Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: Transient CHI Startup		
OP-XP-531	**Revision: 0**	Effective Date: **6/2/05** *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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ATI – ET Group Leader: R. Raman	Date
RLM – Run Coordinator: J. Menard	Date June 10, 2005
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Title: **Transient CHI Startup** **OP-XP-531**

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1. Overview of planned experiment

We will apply the "Transient CHI" scheme developed in HIT-II to demonstrate persistent toroidal current following a pulse of coaxial helicity injection (CHI) applied with the newly upgraded CHI capacitor bank. This XP has three parts: 1) Demonstrating the persistence of CHI-induced toroidal current; 2) handing off the CHI-induced plasma to inductive sustainment and ramp-up, and 3) measuring the benefits of CHI in saving inductive flux.

2. Theoretical/ empirical justification

Using a new CHI-specific capacitor bank, the method of Transient CHI was tested on NSTX during 2004. The capacitor bank produced reliable discharge initiation and operation over a wide range of gas pressure and injector flux conditions. However, analysis of the results pointed to four areas for improvement:

a) The need for improved pre-ionization so that the amount of injected gas can be reduced by a factor of at least four to provide more energy per particle from the fixed capacitor bank energy. The required capacitor bank energy per particle should preferably be about 100eV so that, after losses, the resulting plasma could burn through radiation barriers and reach temperatures of about 30eV or higher.

b) Increasing the capacitor bank voltage above the 1kV operational limit applied in 2004 should enable breakdown at lower gas pressures and increase the available energy by a factor of four over what was available in 2004.

c) Reducing the injector flux footprints is required to produce a sufficiently narrow flux foot print for inducing reconnection near the injector throat region.

d) Improved equilibrium control.

3. Experimental run plan

Prior to the start of this experiment, a related Machine Proposal XMP-39 will have established the conditions necessary for achieving breakdown using the LDGIS (Branch 5) in conjunction with EC pre-ionization in the chamber below the lower divertor plates.

3.1 Demonstrate persistence of toroidal current

Configure the CHI capacitor bank initially with five capacitors in parallel only (C = 25mF). The capacitor bank will be fired at t = 0 throughout this experiment.

Open line and ground switches in the OH circuit to prevent current from flowing in it.

Use 5min HeGDC between shots to maintain constant wall conditions.

Start with the gas timing and plenum pressure developed in XMP-39 for breakdown using fundamental EC resonance in the sub-divertor chamber (B = 0.64T, $I_{TF} \approx 45$kA), extending the TF flattop to 0.5s to prevent possible delayed breakdown as the TF falls.

Start with a capacitor bank charging voltage of 1.0kV.

Program the CHI capacitor bank crowbar ignitron to fire at t = +10ms to rapidly reduce the CHI injector current.

Program constant values: PF1B = +4 kA, PF3L = 0, PF1AL = -1kA. (Note: all PF coil currents are specified in the physics convention, *i.e.* positive current is counter-clockwise from above.) Program PF2L to zero at t = 0, -1.5kA at t = 2ms.

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. Program PF3U and PF1AU to zero at t = 0 and the value listed at t = 2ms. Program PF5 to have the value specified for t ≥ 0. Adjust the timing of the PF ramps to match the discharge evolution. Note that the values **(in bold)** in Table 1 for PF5, PF3U and PF1AU are upper limits calculated using the iSolver code (J. Menard) for hypothetical steady-state, closed-flux equilibria located at R=0.85m, a=0.6m. Calculations of CHI discharge evolution using the TSC code with the most up-to-date NSTX vessel geometry and open-field-line currents always show lower current requirements for the PF3U and PF5 coils than the steady-state calculation. Therefore, initially use a value about 25% of that listed in the table and make further adjustments based on experimental observations.

Table 1: Reference coil currents (kA) for steady-state equilibrium at specified plasma current

I_p(kA)	PF1B	PF1AL	PF2L	PF5	PF3U	PF1AU
50	4.0	-1.5	-2.0	**-0.21**	**-0.38**	**-0.03**
75	4.0	-1.5	-2.0	**-0.33**	**-0.44**	**-0.10**
100	4.0	-1.5	-2.0	**-0.49**	**-0.46**	**-0.05**
150	4.0	-1.5	-2.0	**-0.79**	**-0.53**	**-0.07**
150	4.0	-2.0	-2.0	**-0.77**	**-0.55**	**-0.12**
150	4.0	-2.0	-2.5	**-0.57**	**-0.75**	**-0.60**
150	4.0	-2.0	-3.0	**-0.51**	**-0.90**	**-0.54**
50	4.0	-2.0	-3.0	**-0.19**	**-0.64**	**+0.53**
100	4.0	-3.0	-2.0	**-0.38**	**-0.82**	**+0.14**
200	6.0	-3.0	-4.5	**-0.67**	**-1.32**	**-0.19**
150	6.0	-3.0	-4.5	**-0.51**	**-1.22**	**+0.22**
250	6.0	-3.0	-4.5	**-0.79**	**-1.39**	**-0.90**
200	6.0	-2.5	-3.75	**-0.67**	**-1.06**	**-0.66**
150	6.0	-2.5	-3.75	**-0.48**	**-0.96**	**-0.45**

