National Spherical Torus eXperiment Upgrade

National Spherical Torus Experiment

NSTX-U

REQUIREMENTS DOCUMENT

CS Air-Side Diagnostics

NSTX-U-RQMT-RD-005-01

April 20th, 2018

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Revisions

Rev.	Date	Description
0	12/13/17	Initial Release
1	4/20/18	Updated 4b for improved verbiage
		Added table 2-2
		Corrected title on 3.2-1
		Adjusted Signatures
		Added statement 2i
		Added Section 7
		Added Reference 3

References

[1] NSTX-U-RQMT-SRD-002, NSTX-U SRD - Magnets
[2] NSTX-U-RQMT-SRD-004, NSTX-U SRD - Vacuum Vessel and Internal Hardware
[3] NSTX-U-RQMT-SRD-011, NSTX-U SRD - Diagnostics

1: Scope

a. This document describes the CS air-side diagnostics, namely:

- Poloidal flux loops
- Thermocouples

b. This document supplements the requirements in Refs. [1] [2], and [3].

2: General Requirements

Note: system level requirements for the poloidal flux loops are found in Section 2.3.2 and Section 2.4 of Ref. 3.

a. Each flux loop location shall have a primary and a redundant loop. These two loops shall be located immediately adjacent to each other on the component to which they are mounted.

b. For loops on coils, the flux loops can be applied directly to the surface of the ground wrap. The primary and secondary loops shall not be twisted as they traverse the surface of the coil, but rather can be placed one directly adjacent to each other on the coil surface. The two leads of the primary loop shall be twisted starting at the location where they meet, as shall the two leads of the secondary loop. The diameter of a twisted pair can be taken as 0.06” for design purposes

c. Loops shall be made from 22 AWG insulated magnet wire.

d. The loops shall be protected by a thin wet layup or equivalent. See Table 2-1 of thickness of protection material.

e. The diameter of the type-E TC twisted pair can be taken as 0.08” for purposes of design, with a 0.0035” kapton layer covering, for a total build up of 0.0835”.

f. Provision shall be made for the local high spots where wire bundles cross over flux loops. Exact size requirement to be a design outcome based on chosen wire routing.

g. The flux loop radial build can be taken as in Table 2-1 and Table 2-2.. And see Appendix 2.

Table 2-1*: Nominal height stackup for flux loops on PF-1a, PF-1b, and PF-1c coils as they wrap around the coils*

Item	**Buildup [in.]**
Flux Loop	0.029
Kapton	0.0035

Wet Layup	0.013
Total	0.0455

***Table 2-2**: Nominal height stackup for flux loops on the OH coil as they wrap around the coil.*

Item	**Buildup [in.]**
Kapton	0.0035
Flux Loop	0.030
Kapton	0.0035
Total	0.037

h. The "Z-positions" in Tables 3.1-1, 3.2-1, 3.3-1, 4-1, 5-1 and 5-2 referenced to the vessel midplane.

I. Toroidal routing and exit of leads from flux loops and thermocouples out of the CS assembly can be done as convenient.

3: Inner-PF Coils

Flux loops and thermocouples shall be mounted to inner-PF coils as follows.

3.1: PF-1a Coils

a. Each PF-1a coil shall have the following diagnostics mounted outside the ground insulation, but underneath any support slings or structures:

- Four flux loop locations, approximately uniformly spaced along the coil axially, with a primary and spare loop at each location. Suggested locations are shown in Table 3.1-1, with deviations in vertical position of 2-3 cm acceptable.
- Two thermocouples, approximately uniformly spaced along the coil axially; the toroidal angle of the thermocouples can determined by convenience with regard to lead routing. These shall be type E TC wire.

***Table 3.1-1**: Flux loop positions on the PF-1aU and PF-1aL coils*

Sensor	**Z (m)**
FLPF1AU4	1.80
FLPF1AU3	1.70
FLPF1AU2	1.50

FLPF1AU1	1.40
FLPF1AL1	-1.40
FLPF1AL2	-1.50
FLPF1AL3	-1.70
FLPF1AL4	-1.80

b. The positions in Table 3.1-1 may evolve as the design matures.

