National Spherical Torus eXperiment Upgrade

NSTX-U Gas Delivery and Injection System Parameters

NSTX-U-RQMT-RD-014-01

3/28/19

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Rev. 1

Change Record

Revision	Date	Description of Change
0	12/19/17	Initial Release
1	3/28/19	Updated Table 4: Lower PFR injector moved from 155 to 15 degrees
		Changed Project Engineer to Yuhu Zhai

References

[1] NSTX-U-RQMT-GRD-001, NSTX-U General Requirements Document
[2] NSTX-U-RQMT-SRD-005, NSTX-U SRD - Auxiliary Systems
[3] NSTX-U-RQMT-RD-004, *PFC Diagnostics and Gas Delivery*

0.0 Scope

a. This document provides numerical parameters for gas injector system components: gas valves, plenums and valve controllers.

b. This document augments the requirements found in Ref. [1-3].

c. The mapping to gas delivery system is determined by engineering.

1.0 Common Requirements

1.1. Injector Plenum

a. The plenums shall be able to be filled and evacuated between shots through remote connection.

c. The plenum pressure for each injector must be controlled (either remotely or by modifying the bottle pressure) independent of other plenums unless otherwise noted.

d. All plenums and valves must be able to handle the following gases: deuterium, hydrogen, helium, nitrogen and noble gases, unless otherwise noted.

e. The system must be rated for the maximum operating pressure and able to fill the plenums to the lowest pressure as specified for each injector.

1.2. Connection to PCS

a. All injector controllers must accept open and close commands from the plasma control system (PCS)

b. All injector controllers must be able to remotely enable or disable the acceptance of PCS commands

1.3. Piezo-electric Valves

a. All piezo-electric valve controllers must apply a sufficient voltage to ensure the valve is fully open and small enough (or large enough reverse bias) to ensure the valve is closed.

b. All piezo-electric valves must complete a change in state (open to closed, or closed to open) within 2 ms of a change in the applied voltage.

c. All piezo-electric valves and valve drivers must be capable of handling 5 kHz oscillations in the PCS commands for 10 s. (This requirement is to ensure that the valves could survive the worst-case failure scenario of the PCS).

d. All piezo valves must be able to be sustained in their open state for at least 5 seconds.

e. Valves shall have electrical isolation from the vessel as per the GRD [1].

1.4 Puff Valves

a. All puff valve systems shall empty the entire plenum into its associated gas delivery system or directly into the vacuum vessel.

b. The puff valves must open and close when the valve controller is provided a command from the PCS with a delay between the command to open and the valve response that is less than 3 s.

c. Puff valves must change from fully closed to fully open in less than 10 ms.

d. Puff valve design must allow for the plenums to be pumped out between shots.

e. The plenum pressure must be remotely selectable and able achieve a target value within 50 Torr.

f. Valves shall have electrical isolation from the vessel as per the GRD [1].

1.5 Supersonic Gas Injectors

a. Supersonic gas injectors (SGI) are described in Section 7.0 of NSTX-U-SDD-V&F-R0.

b. SGI valves shall have electrical isolation from the vessel as per the GRD [1].

1.6 Massive Gas Injectors

a. Massive gas injectors (MGI) are described in Section 6.0 of NSTX-U-SDD-V&F-R0.

b. MGI valves shall have electrical isolation from the vessel as per the GRD [1].

1.7 CHI Injectors

a. Gas injectors to support Coaxial Helicity Injection (CHI) are described in Section 9.0 of NSTX-U-SDD-V&F-R0. These injectors are no longer required for NSTX-U.

2.0 Description and Specifications for Gas Injection Systems

2.1. Low field side piezo injectors (PZV)

These valves are used to prefill the vessel to a target pressure and fuel the plasma discharge. These valves are also used for calibration activities. The intended use of these valves is to modulate the open/closed times (pulse width modulation or PWM) to achieve a target time-averaged flow rate.

a. Three low field side valves shall use piezo injectors, as per Table 1.

Table 1: Description of the low field side piezo injectors

Inj. Name	**Location**	**Primary purpose**	**Flow rate range**	**Pressure range**	**Minimum plenum size**
			T l / s	**torr**	**cc**
PZV1	Bay K, Upper	Discharge fueling	50 - 150	250 - 5000	80
PZV2	Between I & J, near midplane	Deuterium Prefill and Discharge fueling	50 - 75	250 - 2500	60
PZV3	Between F & G, near midplane	Backup injector	50 - 75	250 - 2500	60

b. The flow rate is specified for when the valves are fully open.

c. All PZV valves must be able to be opened or closed outside of the shot cycle using the PLC

d. Remote control of the plenum pressure is desirable, but not required.

2.2. High-field side puff valves

These valves are used to provide supplemental or primary fuelling the plasma discharge.

a. Three high field side injectors shall use puff valves, as per Table 2. The present specifications reflect that the ¼" valves would be used for fueling over brief periods, while the ⅛" valve provides fueling for longer periods.

