Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: **HHFW Heating of Low $T_e(0)$, I_p Plasmas**

OP-XP-1009	Revision: **1**	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: G. Taylor & D. Mueller	Date
ATI – ET Group Leader: G. Taylor/D. Mueller	Date
RLM - Run Coordinator: E. Fredrickson	Date
Responsible Division: Experimental Research Operations	

RESTRICTIONS or MINOR MODIFICATIONS

(Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **HHFW Heating of Low $T_e(0)$, I_p Plasmas** No. **OP-XP-1009**

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

DATE: **February 17, 2010**

1. Overview of planned experiment

This experiment tests HHFW heating of low I_p plasmas as a precursor to studying HHFW-assisted I_p ramp-up in the Solenoid-Free Start-up Topical Science Group. The experiment will use the new HHFW double-feed antenna and the increased lithium conditioning coverage available in 2010 to improve on previous HHFW electron heating results obtained with low I_p and $T_e(0)$ plasmas. The goal of the experiment is to couple ~ 3 MW of -14 + -18 m^{-1} (180°) antenna phasing) and k_ϕ = ±8 m^{-1} (±90° antenna phasing) HHFW power into a deuterium plasma with $I_p \leq 200$ kA. Although the primary goal is to study heating of low current plasmas, a secondary goal is to look for current drive. This is a revised version of XP-920, which was approved but not run in 2009. This experiment contributes to the NSTX research milestone R10-2.

2. Theoretical/ empirical justification

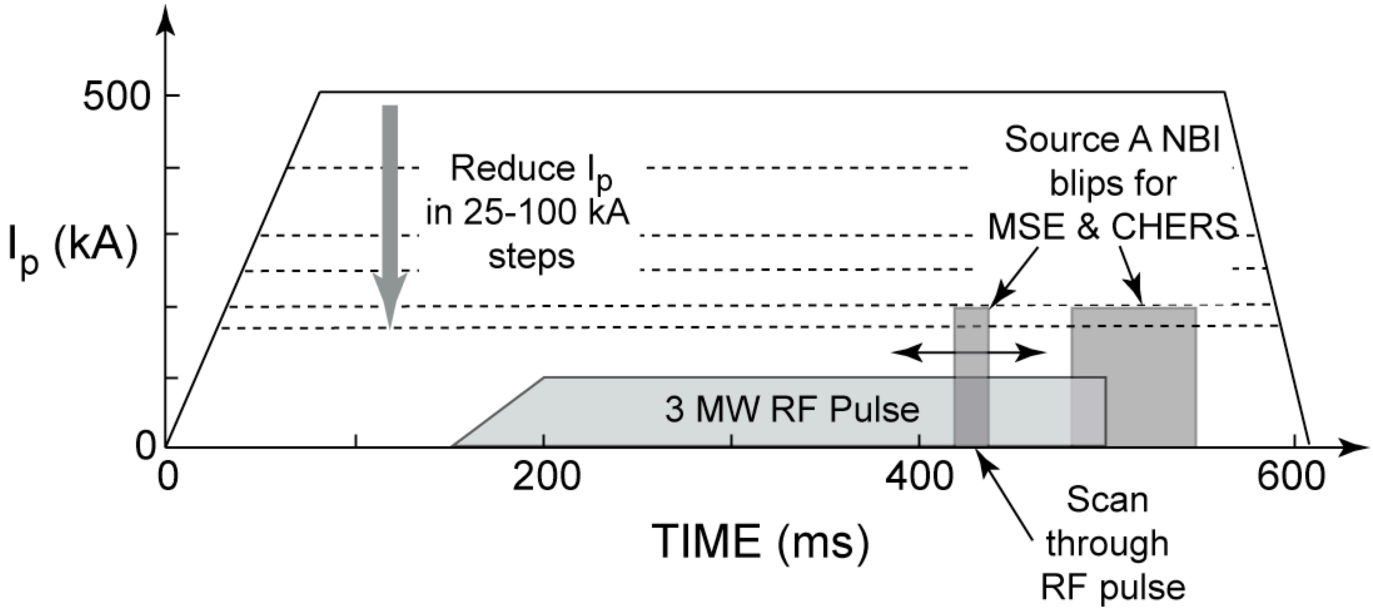
A major goal of the 30 MHz HHFW program on NSTX is to generate bootstrap current overdrive during non-inductive I_p ramp-up. TSC I_p ramp-up simulations predict that coupling 6 MW of HHFW power into the I_p ramp-up can result in bootstrap current overdrive. 85% bootstrap current fraction was achieved in XP-521 by coupling 2.5 MW of -14 + -18 m^{-1} (180°) HHFW power into an I_p = 250 kA deuterium plasma. The goal of this experiment is to couple HHFW power into plasmas with $I_p \leq 200$ kA. HHFW-assisted I_p ramp-up experiments have recently benefited from lithium wall conditioning, which reduces the edge density, improving HHFW heating efficiency. In 2008 XP-817 successfully coupled HHFW power, with k_ϕ = - 8 m^{-1} current drive phasing, into lithium-conditioned deuterium plasmas. 550 kW of RF power coupled after the initiation of a CHI start-up plasma increased $T_e(0)$ from 3 to 15 eV when $n_e(0) \sim 4 \times 10^{18} m^{-3}$ and I_p ~ 100 kA. Also, 1.1 MW was coupled into the early phase of an ohmically-heated I_p ramp-up, when I_p was ramping from 100 kA to 300 kA, increasing $T_e(0)$ from 140 to 700 eV, when $n_e(0) \sim 6\text{-}9 \times 10^{18} m^{-3}$. HHFW low I_p experiments in 2010 will benefit from the recent HHFW antenna upgrade from single-end fed straps to double-end fed straps, which should provide higher power than was previously achieved, as well as allowing coupling of HHFW power during a wider range of plasma edge conditions.

