National Spherical Torus eXperiment Upgrade

NSTX-U Dimensional Control Requirements

NSTX-U-RQMT-RD-011-01

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Record of Revisions

Date	Version	Brief Description of Changes
2/9/18	0	Initial Release
6/30/19	1	Adjust signatures; fewer signatures now.
		Added Ref. 6, which has the origin of the requirements in Section 3.2. Section 3.1 continues to have an origin explained in Ref. 5. Updated statement 1c to reflect this.
		Modified statement 1d
		Clarified in Section 2.1d that the ID of the coils can be a good reference surface, typically better than the OD.
		Updated Table 2.2-1 to change the requirements from the IBDV tile surface to the IBDV metal surface.
		Removed Table 2.2-1 and Table 2.2-2; these PFC tolerances not relevant.
		Removed Table 3.1-2 through 3.1-4; these PFC tolerances not relevant
		Removed 3.2b
		Updated 3.1 b and c to include requirements for the HTP.
		Removed bottom two rows of Table 2.1-2, and Table 2.2-1; these were not relevant to the document.

References

[1] NSTX-U-RQMT-GRD-001, NSTX-U General Requirements Document
[2] NSTX-U-RQMT-SRD-002, NSTX-U SRD - Magnets
[3] NSTX-U-RQMT-SRD-003, NSTX-U SRD - Plasma Facing Components
[4] NSTX-U-RQMT-SRD-004, NSTX-U SRD - Vacuum Vessel and Internal Hardware
[5] NSTX-U-DOC-101, Magnet and PFC Alignment Requirements Basis
[6] NSTX-U-CALC-NSTXU_1-1-2-3-2_CALC_100, Physics Calculations Supporting Alignment Requirements for the PF-4, PF-5, and TF coils

1: Scope

a. This document provides project/physics level requirements for alignments of critical components.

b. The document augments the requirements in Refs. [1-4], providing additional information.

c. Background and justification of these values can be found in Ref. [5] for the requirements in Section 3.1, and in Ref. [6] for the requirements in Section 3.2.

d. This document will provide alignment rules for specific physics-critical components, but will provide only limited practical constraints regarding the implementation of these requirements.

2: Definitions

For the purpose of this document, the following definitions will hold. Note that other definitions may be more appropriate for practical assembly considerations, for instance the use of intermediate reference surfaces.

2.1: Magnet Related Definitions

Definitions related to the inner-leg of the TF coil are shown in Table 2.1-1.

***Table 2.1-1**: Quantities related to the TF coil*

Quantity	Definition
TFIL Axis	The line defined by connecting the center of the two best-fit cylinders of the upper and lower TF inner leg electrical faces

Some PF coils are large aspect ratio coils. For purposes of this discussion, their geometry can be easily represented by a single filament whose current is N_{turns} times the coil terminal current. For the purpose of alignment, the inner diameter is typically a good reference surface, given that coils tend to be wound against their inside diameter.

Other coils are more solenoidal nature, and their field cannot be represented by a single current ring. In this case, the geometric properties of the coil are defined by the equivalent solenoid with perfectly circular windings and a perfectly straight axis.

Definitions related to the large aspect-ratio coils are shown in Table 2.1-2. These coils can reasonably be approximated by a single current filament. Definitions related to the small aspect ratio PF-1a coils are shown in Table 2.1-3.

***Table 2.1-2**: Generic quantities related to the PF-1b, PF-1c, and PF-2 through 5 coils.*

Quantity	Definition
Coil Plane - Single Coil	The best fit plane to the average conductor windings (may be determined by assessments of the ground insulation when reasonable allowance is made for ground insulation variation)
Coil Axis - Single Coil	The normal to the coil plane, centered on the average center of the conductor winding path, the coil ID, or another appropriate datum

***Table 2.1-3**: Quantities related to the PF-1a coils.*

Quantity	Definition
PF-1a Axis	Axis that passes through the bore of the coil, along the axis of the best fit ideal solenoid (may be approximated by measurements of the coil ID if reasonable allowance is made for ground insulation variation)
PF-1a Plane	Plane orthogonal to the coil axis, at the midplane of the equivalent ideal solenoid.

2.2: PFC or Casing Related Definitions

a. Definitions related to the IBDV are in Table 2.2-1, and to tiles are in Table 2.2-2. The intention of some definitions are indicated in Fig. 2.2-1.

***Table 2.2-1**: Quantities related to the casing and PFC surfaces*

Quantity	Definition
IBDVU Axis	The axis defined by the best fit of the upper IBDV to a cylinder
IBDVL Axis	The axis defined by the best fit of the lower IBDV to a cylinder

b. This requirement is removed.

3: Critical Alignments

Note: if it can be determined during fabrication and assembly that some components have final as-installed tolerances tighter than indicated here, it may be possible to relax the tolerances on other components. This would be accomplished with a revision to this requirement document.

