Princeton Plasma Physics Laboratory
NSTX Machine Proposal

Title: **NSTX-U Inductive Startup Scenario Development**		
OP-XMP-101	Revision: **0**	Effective Date: Expiration Date: *(2 yrs. unless otherwise stipulated)*

Proposal Approvals

Responsible author: **Devon Battaglia**	Date
ATI (NSTX Physics Ops): **Dennis Mueller** Dennis Mueller Digitally signed by Dennis Mueller Date: 2015.11.25 14:05:44 -05'00'	Date
RLM (NSTX Expt. Research Ops): **Stefan Gerhardt**	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: 2015.11.25 14:06:25 -05'00'
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 MACHINE PROPOSAL

TITLE: **NSTX-U Inductive Startup Scenario**	No. **OP-XMP-101**
AUTHORS: **Devon Battaglia**	DATE:

1. Overview:

The goal of this XMP is to develop viable NSTX-U startup scenarios for different levels of ohmic (OH) precharge. A startup scenario includes the preheating of the OH solenoid per the OH - TF delta-T constraint in DCPS, a precharge of the OH and PF3 coil to values that avoid premature breakdown, gas injection for establishing an initial fill pressure of NSTX-U, ECH preionization, fast OH and PF3 current ramps around t=0 to establish a poloidal field null and the V_{loop} necessary for breakdown, and the preprogrammed OH and PF currents following breakdown that result in a stable plasma with $I_p \sim 150$ kA at 20ms.

2. Justification:

CD-4 operations used a startup scenario similar to NSTX by running the ohmic (OH) coil with an 8kA precharge. However, the loop voltage was large ($V_{loop} > 4$V) as a consequence of operating with poor wall conditions. Commissioning operations require a viable startup scenario using an OH precharge of 8kA at lower loop voltage. Long pulse operation requires an OH precharge above 8 kA. Establishing a scenario near the maximum allowed OH would enable long-pulse development and inform how to scale the PF currents for arbitrary OH precharge. Relational PF3 scaling to I_p and I_{OH} will be tested which could enable automatic adjustment of the PF3 currents with arbitrary OH precharge and eliminate an abrupt transition in PF3 control that occurred on NSTX around 20ms.

3. Plan:

Work can be done in piggyback toward XMP-126 and XMP-105 to establish I_p, Z, outer gap and vertical stability control with discharges that get beyond 20ms.

Reference vacuum shots are taken to confirm I_p compensation and evaluate field null quality.

3.1 Establish CD-4 startup scenario

This step will attempt to reproduce a 140 kA shot from CD-4 operations. These discharges do not need to reproduce the same I_p evolution; success is achieving > 50 kA in order to implement some control and operational changes using the CD4 scenario.

3.1.1 (1 shot) Repeat shot 201131 that achieved about 140 kA at 25ms during CD-4 operations

- Use PCC pre-programmed PF current control with the proportional gain values for PF3 and PF5 used in PSRTC for CD-4
    - o Revert to day0 control if issues with PCC feed-forward current control with PSRTC proportional gains for PF3 and PF5 matching CD-4
- Neutral beam TIVs should be closed
- Only have PF3*, PF5, OH and TF line switches closed
- If unable to get a plasma, make small changes to OH / PF3 waveforms or alter prefill based on control room observations

- If the CD-4 scenario is not producing a viable breakdown, move on to steps 3.2 and come back to the later steps of 3.1 once a reference plasma is established.

3.1.2 (1 shot) Repeat using PCC control using relational control of PF3 and PF5

- Do this step only if I_p measurement in PCS is adequately compensated and calibrated
- PF3 current versus I_{OH} coefficient: 0.222 with IOH low-pass filter RC = 0.001s
- PF3 current versus I_P coefficient: -0.0075 with I_p low-pass filter RC = 0.001s
- PF5 current versus I_P coefficient: -0.012
- PF3U offset current:

Time (s)	-0.45	-0.4	-0.2	-0.1	-0.136	-0.0038	0.004	0.02	0.05	0.07
Cur (A)	0	2400	1350	800	600	-1850	-3400	-3600	-2900	0

- PF3L offset current:

Time (s)	-0.45	-0.4	-0.2	-0.1	-0.150	-0.0050	0.004	0.02	0.05	0.07
Cur (A)	0	2400	1350	800	600	-1850	-3800	-3700	-2900	0

- Points at 0.02s and 0.05s should be reduced on both waveforms if I_p is larger than 201131, and increased if I_p is smaller.
- PF5 offset current

Time (s)	-0.025	-0.005	0.003	0.008	0.014	0.023
Cur (A)	0	-130	-900	-900	-500	0

- Points at 0.008 and 0.014 could be reduced if I_P is higher than 201131
- The coefficient for PF5 should be reduced after 30ms if gap control is not being used

3.1.3 (1 shot) Open NBI TIVs and close PF1A*, PF1C* and PF2* line switches

- Request reverse offset from PF1A* and PF2* to ensure zero current
- Make sure to change vessel volume in prefill GUI in gas category
- Observe if prefill target is still met with larger pumping

3.2 Develop new startup scenario at 8kA OH precharge

The goal of this step is to develop a startup scenario using less loop voltage and longer OH and PF3 precharge lengths compared to the CD-4 discharges. The longer precharge times are driven by the requirement to preheat the OH coil and the desire to simplify the scaling of each scenario to different OH precharge levels. Lower loop voltage will reduce the currents in the centerstack crowns that were challenging vertical stability for $I_p > 100$ kA.

