Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: Flux savings from inductive drive of a Transient CHI started plasma		
OP-XP-817	**Revision: 0**	Effective Date: **3/10/08** *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible author: R. Raman et al.	Date 3/4/08
ATI – ET Group Leader: R. Raman	Date3/4/08
RLM – Run Coordinator: M. Bell	Date
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Flux savings from inductive drive of a Transient CHI started plasma**	No. **OP-XP-817**
AUTHORS: **R. Raman, B.A. Nelson, D. Mueller, M. Bell, T.R. Jarboe**	DATE: **3/4/2008**

1. Overview of planned experiment

The run plan from X726 will be improved for coupling a transient CHI discharge to induction by using improved lower divertor surface conditions and relying on well established current ramp-up conditions from a pre-charged central solenoid discharge.

2. Theoretical/ empirical justification

Experimental results on the HIT-II Experiment have shown Transient CHI produced discharges to couple to and improve the performance of inductive only discharges. Recently NSTX has produced high levels of closed flux current using Transient CHI. The present XP will optimize these discharges by reducing the extent of absorber arcing using the staged capacitor bank system. This XP will increase the current in the CHI produced discharge using induction from the central solenoid to produce a long-pulse discharge and measure flux savings.

This XP has minor modifications to part 3.1 of XP726 and an improved run plan (part 3.2) that uses well established discharges from a pre-charged central solenoid discharge.

3. Experimental run plan

On the first day of CHI operations, the lower divertor plates should be conditioned as follows.

1. Load shot 124205 (CHI-only discharge) and reproduce with 4 capacitors and diagnose using Thomson and Spectroscopy (2-3 shots). Also repeat shot 124271 once (CHI + OH) and diagnose using Thomson.

2. Now convert shot 124205 to a stuffed injector flux condition case by increasing the injector flux with respect to the toroidal field (increase PF1B, 2L, 3L coil currents) by 50% and repeat with Bank 1 operated at 5ms, Bank 2 at 5.5ms and Bank 3 at 6ms. During this conditioning phase, on different shots, vary the divertor coil currents in either direction by about 25% to sweep the current carrying divertor flux footprints over a larger area of the lower divertor plates. Typically operate at a charging voltage of 1.75kV. Conduct a short deuterium glow after each shot. Monitor the lower divertor region using the divertor IR camera to ensure that the lower divertor plates are not excessively heating up.

3. After 15 discharges, repeat step 1 to assess machine conditions. If current persistence has significantly improved or if the discharge with coupling to OH shows improvement compared to what was obtained in 2007 proceed to part 3.1.

4 Otherwise, repeat step 2 at-least once more and reassess vessel conditions by repeating step1.

5. After the end of the first day of experiments, conduct a 1 hour deuterium glow, followed by 30 minutes of He glow. Then boronize the vessel.

After the vessel boronization, first do step 3.2-1 once or twice to assess machine conditions (use this shot as a fiducial). Then proceed with 3.1 and switch to 3.2 if progress is not rapid enough with procedure 3.1.

3.1 Hand-off to inductive operation using zero pre-charge in the central solenoid

a) Restore a reference CHI produced discharge from XP726 (No. 124205). Reproduce the discharge by using a total of 3 capacitors. After good current persistence is obtained, using the staged bank capability discharge a second capacitor bank (with one or two modules) and third module (one or two modules) as required with about 0.5ms time delays between them to extend the decay portion of the CHI produced toroidal current. After reproducible discharges are obtained diagnose with Thomson.

b) Close the OH circuit line switches and enable the OH power supply. Starting from the time of peak toroidal current, apply the pre-programmed OH wave form from shot 124271.

   The increase in plasma current may be accompanied by vertical motion of the plasma. Initially, adjust the currents in PF1/3 coils to keep the plasma positioned at z=0.

   For PF1, after plasma detachment ramp the current to zero, in preparation for the current programming after the plasma reaches 200kA.