Table 2: Description of the high field side injectors

Injector Name	**Feedthrough Toroidal Angle**	**Tube OD**	**Injection position**	**Maximum Pressure**	**Minimum Plenum Size**
	Left handed coordinate system	**inch**		**torr**	**cc**
Bay C mid eighth	75 degree organ pipe	1/8	midplane	2500	72
Bay I mid quarter	255 degree organ pipe	1/4	midplane	2500	20
Bay E shoulder quarter	105 degree organ pipe	1/4	shoulder	2500	20

b. The system plenum volume can be changed during a maintenance period in response to operational demands.

c. The delay between the command to open and valve response should be repeatable for a given plenum pressure. The jitter in the delay (i.e. the shot-to-shot variation) should be less than 3ms.

d. The design should allow for the plenums to be pumped out between shots.

2.3. Lower outboard divertor injectors

These valves are used to support operations through deuterium or impurity fueling to mitigate heat flux to plasma facing components and support physics research activities. The anticipated use of these valves is to select the flow rate by setting the system pressure, then injecting gas with the valves fully open.

a. The outboard divertor injectors shall use piezo valves, with parameters as per Table 3a for baseline design requirements with Table 3b capturing upgrade performance requirements.

Table 3a: Baseline design parameters for outboard divertor piezo injectors

Injector Name	**Location**	**Flow rate range**	**Pressure range**	**Minimum plenum**
		T l / s	**torr**	**cc**
DivL-C	Bay C, Lower Dome	10 - 250	50 - 5000	350
DivL-I	Bay I, Lower Dome	10 - 250	50 - 5000	350

Table 3b: Upgrade performance requirements for outboard divertor piezo injectors

Injector Name	**Location**	**Flow rate range**	**Pressure range**	**Minimum plenum**
		T l / s	**torr**	**cc**
DivU-1	Upper Dome, Bay TBD	10 - 250	50 - 5000	350
DivU-2	Upper Dome, Bay TBD	10 - 250	50 - 5000	350

b. The plenum pressure should be remotely selectable and achieve a target pressure within 50 Torr.

c. The ability to use PWM to modify the flow rate should be retained.

2.4. Private flux region injectors

These valves are used to support operations through deuterium or impurity fueling to mitigate heat flux to plasma facing components and support physics research activities. The anticipated use of these valves is to select the flow rate by setting the system pressure, then injecting gas with the valves fully open.

a. The private flux region injectors shall use piezo valves, with baseline performance requirements as per Table 4.

Table 4: Parameters for private flux region injectors

Injector Name	**Location**	**Flow rate range**	**Pressure range**	**Minimum plenum**
		T l / s	**torr**	**cc**
Upper PFR	285 degree organ pipe	10 - 250	50 - 5000	350
Lower PFR	15 degree organ pipe	10 - 250	50 - 5000	350

b. The plenum pressure should be remotely selectable and achieve a target pressure within 50 Torr.

c. The ability to use PWM to modify the flow rate should be retained.

2.5. Supersonic gas injector (SGI)

The supersonic gas injector (SGI) parameters are as per Table 5. The SGI consists of a piezo valve with a specialized nozzle mounted on a moveable probe near the outboard midplane. See also Section 7.0 of NSTX-U-SDD-V&F-R0.

a. The plenum for the SGI system is described in table 5.

Table 5: SGI Parameters

Injector Name	**Location**	**System Pressure**	**Plenum Size**
		torr	**cc**
SGI	Bay I or J	5000	350

2.6. Massive gas injector (MGI)

a. The massive gas injection (MGI) system contains three custom valves as per Table 6. See also Section 6.0 of NSTX-U-SDD-V&F-R0

Table 6: MGI Valves

Injector Name	Location
MGI1	345 degree upper organ pipe
MGI2	180 degree lower organ pipe
MGI3	Bay I Midplane, 7:30 location

b. Each MGI valve has a secondary plenum that is maintained in the range of 1000 - 3000 T by a dedicated gas feed line with a regulator.

c. The primary plenum shall be filled to a pressure between 1000 - 5000 Torr.

d. For improved operation, the integrity of the gas lines should be qualified for operation at a pressure of 10,000 Torr (the present gas lines are probably suitable for this pressure, but it needs to be verified)

e. To accommodate the higher pressure, pressure transducers in these lines should also be qualified for 10,000 Torr operation

2.7. Diagnostic and Impurity injectors

The gas puff imaging (GPI) and impurity injector parameters are systems dedicated to diagnostics or specific experiments. The anticipated use of these valves is to select the flow rate by setting the system pressure, then injecting gas with the valves fully open.

a. These shall use piezo valves with parameters as per Table 7.

Table 7: Parameters for GPI and Impurity Injectors

Name	Location	Flow rate range	Pressure range	Minimum plenum

		T l / s	Torr	cc
GPI	Bay B midplane, 1:00 location	50 - 125	250 - 2500	25
Impurity	Bay B midplane, 4:00 location	50 - 125	250 - 2500	40

b. The plenum pressure should be remotely selectable and achieve a target pressure within 50 Torr.

c. The ability to use PWM to modify the flow rate should be retained.

2.8. CHI injectors

a. CHI injectors are no longer required.