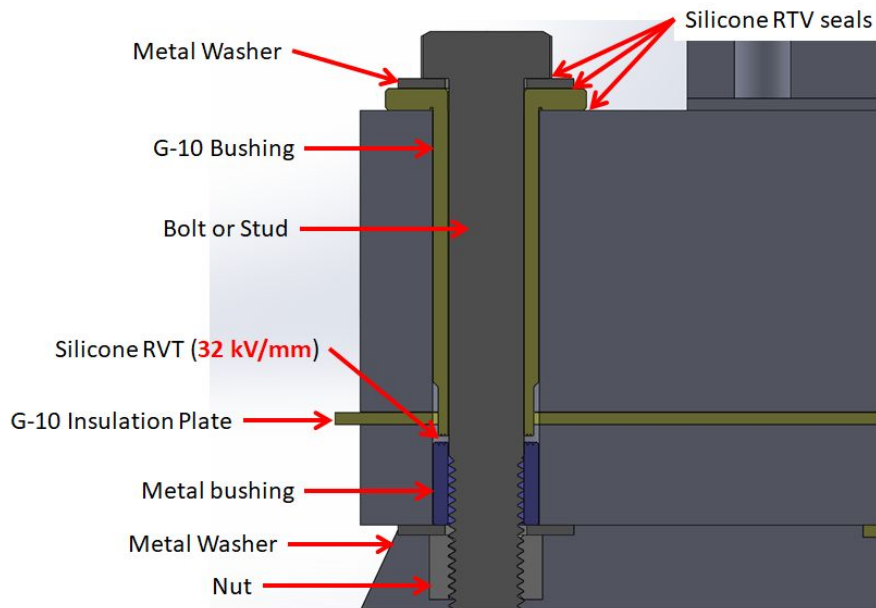


This assembly is a turnbuckle device

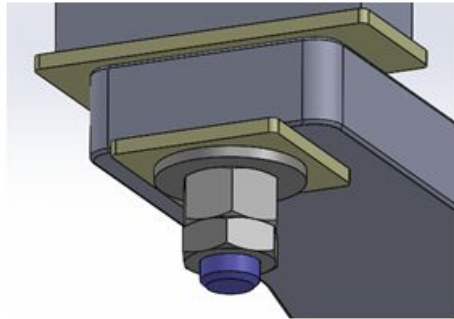
- Right hand thread on one end
- Left handed on the other
- Subject +27 klb and -15 klb impacts
- Without locking, will self loosen

