Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: Solenoidless Start-up		
OP-XP-431	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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Responsible Division: Experimental Research Operations	

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MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Solenoidless Start-up **OP-XP-431**

1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

The goal is to demonstrate plasma current start-up in the ST configuration without using the center solenoid (OH coil). The role of noninductive plasma production (preionization ECH and/or HHFW) and requirements for magnetic configuration (scenarios 2A, 2B and 3, described in Sec. 2) will be evaluated. In particular, it is important to determine if a field null is required for successful start-up (comparison of scenarios 2A and 2B).

2. Theoretical/ empirical justification

Brief justification of activity including supporting calculations as appropriate

Several start-up scenarios were considered for NSTX: (1) Pressure-driven start-up by ECH (CDX-U scenario), (2) RF ionization + PF induction (JT-60U scenario), and (3) merging-compression (MAST/TS-3 scenario). These scenarios have been modeled by Jon Menard's LRDIAG code and the results were presented at the NSTX Physics Meeting on March 24, 2003. This analysis has accurate models of the NSTX PF coils and conducting structures, and takes into account the effects of eddy currents which are important during I_p start-up. The plasma was modeled by a set of passive coils with resistivities chosen to reproduce the ramp-up of a 1 MA NSTX plasma.

(1) Pressure-driven start-up requires operation at low neutral pressures and a positive B_p curvature to create trapped particles. NSTX has the capability of generating magnetic configurations with varying degrees of curvature. Based on previous experiments on CDX-U, DIII-D and TST-2 it is estimated that several kA of plasma current could be generated by 20 kW of ECH power available on NSTX. This scenario is not investigated in the present XP, but may be explored in a separate XP.

(2) JT-60U has demonstrated generation of 200 kA of plasma current by PF coil induction (there was 20% flux contribution from the inboard coils). The plasma current was further ramped up to 600 kA (700 kA in some cases) by LHCD and NB heating, resulting in an "advanced tokamak" plasma with $\beta_p = 3.6$, $\beta_N = 1.6$, $H_H = 1.6$, and $f_{BS} > 90\%$. This scenario looks most promising for NSTX. In JT-60U, the presence of inboard coils produced a field null on the inboard midplane, but it is unclear from this experiment alone how important it is to have a field null.* Therefore, two start-up scenarios were developed, with (2A) and without (2B) a field null. Under favorable conditions, it may be possible to ramp up the plasma current to over 500 kA for both scenarios, as shown in Fig.1 (scenario 2B) and Fig. 2 (scenario 2A). Even under pessimistic assumptions, with the plasma restricted to grow on the outboard side keeping a small cross section, it should be possible to ramp up to over 100 kA (Fig. 3).

*In a recent JT-60U experiment (Jan. 2004) I_p ramp-up to 80 kA was achieved without any inboard coils.

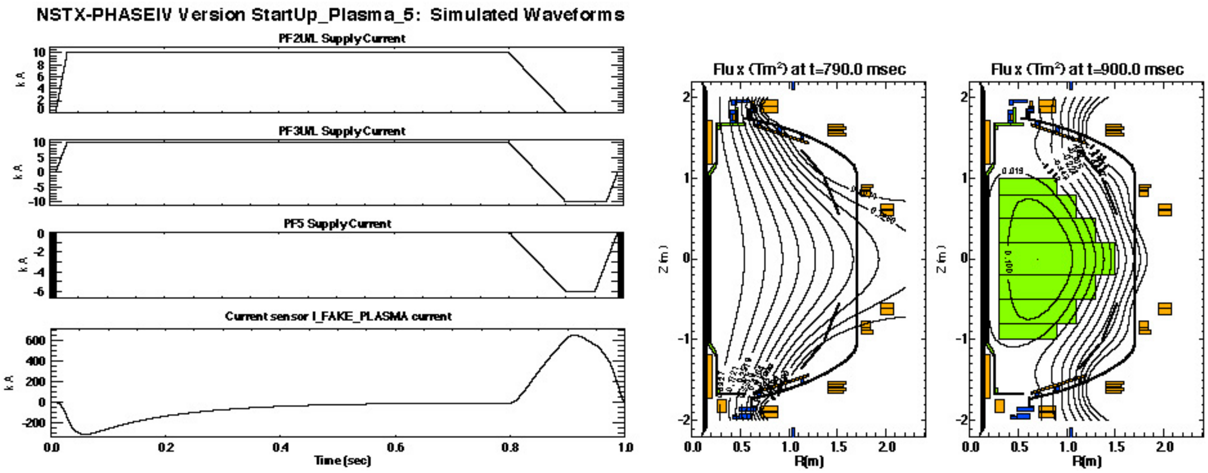

Fig. 1. LRDIAG modeling of scenario (2B). Initial B_v is in the opposite direction (left). Strong preionization is required for I_p start-up. Ramp-up to I_p = 650 kA is predicted.