3.2: PF-1b Coils

a. Each PF-1b coil shall have the following diagnostics mounted outside the ground insulation, but underneath any support slings or structures:

- Two flux loop locations, approximately uniformly spaced along the coil axially, with a primary and spare loop at each location. Suggested locations are shown in Table 3.2-1, with deviations in vertical position of 2-3 cm acceptable in order to center the loops on the coil

- Two thermocouples, approximately uniformly spaced along the coil axially; the toroidal angle of the thermocouples can determined by convenience with regard to lead routing.

Table 3.2-1*: Flux loop positions on the PF-1bU and PF-1bL coils*

Sensor	**Z (m)**
FLPF1BU2	1.85
FLPF1BU1	1.75
FLBF1BL1	-1.75
FLBF1BL2	-1.85

b. The positions in Table 3.2-1 may evolve as the design matures.

3.3: PF-1c Coils

a. Each PF-1c coil shall have the following diagnostics mounted outside the ground insulation, but underneath any support slings or structures:

- Two flux loop locations, approximately uniformly spaced along the coil axially, with a primary and spare loop at each location. Suggested locations are shown in Table 3.3-1, with deviations in vertical position of 2-3 cm acceptable in order to center the loops on the coil.

- At least two[1] thermocouples, approximately uniformly spaced along the coil axially; the toroidal angle of the thermocouples can determined by convenience with regard to lead routing.

***Table 3.3-1**: Flux loop positions on the PF-1cU and PF-1cL coils*

Sensor	**Z (m)**
FLPF1CU2	1.87
FLPF1CU1	1.76
FLBF1CL1	-1.76
FLBF1CL2	-1.87

b. The positions in Table 3.3-1 may evolve as the design matures.

4: OH Coil

a. The OH coil shall have 9 flux loop locations as enumerated in table 4-1.

***Table 4-1**: Locations of flux loops on the OH coil*

Sensor	R	Z
	[m]	[m]
FLOHU4	0.2800	1.000
FLOHU3	0.2800	0.750
FLOHU2	0.2800	0.500
FLOHU1	0.2800	0.250
FLOHM	0.2800	0.000

[1] The legacy PF-1c coil had six thermocouples, as enumerated in 9D1095, sheet 37, and 36. Each coils had an array of 2 axially (uniformly spaced) by 3 toroidal. If these are retained, the toroidal angles of the sensors would ideally be 15, 155, and 255 degrees toroidal, though deviations from this are allowed. These shall be type E TCs. These may be retained if convenient, but a minimum of two TCs are required.

FLOHL1	0.2800	-0.250
FLOHL2	0.2800	-0.500
FLOHL3	0.2800	-0.750
FLOHL4	0.2800	-1.000

b. There shall be 20 thermocouples mounted to the surface of the OH coil, as per the following guidance:

- 2 axial arrays of 9 TCs, with one TC at the OH coil midplane, and 4 each above and below the midplane. The spacing of the TCs in these arrays shall be ~11.8”.
- There two axial arrays shall be 180 degrees toroidally displaced.
- At the midplane, there shall be two additional TCs, intermediate in toroidal angle between the axial arrays.

5: Casing and Coil Supports

a: If practical, the flux loop pairs (primary and redundant loop) should be installed inside the transition sleeve (air side) at approximately the locations in the following table. These loops leads will need to exit the CS assembly along with the loops on the PF-1a and OH coils.

Table 5-1: Flus loop locations within the transition sleeve.

Name	R	Z
---	m	m
FLCSCL2	0.349	-1.28
FLCSCL1	0.309	-1.18
FLCSCU1	0.309	1.18
FLCSCU2	0.349	1.28

b: If practical, flux loops shall be installed on the casing and coils support structures as in the following table.

Table 5-2: Flux loop locations on the casing and on the coil support flanges.