Program the crowbar ignitron to fire at the time of peak toroidal current to assess the persistence of the toroidal current after the injector current has decayed to zero. Measure the plasma temperature and density profiles with MPTS at the time of the peak plasma current and during its decay when the injector current is zero.

Once the maximum current has been attained in the five capacitor configuration, increase the number of capacitors to 7 then all 10.

Increase the magnitude of closed flux current by raising PF1B to 6kA, using guidance from Table 1 for the required currents in other PF coils.

If the limit on the capacitor voltage has been raised above 1kV, assess the need for repeating the steps above at higher capacitor voltage. If the results obtained above at 1kV are satisfactory, raising the voltage may be deferred to a later stage of this experiment after completing steps 3.2 and 3.3 below.

3.2 Hand-off to inductive operation using the central solenoid

a) Close the OH circuit line switches and enable the OH power supply. Starting from the time of peak toroidal current, ramp the OH from zero to -10kA in progressively shorter periods to determine the response of the plasma to induction, as follows:

   2V/turn: t_1 to t_1+62ms, t_1 = time of peak CHI-induced current when OH ramp is initiated;

   4V/turn: t_1 to t_1+41ms;

   6V/turn: t_1 to t_1+21ms (Note: this capability will not be available if the OH power supply voltage is limited to 4kV during CHI operation).

b) Apply the OH induction for the time needed to ramp the plasma current by about 100% of the minimum of the plasma current during hand-off or by 100kA, whichever is higher.

   i. At the time that the inductive ramp is initiated, the PF1B coil current should to be ramped to zero. (See the timing diagram in the Physics Operation Request.)

   ii. Simultaneously the currents in the upper and lower PF2 and PF3 coils should become balanced to maintain vertical equilibrium, using the ratios I_{PF3}/I_p = –2.4kA/100kA and I_{PF2}/I_p = +1.2kA/100kA. Program the current in PF5 approximately in the ratio I_{PF5}/I_p = –0.3kA/100kA, to provide radial equilibrium.

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

   i. Apply a 40ms, 1 – 2 MW pulse of HHFW power phased for plasma heating (0-π), or

   ii. 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 20 ms pulse of NBI at 60 keV, initially from one source and adding sources if needed.

d) After the initial inductive ramp to I_{OH} = -10kA, continue to ramp the OH current, if necessary at a lower rate, until the OH coil current reaches the maximum of -24kA, to maximize the plasma current. Use EFIT reconstructions to adjust the currents in PF3 and PF2 coils.

e) Attempt to introduce normal feedback control of the equilibrium and plasma current using the PCS after I_p reaches 100kA and after imposing a time delay of at least 25ms from start time of current in the OH coil.

3.3 Assessment of Inductive Flux Saving

a) After reliable, reproducible discharges are obtained, repeat 5 shots using CHI start-up assist. If magnetic analysis shows that the plasma is reasonably well controlled during the startup phase, open shutters of spectroscopic diagnostics, soft-x-ray arrays and MPTS and document plasma characteristics. If necessary, use feedback controlled current ramp after an initial phase of pre-programmed current ramp. Based on the observed current evolution, the value for the current setting at which feedback controlled operation commences may need to be revised in the plasma control system software.

b) Develop an inductive startup discharge which reaches the same current and configuration in the same time as the CHI-assisted discharges in a). This will require bipolar operation of the OH, reprogramming the initial PF waveforms and switching to the standard LFS gas injector. 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 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.

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 for 2kV operation.

4.5 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.

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

4.7 Increase the gain on the Mirnov coils by connecting the appropriate cables and changing the attenuation factor. For Step 3.2 on, return the Mirnov coil gains to the standard values used for inductive discharges.

