Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Merging Start-up		
OP-XP-511	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS	
Author: Y. Takase, Y. Ono, O. Mitarai, D. Gates, J. Menard, J.R. Wilson, M. Yamada	Date
ATI – ET Group Leader: R. Raman	Date
RLM - Run Coordinator: J. Menard (S. Sabbagh)	Date August 8, 2005
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

The goal is to demonstrate plasma current start-up without the use of the central solenoid (OH coil). In this XP, plasma current start-up by merging of two ST plasmas, using only PF1A, PF2, PF3, PF4 and PF5 coils, is proposed. The role of noninductive plasma production (EC preionization) and requirements for magnetic configuration will be evaluated.

2. Theoretical/ empirical justification

Brief justification of activity including supporting calculations as appropriate

Several start-up scenarios have been considered for NSTX: (1) pressure-driven start-up by ECH (CDX-U scenario), (2) RF ionization + PF induction (JT-60U scenario), and (3) plasma merging (TS-3/TS-4/START/MAST scenario). These scenarios have been modeled by LRDIAG, with the plasma modeled by a set of passive coils whose resistivities were chosen to reproduce I_p ramp-up of a 1 MA NSTX plasma.

JT-60U has demonstrated generation of 100 kA of plasma current by EC preionization and outboard PF coil induction only [Y. Takase, et al., IAEA Fusion Energy Conf. (Vilamoura, 2004), paper EX/P4-34]. A scenario similar to this, but with HHFW preionization, was attempted on NSTX in May 2004 (XP431). However, a convincing evidence of current channel formation was not observed. The most likely reason is the mismatch in the optimum range of neutral gas pressure between efficient delivery of RF power and plasma current start-up. A merging scenario was proposed in XP431 as scenario (3), but this was not attempted because of limited time allocated to the experiment.

In the merging start-up scenario, magnetic reconnection takes place, and part of magnetic field energy is converted into plasma kinetic energy. Because of the large heating power provided by reconnection, this scenario is suitable for forming a high-β ST plasma quickly. This technique was pioneered in TS-3 (Fig. 1), and was successfully applied to START, TS-4, and MAST. All of these experiments made use of either electrodes or coils located inside the vacuum vessel.

This XP proposes to demonstrate a merging start-up scenario which uses only PF coils located outside the vacuum vessel. An example of LRDIAG simulation of such a scenario is shown in Fig. 2. Plasma currents of the order of 100 kA are predicted to be driven. PF1A, PF3 and PF4 coils are used to create X-points in the plasma formation regions at the top and bottom ends of the vacuum vessel, near the divertor plates. The radial position of the X-point is controlled by the ratio of PF1A to PF3/PF4 currents, while the vertical position can be controlled by PF2 current. The ratio of PF3 to PF4 current can be adjusted to lead the separatrix flux surface to the HHFW antenna. Inductive flux is provided mainly by PF2, PF3 and PF4 coils during the plasma formation phase, and further current ramp-up is accomplished by inductive flux provided mainly by PF3 and PF5 coils.

If successful plasma current start-up were accomplished, optimization of the merging process will be attempted to maximize ion heating due to reconnection.