Improved Vessel Leg Isolation

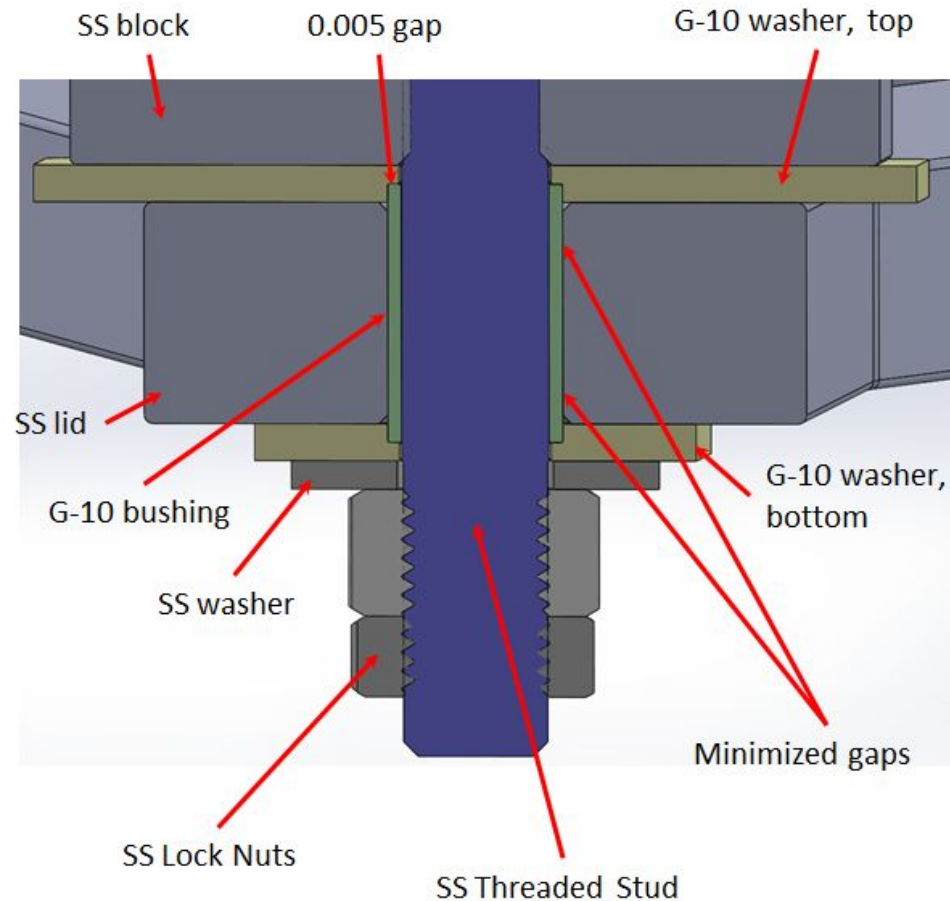
- Inspection revealed misalignments in the leg components and exposed line of sight, resulting in tracking and loss of ground isolation
- Modified G10 parts and cleaning proved effective during mock up
- New G10 parts and cleaning process is developed for implementation



Improved Vessel Lid Isolation



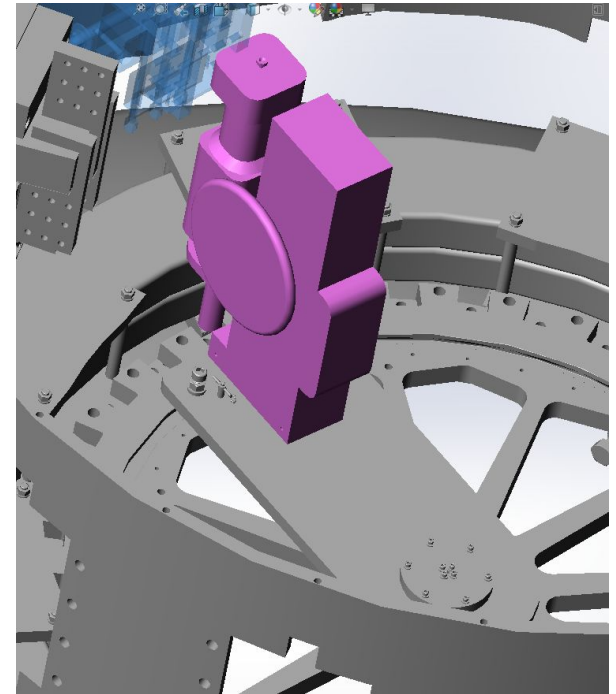
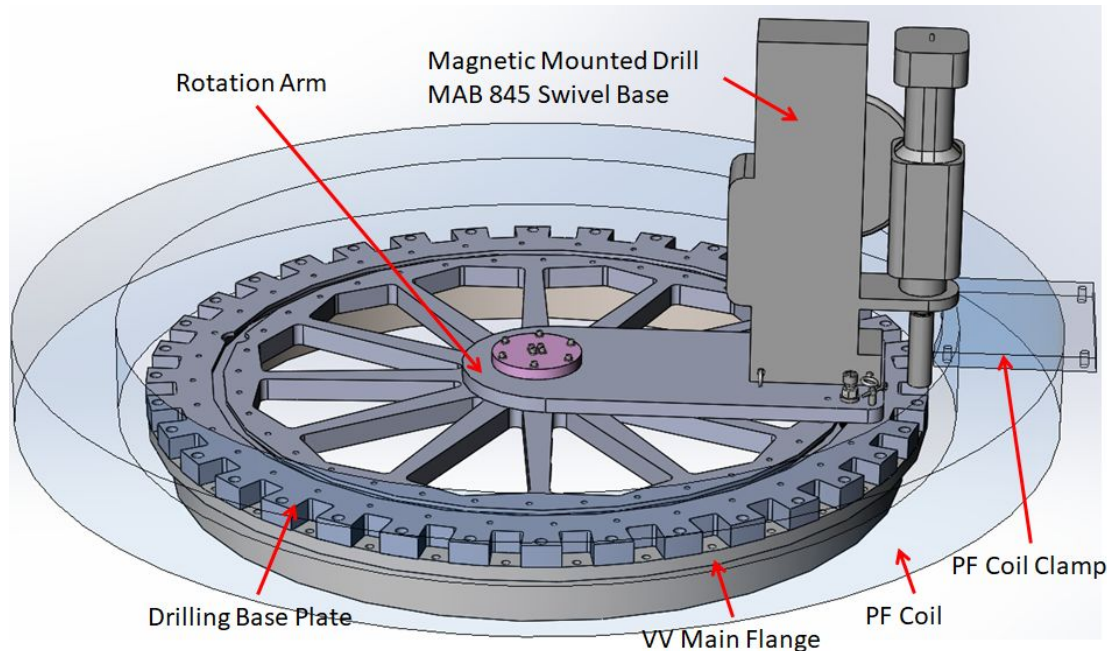
- Relies on shear strength of stud, not on friction
- Lock nut manages clamping force
- Decouples friction and shear functions
- Minimal vertical load; Vs high torsional load



