Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

HHFW Heating and Current Drive Phase Scans in NB Deuterium H-mode Plasmas

OP-XP-835	Revision:	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author:	Date
ATI – ET Group Leader:	Date
RLM - Run Coordinator:	Date
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 Current Drive Phase Scans in NB Deuterium H-mode Plasmas** No. **OP-XP-835**

AUTHORS: **P. Ryan, J. Hosea, R. Bell, L. Delgado-Aparicio, S. Kubota, B. LeBlanc, F. Levinton, C.K. Phillips, S. Sabbagh, G. Taylor, K. Tritz, J. Wilgen, J.R. Wilson** DATE: **July 8, 2008**

1. Overview of planned experiment

The primary goal of this experiment is to develop operational techniques to couple HHFW power to H-mode plasmas, produced in combination with neutral beams. Comparisons of RF plasma loading and heating efficiency as a function of array phasing (spectral wavenumber) in H-mode will be made with previous operation in L-mode. Power deposition channels (edge heating of ion and electrons, damping on fast beam ions, and core electron heating) will be determined.

2. Theoretical/ empirical justification

HHFW/NBI H-mode experiments were carried out in 2004 with Ben LeBlanc as the principal investigator under XP413. The first part of the experiment applied NBI modulations to an HHFW pre-heated plasma; stored energy and neutron rates increased compared to NBI alone, but the efficiency was low. The second part of the experiment applied HHFW to an NBI-driven H-mode plasma. There was little indication that the HHFW power was coupling through the edge (small changes in Te, W, Sn). These experiments used $B_T = 0.45$ T.

One operational challenge anticipated with running HHFW power in H-mode plasmas is the lower plasma loading, due to steeper density profiles in H-mode and to larger gaps (which may be necessary to protect the antennas from NBI-heated plasmas). This reduced loading could limit the power delivered by the present HHFW antennas. We plan to establish the minimum gap at which the array can operate reliably into H-mode profiles as a function of phase shift (launched wavelength), as well as determining the heating efficiency for these cases. These issues will be addressed during the first phase of the experiment by applying HHFW into an NBI-established H-mode, after density profiles and outer gap have stabilized.

Techniques to maintain RF power coupling through the L-H mode transition will be developed during the second phase of the experiment, when a NBI pulse will be applied to an HHFW-heated L-mode plasma to send it into H-mode. During the antenna conditioning operation this year (MP26), a 40 ms NBI pulse into an HHFW-heated, L-mode plasma triggered a transition into H-mode. H-mode was maintained for the remaining 100 ms of the RF power application for 70 kV, 1.1 MW NBI, even though the density profile steepened and moved away from the antenna (128155). Profile steepening and movement were more pronounced during the transition to H-mode when 90 kV, 2 MW NBI was used a the trigger (128157). As a result of this transition, the antenna voltage increased and the RF transmitters tripped, terminating H-mode operation.

3. Experimental run plan

PHASE 1: HHFW INTO NBI-DRIVEN H-MODE (~ 25 shots)

