Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Flux savings from inductive drive of a Transient CHI started plasma**		
OP-XP-928	Revision:	Effective Date: **5/18/09** *(Approval date unless otherwise stipulated)* Expiration Date: **5/18/11** *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: R. Raman	Date 5/13/09
ATI – ET Group Leader: D. Mueller	Date 5/13/09
RLM - Run Coordinator: R. Raman / E. Fredrickson	Date 5/13/09
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-928**

AUTHORS: **R. Raman, B.A. Nelson, D. Mueller, M. Bell, T.R. Jarboe** DATE: **5/13/09**

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1. Overview of planned experiment

The run plan from X817 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 and has shown coupling of CHI produced discharges to induction. The present XP will optimize these discharges by reducing the extent of low-Z impurities through improved divertor conditioning, through the increased use of Li and when available through the use of the absorber PF coils. This XP has minor modifications to part 3.1 of XP817.

3. Experimental run plan

The plan is to first reproduce the CHI coupled discharges to induction that were produced in 2008. To determine if the low-Z impurity behavior with 1, 2 and 3 capacitors is the same as that seen last year under the present divertor conditions. Then to use the coil currents developed as part of XP 927 to improve these discharges by reducing the extent of absorber arcing. A lithium evaporation rate of 10-15mg/min would be used with no HeGDC between shots.

If minimal or no improvements are seen, we will conduct a day of lower divertor electrode cleaning using long-pulse CHI discharges in the stuffed injector flux condition using the DC power supply. Several high-current upper single null discharges (high beam power with no CHI) will also be run to clean the upper divertor plates. The OH for this part will be configured for 6kV as OH will not be used in conjunction with CHI.

We will then redeposit Lithium, initially at a higher rate then, stabilize at 10-15mg/min and repeat the shots conducted before the divertor plate conditioning day and then continue to improve these discharges.

Reference discharges with reversed TF will also be generated for use with LLD in FY10

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

PART 1

a) Start with 12mg/min Li evaporation rate for 8.5min, 1 min pump out before shot (10 min clock cycle).

b) Restore a reference CHI produced discharge from XP817 (No. 128401, 128407, 129569, or 129614). Reproduce the discharge by using a total of 1, 2 and 3 capacitors. Assess current persistence.

c) 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 129614.

d) Use the same gas injection conditions as in 129614.

e) As in 129614, 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.

f) After the plasma current exceeds 200kA, turn on NBI SRC A at 90kV for >50ms.

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

h) Vary the beam timing and use Thomson scattering to verify that the beams help.

i) After the Li dropper capability is available, use it during the discharge to coat the upper divertor with Li (to reduce oxygen impurities in subsequent discharges).

j) Repeat for the cases of 1, 2 and 3 capacitors as in shots 128400, 128401 and 128402.

k) Using absorber PF coil currents developed as part of XP927, use the absorber PF coils to reduce the extent of absorber arcing and influx of low-Z impurities.

l) Collect Spectroscopic, Thomson and MSE data.

PART 2

Reproduce shot 120875 and repeat with fewer capacitors to reduce absorber arcs. Use suitable magnitude of currents (developed as part of XP927) in PFAB1 and 2 to further reduce absorber arcs. Use a Li evaporation rate of about 12-15 mg/min and readjust the Branch-5 plenum pressure.

Repeat with TF increased to 65kA and TF reduced to 45kA. Note that some adjustments to the PF1B coil current may be needed.

Select a suitable high-current case and apply induction using the PF waveforms from 3.1 or a more recent case to see if these discharges couple to induction

If time remains after the end of the first or the third day of operations, then:

1. Use the remaining time to feedback control the loop voltage by specifying a programmed plasma current request.

2. Turn on isoflux control capability at 150ms to transition from gap control to rtEFIT control.

No-CHI Comparison

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

1) Turning off the CHI Power Supply voltage. Use ECH for pre-ionization.

