Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: **Low Plasma Current, Fully Non-Inductive, HHFW H-Mode Plasmas**		
OP-XP-1160	Revision: **2**	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*
PROPOSAL APPROVALS		
Responsible Author: G. Taylor		Date
ATI – ET Group Leader: G. Taylor/R. Raman		Date
RLM - Run Coordinator: S. Sabbagh		Date
Responsible Division: Experimental Research Operations		
RESTRICTIONS or MINOR MODIFICATIONS (Approved by Experimental Research Operations)		

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Low Plasma Current, Fully Non-Inductive, HHFW H-Mode Plasmas** No. **OP-XP-1160**

AUTHORS: **G. Taylor, D. Mueller, S. Gerhardt, J.C. Hosea, C. Kessel, B.P. LeBlanc, C.K. Phillips, S. Zweben, R. Raman, R. Maingi, P.M. Ryan**

DATE: **May 6, 2011**

1. Overview of planned experiment

HHFW heating and current drive may enable fully non-inductive plasma current (I_p) ramp-up in NSTX. The initial approach to achieving this goal has been to heat a low plasma current (I_p = 250-300 kA) inductive plasma with HHFW power in order to generate an H-mode with significant bootstrap and RF-driven current. This experiment aims to achieve a non-inductive current fraction, $f_{NI} \geq 1$ by coupling 3-4 MW of RF power into an I_p = 250-300 kA plasma. This experiment contributes to the NSTX research milestone R12-2.

2. Theoretical/ empirical justification

TSC simulations predict that coupling 6 MW of HHFW power into the I_p ramp-up can result in bootstrap current overdrive. In 2005 (XP-521) 2.5 MW of k_ϕ = 14 + 18 m^{-1} HHFW power (heating antenna phasing) was coupled into an I_p = 250 kA deuterium plasma, but RF coupling could not be maintained when the plasma transitioned to H-mode due to poor plasma position control. HHFW experiments with I_p = 300 kA deuterium plasmas in 2010 (XP-1009) coupled 1.4 MW of k_ϕ = -8 m^{-1} HHFW power (current drive antenna phasing) producing a sustained H-mode with an internal transport barrier (ITB) and achieving an f_{NI} ~ 0.65. This positive result was the consequence of better plasma control, improved RF coupling due to Li conditioning, and the positive feedback between the generation of the ITB, a high $T_e(0)$ ~ 3 keV, and a relatively high RF current drive efficiency ~ 0.1 MA/MW. However, the RF antenna was poorly conditioned so that the maximum arc-free HHFW power was only ~ 1.4 MW, insufficient to achieve an $f_{NI} \geq 1$ at I_p ~ 300 kA.

3. Experimental run plan

This experiment is expected to take 1-1.5 run days to complete. The experiment requires clamping the OH coil current, instead of feeding back on I_p. Shots without HHFW power will therefore have decaying I_p and when RF power is applied I_p will be sustained or decay more slowly depending on the amount of RF current drive and bootstrap current resulting from RF heating. It may be necessary to run some ohmic discharges with I_p feedback on to gain an estimate of the OH current needed to minimize plasma motion at low I_p.

The run plan is as follows:

1. Setup an ohmically-heated I_p = 300 kA deuterium discharge similar to shot 138506 from XP-1009. Add k_ϕ = -8 m^{-1} HHFW power (-90^o antenna phasing), coupled from 150 to 450 ms, with a 50 ms ramp-up in power at the start of the RF pulse. A 50 ms beam pulse for MSE and CHERS will be injected from 430 to 480 ms. The HHFW power will be increased to 3-4 MW, while adjusting the lithium evaporation rate, the

gas injection rate and the outer gap to optimize HHFW heating efficiency. When reproducible plasmas have been obtained a second 20 ms beam blip will be scanned from 400 ms to 250 ms over a sequence of 4 shots to acquire the time evolution of q(R) and T_i. RF power will increased above 4 MW if more power is available. The HHFW and NBI pulse timing are shown schematically in Fig. 1.
(10-15 shots)