Name	R	Z
---	m	m
FLMDLL2	0.63	-1.97
FLMDLL1	0.29	1.94
FLMDLU1	0.29	1.94
FLMDLU2	0.63	1.97
FLCSCL4	0.48	1.705
FLCSCL3	0.43	-1.705
FLCSCU3	0.43	1.705
FLCSCU4	0.48	1.705

6: Ceramic Break

a. Thermocouples shall be mounted to the ceramic break in four quadrants

b. The exact orientation of the ceramic break TCs can be determined by convenience

7. Plasma Current Rogowski Integration

Note: System level requirements for the plasma current rogowski, including requirements on sensor sensitivity, are found in Section 2 of Ref. [3].

a. There shall be three plasma current rogowski coils integrated to the center-stack assembly.

b. The rogowski coils shall be located along the surface of the OH coil along the distance of that coil behind the CSFW. ~~between the PF-1a coils/assemblies~~.

c. The rogowski coils routing shall not pass them through the bore of the PF-1a coils, thereby ensuring that the rogowski does not link their current.

d. The rogowski coils routing may pass through the bore of the PF-1b and PF-1c coils, and thus link their current.

e. The rogowski coils may be routed out of the CS assembly at toroidal angles conducive to machine assembly and alignment, consistent with route availability along the outer NSTX-U vacuum vessel.

f. Bends of the rogowski coil along its the long dimension, or twists in the Rogowski coil, should be minimized, and configured in such a way as to not risk damage to the windings.

g. The rogowski coils shall be located behind microtherm along any part of its trajectory where it would otherwise be exposed to elevated-temperature components within the casing assembly.

h. After exiting the CS assembly, the Rogowskis shall not directly contact any vessel components that are held at ~150 C by the medium temperature water system.

i. Any clamps that hold the Rogowski coil along the outer vessel shall have insulating components to aid in voltage isolation. Components shall be designed to provide 2 kV AC RMS isolation between the rogowski and the outer vessel.

j. The location where the ends of the rogowski join can be at any convenient location along the poloidal path of the outer vessel.

k. For purposes of design, the cross-section of a Rogowski coil shall be taken as 1.30” by 0.16“.

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Appendix 1: Legacy Wire Routing

It is desirable that the field cabling from the previous incarnation of NSTX-U be retained, in order to minimize expense and effort in the instrumentation racks. To that end, references to the appropriate sheets of the control wiring diagrams are provided:

Table A1-1: Connectors for Inner-PF flux loops

Sensor	9D1095 Sheet	Connector
FLPF1AU4	025	X2-U-1
FLPF1AU3	025	X2-U-1
FLPF1AU2	025	X2-U-1
FLPF1AU1	025	X2-U-1
FLPF1AL1	030	X2-L-6
FLPF1AL2	030	X2-L-6
FLPF1AL3	010	X2-L-1
FLPF1AL4	010	X2-L-1
FLPF1BU2	046	X2-U-4
FLPF1BU1	046	X2-U-4
FLBF1BL1	010	X2-L-1
FLBF1BL2	010	X2-L-1
FLPF1CU2	New Sensor	
FLPF1CU1	New Sensor	
FLBF1CL1	New Sensor	
FLBF1CL2	New Sensor	

Table A1-2: Connectors for OH loops

Sensor	9D1095 Sheet	Connector
FLOHU4	025	X2-U-1
FLOHU3	025	X2-U-1
FLOHU2	025	X2-U-1
FLOHU1	025	X2-U-1
FLOHM	030	X2-L-6
FLOHL1	030	X2-L-6
FLOHL2	030	X2-L-6
FLOHL3	030	X2-L-6
FLOHL4	030	X2-L-6

Table A1-3: Connectors for casing and coil support loops

Sensor	9D1095 Sheet	Connector
FLCSCL2	010	X2-L-1
FLCSCL1	010	X2-L-1
FLCSCU1	046	X2-U-4
FLCSCU2	046	X2-U-4
FLMDLL2	010	X2-L-1
FLMDLL1	010	X2-L-1
FLMDLU1	046	X2-U-4
FLMDLU2	046	X2-U-4
FLCSCL4	011	X2-L-5
FLCSCL3	011	X2-L-5
FLCSCU3	046	X2-U-4
FLCSCU4	046	X2-U-4