New Bolt Circles Will Be Drilled and Tapped

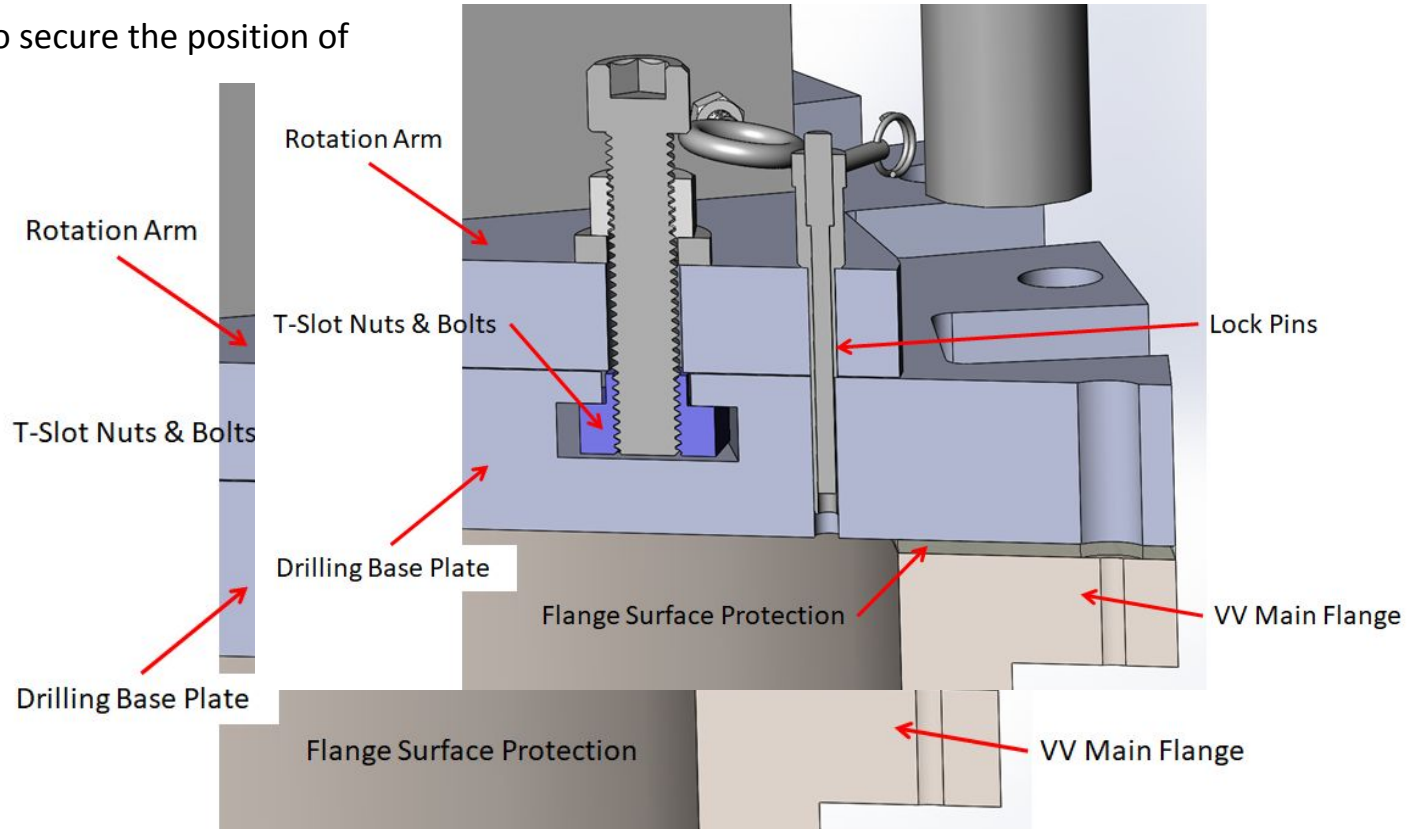
Existing holes in vessel flange are poorly aligned, complicating achievement of project alignment goals