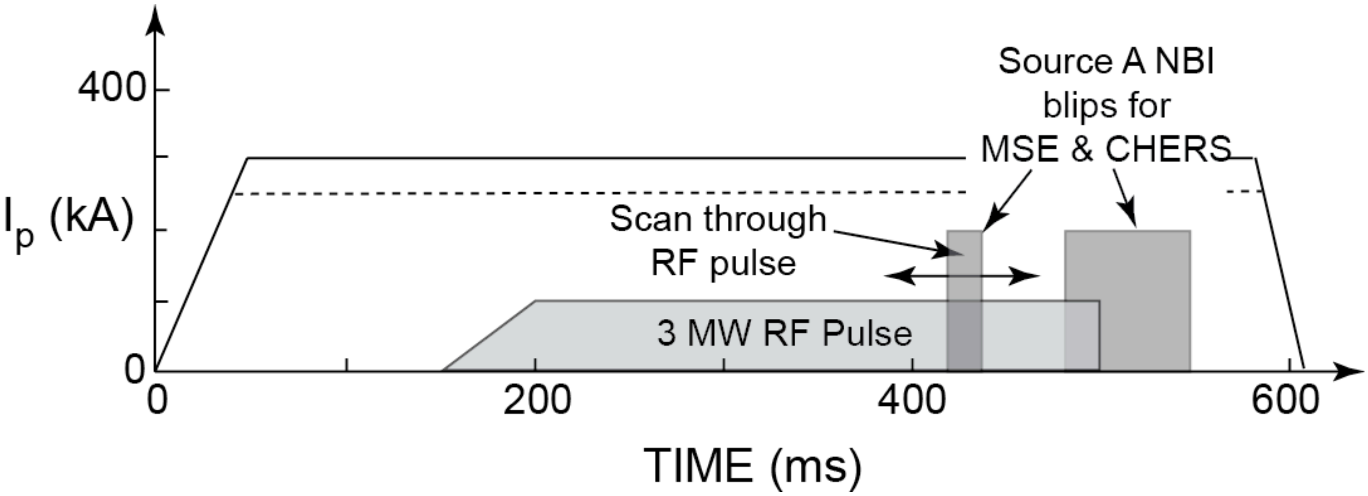

Figure 1: Schematic of the HHFW and NBI pulse timing relative to the time evolution of I_p.

2. Reduce I_p to 250 kA and couple 3-4 MW of $k_\phi = -8\ m^{-1}$ HHFW power. Adjust lithium evaporation rate, gas injection rate and outer gap to optimize HHFW heating efficiency. Measure q(r) and T_i as in step 2. **(10-15 shots)**

3. Adjust RF pulse to start as soon as I_p reaches the flattop value. Then use open loop OH programming to provide no ohmic drive after plasma current reaches the minimum value, (< 200 kA at approximately 25 ms). **(5-10 shots)**

4. At I_p = 300kA, move the RF pulse start time as early as possible in time and obtain data at 1.5 and 3 MW RF power levels **(4-6 shots)**, with a 20ms NBI blip applied 100 to 150ms after start of TF flat-top. For FY12, increase the RF power level to >4MW **(9 shots)**

5. If time permits repeat steps 1 and 2 with -60^o antenna phasing.

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

This experiment should follow the HHFW plasma conditioning XMP, and requires P_{RF} = 3-4 MW at $k_\phi = -8\ m^{-1}$, although could still be scheduled if only 2.5 MW is available, since this is significantly more power than was used in XP-1009. This experiment also requires rtEFIT isoflux control for the outer gap, and a LiTER deposition rate sufficient to maintain good RF coupling. A 90 keV NBI blip from source A is needed for MSE q(r) and CHERS T_i data from 480 to 550 ms. In addition a 20 ms 90 keV NBI blip from source A will be scanned through the RF pulse once good, reproducible, 3-4 MW RF heating has been established. Thomson scattering T_e and n_e data are required for core and edge electron heating data. For analysis of edge power loss and coupling efficiency the experiment also requires SOL reflectometry and edge ion heating data from edge rotation diagnostic. Visible and IR camera imaging of the antenna and lower divertor are also required.