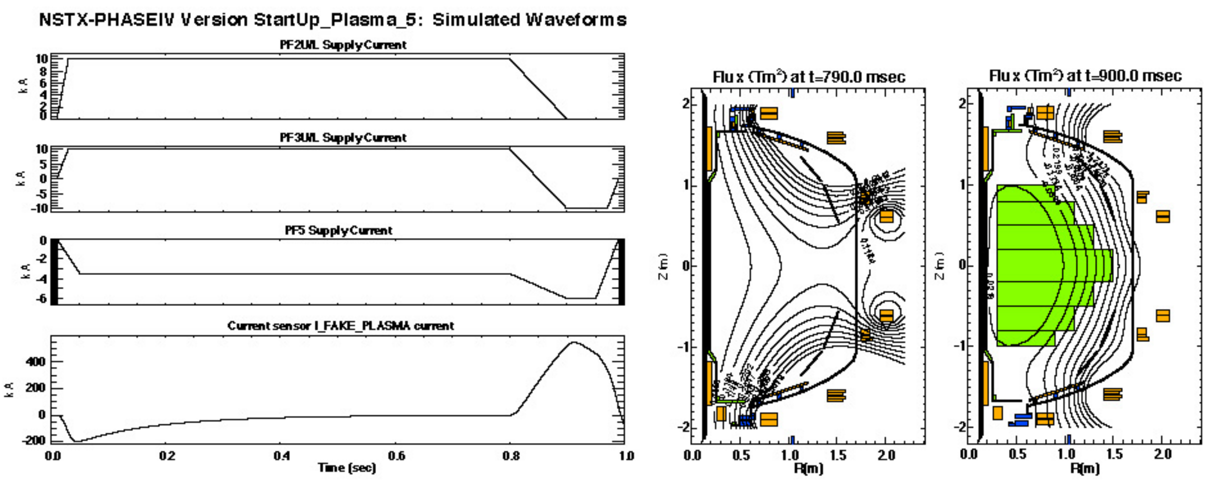

Fig. 2. Scenario (2A). Initially, an X-point field null exists on the outer midplane. I_p = 550 kA.

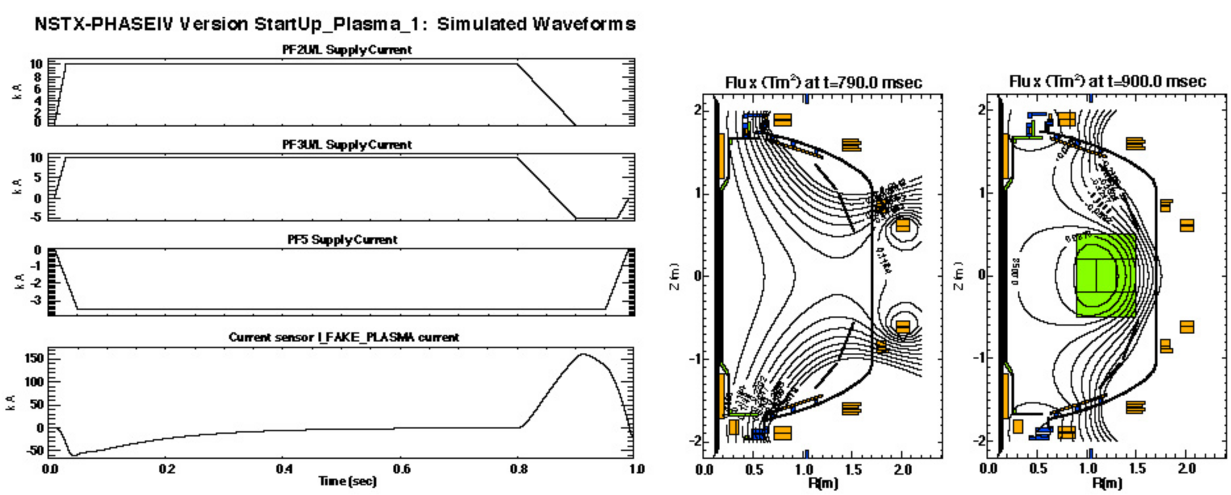

Fig. 3. Scenario (2A), in which plasma is restricted to grow on the outboard side. I_p = 160 kA.