Drilling fixture will ensure position and alignment accuracy of the drilled and tapped holes



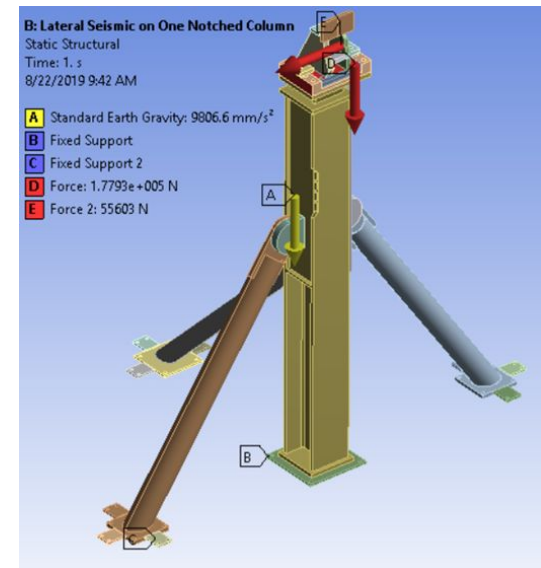
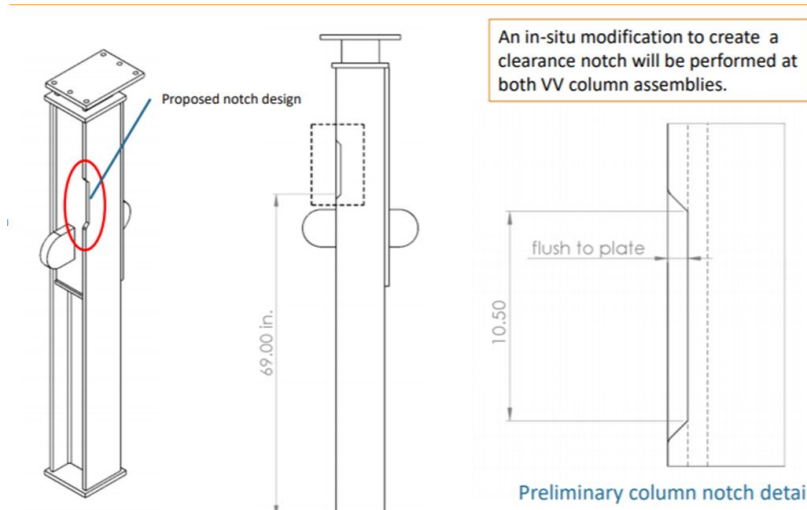
New Bolt Circles Will Be Drilled and Tapped