2) If there is no breakdown, turn off the PF1B, PF2L and PF1AL coil current used for injector flux programming (i.e. from 0 to 20ms). If the shot fizzles, the amount of pre-fill may need to be varied.

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

3.2 Divertor electrode discharge cleaning

Note: Before the start of these experiments the Filter scope attenuation should be increased by a factor of 2.

Upper Divertor Cleaning

Load shot 132721 (800kA, elongation ~2, average triangularity ~0.3, this will have low PLH and not under isoflux control, interchange PF2U and 2L signals to make it USN, use 6MW of NBI power) and repeat it 10 times. An alternate shot is 132717 (800kA, elongation ~1.9, average triangularity ~0.5, this will have intermediate PLH and is an isoflux controlled shot, and change drSep to be positive. This does not use PF2)

Lower Divertor Cleaning

Note: Ensure OH line switches are open

Note: Ensure that a test has been run to check that the DC power supply will trip if the PF1B power supply trips.

1. Load shot 124205 (CHI-only discharge) and change the PF coil currents so that PF1B = +7750A, PF3L = -500A and PF2L = 0A (physics convention) to produce a heavily stuffed injector flux condition. All other coils should be programmed to have zero current. Set the TF to 0.35T.

2. Fill the four LDGIS plenums to a fill pressure of 2400 Torr D_2 and trigger them at -15ms. As an option, consider running a few pulses with Helium and then repeat with deuterium to see if the oxygen is removed at a faster rate in helium plasmas.

3. Apply a 1kV pulse using the DC rectifier power supplies from t = 0 to +10ms to ensure that a discharge is produced. Verify that the injector current is clamped at about the 9kA level, limited by the series resistor. Mid-plane EC-Pi may be needed for a breakdown. If the attained CHI injector

current is much less than 6kA, consider using a controlled access to reduce the series resistance from 77mOhm to 51mOhm. Prior to this changeover, run about 6 shots at the maximum attained current and at the maximum possible pulse length to verify that all systems are operating reliably.

4. After a reliable discharge has been obtained, extend the applied voltage pulse in steps to +50ms, +100ms, +200ms and then to +400ms.

5. As the pulse length is increased, if the injector current decays away to zero (due to neutral density reduction in the injector, try initiating the CHI discharge using only one, two or three LDGIS plenums, and inject gas from the remaining plenums at a suitable time during the 200-400ms injector current pulse. Go back to 50ms pulses to test discharge initiation with reduced gas injection.

6. Conduct a 5 minute 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.

7. After reproducible discharges have been obtained, starting from t=10ms to t=200ms (or to 400ms if possible), ramp the current in the PF2L coil from zero -400A.

8 Continue with these shots until the end of the day.

9. After the end operations, conduct a 30 minute deuterium glow, followed by 1 hour of He GDC.

3.3 Assessment of Divertor Cleaning

Repeat the reference shots from step 3.1 to assess the benefits of divertor cleaning. Initially use a Li evaporation at a rate of about 14 mg/min and readjust the Branch-5 plenum pressure.

Later increase the Li evaporation rate to 20-30mg/min to see if this reduces the amount of oxygen in the CHI produced discharge and leads to a higher electron temperature plasma with longer current decay times.

After the Li dropper capability is available, use it during the discharge to coat the upper divertor with Li (to reduce oxygen impurities from the absorber in subsequent discharges).

After HHFW is available repeat a CHI-only reference discharge and CHI started discharge that has transitioned to an inductive discharge with HHFW applied in the heating phase to assess improvements to the electron temperature.

3.4 Assessment with metal outer divertor electrode

Reverse the TF, and after the CHI power feed connections have been reversed (positive inner electrode), repeat standard discharges produced in step 3.1 and 3.3, and produce reference discharges that could be repeated after the metal outer divertor is installed in NSTX.