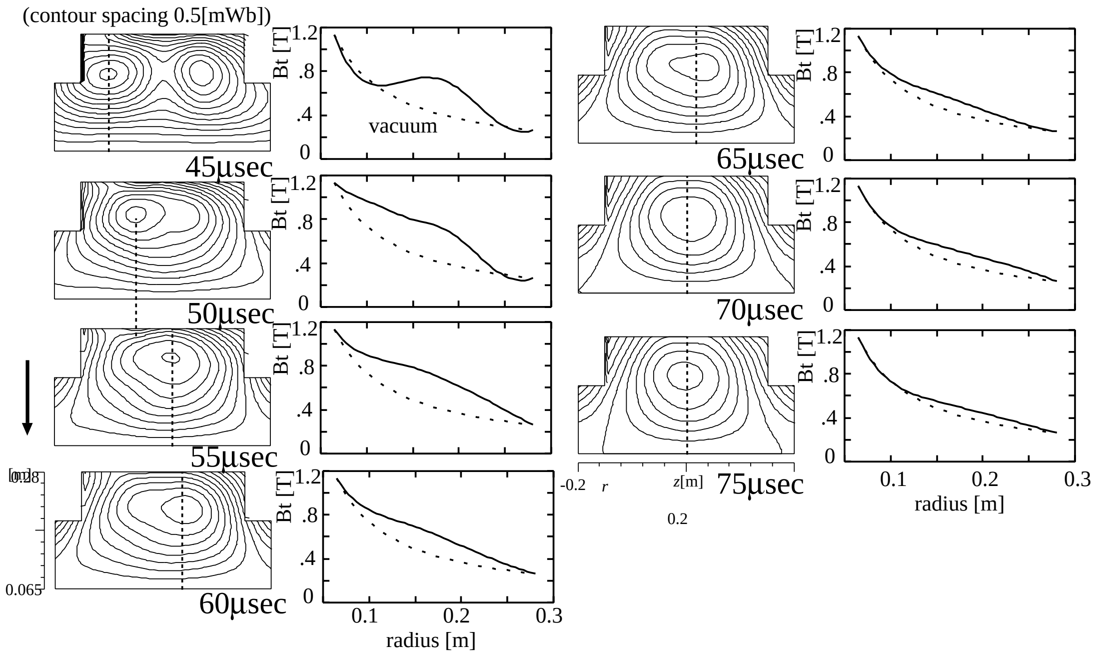

Fig. 1. Merging formation of a high-β ST plasma on TS-3. High power heating due to magnetic reconnection helps create a high-β ST plasma quickly.

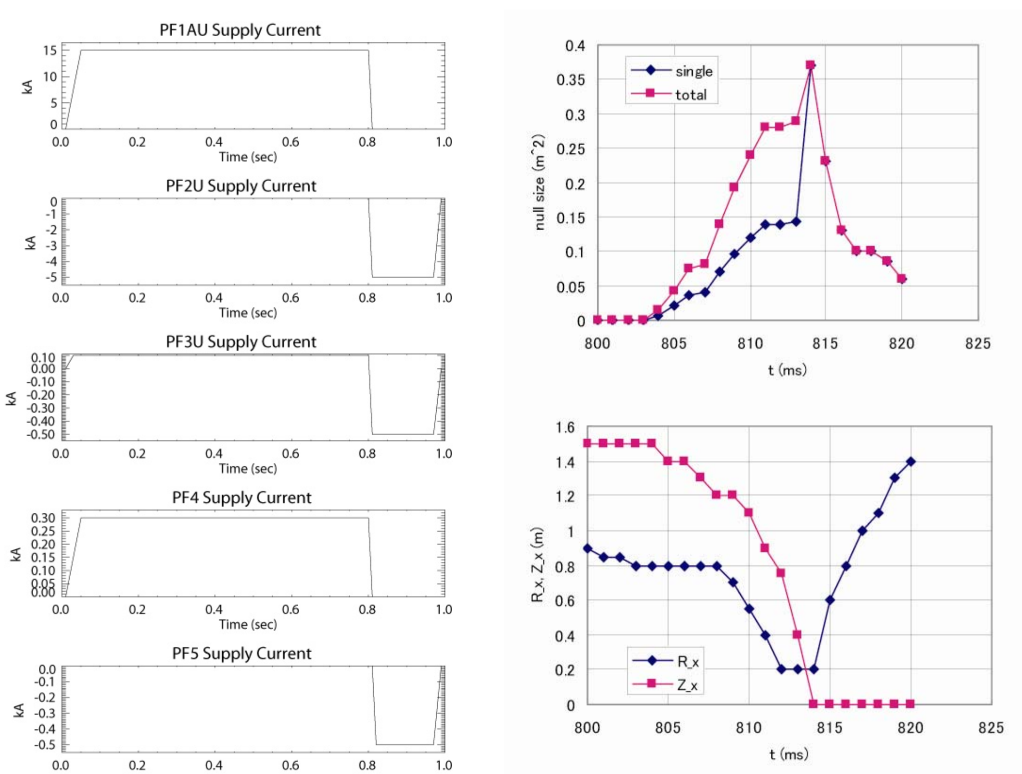

Fig. 2. A merging start-up scenario on NSTX. Plasmas are initially formed at the X-points created by PF1A, PF3 and PF4 coils at the top and the bottom of the vacuum vessel. The two plasmas merge near the midplane and form a single ST plasma.

