Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: **Flux savings from inductive drive of a Transient CHI started plasma**		
OP-XP-1034	Revision:	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS	
Responsible Author: R. Raman et al.,	Date **6/16/10**
ATI – ET Group Leader: R. Raman / D. Mueller	Date **6/16/10**
RLM - Run Coordinator: E. Fredrickson	Date
Responsible Division: Experimental Research Operations	

RESTRICTIONS or 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-1034**

AUTHORS: **R. Raman, B.A. Nelson, D. Mueller, M.G. Bell, T.R. Jarboe, D. Battaglia** DATE: **6/16/10**

1. Overview of planned experiment

The run plan from XP928 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 further reducing the extent of low-Z impurities through improved divertor conditioning, through the use of outer metallic divertor plates, through the increased use of Li and through the use of higher currents in the absorber PF coils. This XP has minor modifications to part 3.1 of XP928.

3. Experimental run plan

The plan is to first reproduce the CHI coupled discharges to induction that were produced in 2009. To determine if the low-Z impurity behavior with 1, 2, 3 and 4 capacitors is the same or better than that seen last year but under the present divertor conditions. Then to further optimize the early phase of the discharge to improve start-up and ramp-up. When available, currents > 1kA (up to 3.3 kA) will be used in the PFAB1 and 2 coils to more effectively suppress absorber arcs at plasma currents above 250kA. A lithium evaporation rate of 10-15mg/min would be used with no HeGDC between shots. A warm Li divertor would be used in some discharges to assess the impact of a liquid Li divertor on CHI start-up.

Compared to FY09 results, if degradation in plasma performance is 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 rectifier power supply. Several high-current double-null discharges, but slightly biased to be upper null (with high beam power and with no CHI) will also be run to clean the upper divertor plates.

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.

References discharges from FY09 will be repeated under as nearly identical conditions as possible to obtain an assessment of the benefits of a partial metal electrode.

Time permitting CHI start-up with reversed TF will also be studied, to assess the benefits of a metallic cathode.

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

PART 1

Reproduce FY2009 results:

a) Start with 12mg/min Li evaporation rate for 8.5min, 1 min pump out before shot (10 min clock cycle). Ensure that there is no NBI gas injection pulse just before the CHI discharge.

b) Restore a reference CHI produced discharge from XP928 (No. 135614, 135618, 135620, or 135619). Reproduce the discharge by using a total of 1, 2, 3 and 4 capacitors. Assess current persistence. Adjust the prefill or Li as needed.

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 waveform from shot 135614. Use the same gas injection conditions as in 135614.

d) As in 135614, 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.

e) After reproducible discharges are obtained test with the CHI capacitor bank power supply configured for 5 and 6 capacitors. Increase the magnitude of the currents in PFAB1, PFAB2 and PF2U to avoid absorber arcs. Compare with FY09 results to determine if divertor conditioning is required.

f) If it is determined that divertor conditioning is required, then as a first step, use all 10 capacitors of the cap bank (load shot 127634) and in combination with between shot D2-GDC, run 15 high injector current discharges and repeat the reference discharges again to see if this is adequate. Note that Li will not be applied between shots during this divertor conditioning work. The LITERs will be cooled to below melting temperature before start of D2GDC.

Improve on 2009 results:

g) Readjust the initial applied loop voltage by decreasing it below 4V to see if a lower initial loop voltage is beneficial. Use approximately the normal inductive voltage.

h) Improve the gas fueling during the coupling phase to induction: Readjust the gas injection during the inductive ramp-up phase, including using the high-field side injector. Use one or two sources of NBI to heat the evolving discharge as in FY08. Start by reloading gas conditions from shot 128407, and optimize so as to transition into an H-mode later in the discharge.

