National Spherical Torus eXperiment Upgrade

NSTX-U Dimensional Control Requirements

NSTX-U-RQMT-RD-011-00

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Record of Revisions

Date	Version	Brief Description of Changes
2/9/18	Rev 0	Initial Release

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

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]

d. This document will provide alignment rules for specific physics-critical components, but will not provide practical constraints regarding the implementation of these requirements. For instance, while the CS-casing is likely a critical reference surface, it will not be prominent here as it by itself has no physics significance.

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 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 TF flag 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. 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
Coil Axis - Single Coil	The normal to the coil plane, centered on the average center of the conductor winding path.
Coil Radius - Single Coil	The average radius of the conductor, measured from the magnetic axis
Coil Axis - Coil Pair	Axis connecting the center points of the upper and lower coils in a pair.

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
PF-1a Plane	Plane orthogonal to the coil axis, at the midplane of the equivalent ideal solenoid.

2.2: PFC 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*

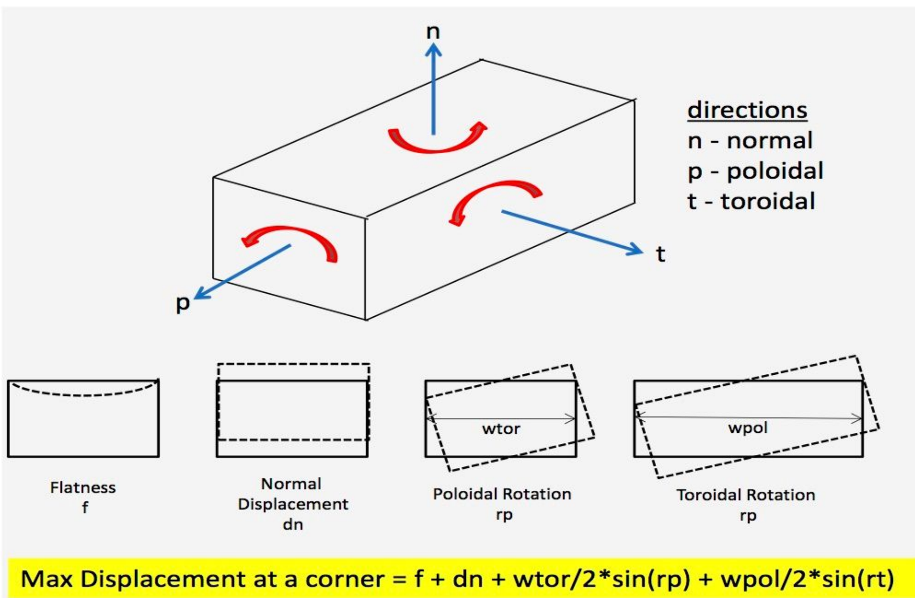
Quantity	Definition
IBDVU Axis	The axis defined by the best fit of the upper IBDV tile surface to a cylinder
IBDVL Axis	The axis defined by the best fit of the lower IBDV tile surface to a cylinder
IBDVU Radius	The radius defined by the best fit of the upper IBDV tile surface to a cylinder
IBDVL Radius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

b. It is assumed that the tolerance on the cooling plate installation shall be determined in order to meet the final horizontal target tile alignment requirement.

***Table 2.2-1**: Quantities related to PFC alignment tolerances*

Normal Displacement	Normal displacement from the nominal geometric position
Poloidal Rotation	Rotation around a poloidally pointing axis, that either increases or decreases the effective fish-scale angle of a tile
Toroidal Rotation	Rotation of a tile around a toroidally pointing axis.
Surface Flatness	Flatness of the tile surface

***Fig. 2.2-1**: Definition of tile translations and rotations.*



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 IBDV axis
    b. Lower PF Coils are referenced to the lower 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 middle IBDV row.
    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

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

c. Tiles in the high heat flux regions (IBDV, IBDH, OBDR1) shall be toleranced for criteria in Table 3.1-2 though 3.1-4. Quantities in bold at the positional tolerances, while quantities not in bold are the underlying assumptions on the design. If the design does not match these criteria, then the tolerances may be adjusted.

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

Table 3.1-2: *Alignment requirements on Horizontal Target PFCs. Quantities in bold are the required tolerances.*

Horizontal Target	**Normal Displacement Tol**	**in**	**0.005**	**mm**	**0.1**
	assumed toroidal width	in	5.000	mm	127.0
	assumed tile gap	in	0.062	mm	1.6
	assumed tile offset	in	0.013	mm	0.3
	Maximum Field Line Angle	deg	5.000	mrad	87.3
	Poloidal Rotation Tol.	**deg**	**0.023**	**mrad**	**0.4**
	Toroidal Rotation Tol.	**deg**	**0.018**	**mrad**	**0.3**
	Fishscale Angle	deg	0.360	mrad	6.3
	Surface Flatness Tol	**in**	**0.001**	**mm**	**0.03**
	Reference Plane	Normal to PF-1a axis, at nominal height of IBDH tiles			

Table 3.1-3: *Alignment requirements on Vertical Target PFCs. Quantities in bold are the required tolerances.*

Vertical Target	**Normal Displacement Tol**	**in**	**0.010**	**mm**	**0.3**
	assumed toroidal width	in	4.123	mm	104.7
	assumed tile gap	in	0.062	mm	1.6
	assumed tile offset	in	0.013	mm	0.3
	Maximum Field Line Angle	deg	5.500	mm	139.7
	Poloidal Rotation Tol.	**deg**	**0.028**	**mrad**	**0.5**
	Toroidal Rotation Tol.	**deg**	**0.029**	**mrad**	**0.5**
	Fishscale Angle	deg	0.444	mrad	7.8
	Normal Displacement Tol	**in**	**0.001**	**mm**	**0.03**
	Reference Surface	Cylinder concentric with TF axis, with radius given by the IBDV tile cylinder			

Table 3.1-4: *Alignment requirements on Outboard Divertor Row 1 PFCs. Quantities in bold are the required tolerances.*

OBDR1	**Normal Displacement Tol**	**in**	**0.010**	**mm**	**0.3**
	assumed toroidal width	in	3.453	mm	87.7
	assumed tile gap	in	0.062	mm	1.6
	assumed tile offset	in	0.013	mm	0.3
	Maximum Field Line Angle	deg	5.000	mrad	87.3
	Poloidal Rotation Tol.	**deg**	**0.033**	**mrad**	**0.6**
	Toroidal Rotation Tol.	**deg**	**0.019**	**mrad**	**0.3**
	Fishscale Angle	deg	0.521	mrad	9.1
	Surface Flatness Tol	**in**	**0.001**	**mm**	**0.03**
	Reference Surface	Ideal faceted surface referenced to the TF inner leg axis			

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

a. The axis and planes of the PF-4 and 5 coils shall be aligned to each other to within the parameters of Table 3.2-1.

b. The PF-4 and 5 coils shall be aligned to the TF inner-bundle within the parameters of Table 3.2-1.

Table 3.2-1*: Alignment of the Outer-PFs to each other and to the TF inner-legs.*[2]

Quantity	**shift**	**tilt**
	mm	**mrad**

[2] 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.

Displacements between PF-5U and PF-5L axis	2	0.7
Displacements between PF-4U and PF-4L axis	2	0.7
Displacements between inner TF axis and PF-5 Axis	1.5	0.5
Displacements between inner TF axis and PF-4 Axis	2	0.5

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-build 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 component be redesigned or substantially modified for other reasons, these requirements may change.