Table A1-4: Connectors for inner-PF thermocouples

Sensor	9D1095 Sheet	Connector
TC-PF1A-L-1	020	X2-L-4
TC-PF1A-L-2	020	X2-L-4
TC-PF1A-U-1	035	X2-U-2
TC-PF1A-U-2	035	X2-U-2
TC-PF1B-L-1	Could not locate; consider combining on sheet 037	
TC-PF1B-L-2		
TC-PF1B-U-1	Could not locate; consider combining on sheet 036	
TC-PF1B-U-2		
TC-PF1C-L-1	See sheet 037, connector X2-L-8	
TC-PF1C-L-2		
TC-PF1C-U-1	See sheet 036, connector X2-U-5	
TC-PF1C-U-2		

Table A1-5: Connectors for inner-PF thermocouples

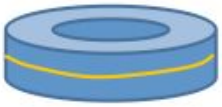
Sensor	9D1095 Sheet	Connector
TC-CB-1	See sheet 42 for connections that can be repurposed. Names more descriptive than in the left column may be selected.	
TC-CB-2		
TC-CB-3		
TC-CB-4		

Table A-6: Connectors for OH thermocouples

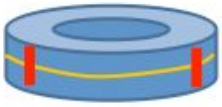
Sensor	9D1095 Sheet	Connector
TC-OH-U-1	035	X2-U-2
TC-OH-U-2	035	X2-U-2
TC-OH-U-3	035	X2-U-2
TC-OH-U-4	040	X2-U-3
TC-OH-U-5	040	X2-U-3
TC-OH-U-6	040	X2-U-3
TC-OH-U-7	040	X2-U-3
TC-OH-U-8	040	X2-U-3
TC-OH-U-9	035	X2-U-2
TC-OH-U-10	035	X2-U-2
TC-OH-U-11	035	X2-U-2
TC-OH-U-12	035	X2-U-2
TC-OH-L-1	045	X2-L-7
TC-OH-L-2	045	X2-L-7
TC-OH-L-3	045	X2-L-7
TC-OH-L-4	045	X2-L-7
TC-OH-L-5	045	X2-L-7
TC-OH-L-6	045	X2-L-7
TC-OH-L-7	045	X2-L-7
TC-OH-L-8	045	X2-L-7

Appendix 2: Schematic of Flux Loop Build-Up

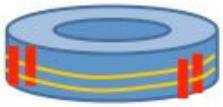
This schematic was provided by Mark Smith to illustrate the build-up on the inner-PF coils.



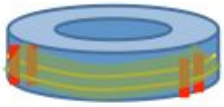
Primary Flux Loop – Single 22 AWG……thickness 0.029 inch
Total Radial Build 0.029 inch



Primary Flux Loop – Single 22 AWG: thickness 0.029 inch
Kapton + Adhesive : 90 Degree Spaced…thickness 0.0035 inch
Total Radial Build 0.0325 inch



Primary Flux Loop – Single 22 AWG: thickness 0.029 inch
Kapton + Adhesive : 90 Degree Spaced…thickness 0.0035 inch
Spare Flux Loop – Single 22 AWG: thickness 0.029 inch
Kapton + Adhesive : 90 Degree Spaced…thickness 0.0035 inch
Total Radial Build 0.0325 inch



Primary Flux Loop – Single 22 AWG: thickness 0.029 inch
Kapton + Adhesive : 90 Degree Spaced…thickness 0.0035 inch
Spare Flux Loop – Single 22 AWG: thickness 0.029 inch
Kapton + Adhesive : 90 Degree Spaced…thickness 0.0035 inch
Wet Glass Layup: thickness 0.013 inch
Total Radial Build 0.0455 inch

Type E TC twisted pair .078"
Single 22AWG magnet wire .029"
Twisted pair 22AWG magnet wire .059"