i) Test the effect of over fuelling during the CHI start-up phase: Starting with 3 or 4 capacitors (just below the threshold for producing absorber arcs) and with No-OH, using the SGI (at its parked position, R=170cm, near the outer wall), time it so that gas is injected into the evolving CHI discharge. Quite likely the discharge will quench due to over fuelling. On the subsequent shot, increase the number of capacitors but do not use the SGI to see if the plasma is able to evolve into an absorber arc-free discharge. Try this a few times to look for possible improvements.

j) Once stable discharges have been produced, move the gap-control feedback time from the present 40ms start to as close as possible to 20ms, in 5 or 10ms steps. At each step, readjust the pre-programmed portion of the PF5 and PF3 coil currents to obtain a smooth Ip ramp-up.

k) Now increase the number of capacitors to more than 4 in steps as follows. Note that small increases to the magnitude of the PF1B and PF2L coil currents may be needed as the capacitor bank size is increased.

- First, increase the PFAB coil currents to the extent possible to suppress absorber arcs.
- After this limit has been reached, readjust the later part of the inductive discharge so that it is weakly biased up. After, t=100ms, deposit Li using the Li dropper to coat the upper divertor.
- After a few discharges conducted this way, repeat without the Li dropper to assess if the Li coating on the upper divertor is able to reduce the influx of oxygen impurities during a discharge that uses more than 4 capacitors. Optionally, a long pulse inductive only discharge may be needed for this upper divertor Li conditioning, as described in the first part of Section 3.3.
- Adjust PF3 and 5 as needed to maintain Rp.

Heat the CHI target discharge:

l) After stable reproducible discharges are obtained at the highest CHI start-up currents, inject RF in the heating phase from 10 to 100ms to heat the CHI portion of the discharge. Compare with several NO RF cases to assess if RF is increasing the temperature of the CHI portion of the discharge.

m) Re-optimize NBI injection times to improve the discharge.

n) As in FY09, obtain Thomson data during the CHI portion of the discharge and during the hand-off portion to induction. Obtain Spectroscopic and MSE data.

TF scan:

Return to a CHI-only case and repeat at TF = 0.4, 0.45 and 0.5T, or obtain a new data point at a field close to 0.55T.

Test with warm LLD

Conduct this part after project approval for operation of CHI with warm LLD.

a. Using a reference CHI+OH discharge from the above steps, repeat it to re-establish the target.

b. Then, repeat it with a cold LLD, but with the amount of deposited Li increased, to assess the benefits of the higher levels of Li.

c. Using the best discharges from (a) or (b), increase the LLD temperature to 250^0C (or based on the results of XP1059, that specifies the temperature at which LLD has shown Li to be in the melted state), to assess the benefits of a warm LLD. If the discharges improve with a warm LLD, increase the Li deposition rate in steps to maximize the benefits to CHI start-up.

Improve Feedback Control

If time remains after the end of 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 70-100ms to transition from gap control to rtEFIT control.

PART 2

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 Assessment of Inductive Flux Saving

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

b) For procedure 3.2, develop an inductive startup discharge which reaches the same current and configuration in the same time as the CHI-assisted discharge. 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.

3.3 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

Use one of the following three options.

1. Load a standard double null fiducial and bias it to be slightly upper single null. Change drSep to be +0.5.

2. Load 135713 and change drSep from -3.8 to +0.5

3. Load shot 132721 (800kA, elongation ~2, average triangularity ~0.3, this will have low P_{LH} and not under isoflux control, interchange PF2U and 2L signals to make it USN, use up to 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 P_{LH} and is an isoflux controlled shot, and change drSep to be positive. This does not use PF2)

Run about 15 discharges in this configuration to condition the upper divertor surfaces.

Lower Divertor Cleaning

Note: Ensure OH line switches are open. Prior to the start of the conditioning phase, reduce the series resistance from 77mOhm to 51mOhm between the DC PS and the CHI load.

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 133615 or 133616 (CHI-only DC PS discharge). TF should be 0.35T. LDGIS gas should be staggered as in 133615, but only 3 out of the four plenums will be functional.

2. Fill the three LDGIS plenums to a fill pressure of 2400 Torr D_2 and trigger them as in 133615, accounting for the missing fourth plenum.

