Princeton Plasma Physics Laboratory

NSTX-U Machine Proposal

Title: **Gas Flow Rate Calibration for NSTX-U Operation**

OP-XMP-102	Revision**: 4**	Effective Date: Expiration Date: *(2 yrs. unless otherwise stipulated)*

Proposal Approvals

Responsible author: **Devon Battaglia**	Date **7/28/15**
ATI (NSTX-U Physics Ops): Dennis Mueller Digitally signed by Dennis Mueller Date: 2015.08.30 16:47:10 -04'00'	Date
RLM (NSTX-U Expt. Research Ops):	Date

Responsible Division: **Experimental Research Operations**

Procedure Requirements

designated by RLM

	NSTX Work Permit		T-MOD (OP-AD-03)
	Independent Review		ES&H Review

RESTRICTIONS AND MINOR MODIFICATIONS

Approved by RLM

REVIEWERS (designated by RLM)		
Organization/Position	Name	Signature
ATI	D. Mueller	Dennis Mueller Digitally signed by Dennis Mueller Date: 2015.08.30 16:47:49 -04'00'
Test Director		
Independent Reviewer		
NB system		
RF systems		
FCPC systems		
Diagnostics		

TRAINING (designated by RLM)

Training required: No ■ Yes ☐ Instructor _____

Personnel (group, job title or individual name)	Read Only	Instruction	Hands-On

RLM _____

NSTX-U MACHINE PROPOSAL

TITLE: **Gas Flow Rate Calibration** No. **OP-XMP-102**
AUTHORS: **D.J. Battaglia** DATE: **7/28/15**

1. Overview:

This XMP establishes the minimum on (off) time required to fully open (close) the piezo-electric valves (PZVs), provide the flow rate / fill pressure calibration factor for each PZV, confirm the vessel pressure gauge measurements (IG1, IG2), confirm the plenum pressure measurements (sensotecs) and demonstrate prefill and flow control algorithms for NSTX-U operations.

Testing and calibrating SGI, CHI and MGI gas systems are outside the scope of this XMP.

2. Justification:

Low-field side PZVs (injectors 1-3) and centerstack gas (injector 4) are required for standard H-mode fiducial operation. IG1 and IG2 vessel pressure measurements are required for prefill feedback. Divertor, GPI and Impurity gas valves will also require flow rate calibrations to be useful for operations.

3. Plan:

At least one vessel pressure measurements (IG1, IG2 and/or baratron) should be on digitizers with a long time range. All calibration shots should be done with pump TIVs closed during injection and then opened one minute after shot is complete, unless otherwise noted. The plenums should be refilled before all shots to the reference fill pressure.

The following should be recorded and submitted with documentation of results:

1) Shot number
2) Valve
3) Gas type
4) Step in XMP
5) Initial plenum pressure
6) Initial baratron pressure
7) Final plenum pressure
8) Final baratron pressure
9) Comment on results

3a. Plenum Volume Measurement

The plenum volume and ion gauge vessel pressure measurements are calibrated by filling each plenum to a known pressure and emptying the plenum into the vacuum vessel. The sensotec plenum pressure and baratron vessel pressure (above 10^{-5} Torr) are treated as true measurements. The NSTX-U volume was measured to be 28,312 liters with the NBI TIVs closed.

1) Setup for calibrations:

a. Fill the piezo and centerstack plenums to above 2,000T. Close NBI and turbo pump TIVs. Close any TIVs that were closed during the initial measurement of the NSTX-U volume. Ensure RGA is isolated from the vacuum vessel. Turn off all ion gauges.
b. In PCS: Ensure all gas valves being tested are enabled. Turn off all prefill feedback.

2) Empty a single plenum into the vacuum vessel during one shot. Record the initial and final plenum pressure and the initial and final vessel pressure as read from the baratron. The plenum volume is determined using: V_{plenum} (liter) = V_{vessel} (liter) * P_{vessel} / P_{plenum}

3) If time, repeat and average results to reduce error on the plenum volume measurement

3b. Calibration of PZV1 and PZV2 with D_2 gas

These two valves are located on the low-field side (LFS) of the torus at Bay-K top (PZV1) and Bay-I mid (PZV2). These valves are used for deuterium prefill and deuterium injection during the plasma discharge.

If both valves are being tested in a single session, each step should be repeated for each valve before moving on to the next step in order to minimize the impact of wall outgassing on results.