After installation of the metal outer divertor, repeat the CHI-only and the CHI-transitioned reference discharges for an assessment of the benefits of a partial metal divertor electrode. Use spectroscopy data, radiated power data and electron temperature measurements for this assessment.

3.5 Assessment of Inductive Flux Saving

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

b) For procedure 3.3, develop an inductive startup discharge which reaches the same current and configuration in the same time as the CHI-assisted discharges in 3.3. 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.

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 or if the series resistor used during the DC power supply operation needs to be changed.

The 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).

Between shot deuterium glow discharge capability is needed.

Capacitor Bank and DC Power Supply Configurations:

DAY-1: Start with the Capacitors in the following configuration.
All MOVs to be connected during this operation
Bank-1: 1 capacitors, Bank 2: 2 capacitors, Bank3: 2 capacitors
Absorber PF coils if available

OH to be configured for 4kV
DC power supply not needed

DAY-2: Configure for DC Power Supply Operation (1kV)
All MOVs to be connected during this operation
Absorber PF coils not needed
OH to be configured for 6kV
Capacitor bank power supply not needed

DAY-3 and beyond: Configure as Day 1

Configuration

4.1 Connect the CHI capacitor (for Day 1, 3 and beyond) or the DC power supply (for Day 2) to the CHI bus at the machine and connect the snubber capacitor and the MOV protection devices.

4.2 During capacitor bank operation, 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.

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 Configure EC-Pi to provide mid-plane injection (normal configuration). 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 >70kV 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 2400 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.

PHYSICS OPERATIONS REQUEST

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Describe briefly the most important plasma conditions required for the XP:

This is not a standard plasma discharge. A CHI produced discharge is then driven by induction.

List any pre-existing shots:

128400, 128401 and 128402

Equilibrium Control: Gap Control / rtEFIT(isoflux control): Gap Control

Machine conditions *(specify ranges as appropriate, use more than one sheet if necessary)*

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

I_P (MA): 0.6 – 1.0 Flattop start/stop (s): n/a

Configuration: **LSN and unbalanced double null**

Outer gap (m): **>8cm** Inner gap (m): **>2cm** Z position (m): **0**

Elongation κ: >**1.7** Upper/lower triangularity δ: >**0.4**

Gas Species: **D2** Injector(s): LDGIS, Inj. 2, Inj.1, Inj. 3

NBI Species: **D** Voltages (kV or off) **A: 90** **B: 70-90** **C: 70-90** Duration (s): **1**

ICRF Power (MW): 2 Phasing: o-π (Heating) Duration (s): 0.5s

CHI: **On** Bank capacitance (mF): **2-50**

LITERs: On Total deposition rate (mg/min): **5 to 30**

EFC coils: OFF Configuration: **SPAs drive Absorber PF coils**

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	Need	Want
Bolometer – tangential array	X	
Bolometer – divertor		X
CHERS – toroidal		X
CHERS – poloidal		X
Divertor fast camera		X
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.		X
Edge pressure gauges	X	
Edge rotation diagnostic		X
Fast ion D_alpha - FIDA		X
Fast lost ion probes - IFLIP		X
Fast lost ion probes - SFLIP		X
Filterscopes	X	
FIReTIP	X	
Gas puff imaging		
Hα camera - 1D		X
High-k scattering		
Infrared cameras		X
Interferometer - 1 mm		X
Langmuir probes – divertor		X
Langmuir probes – BEaP		X
Langmuir probes – RF ant.		
Magnetics – Diamagnetism	X	
Magnetics – Flux loops	X	
Magnetics – Locked modes		X
Magnetics – Pickup coils	X	
Magnetics – Rogowski coils	X	
Magnetics – Halo currents		X
Magnetics – RWM sensors		
Mirnov coils – high f.	X	
Mirnov coils – poloidal array	X	
Mirnov coils – toroidal array	X	
Mirnov coils – 3-axis proto.		X

Note special diagnostic requirements in Sec. 4

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