3. Experimental run plan

Describe experiment in detail, including decision points and processes

Plasma initiation and plasma current formation at the X-points will be attempted first, starting with the PF coil waveforms shown in Fig. 2 (scenario 1). This places the X-points at R = 0.9 m and Z = ± 1.55 m, and a maximum loop voltage at the X-points of up to 4 V is predicted. Preionization ECH will be used at full power (CHI ECH needs to be redirected to the main chamber). HHFW will also be used for preionization at a few hundred kW power level. The toroidal field should be 0.45 T, which places the preionization electron cyclotron (18 GHz) resonance layer at R = 0.6 m, to the high field side of the X-point. In this scenario PF1A, PF2, PF3 and PF4 coil currents are ramped simultaneously over 10 ms, while PF5 coil current is ramped over 10 ms after PF4 current reaches 0. Start the experiment with prefill pressure at 1.5×10^{-5} Torr (gauge). Proceed according to the following sequence.

1. Scan down in pressure to find the optimum pressure for start-up, which is expected to be in the lower pressure range (5 shots).
2. Reduce the toroidal field: B_t = 0.36, 0.3 T (2 shots). [Also increase to maximum allowed B_t if downward scan indicates degradation (1 shot).]]
3. Vary the X-point major radius to R_X = 0.75, 0.6 m (2, 3). In this sequence, B_t should be scaled from 0.3 T to maintain the same relationship between the resonance layer and the X-point, i.e., 0.36 T for R_X = 0.75 m and 0.45 T for R_X = 0.6 m (2 shots).
4. Vary the X-point height to Z_X = 1.4, 1.3 m (4, 5) (2 shots).
5. Vary PF coil current ramp rates: ramp time 5 ms, 20 ms, and 50 ms to document the dependence on the applied loop voltage (3 shots).
6. Reduce EC and/or HHFW power until plasma current fails to start (6 shots).
7. Using the optimized condition for plasma current initiation, optimization of further current rise is attempted by controlling the subsequent poloidal field evolution, including PF coil current ratios, ramp rates and timings (~ 10 shots).
8. After completion of this sequence, optimize merging to maximize ion heating due to reconnection. According to the experience on TS-3 and TS-4, initial separation of the two plasmas and subsequent control of the reconnection speed by PF coils are important (~ 5 shots).

Scenario	PF1A (kA)	PF2 (kA)	PF3 (kA)	PF4 (kA)	PF5 (kA)	comments
1	15→0	0→–5	0.1→–0.5	0.3→0	0→–0.5	R_X/Z_X = 0.9/1.55 m
2	same as 1	same as 1	same as 1	1→0	same as 1	R_X = 0.75 m
3	same as 1	same as 1	0.5→–0.5	1→0	same as 1	R_X = 0.6 m
4	same as 1	–0.2→–5	same as 1	same as 1	same as 1	Z_X = 1.4 m
5	same as 1	–0.4→–5	same as 1	same as 1	same as 1	Z_X = 1.3 m

If successful start-up to 100 kA level were achieved, position feedback control will be implemented, and HHFW power (~1 MW) will be applied to increase the electron temperature and drive current. NBI may be used in addition, or in stead.

The total number of shots required for this experiment is estimated to be a little over 30 shots. Adjustments to optimization steps may be made depending on the outcome of the experiment.

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

Describe any prerequisite conditions, development, XPs or XMPs needed.
Attach completed Physics Operations Request and Diagnostic Checklist

PF4 is needed in the polarity opposite to PF5. PF2 needs to be reconnected to provide current in the polarity opposite to normal operation. EC preionization at full power (redirection of CHI ECH to the main chamber is necessary) is required. HHFW will also be used for preionization. If start-up were successful, HHFW electron heating/current drive (1-3 MW) will be attempted. NBI may be used in combination. Diagnostics adjusted to study the low current start-up phase (higher gain, etc.) are needed. Magnetics and EFIT are essential. Kinetic measurements are needed (Thomson, and if available CHERS) to constrain EFIT reconstruction and to evaluate plasma resistivity and bootstrap current. Fast visible camera (Nishino camera in wide angle view) as well as tangential X-ray camera (with filter removed) will be used to identify plasma boundary and core during the start-up phase. Short pulse (50 ms) NBI is needed for start-up assist, and also when ready to take MSE and/or CHERS data.