- Locking pin to assist in accurate positioning
- T slots/nuts to secure the position of rotation arm



Vessel Columns Notching

- Column notch was proposed to prevent chance of interference between the coil and column flange in two locations.
- Proposed notch was modeled and analysis and calculation proved that there were no considerable loss of strength of the legs
- Drawings and procedure are prepared



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Requirements Defined and Met

Source	Requirements	met
NSTX-U-RQMT-GRD-001	Vessel isolation requirements - Must design for 2 kV AC RMS	✓
NSTX-U-RQMT-GRD-001	Design point - $I_p=2$ MA, $B_T=1$ T, $P_{inj} = 10\text{-}12$ MW, $\tau_{\text{flat-top}}=5$ sec	✓
NSTX-CRIT-0001	Design Criteria - Provides the project definition of margin for loads vs. allowables for mechanical design	✓
NSTX-U-RQMT-SRD-004	Vessel leg requirements - functions, loads	✓
NSTX-U-RQMT-SRD-004	TF truss requirements - functions, loads	✓

Complete RVTM maintained by Project Systems Engineering

The Design Accommodates Required Interfaces

The designs here conform to the bolt patterns and spatial envelopes of existing components → no new interface challenges.

“Handcuff” turnbuckle restraints interface only to the trusses.

Details of Interfaces Defined in Interface Control Documents

System 1	System 2	ICD Link	Exposition
Magnets	Vacuum Vessel	link	Defines interface between the Magnets (TF Outer Leg) and the Vacuum Vessel Leg

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Comprehensive Calculations

Verify Design will Meet Requirements

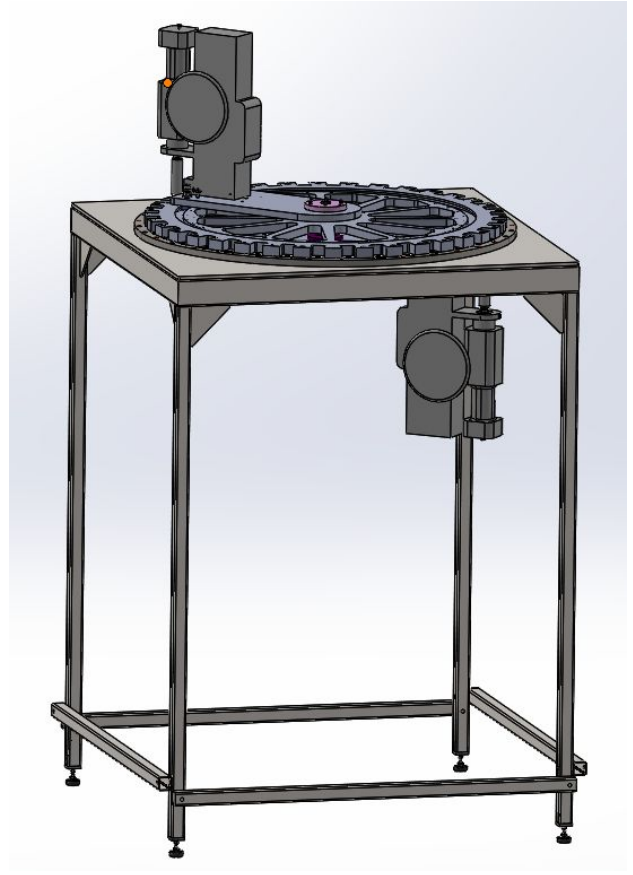
Physical Quantity	Calculation #	Content
vessel leg stress	NSTXU_1-1-2_CALC_101	calculation shows that the vessel leg stresses are within allowables even with required notches to alleviate potential interference with TF coil
Electrical and Mechanical strength of G10 at Spoked lids	NSTXU_1-1-2_CALC_102	Calculation shows that new design for insulators at the interface of the lower spoked lid and umbrella structure supports the required loads and insulating values
PF-4/5 Clamp Grounding	NSTXU_1-1-3_CALC_100	Shows that the grounding system for the PF-4/5 clamps is sufficient
Radial Bolts	NSTXU_1-1-3-1-4_CALC_100	Shows that radial bolts do not have a significant impact on coil deformation or stresses and can be removed.
Outer TF leg clamps	NSTXU_1-1-3-2_CALC_100	Calculation show that the outer TF leg struts can be locked with aluminum clamps to against the potential rotations under the impact of axial loads. And fatigue analysis confirm that the clamps and related hardware have sufficient strength to perform the functions.
Vacuum vessel flange tapping fixture	NSTXU_1-1-2-1-1_CALC_100	Calculation show that all the parts have sufficient mechanical strength for the drilling and tapping functions. The max deformations on the base plate and rotation arm are 0.0035 and 0.0080 inches, respectively, which will not cause a significant influence on the accuracies of drilling and tapping.
PF-2/3 coil clamp tubes	NSTXU_1-1-3-1_DOC_100	Shows that the tubes around the threaded rods on the PF-2/3 clamps can be shortened without risk as the PF-4/5 has the same construction, higher loads and no tubes around the threaded rods.
TF Bundle missing pedestal bolt	NSTX_1-1-3-3_CALC-ONRL_Signed	A single bolt was galled and broken. Calculation showed removal and/or replacement of the bolt was unnecessary due to adequate strength in the remaining bolts.