3.1: Alignments within the CS assembly

a. Tolerance budget for alignment of the inner-PF coils are in Table 3.1-1.

1. PF-1 Coils
    a. Upper PF Coils are referenced to the upper casing IBDV axis
    b. Lower PF Coils are referenced to the lower casing IBDV axis
    c. Shifts are measured between the IBDV axis and the coil axis, at the coil midplane
    d. Tilts are measured between the IBDV axis and the coil axis
2. TF Bundle
    a. The TF Bundle must be within specification with respect to both the upper and lower IBDV
    b. Shifts are measured between the TFIL Axis and the respective IBDV axis at the center of the IBDV cylinder.
    c. Tilts are measured between the TFIL Axis and the respective IBDV axis.

Note that the shift and tilt tolerances comes from Monte-Carlo analysis with random phases. Hence, they should be considered as being in any direction from the ideal center.

***Table 3.1-1**: Alignment of Inner PF and TF coils*[1]

Coil	Tilt Tolerance	Shift Tolerance
	mrad	**mm**
PF-1a	2	3
PF-1b	2	3
PF-1c	4	5
TF Inner Legs	0.4	2[2]

Note: In forming Table 3.1-1, an n=2 (elliptical) deviation of up to 2 mm was assumed.

[1] This corresponds to Case 7 of the tolerance budgets defined in Ref. [5].

[2] While the physics analysis can tolerate this 2 mm tolerance, calculation report NSTXU-CALC-133-37-01 establishes tighter tolerances for this alignment

b. The heat transfer plates (top and bottom) shall be aligned with respect to the local casing vertical target sleeves to within a shift of 0.02”, and a tilt of 0.5 mrad.

c. The heat transfer plates shall have a surface flatness of 0.01”.

3.2: Alignments of the outer PF coils relative to each other, and to the toroidal field coil

a. The PF-4, PF-5 and TF coils shall be aligned to the global coordinate system to within the parameters of Table 3.2-1.[3]
b. This requirement removed.
c. The individual pancakes of the PF-4 and PF-5 coils shall be aligned to each other to within the tolerance state in Table 3.2-2.

***Table 3.2-1**: Alignment of the Outer-PFs to each other and to the TF inner-legs.[4]*

Tolerance	Symbol	units	Tolerance
PF-4U, Shifts, Coil	$\sigma_{\text{-4U, shift, coil}}$	mm	2
PF-4L, Shifts, Coil	$\sigma_{\text{-4L, shift, coil}}$	mm	2
PF-5U, Shifts, Coil	$\sigma_{\text{-5U, shift, coil}}$	mm	2
PF-5L, Shifts, Coil	$\sigma_{\text{-5L, shift, coil}}$	mm	2
PF-4U, tilt	$\sigma_{\text{-4U, tilt}}$	mrad	0.9
PF-4L, tilt	$\sigma_{\text{-4L, tilt}}$	mrad	0.9
PF-5U, tilt	$\sigma_{\text{-5U, tilt}}$	mrad	1.1
PF-5L, tilt	$\sigma_{\text{-5L, tilt}}$	mrad	1.1
TF, shift	$\sigma_{\text{TF, shift}}$	mm	0.8
TF, tilt	$\sigma_{\text{TF, tilt}}$	mrad	0.6

***Table 3.2-2**: Alignment of the individual pancakes to each other*

Tolerance	Symbol	units	Tolerance
PF-4U, Shifts, Pancakes	$\sigma_{\text{-4U, shift, pancakes}}$	mm	8
PF-4L, Shifts, Pancakes	$\sigma_{\text{-4L, shift, pancakes}}$	mm	8
PF-5U, Shifts, Pancakes	$\sigma_{\text{-5U, shift, pancakes}}$	mm	7
PF-5L, Shifts, Pancakes	$\sigma_{\text{-5L, shift, pancakes}}$	mm	7

[3] The tolerances in Tables 3.2-1 and 3.2-2 intrinsically consider variations in the ground insulation thickness, as noted in Ref. [6]. Therefore, these tables are to be understood as referring to the ground insulation.

[4] The fixturing design for the PF-5 coil is designed to allow elliptical distortions under thermal load; the coil is only radially restrained at two toroidally opposite locations, with one near the lead area. Therefor, elliptical and triangular distortions are not specified.

4: Accepted As-Built Conditions

a. Based on the discussion in Ref. [5] and the potential scope associated with modifications, the following are accepted in their as-built conditions:

1	PF-2 position
2	PF-3 position
3	TF outer leg positions
4	OH coil position relative to the TF inner legs

b. It is anticipated that the positions of the outboard divertor tiles will be adjusted by shim plates, rather than adjustment to the underlying metal structures.

c. Should these components be redesigned or substantially modified for other reasons, these requirements may change.