1) Setup for calibrations:
   a. Fill the piezo plenum to about 1400T, which was a typical fill pressure for NSTX operations. Close NBI and turbo pump TIVs. Close any TIVs that were closed during the initial measurement of the NSTX-U volume. Ensure RGA is isolated from the vacuum vessel.

   b. In PCS: Ensure PZV1 and PZV2 are enabled, have "Deuterium" as a gas type and prefill fraction is zero. Also ensure prefill gas type is "Deuterium."

2) Test the injector with a single 2ms open request.

3) In two separate shots:

   a. Inject a 0.4ms pulse every 0.5s for ten pulses total.

   b. Inject a single 4ms pulse.

4) Repeat the two shots in step 3 with longer open intervals: +0.2ms in step 3a and +2ms in step 3b. Continue repeating step 3 with longer increments until total gas injected in step 3a is about equal to total gas injected from step 3b in order to establish minimum open time.

5) Establish minimum off time by requesting two 3ms pulses separated by 0.4 ms. Repeat with longer off times until total injected gas is not significantly changing when compared to the previous shot.

6) Inject a single pulse of different lengths if not already accomplished from step 3: 8ms, 16ms, 32ms. Do not take shot if vessel pressure will exceed 10^{-3} Torr in order to protect ion gauges.

7) (Optional) Inject a single pulse per shot with the turbo pump TIVs open during the shot to measure pumping speed at different vessel pressures. Test different open times: 4ms, 8ms, 16ms, 32ms. Do not take shot if vessel pressure will exceed 10^{-3} Torr in order to protect ion gauges. This step only needs to be performed with PZV2.

    a. If time and available, it would be beneficial to repeat some or all of the shots in step 7 with each NBI TIV open and both NBI TIVs open to confirm their pumping speeds in combination with the turbo valves. This would only be performed with PZV2 using deuterium.

8) Demonstrate flow rate PWM control with target tracking with updated calibrations.

    a. Three 2s steps at different Torr-l/s
    b. Ramp up to maximum Torr-l/s and then back to 0 over 2s, three times in one shot.

9) Demonstrate prefill control. Do three increasing steps in the target prefill, with each step 2s long: 2, 4, 6 uTorr with updated calibrations.

    a. If time, compare new prefill control algorithm using PZV2

3c. Calibration of centerstack (Injector 4) puff valves with D_2 gas

These four valves empty a single plenum into the vacuum vessel from a location on the centerstack. The controllable parameters are the plenum pressure and the time to open the valve. All valves use deuterium gas.

1) Setup for calibrations:
    a. Fill the CS plenums to 600T. Close NBI and turbo pump TIVs. Close any TIVs that were closed during the initial measurement of the NSTX-U volume. Ensure RGA is isolated from the vacuum vessel.

    b. In PCS: Ensure CS valves are enabled.

2) Inject gas using each injector in four separate shots.

3) Repeat step 2 with plenum pressures at 900T, 1200T, 1500T, 1800T and 2100T unless vessel fill pressure is expected to exceed limits. Do not take shot if vessel pressure will exceed 10^{-3} Torr in order to protect ion gauges.

3d. Calibration of PZV3 with He gas

PZV3 is located at Bay F midplane and is used for HeGDC and Helium fueling for RF experiments. The same procedure should be followed for PZV1 and PZV2, but it is recommended that it be performed separate from these two valves to avoid confusion with gas types and possible gas purity issues in the vessel.

1) Setup for calibrations:
    a. Fill the piezo plenum to about 950T, which was a typical fill pressure for NSTX operations. Close NBI and turbo pump TIVs. Close any TIVs that were closed

during the initial measurement of the NSTX-U volume. Ensure RGA is isolated from the vacuum vessel.

b. In PCS: Ensure PZV3 is enabled, has "Helium" as a gas type and its prefill fraction is zero. Also ensure prefill gas type is "Helium."

Repeat steps 2 – 6, 8 - 9 from PZV1/2 procedure in order to calibrate the valve and verify algorithms with different gas type.

3e. Calibration of Divertor, Impurity and GPI PZVs

Repeat steps 3a and 3b (excluding steps 7 and 9) for these valves with appropriate plenum pressure and gas types. Ensure gas type in PCS is accurate.

4. Required machine, beam, ICRF and diagnostic capabilities:

Shot cycle with no plasma.

5. Sign off at run time:

5.1 Permission to Proceed: _____

Physics Operations Head

5.2 Documentation of results:

Documentation of the results completed, attached to proposal and sent to Ops. Center with copies to Cognizant Physicist and Head of Physics Operations.

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Cognizant Physicist/Test Director