   For currents below 200kA, Use only PF5 and PF3 coils in the ratios:

   I_{PF3}/I_p = +20kA/MA [PCS Programming convention, actual PF3 current is negative], and

   I_{PF5}/I_p = +10kA/MA [PCS Programming convention]

   After the current exceeds 200kA, change the ramp rate to obtain the ratios,

   I_{PF3}/I_p = +4.6kA/MA [PCS Programming convention]

   I_{PF5}/I_p = +10kA/MA, [PCS Programming convention]

   I_{PF1A}/I_p = +12kA/MA[PCS Programming convention]

   Use Table 1 in the Appendix as a reference. Note that the OH coil current sensor has changed. It may be necessary to lower the OH zero value (and after) by 0.3kA.

c) Using Injector 2 at a rate of about 100 Torr.L/s inject from 10 to 20ms, to ensure the discharge has sufficient electron density. Based on the resulting current ramp rates and the Thomson electron density profile adjust the gas injection conditions to maintain sufficient electron density in the discharge. If operation with Injector 2 does not result in adequate electron density attempt to use the SGI for a few shots with the SGI head positioned at a radius larger than that of the RF antenna.

d) Use pre-programmed current ramp-up in the OH coils for 30-80ms.

e) During the pre-programmed phase increase or decrease the applied loop voltage to maintain a positive current increase during the 30-80ms current ramp.

f) After plasma reproducibly ramps up during the preprogrammed phase, turn on the normal feed-back control of the equilibrium and plasma current using the PCS after I_p reaches 100-150kA and after imposing a time delay of at least 25ms from start time of current in the OH coil.

g) Ramp to take over at a suitable current level, which may vary from 100 to 200 kA.

h) During this phase ramp the current to the level allowed by the flux in the central solenoid.

i) After the plasma current exceeds 200kA, turn on NBI SRC A at 90kV for the duration needed for a MSE measurement.

j) Add additional beam sources to maximize the total current that can be produced using this condition.

k) If induction is not able to sustain the CHI-induced current, either:

- Apply a 40ms, 1 – 2 MW pulse of HHFW power phased for plasma heating (0-π), or
- If the CHI-induced plasma current is above 100kA and the edge neutral pressure is below 5E-5 Torr (\ENGINEERING::GS_IG_TORR) during the current decay, apply a 50 ms pulse of NBI at 40-50 keV, initially from one source and adding sources if needed.

No-CHI Comparison

After reliable, reproducible discharges are obtained conduct a no-CHI comparison by:

1) Turning of the CHI Power Supply voltage (this will most likely not allow an inductive breakdown because of a poor field null)

2) Turn off the PF1B, PF2L and PF1AL coil current used for injector flux programming (i.e. from 0 to 20ms).

3) If step (2) still does not produce an inductive breakdown, turn off all of the other coil currents during the break-down phase and begin ramping these coils 5-10ms after breakdown is achieved.

NOTE: The EC-Pi needs to be configured for mid-plane injection instead of Lower Divertor injection.

3.2 Hand-off to inductive operation using full pre-charge in the central solenoid

The advantage of this method is that the conditions needed for the inductive ramp are part of routine NSTX operations. The required change is to add a CHI initial condition so that current generation is not dependent on a good quality field null. The difficulty with this approach is in being able to get reliable gas breakdown and CHI current initiation under conditions of a pre-charged solenoid.

NOTE: During the first CHI run, obtain enough data to establish breakdown conditions and evidence for the CHI discharge pulling into the vessel. Analysis of this data may be required for further optimization during the second CHI run, including coil polarity changes for PF2L.

1. Restore inductive discharge No. 120406 (OH at 4kV, No PF2, No PF1B – DN, 3 NBI sources). Increase TF to 58.5kA and repeat (to be consistent with TF currents used in recent CHI discharges).
2. Now add in the CHI injector waveforms as follows:
   From -200ms to +2ms: PF1AL/U = +15-16kA, zero at +5ms [Note: -15kA for PCS convention]
   From -200ms to +2ms: PF1B = +10kA, zero at +5ms [Note: -10kA PCS convention]
   Reduce the pre-charge in the CS to +12kA (50% of nominal value) [-12kA PCS convention]
3. Apply CHI voltage and gas injection as in reference CHI discharges (cap bank trigger time = +5ms, dwell time = +3ms, Branch 5 gas injection at -13ms). Apply voltage from 1.5 to 1.75kV in steps of about 100V. Start with capacitor module 1 and add 2 and 3 as needed.
4. If reliable breakdown is not achieved, further reduce the OH pre-charge. After breakdown is achieved, reduce the current in PF1A in steps of 2kA to optimize the required current in this coil.
5. After full +20kA capability is available in PF1A, repeat step 2 by using +19kA in PF1A [-19kA for PCS convention] and increase the level of CS pre-charge in steps of 4kA.
6. If reliable breakdown is still not achieved, it may be necessary to add about +2kA in PF2L [-2kA PCS convention] programmed to be from -200 to +3ms, ramping to zero at +9ms. This would require a two hour controlled access to change the coil configuration.
7. After breakdown, if necessary adjust the PF1B and 1AL current ramp down times.

