Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **HHFW Heating and Edge Effects in L-mode Plasmas**

OP-XP-944	Revision: **0**	Effective Date: **7/1/09** *(Approval date unless otherwise stipulated)* Expiration Date: **7/1/11** *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Authors: J. Hosea	Date 6/30/09
ATI – ET Group Leaders: G. Taylor	Date
RLM - Run Coordinator: R. Raman	Date 6/30/09

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **HHFW Heating and Edge Effects in L-mode Plasmas** No. **OP-XP-944**
AUTHORS: **P. Ryan, J. Hosea, R. Bell, B. LeBlanc, C.K. Phillips, G. Taylor, J. Wilgen, J.R. Wilson** DATE: **June 25, 2009**

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1. Overview of planned experiment

Goal: Study heating and CD in deuterium L mode plasmas and compare results to those obtained in helium under XPs 712 and 717.

- **Heating in D_2 L mode:**
  - Determine if density in deuterium can be held below onset for wave propagation at the wall.
  - Show how efficiency depends on wavelength in deuterium
  - Need to establish behavior in deuterium L mode to optimize current drive for startup and in preparation for H mode studies
- **CD in D_2 L mode:**
  - Phase scan for HHFW CD with time-resolved MSE; compare with loop voltage differences.
  - MSE beam blip at end of HHFW pulse and progressively move it forward in time upon succeeding shots to determine the current relaxation time

2. Theoretical/ empirical justification

This XP is a continuation of XP825 which showed that HHFW heating efficiencies in deuterium L-mode plasmas could made comparable to those in He plasmas, provided the edge density could be kept suitably low. The second half of XP825, time resolved MSE measurement of CD, was not run due to lack of neutral beams. The expected improvement in power capability should allow operation at 3-4 MW for improved MSE CD measurements.

Last year's HHFW operation in H-mode (XP835) indicated power flow to divertor could be an important edge loss mechanism. Want to take advantage of higher power HHFW array to measure core heating vs edge heating as a function of array phase, edge density, and magnetic pitch angle in L-mode plasmas.

The approach used in these experiments and further justification of these experiments can be found in XPs 712, 717 and 825.

3. Experimental run plan

This experiment has two parts:

A. Heating of L mode deuterium plasma, dependence on edge density and wavenumber
B. Phase scan for HHFW CD with time-resolved MSE

A. Heating of L mode deuterium plasma - dependence on edge density and wavenumber

- Setup conditions TBD from 2009 Plasma Conditioning XMP-26.
- LSN, deuterium L-mode, gap ~ 4 - 5 cm, B = 0.55 T, Ip = 1 MA
- Apply P_{RF} as for ~ 300-400 ms, on at 0.200 ms
- Apply 90 kV NB pulse at end of RF pulse for MSE (30 ms overlap) –
  use 70 kV beam to measure T_i and rotation some shots to use 10 Hz modulation for power deposition, transport studies.

Perf(orm wavenumber scan at ~ 4 cm (Scan vs phase is limited by need to complete it in 1 day)

I With plasma settings as for shot 123435 but with deuterium - Gap at ~ 4 cm:

- 3 shots @ -13 m^{-1} (-150^o), P = 3, 4, 5 (establish H-mode threshold)
- 1 shots @ -13 m^{-1} (-150^o), P = highest L-mode, 10 Hz modulation
- 1 shots @ -8 m^{-1} (-90^o), P = highest L-mode
- 1 shots @ -8 m^{-1} (-90^o), P = highest L-mode, 10 Hz modulation
- 1 shots @ -3 m^{-1} (-30^o), P = highest L-mode
- 1 shots @ -3 m^{-1} (-30^o), P = highest L-mode, 10 Hz modulation
- 1 shots @ +8 m^{-1} (+90^o, cntr-CD), P = highest L-mode
- 1 shots @ +8 m^{-1} (+90^o), P = highest L-mode, 10 Hz modulation
- 1 shot with no RF (ohmic comparison)
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II Current Scan (-90^o phasing, highest reliable power)
Observe divertor with IR camera and wide angle, fast visible light camera

- 2 shots @ Ip = 1.1 MA (RF on/off)
- 2 shots @ Ip = 1.0 MA (RF on/off)
- 2 shots @ Ip = 0.9 MA (RF on/off)
- 2 shots @ Ip = 0.8 MA (RF on/off)
- 2 shots @ Ip = 0.7 MA (RF on/off)

Repeat with -150° phasing – 5 shots (RF off of -90° scan to be used)

III Upper Divertor Scan (1 MA, upper single null)
Observe divertor with IR camera and wide angle, fast visible light camera

- 2 shots @ -150º (RF on/off)
- 2 shots @ -90º (RF on/off)
- 2 shots @ Ip = 0.9 MA (RF on/off)
- 2 shots @ Ip = 0.8 MA (RF on/off)
- 2 shots @ Ip = 0.7 MA (RF on/off)

B. Phase scan for HHFW CD with time-resolved MSE

- ➢ Increase HHFW power to 3-4 MW range, or as high as achievable, for 300-400 ms pulses.
- ➢ Run similar conditions to where loop voltage differences have been seen in the past upon phase change (107899, 107907) but also at higher B (.55 T); or the conditions of part A if loop voltage response is adequate.