3. Initially, apply a 1kV pulse using the DC rectifier power supply from t = 0 to +50ms to ensure that a discharge is produced. Verify that the injector current is clamped at about the 9kA level or less, limited by the series resistor. Mid-plane EC-Pi may be needed for a breakdown.

4. After a reliable discharge has been obtained, extend the applied voltage pulse in steps to +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 sustaining the discharge using the flow capability of LDGIS to continue to feed gas after the gas plenums have been depleted.

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.

8 Continue with these shots until the end of the day or until about 30 discharges have been obtained.

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

3.4 Assessment of Divertor Cleaning

Repeat the reference shots from step 3.1 to assess the benefits of divertor cleaning. Initially use 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.

3.5 Assessment with metal outer divertor electrode as a cathode

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.

Use spectroscopy data, radiated power data and electron temperature measurements for this assessment and compare to FY09 results with graphite anode and FY10 results with Mo anode.

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 fast camera is required for this experiment.

The divertor Langmuir 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.

The Li dropper system is desired.

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

DAY-2: [If it is decided to run divertor conditioning discharges using the DC PS}
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 4kV
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 (12 pulse rectification) 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 (12 pulse rectification), with coil current in the clockwise direction (opposite of normal operation).

4.5 Configure PF1A software limits to provide full 20kA capability.

4.6 Configure PFAB1 and 2 for the highest possible current and readjust the current limits on PF2U to be consistent with the coil currents in PFAB1 and 2. PF2U may have to be limited to 2kA.

4.7 Configure EC-Pi to provide mid-plane injection (normal configuration). Apply the EC-PI power from t = -3 to +8ms.

4.8 Configure HHFW for 0-π phasing during heating.

4.9 Operate the NB sources at >70kV acceleration voltage during the current ramp-up phase.

LDGIS system checks

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

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

4.12 Set LDGIS operating line pressure to 100Psig helium.

4.13 Ensure 2400 Torr D_2 filling gas pressure in LDGIS system

Pre-operational checklist

4.14 Ensure MIG and Penning gauges are selected for operation.

4.15 Remove CHI jumpers.

4.16 Check TF interlock is set to 10kA.

4.17 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:

135614, 135618, 135620

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): **5-50**

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**
Beam Emission Spectroscopy		
Bolometer – divertor		**X**
Bolometer – midplane array	**X**	
CHERS – poloidal		**X**
CHERS – toroidal		**X**
Dust detector		
Edge deposition monitors		
Edge neutral density diag.		**X**
Edge pressure gauges	**X**	
Edge rotation diagnostic		**X**
Fast cameras – divertor/LLD	**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 – divertor		
Gas puff imaging – midplane		
Hα camera - 1D		**X**
High-k scattering		
Infrared cameras		**X**
Interferometer - 1 mm		**X**
Langmuir probes – divertor		**X**
Langmuir probes – LLD		**X**
Langmuir probes – bias tile		**X**
Langmuir probes – RF ant.		**X**
Magnetics – B coils	√	
Magnetics – Diamagnetism	**X**	
Magnetics – Flux loops	√	
Magnetics – Locked modes	**X**	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents	**X**	
Magnetics – RWM sensors		**X**
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 – E||B scanning		
NPA – solid state		
Neutron detectors	**X**	
Plasma TV	**X**	
Reflectometer – 65GHz		**X**
Reflectometer – correlation		**X**
Reflectometer – FM/CW		**X**
Reflectometer – fixed f		**X**
Reflectometer – SOL		**X**
RF edge probes		
Spectrometer – divertor		**X**
Spectrometer – SPRED	**X**	
Spectrometer – VIPS	**X**	
Spectrometer – LOWEUS		**X**
Spectrometer – XEUS		**X**
SWIFT – 2D flow		
Thomson scattering	**X**	
Ultrasoft X-ray – pol. 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 tang. pinhole camera		