Prototyping and Testing

- Grounding system on PF4/5 coils was tested and proved adequate
- Carbonite contact friction properties were determined through sample production and testing
- Vacuum Vessel Leg isolation solution was prototyped to show efficacy of cleaning method and redesigned new components
- Vacuum Vessel Flange drill Mock up

Prototyping

- Drill and tapping will be performed on similar flange on both upward and downward position to ensure accuracy and precision
- Verify the procedure is adequate
- Work is planned to begin post FDR




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All Chits Generated up to and post FDR Have been Resolved/Closed

Chits closed at and post-FDR are [here](#).

APPROVED
PPPL

PRINCETON
PLASMA PHYSICS
LABORATORY

ENG-033 - CRR - CHIT RESOLUTION REPORT
FIELD SCOPE CHIT RESOLUTION REPORT

NSTXU_1-1-2_CRR_100
Rev. 2

Work Planning #:
Effective Date: **03/09/2020**
Prepared By: **Peter Dugan**

Reviewed By	Mojtaba Safabakhsh, Cognizant Individual	03/09/2020 10:06:32 AM
Reviewed By	Yuhu Zhai, Project Engineer	03/09/2020 10:33:15 AM
Approved By	Robert A. Ellis, Chief Engineer	03/09/2020 10:57:52 AM

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Procurement, Fabrication, Installation

DESCRIPTION	PROCUREMENT	FABRICATION	INSTALLATION	TESTING/ VALIDATION
Turnbuckles on OTF Support Clamps	Raw Material purchase	Inhouse machining of turnbuckle components	Installation Post CD-3B	None
Vessel support Leg G10 isolation	Raw material purchase	Inhouse fabrication of bushings	Removal, cleaning and redo new bushings Post CD-3B	Hi Pot Testing
Vessel nozzle flange drilling	Raw material Mag drill and tools	In house machining	Implementation Post CD-3B	Mock up of drilling
Vessel column notching	Consumables	Metal working	Implementation Post CD-3B	None
PF Coil clamps	None	None	Inspection and torque adjustment Post CD-3B	None
Electrical and mechanical strength of G10 at Spoked lid	G10 , SS metal blocks, and Fastener	In house fabrication of Blocks	Part of assembly WAF	None

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Project Risks are Actively Being Managed

Risk	Score (1-81)	Open/Retired	Risk Retirement Event
If the bolt cannot be removed and analysis cannot qualify joint w/o bolt in place	15	RETIRED	Analysis showed we can do without one bolt
If Field scope assessments (carbonIte, spoked lid etc.) are negative	15	RETIRED	Testing showed no considerable reduction in contact coefficient of friction
If stress from radial restraint implications on Outer PF support is too high	12	RETIRED	Radial restraint bolts are to be disengaged
If there is any fit-up effect or stress issue with TFOH shims	12	RETIRED	Design is adaptable to the rods alignment; Shims are not under any stress