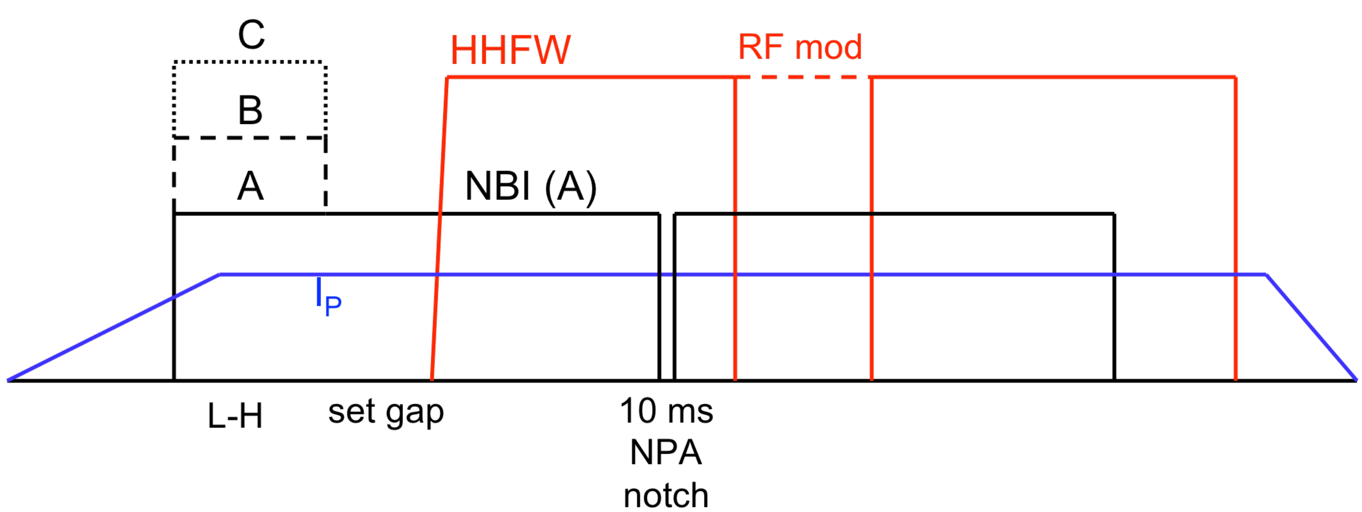
- Target plasma shot **129386**: D_2, CS feed, 5.5 kG, I_p ~ 1 MA (I_p chosen for MHD stability and beam confinement.)
- 5-10 mg/min Li evaporation, no He glow discharge. Increase Li evaporation rate if there is no central heating from HHFW.
- Establish minimum NB power for stable H-mode (~ 5 shots).
  - Begin with NB source A throughout (90 kV), with 10 ms notch
  - If H-mode not achieved, add NB sources B or B & C (70 kV) if required for H-mode for as short a duration as possible.
  - Keep density as low as possible while maintaining stability
  - Keep edge density at desired level by adjusting outer gap if possible. Check with reflectometer (ne < $2e10^{18}$ at 2 cm from FS)
- Outer gap 7 cm (8 shots)
  - phase -150°, increase RF power until V_{cube} ~ 14-15 kV, full & modulated RF pulse (4 shots)
  - repeat for phase -90° (4 shots)
- IF there was no problem with low loading for 7 cm gap, THEN increase gap to 9 cm and repeat (8 shots)
- IF the loading was too low for a 7 cm gap AND there was no problem with beam interaction with antenna (visible glows, breakdowns) THEN go to 5 cm gap and repeat (8 shots)
- IF the loading was too low for a 7 cm gap AND there was A problem with beam interaction with antenna (visible glows, breakdowns) THEN go to Phase 2.
- Return to best gap, repeat for +90° phase. (4 shots)
- Lower beam voltage to study coupling to fast ion tail (if time)
  - Best gap, substitute B&C (70 kV) for A (90 kV), same total power
  - -90° and -150° phasing (8 shots)
  - 40 ms source A beam blip for MSE

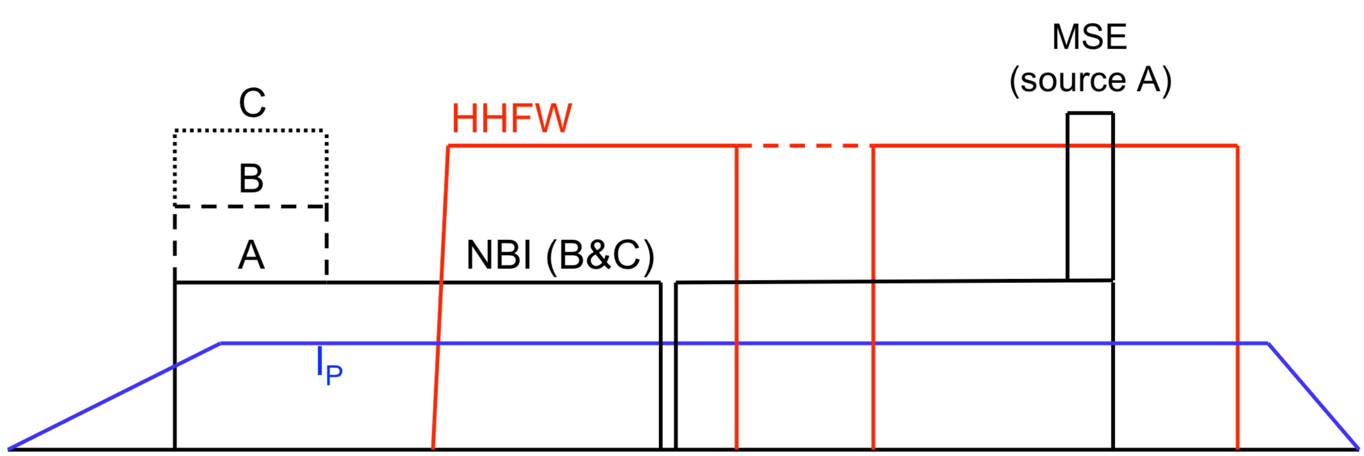
PHASE 2: NBI-TRIGGERED, HHFW-DRIVEN H-MODE (25 shots)