3.2.1 (2 – 4 shots) Lengthen precharge

- PF3 precharge should start before TF ramp begins at -0.6s
- PF3 offset waveform in PCC should be 600A for all time points before -0.15s if using relational control (step 3.1.3)
- Remove OH preheat pulse and make a single long OH precharge at 8 kA level. Simulations suggest this will move the null timing later. Preheat should be compatible with maximum TF.

- Reduce OH ramp rate to reduce V_{loop}. Simulations suggest this will move null timing earlier.
- Decrease OH precharge or increase PF3 precharge if null timing is too early. Do the opposite if null timing is too late.
- If time, add integral gain to PF3* current and adjust PF3* offset and proportional gain to recover target currents

3.2.2 (1 shot) Increase TF if maximum allowed TF current is larger than CD-4 operations

- Increase TF ramp rate (keep starting and ending time points of TF ramp the same)

3.2.3 (3 - 8 shots) Find minimum V_{loop} needed to get I_p ~ 150 kA at 20ms with prefill used in step 3.1

- Use camera, magnetics and reconstructions to evaluate vertical centering and evolution of the outer gap. Make small (3-5%) adjustments to PF3L, PF3U and PF5 currents to correct.
- If time, adjust PF3* and PF5 proportional and integral gains to improve control to targets
- Vacuum shots may be taken to evaluate timing and quality of magnetic null
- Active control of the I_p and outer gap can be used if discharges are lasting past 20ms
- Identify minimum V_{loop} needed to achieve I_p ~ 150 kA at 20ms
- Take a vacuum reference shot for the minimum V_{loop} condition

3.2.4 (3 – 8 shots) Evaluate if minimum breakdown loop voltage is lower with reduced prefill

- Use OH programming for discharge where the loop voltage was too low in step 3.2.3
- Reduce prefill until breakdown scenario achieves I_p ~ 150 kA at 20ms
- Take a vacuum reference shot
- This step can be repeated to identify the lowest viable breakdown loop voltage. Care must be taken to avoid operating at too low of density. LFS gas should be added following breakdown (about +20ms) if signs of instabilities or runaway electrons at low density.

3.2.5 [optional] Tune OH, PF3 and/or PF5 proportional gain for current control if improvements in the control are needed.

3.2.6 [optional] Investigate if longer glow discharge periods reduce the minimum loop voltage required for startup

3.2.7 [optional] Investigate if trapped-particle configuration reduces required loop voltage.

- Use -8kA PF1C* precharge. Increase PF3 precharge to about +2.2 kA.
- If breakdown occurs, establish lower limit of breakdown loop voltage
- If no breakdown, reduce PF1C* precharge. This will reduce the stray fields, but also reduce the mirror ratio.

3.3 Develop startup scenario at larger OH precharge

As the OH precharge increases, the residual vertical field from the incomplete cancelling of the OH fringe field by the PF3 coils also increases. This leads to a different structure of the field null and changes the field index evolution following breakdown. At larger OH precharge, the vertical and radial extent of the field null is reduced, which may result in a larger loop voltage requirement.

Furthermore, the field index tends to be more positive that may motivate a rebalancing of the PF3 and PF5 ramp rates following breakdown.

(4 – 12 shots) Increase OH waveform by 12kA such that the OH precharge is 20kA. Increase PF3 waveform by about 2.66 kA. If relational PF3 control is used (step 3.1.3) then no changes to the PF3 are needed for the first shot.

- Reduce length of OH precharge to near the minimum length required by the OH precharge requirement
- Adjust OH ramp rate if higher precharge leads to larger initial loop voltage (increased back bias of coil)
- Adjust PF3 current offset to achieve correct null timing.
- If not getting I_p ~ 150kA, increase loop voltage and/or reduce the prefill
- Evaluate vertical and radial stability and adjust PF3 and PF5 after breakdown if improvements are needed
- If unable to develop viable scenario within a few hours, try OH precharge of 14 kA and repeat
- Take a vacuum reference shot

3.4 [Optional] Develop startup scenario with no OH precharge

Developing breakdown with no OH precharge would test the scaling of the breakdown scenarios over a wider range of OH precharge. This scenario may also be useful in future operations. Tasks would be similar to 3.3 except that an OH preheat pulse must be used.

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

No external heating (beams, RF) required. Magnetics, plasma TV and neutron measurements are required. Spectroscopy, Thomson Scattering, between shot EFIT would be very useful.

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