3. Experimental run plan

This experiment is expected to take about 1.5-2 run days to complete. Considerable effort may be needed to develop a discharge with $I_p \leq 200$ kA.

Normally the rtEFIT isoflux control is set to operate when $I_p \geq 250$ kA. Set rtEFIT isoflux control for $I_p \geq$ 150 kA and OH ramp-down multiplier to > 1. Needs XMP to test control at I_p = 200-300 kA before XP is run. 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 a 600 ms I_p flattop plasma, similar to RF conditioning shot 135260 (I_p = 650 kA, B_T = 5.5 kG, helium), but run in deuterium and initially operate at I_p = 500 kA. Add k_ϕ = 14 + 18 m^{-1} (180°) HHFW power, coupled from 150 – 500 ms, with a 50 ms ramp-up in power at the start of the RF pulse. Increase RF power to 3 MW, while adjusting lithium evaporation rate, gas injection rate and outer gap to optimize HHFW heating efficiency. **(5-10 shots)**

2. Run a sequence of shots, reducing I_p in 100 kA increments from 500 kA to 300 kA, while coupling 3 MW of k_ϕ = 14 + 18 m^{-1} (180°) HHFW power. Adjust lithium evaporation rate, gas injection rate and outer gap to optimize HHFW heating efficiency. Take no RF shot at the lowest I_p achieved with good RF coupling **(10 shots)**

3. Repeat (1) and (2) with -8 m^{-1} (-90°) heating. **(10 shots)**

4. Reduce I_p from 300 kA to ≤ 200 kA in 25-50 kA steps, while maintaining plasma position control so that the outer gap is 5-10 cm. **(5-10 shots)**

5. At the lowest I_p achieved with good plasma control, add k_ϕ = 14 + 18 m^{-1} (180°) power, coupled from 150 – 500 ms, with a 50 ms ramp-up in power at the start of the RF pulse. Increase RF power to ~ 3 MW. **(5 shots)**

6. Repeat (5) with -8 m^{-1} (-90°) heating. **(5 shots)**

7. Repeat (5) with k_ϕ = +8 m^{-1} (+90°) heating. **(5 shots)**

8. Perform a density scan with k_ϕ = -8 m^{-1} (-90°) heating. **(5-10 shots)**

9. 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 shots to get start time, 5-10 shots to perform CD with ohmic current flat)**

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

This experiment should follow the first two days of the HHFW plasma conditioning XMP, and requires P_{RF} ~ 3 MW at 14 + 18 $m^{-1}$and ±8 m^{-1}. This experiment needs rtEFIT isoflux control for the outer gap. LITERs are required, but the LLD should be maintained in “cold”, solid lithium state. An NBI blip from source A at 90 keV should be added for MSE and CHERS data acquisition from 480 to 550 ms. In addition a 20 ms NBI blip from source A at 90 keV will be scanned through the RF pulse once good, reproducible, ~ 3 MW RF heating has been established. Thomson scattering 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.

5. Planned analysis

Planned analysis includes analysis of heating efficiency at k_ϕ = ±8 m^{-1} and 14 + 18 m^{-1}, TRANSP and GENRAY/CQL3D modeling.

6. Planned publication of results

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

PHYSICS OPERATIONS REQUEST

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DATE: **February 17, 2010**

Brief description of the most important operational plasma conditions required:

I_p as low as possible, preferable I_p < 200 kA. Stable, reproducible plasma with outer gap = 0.05 – 0.1 m.

Request D. Mueller as operator. Set rtEFIT isoflux control for $I_p \geq$ 150 kA and OH ramp-down multiplier to > 1. Needs XMP to test control at I_p = 200-300 kA before XP is run.

Previous shot(s) which can be repeated:

Previous shot(s) which can be modified: RF plasma conditioning shot 135260

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

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

I_P (MA): **0.15-0.5** Flattop start/stop (s): **0.08/0.6**

Configuration: **LSN**

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

Outer gap (m): **0.05-0.1** 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): **3** Phase between straps (°): **±90, 180** 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: Cold 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		√