4.8 Operate the NB sources at 60kV acceleration voltage if NBI is needed.

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 MFIT, EFIT and ESC 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

Title**: Transient CHI Startup** **OP-XP-531**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **-45** Flattop start/stop (s): **-0.02 / 0.5**

I_P (MA): **0.5** Flattop start/stop (s): **n/a**

Configuration: **CHI transitioning to CS limited**

Outer gap (m): **N/A**, Inner gap (m): **N/A**

Elongation κ: **N/A**, Triangularity δ: **N/A**

Z position (m): **0**

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

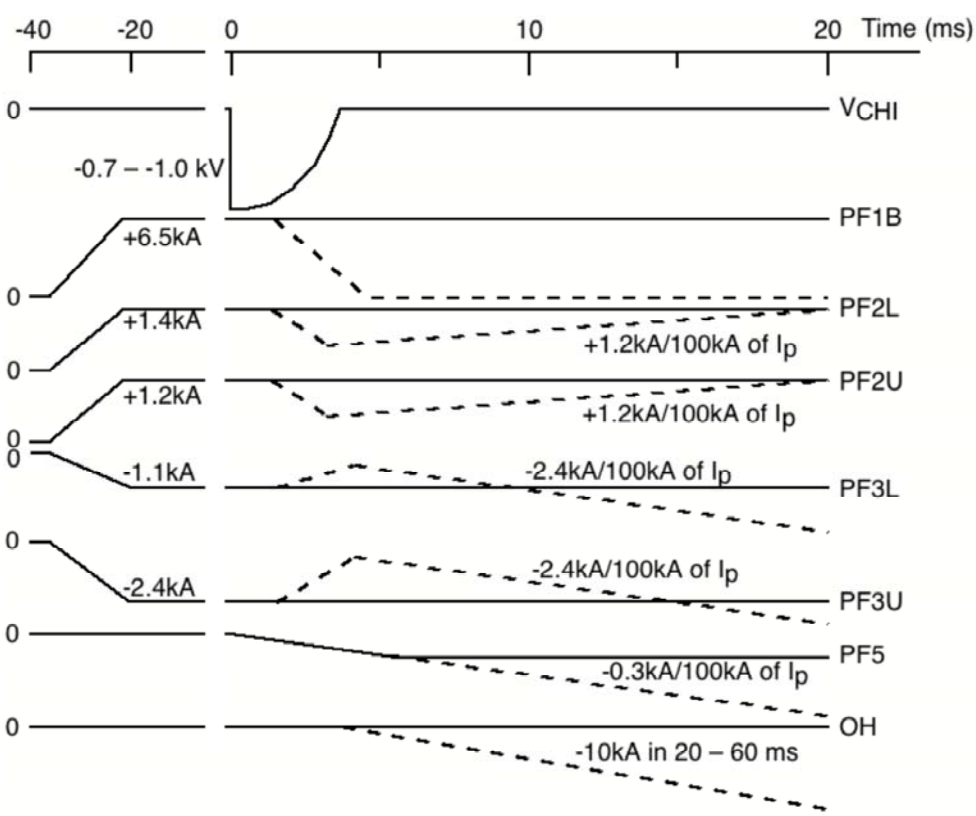
NBI- **Possibly needed for Phase 3.3 on; 60kV D^0 injection, 20ms pulse**

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

CHI- **Capacitor bank operation, 2 – 10 capacitors active**

Shot numbers for setup: **109635.**

CHI and PF coil timing. The solid lines are for the initial breakdown and persistence studies (3.1, 3.2); the dashed lines are for handoff to induction (3.3, 3.4).



DIAGNOSTIC CHECKLIST

Transient CHI Startup **OP-XP-531**

Diagnostic	**Need**	**Desire**	**Instructions**
Bolometer – tangential array	4		* Use when reproducible conditions are achieved
Bolometer array - divertor		4	
CHERS			
Divertor fast camera		4	
Dust detector			
EBW radiometers			
Edge pressure gauges	4		
Edge rotation spectroscopy		4	*
Fast lost ion probes - IFLIP			
Fast lost ion probes - SFLIP			
Filterscopes		4	
FIReTIP		4	*
Gas puff imaging			
H□ camera - 1D		4	*
Infrared cameras		4	
Interferometer - 1 mm			
Langmuir probe array			
Magnetics – Diamagnetism	4		
Magnetics - Flux loops	4		
Magnetics - Locked modes			
Magnetics - Pickup coils	4		
Magnetics - Rogowski coils	4		
Magnetics - RWM sensors			
Mirnov coils – high frequency	4		
Mirnov coils – poloidal array	4		
Mirnov coils – toroidal array	4		
MSE			
Neutral particle analyzer			
Neutron measurements			
Plasma TV	4		
Reciprocating probe			
Reflectometer – core			
Reflectometer - SOL			
RF antenna camera			
RF antenna probe			
SPRED		4	
Thomson scattering		4	*
Ultrasoft X-ray arrays		4	*
Ultrasoft X-ray arrays – bicolor		4	*
Visible bremsstrahlung det.		4	*
Visible spectrometer (VIPS)		4	
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray fast pinhole camera		4	*