   Delay the OH inductive application phase to start at +5ms.

   Make a corresponding change to the current ramp rate in the PF3 coils.
8. Initially turn off the mid-plane gas injection that begins at 14ms. After the initial results, turn it back on. Similarly, turn off the NBI injection and turn it back on after sufficient current is generated.

3.3 Assessment of Inductive Flux Saving

a) After reliable, reproducible discharges are obtained, repeat 5 shots using CHI start-up assist.

b) For procedure 3.1, develop an inductive startup discharge which reaches the same current and configuration in the same time as the CHI-assisted discharges in 3.1. Note that since the OH power supply voltage will be limited to 4kV for CHI experiments, some discharge development will be needed. Run 5 shots with inductive-only start-up to measure the poloidal flux consumption under identical current ramp-up conditions. Determine differences in density profile, current profile and temperature profile evolution.

c) For procedure 3.2 suitable comparison shots will have been produced during the initial start of step 3.2

4. Required machine, NBI, RF, CHI and diagnostic capabilities

NOTE: Do NOT conduct "hi-pot" tests of any of the NSTX vacuum vessel components above 2kV with either the CHI supply capacitors or the CHI snubber capacitors or the MOVs connected to NSTX, as these capacitors have a rating of only 2kV.

NOTE: Ensure LDGIS interlocks are in the "green" state prior to conducting any "hi-pot" tests.

NOTE: The trained personnel identified in the procedure for changing the capacitor bank configuration should be available during the initial phase of CHI operations when the capacitor bank size is being changed.

The Phantom fast camera is required for this experiment.

The newly installed divertor halo current probes are desirable.

Configure one of the Soft X-ray arrays that views the central plasma to be in bolometer mode.

Good machine wall conditions are required (low oxygen levels).

The vessel should be boronized after the end of Day-1 CHI operations as described below.

Between shot deuterium glow discharge capability is needed.

On the Friday or Saturday before the start of experiments conduct a 1 hour deuterium glow followed by 30 minutes of He glow.

Capacitor Bank Configurations:

1. For Lower divertor plate conditioning (Day 1 of a run sequence)

Note: All MOVs to be connected during this operation

Bank-1: 3 capacitors, Bank 2: 1capacitors, Bank3: 6 capacitors

2. For Normal Operations (Day 2 and later of a run sequence)

Note: Use the MOV conditions required for 6 capacitor modules

Bank-1: 3 capacitors, Bank 2: 1capacitors, Bank3: 2 capacitors

Configuration

4.1 Connect the CHI capacitor to the CHI bus at the machine and connect the snubber capacitor and the MOV protection devices.

4.2 Reduce the maximum voltage capability on the OH circuit to 4kV (from the normal 6kV).

4.3 Configure PF1B for 2kV operation to drive current in the anti-clockwise direction as seen from above (normal for CHI). Change PF1B RIS and software limits to provide 10kA capability (from the present 5kA).

4.4 Configure PF2L and PF2U for 2kV operation, with coil current in the clockwise direction (opposite of normal operation).

4.5 Configure PF1A software limits to provide full 20kA capability. For the first CHI run a lower limit of 15-16kA would be acceptable.

4.6 Enable the EC-PI klystron #2 to provide the divertor chamber preionization and disable klystron #1 connected to the midplane EC-PI launcher. Apply the EC-PI power from t = -3 to +8ms.

4.7 Configure HHFW for 0-π phasing during heating, if required.

4.8 Operate the NB sources at >80kV acceleration voltage during the current ramp-up phase.

LDGIS system checks

4.9 Ensure LDGIS is in the "Puff" mode and has been tested prior to the experiment.

4.10 Ensure LDGIS gas pressure interlocks (PE107, PE104) are functional.

4.11 Set LDGIS operating line pressure to 100Psig helium.

4.12 Ensure 2000 Torr D_2 filling gas pressure in LDGIS system

Pre-operational checklist

4.13 Ensure MIG and Penning gauges are selected for operation.

4.14 Remove CHI jumpers.

4.15 Check TF interlock is set to 10kA.

4.16 Check for the appearance of ionization light on the fast camera during the EC-PI pulse to ensure correct triggering.