FMECA for VV&IH Scope (I)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Umbrella structure & Spoked Lids	Umbrella proper crack or otherwise structurally fail	EM loads (static or after fatigue)	TF out-of-plane loads no longer restrained by umbrella; may ultimately lead to coil damage	12	DCPS Software	None	None	4
Umbrella structure & Spoked Lids	Bolts on umbrella feet fail	EM loads (static or after fatigue)	damage to umbrella, reduced ability to handle TF out-of-plane moment	12	DCPS Software	None	None	4
Outer TF Truss System	Failure of ball joints in the tie rods	EM loads, especially with asymmetry in tie rods	overturning moment of TF is not restrained; potential coil damage	12	DCPS Software	Fiber Optic Strain, Temp., Disp. Meas.	None	4
Outer TF Truss System	Failure of welds that attach outer-TF clevis blocks to the vessel;	EM loads, especially with asymmetry in tie rods	overturning moment of TF is not restrained; potential coil damage	8	Fiber Optic Strain, Temp., Disp. Meas.	DCPS Software	None	4
Umbrella structure & Spoked Lids	Sliding joints on umbrella begin to "stick"	Degradation of coating; misalignment of components	Excessive stress and/or deformation, and possible mechanical damage in umbrella, VV & SS	6	Fiber Optic Strain, Temp., Disp. Meas.	None	None	6
Vessel Legs	Sliding joints on vessel legs become "stuck"	Degradation of coating; misalignment of components	bending/buckling of the vessel leg; asymmetric motion of the machine on its legs creating problems at interfaces to fixed points	6	None	None	None	6

FMECA for VV&IH Scope (II)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Vessel Legs	Separation of vessel leg clevis from the machine	Excessive load	vessel moves; stress on vacuum connections, coil bus work, etc.	6	None	None	None	2
Vessel Legs	Vessel leg electrical isolation fails	Excessive dust or debris, or a component or wire, bridges the insulator; water leak potentially as well	Excessive noise on diagnostics	4	Vessel and Diagnostic Grounds	None	None	4
Outer TF Truss System	Loosening of turnbuckles in tie rods	Vibration	overturning moment of TF is not restrained; potential coil damage	4	None	Fiber Optic Strain, Temp., Disp. Meas.	None	0

9 Failure Modes, all mitigated to acceptable risks

Digital Coil Protection System, which ensure the machine operates within the analysed envelope, is a key operations mitigation system

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Laboratories QA Program Supports the Work

Graded approach requirements have been applied:

- Draft of procedures
- Review and sign off of calculations
- Release of documents and drawings
- Procurement from qualified suppliers
- Traceability of materials to CMTR's for fabrication of new A1 and A2 components

ES&H

- In the ES&H section of the procedures, safety issues resulting from use of powered hand tools, working in awkward/elevated positions, tie off, and lifting/hoisting and rigging, and use of PPE are called out.
- Guidelines regarding safety and health hazards of welding is addressed in the procedures, as well as in weld procedure specifications.
- Mock up of drilling the vessel in both overhead and downward will assist in understanding the challenges of machining the vessel nozzle in term of safety and the hazards of this operation
- Mock up of the cleaning process for the G10 shims on vessel leg was helpful in understanding safety and hazards associated with that work.

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Summary

- Requirements have been met via a combination of analysis, calculations, and tests.
- Interfaces are considered in the design and documented in the ICDs
- All chits related to the entire project, including post FDR are closed
- Risks are mitigated through:
 - Cross checking of calculations and analyses
 - Lab testing of materials' inherent properties
 - Prototyping and mock up to validate the outcome of procedures and ensure satisfactory results are produced
- Standard safety cautions are enforced through standard procedures; as well as new safety measures through mock up and validation