5. Planned analysis

What analysis of the data will be required: EFIT, TRANSP, etc.

EFIT reconstruction is essential. It is important to be able to reconstruct from as early as possible in time, and while there are two plasmas separated from each other. It may be necessary to use filament reconstruction during early times. Time evolution will be modeled by TRANSP, LRDIAG, and eventually TSC, and compared with experimental results.

6. Planned publication of results

What will be the final disposition of the results; where will results be published and when?

Successful outcome of this experiment has a very large impact on tokamaks in general and STs in particular, and will be published in Phys. Rev. Lett. More comprehensive analyses will be published in Physics of Plasmas or Nuclear Fusion.

PHYSICS OPERATIONS REQUEST

Merging Start-up **OP-XP-511**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **35 to max. allowed** Flattop start/stop (s): **0.0 / 0.2**

I_P (MA): **NA** Flattop start/stop (s): **NA**

Configuration: **Inner Wall (initially top/bottom limited)**

Outer gap (m): **NA**, Inner gap (m): **NA**

Elongation κ: **NA**, Triangularity δ: **NA**

Z position (m): **0.00 after merging**

Gas Species: **D** , Injector: **Midplane / Inner wall**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **80** , Duration (s): **50ms/1s**

ICRF – Power (MW): **1-3 MW**, Phasing: **Heating/CD**, Duration (s): **1s**

CHI: **Off**

Either: List previous shot numbers for setup: ______________________________

Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

Merging Start-up **OP-XP-511**

Diagnostic	Need	Desire	Instructions
Bolometer - tangential array		✓	
Bolometer array - divertor		✓	
CHERS		✓	
Divertor fast camera		✓	
Dust detector			
EBW radiometers		✓	
Edge deposition monitor			
Edge pressure gauges		✓	
Edge rotation spectroscopy		✓	
Fast lost ion probes – IFLIP			
Fast lost ion probes – SFLIP			
Filtered 1D cameras		✓	
Filterscopes		✓	
FIReTIP		✓	
Gas puff imaging			
High-k scattering			
Infrared cameras		✓	
Interferometer – 1 mm		✓	
Langmuir probes - PFC tiles		✓	
Langmuir probes - RF antenna		✓	
Magnetics – Diamagnetism		✓	
Magnetics – Flux loops	✓		
Magnetics – Locked modes		✓	
Magnetics – Pickup coils	✓		
Magnetics - Rogowski coils	✓		
Magnetics - RWM sensors		✓	
Mirnov coils – high frequency		✓	
Mirnov coils – poloidal array		✓	
Mirnov coils – toroidal array		✓	
MSE		✓	
Neutral particle analyzer		✓	
Neutron Rate (2 fission, 4 scint)		✓	
Neutron collimator		✓	
Plasma TV		✓	
Reciprocating probe		✓	
Reflectometer - FM/CW		✓	
Reflectometer - fixed frequency homodyne		✓	
Reflectometer - homodyne correlation		✓	
Reflectometer - HHFW/SOL		✓	
RF antenna camera		✓	
RF antenna probe		✓	
Solid State NPA		✓	
SPRED		✓	
Thomson scattering - 20 channel	✓		
Thomson scattering - 30 channel			
Ultrasoft X-ray arrays		✓	
Ultrasoft X-ray arrays - 2 color		✓	
Visible bremsstrahlung det.		✓	
Visible spectrometers (VIPS)		✓	
X-ray crystal spectrometer - H		✓	
X-ray crystal spectrometer - V		✓	
X-ray PIXCS (GEM) camera		✓	
X-ray pinhole camera		✓	
X-ray TG spectrometer		✓	