- Start MSE beam blip at end of HHFW pulse and progressively move it forward in time upon succeeding shots to determine the current relaxation time (3 steps)

Phase scan for HHFW CD with time-resolved MSE (Scan for CD is limited to ½ day)

i. **With NB pulse near end of RF pulse:**

- 1 shot @ 14 m^{-1} (180^o)
- 1 shot @ -8 m^{-1} (-90^o)
- 1 shot @ +8 m^{-1} ($+90^o$)
- ❖ Check that voltage is responding to phase. If not change conditions (lower density)

ii. **With NB stepped in toward start of RF pulse**

- 2 shots @ +8 m^{-1} ($+90^o$)
- 2 shot @ -8 m^{-1} (-90^o)
- 1 no RF shot

(Additional shots may be required to set matching for each $k_{||}$.)

iii. **Put on long NB pulse and see if reaction depends on phase**

- 1 shot @ -8 m^{-1} (-90^o)
- 1 shot @ +8 m^{-1} ($+90^o$)
- 1 shot @ 14 m^{-1} (180^o)

These shots are intended to see if we can drive current (or even operate) in the presence of high power NBI. May also go into H-mode. May need to go to 70 kV beams.

Some of this may be accomplished during the time-resolved MSE measurements.

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

Stable or at least reproducible plasma conditions are required for the quantitative comparisons of this XP.

NB pulses are needed at 90 kV for MSE measurements

Critical diagnostics include:

- EFIT with high time resolution
- Reflectometry for edge density and PDI
- Reflectometry for wave measurements for opposite side from antenna
- Edge probe for PDI
- Gap RF probes for leakage
- 4 RF probe(s) for edge RF field
- MSE for some shots for effects on current

5. Planned analysis

Expected results:

- Heating efficiency in deuterium L mode vs wavenumber: 14 m^{-1}, -8 m^{-1} (co CD), -3m^{-1}, -11m^{-1}, etc.
  - Core heating from EFIT W

  - Core electron heating from Thomson scattering
  - Ion heating and core rotation from Chers
- Edge heating/power loss
  - Edge ion heating from edge rotation diagnostic
  - Edge electron heating from Thomson scattering
  - Rotation effects
- MSE measurements of current drive
  - Co vs counter for conditions where loop voltage is reduced for co

- Plasma profiles, core and edge, for permitting predictions of wave propagation damping and CD characteristics

Planned analysis:

- Compare efficiencies vs wavenumber to those for helium
- Determine CD profile vs time in RF pulse
- Determine if stability with NB is dependent of antenna phase
- Analysis of wave propagation, damping and CD characteristics from onset density into the core of plasma - along field and perpendicular directions of the ray path, and including collisions - for predicting CD and surface losses
- Benchmarking of RF codes that include surface losses

6. Planned publication of results

The results will be submitted for publication.

C. PHYSICS OPERATIONS REQUEST

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DATE: **June 25, 2009**

(use additional sheets and attach waveform diagrams if necessary)

Describe briefly the most important plasma conditions required for the experiment:

Setup conditions TBD from 2009 Plasma Conditioning XMP-26. LSN, deuterium L-mode, gap ~ 4 - 5 cm, B = 0.55 T, Ip = 1 MA. Apply P_{RF} as for ~ 300-400 ms, on at 0.200 ms. Apply 90 kV NB pulse at end of RF pulse for MSE (30 ms overlap) – use 70 kV beam to measure T_i and rotation some shots to use 10 Hz modulation for power deposition, transport studies.

Previous shot(s) which can be repeated:

Previous shot(s) which can be modified: 123435, or 127449, but with deuterium

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

I_{TF} (kA): **-53 – -65** Flattop start/stop (s): **0/0.7**

I_P (MA): **0.4 – 1.2** Flattop start/stop (s): 0.1/0.6

Configuration: LSN

Equilibrium Control: **Outer gap / Isoflux** (rtEFIT)

Outer gap (m): **0.05-0.1** Inner gap (m): **~0.04** Z position (m): **0.0**

Elongation κ: Upper/lower triangularity δ:

Gas Species: **D** Injector(s): **Inner wall to start**

NBI Species: **D** Voltage (kV) **A: 90 B: C: 70** Duration (s): **0.04 - 0.4**

ICRF Power (MW): **3-4** Phase between straps (°): **Various**

Duration (s): 0.2 – 0.4 modulated

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

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

EFC coils: Off Configuration: **Odd / Even / Other** *(attach detailed sheet)*

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Bolometer – tangential array	√	
Bolometer – divertor	√	
CHERS – toroidal	√	
CHERS – poloidal	√	
Divertor fast camera	√	
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.		√
Edge pressure gauges		√
Edge rotation diagnostic	√	
Fast ion D_alpha - FIDA		√
Fast lost ion probes - IFLIP		√
Fast lost ion probes - SFLIP		√
Filterscopes	√	
FIReTIP		√
Gas puff imaging		
Hα camera - 1D		√
High-k scattering		
Infrared cameras	√	
Interferometer - 1 mm		√
Langmuir probes – divertor		√
Langmuir probes – BEaP		
Langmuir probes – RF ant.		√
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
Magnetics – Pickup coils	√	
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 measurements		√
Plasma TV	√	
Reciprocating probe		
Reflectometer – 65GHz	√	
Reflectometer – correlation	√	
Reflectometer – FM/CW	√	
Reflectometer – fixed f	√	
Reflectometer – SOL	√	
RF edge probes	√	
Spectrometer – SPRED	√	
Spectrometer – VIPS	√	
SWIFT – 2D flow		
Thomson scattering	√	
Ultrasoft X-ray 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 fast pinhole camera		√
X-ray spectrometer - XEUS		√