5. Planned analysis

The RF deposition, bootstrap current and rf–driven current profile will be calculated by TRANSP-TORIC and GENRAY-ADJ.

6. Planned publication of results

The results will be submitted for publication in *Physical Review Letters*, *Nuclear Fusion* or *Physics of Plasmas*, and may contribute to an HHFW IAEA paper.

PHYSICS OPERATIONS REQUEST

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Brief description of the most important operational plasma conditions required:

Stable plasma operation at I_p = 250-300 kA, with reproducible outer gap = 0.05 – 0.1 m.

Request D. Mueller as operator.

Previous shot(s) which can be repeated: 138506

Previous shot(s) which can be modified:

Machine conditions *(specify ranges as appropriate, strike out inapplicable cases)*

I_{TF} (kA): **66** Flattop start/stop (s): **0/0.7**

I_P (MA): **0.25-0.3** Flattop start/stop (s): **0.08/0.6**

Configuration: **LSN**

Equilibrium Control: **Outer gap / Isoflux** (rtEFIT) **/ Strike-point control** (rtEFIT)

Outer gap (m): **0.05-0.08** Inner gap (m): Z position (m): **0.0**

Elongation: Triangularity (U/L): OSP radius (m):

Gas Species: **D** Injector(s):

NBI Species: **D** Voltage (kV) **A: 90 B: C:** Duration (s): **480-550 ms, and 20 ms blip stepped between 250 to 450 ms from shot to shot**

ICRF Power (MW): **2.5-4** Phase between straps (°):**-60, -90** Duration (s): **0.35**

CHI: **Off** Bank capacitance (mF):

LITERs: On Total deposition rate (mg/min): **20 mg/min to start, adjust as needed**

LLD: N/A Temperature (°C):

EFC coils: Off Configuration: **Odd / Even / Other**

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Beam Emission Spectroscopy		
Bolometer – divertor	√	
Bolometer – midplane array	√	
CHERS – poloidal	√	
CHERS – toroidal	√	
Dust detector		
Edge deposition monitors		
Edge neutral density diag.		√
Edge pressure gauges		√
Edge rotation diagnostic	√	
Fast cameras – divertor/LLD	√	
Fast ion D_alpha - FIDA		
Fast lost ion probes - IFLIP		
Fast lost ion probes - SFLIP		
Filterscopes	√	
FIReTIP		√
Gas puff imaging – divertor		
Gas puff imaging – midplane		√
Hα camera - 1D		√
High-k scattering		
Infrared cameras	√	
Interferometer - 1 mm		√
Langmuir probes – divertor		√
Langmuir probes – LLD		
Langmuir probes – bias tile		√
Langmuir probes – RF ant.		√
Magnetics – B coils	√	
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents	√	
Magnetics – RWM sensors	√	
Mirnov coils – high f.	√	
Mirnov coils – poloidal array	√	
Mirnov coils – toroidal array	√	
Mirnov coils – 3-axis proto.	√	

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
MSE	√	
NPA – E||B scanning		
NPA – solid state		
Neutron detectors		
Plasma TV	√	
Reflectometer – 65GHz		
Reflectometer – correlation		
Reflectometer – FM/CW		
Reflectometer – fixed f		
Reflectometer – SOL	√	
RF edge probes	√	
Spectrometer – divertor	√	
Spectrometer – SPRED	√	
Spectrometer – VIPS	√	
Spectrometer – LOWEUS		
Spectrometer – XEUS		√
SWIFT – 2D flow		
Thomson scattering	√	
Ultrasoft X-ray – pol. arrays	√	
Ultrasoft X-rays – bicolor	√	
Ultrasoft X-rays – TG spectr.		
Visible bremsstrahlung det.	√	
X-ray crystal spectrom. - H		
X-ray crystal spectrom. - V		
X-ray tang. pinhole camera		