3. Experimental run plan

Describe experiment in detail, including decision points and processes

Three types of start-up scenarios (defined in Sec. 2) will be tried in the order (2A), (2B), (3).

Preionization ECH will be used in all scenarios. In addition, HHFW will be used for preionization at a few hundred kW level (typically 1.5–3 MW of RF power was used in JT-60U). In particular, scenario (2B) requires a strong source of plasma, because radial force balance is not satisfied during the initial start-up phase. If plasma current does not ramp up, raise the HHFW power to over 1 MW. Initial experiments will use preprogrammed coil currents. If successful start-up to 100 kA is achieved, vertical position control will be implemented.

Start with scenario (2A), with the coil currents as shown in Fig. 2, but with 50 ms PF coil ramp time instead of 100 ms (the pre-charge flat-top time can be reduced to 40 ms instead of 80 ms). This scenario has a field null on the outboard midplane. A loop voltage of ~10 V can be induced at the field null by PF coil ramps. The toroidal field should be as high as possible (at least 0.45 T, preferably 0.6 T). Start the experiment with prefill pressure in the lower range of normal OH start-up, and find the optimum pressure for most efficient ramp-up. The ramp rate is varied to optimize start-up. Apply HHFW (~1 MW) in the electron heating mode to increase the electron temperature.

Investigate scenario (2B), which has no field null. This is the scenario closest to the successful JT-60U case, except in JT-60U there was a field null on the inboard midplane. Start with the coil currents as shown in Fig. 1. Faster ramp rate, higher RF power, and/or different prefill compared to scenario (2A) may be required.

Try the merging-compression scenario (3) using external coils only, at a toroidal field of 0.45 T. Start with coil currents as shown in Fig. 4 and find the optimum condition for current rise, varying the initial field null configuration and subsequent poloidal field evolution for merging and compression.

Choose the scenario from (2A), (2B), and (3) that appears most promising. Final coil currents are varied to optimize start-up and the produced plasma. Pre-bias coil currents may also be adjusted if it is judged necessary for better balance between the flux swing and the resultant vertical field.

The total number of shots required for this experiment is estimated to be about 30 shots. Adjustments to optimization steps will be made depending on the outcome of the experiment.

Scenario	PF1A (kA)	PF2 (kA)	PF3 (kA)	PF5 (kA)	ramp time (ms)	RF (MW)	NB (MW)	comments	shots
2A	0	10→0	10→–10	–3.5→–6	50	1	0	scan prefill	5
2A	0	10→0	10→–10	–3.5→–6	30, 70,100	1	0	scan ramp time	3
2B	0	10→0	10→–10	0→–6	100	>=1	0	vary RF power	3
2B	0	10→0	10→–10	0→–6	<=100	1	0	vary ramp time	3
3	10→0	0→–5	0→–1.2	1→–0.8	100	1	0	optimize null and current rise	6
best case	optimize	optimize	optimize	optimize	optimize	3	5	optimize coil currents	~10
								total	~30

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

EC preionization at full power. HHFW preionization (1 MW) and electron heating/current drive (3 MW), phasing to be determined (likely to be heating phasing for better absorption). NBI if high enough current (500 kA) could be obtained. Diagnostics adjusted to study the low current start-up phase (higher gain, etc.). Magnetics and EFIT are essential. Kinetic measurements are highly desirable to constrain EFIT reconstruction and to evaluate plasma resistivity and bootstrap current. Fast visible camera is required to identify the plasma boundary during the start-up phase. MSE data would be very helpful, if available.

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. It may be necessary to use filament reconstruction during early times when Grad-Shafranov equilibrium may not be satisfied. Time evolution will be modeled by TRANSP, LRDIAG, and eventually TSC, and compared with experimental results. EC and HHFW wave codes will be used to calculate power deposition, which will be compared to measured response to power steps (turn on/off, modulation).

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

Solenoidless Start-up **OP-XP-431**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **53**   Flattop start/stop (s): **0.0 / 0.2**

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

Configuration: **Inner Wall (Outer Wall During Start-up)**

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

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

Z position (m): **0.00**

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

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **80**,   Duration (s): **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	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			
Infrared cameras		√	
Interferometer - 1 mm		√	
Langmuir probe array		√	
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 measurements		√	
Plasma TV	√		
Reciprocating probe		√	
Reflectometer – core		√	
Reflectometer - SOL		√	
RF antenna camera	√		
RF antenna probe		√	
SPRED		√	
Thomson scattering		√	
Ultrasoft X-ray arrays	√		
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		√	