5. Planned analysis

The magnetic analysis codes LRDFIT and EFIT will be used to analyze the plasma equilibrium. It is hoped to be able to use data from the MPTS and other kinetic diagnostics to supplement the magnetic data for the assessment of flux closure.

6. Planned publication of results

These results will be published at meetings and in journal articles.

APPENDIX 1

Based on the evolution of the discharge, adjust PF currents to obtain an equilibrium of the evolving discharge and maximize the toroidal plasma current. Use the values listed in Table 1 as a guide. Adjust the timing of the PF ramps to match the discharge evolution. All PF coil currents are specified in the physics convention, *i.e.* positive current is counter-clockwise from above.).

Table 1:Reference coil currents (kA) for equilibrium at specified plasma current based on actual plasma shots.

Shot	Ip	PF1B	PF5	PF3L	PF3U	PF1AL	PF1AU
120404	600	+4.5	-6.3	-2.3	-2.1	-1.1	+5.18
Scaled to	100kA	+0.75	-1.05	-0.4	-0.35	-0.18	+0.86
Actual	@100kA	0	-1	-1.8	-1.8	0	0
Actual	@200kA	0	-1.6	-2.2	-2.2	0	0
120406	1000	0	-10.0	-4.6	-4.6	+12	+12

Scaled to	100kA	0	-1.0	-0.46	-0.46	+1.2	+1.2
Actual	@100kA	0	-1.05	-2	-2	0	0
Actual	@200kA	0	-1	-2.6	-2.6	0	0

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **-41 to -65** Flattop start/stop (s): **-0.02 / 0.7**

I_P (MA): **1.0** Flattop start/stop (s): **n/a**

Configuration: **CHI transitioning to CS driven with NBI & HHFW**

Outer gap (m): **>8cm** Inner gap (m): **>2cm**

Elongation κ: **>2** Triangularity δ: **>0.4**

Z position (m): **0**

Gas Species: **D**, Injector: **LDGIS + LFS midplane**

NBI- **80kV to 90kV D^0 injection, Nominal Pulse during inductive drive**

ICRF- **Up to 2MW in the heating phasing (0-π).**

CHI- **Capacitor bank operation, 3 Bank modules**

Shot numbers for setup: **124271**, Other useful shot numbers: **120870, 120888, 120890**

DIAGNOSTIC CHECKLIST

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Diagnostic	Need	Want
Bolometer – tangential array	✓	
Bolometer – divertor		✓
CHERS – toroidal		✓
CHERS – poloidal		✓
Divertor fast camera		✓
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.		✓
Edge pressure gauges	✓	
Edge rotation diagnostic		✓
Fast ion D_alpha - FIDA		
Fast lost ion probes - IFLIP		
Fast lost ion probes - SFLIP		
Filterscopes	✓	
FIReTIP		✓
Gas puff imaging		
Hα camera - 1D		✓
High-k scattering		
Infrared cameras		✓
Interferometer - 1 mm		
Langmuir probes - divertor		✓
Langmuir probes – RF ant.		
Magnetics – Diamagnetism	✓	
Magnetics - Flux loops	✓	
Magnetics - Locked modes		✓
Magnetics - Pickup coils	✓	
Magnetics - Rogowski coils	✓	
Magnetics - RWM sensors		✓

Diagnostic	Need	Want
Mirnov coils – high f.	✓	
Mirnov coils – poloidal array	✓	
Mirnov coils – toroidal array	✓	
MSE		✓
NPA – ExB scanning		
NPA – solid state		
Neutron measurements		✓
Plasma TV	✓	
Reciprocating probe		
Reflectometer – 65GHz		
Reflectometer – correlation		
Reflectometer – FM/CW		
Reflectometer – fixed f		
Reflectometer – SOL		
RF edge probes		
Spectrometer – SPRED	✓	
Spectrometer – VIPS	✓	
SWIFT – 2D flow		
Thomson scattering	✓	
Ultrasoft X-ray arrays	✓	
Ultrasoft X-rays – bicolor		✓
Ultrasoft X-rays – TG spectr.		✓
Visible bremsstrahlung det.		✓
X-ray crystal spectrom'r - H		
X-ray crystal spectrom'r - V		
X-ray fast pinhole camera		✓
X-ray spectrometer - XEUS		