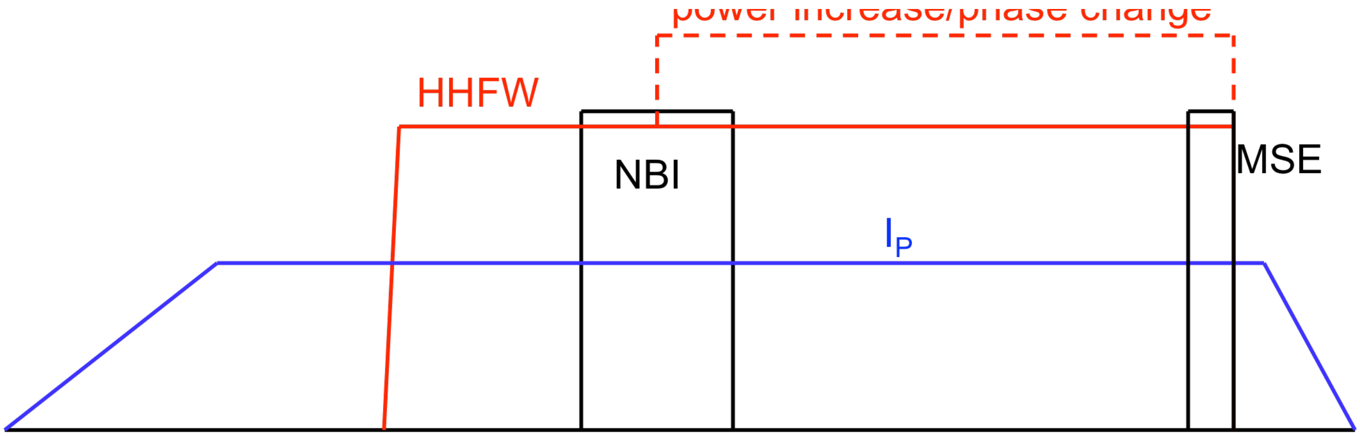
- Target shot **129715**
- -150° phasing, trigger H-mode with 70 kV, 40 ms beam (B).
- Add 90 kV 40 ms pulse (A) for MSE at end of HHFW H-mode phase.

- If H-mode transition trips RF due to decreased loading, try
  - Programming plasma to move closer to antenna after beam comes on (5 shots)
  - Switching from -150º to -90º phasing (higher loading) during beam (3 shots)
  - Matching to H-mode loading, tolerate reflected power during L-mode (3 shots)
- If H-mode is not sustained even if RF does not trip, increase HHFW during the NBI trigger (3 shots).
- If H-mode still not sustained, increase NBI power by adding 70 kV, source C (3 shots)
- Go to -90º phasing and repeat
  - Programming plasma to move closer to antenna after beam comes on (5 shots)
  - Matching to H-mode loading, tolerate reflected power during L-mode (3 shots)
- Repeat with 90 kV, 40 ms & 100 ms source A, using best L-H mode transition technique established above (6 shots). (This is to test the effect of the density profile gradient).

PHASE 1: HHFW INTO NBI-DRIVEN H-MODE (90 and 70 keV beams)







PHASE 2: NBI-TRIGGERED, HHFW-DRIVEN H-MODE

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

Stable, reproducible plasma conditions are required for the quantitative comparisons of this XP. NB sources A (90 kV), B (70 kV), and C (70 kV) are needed. In addition to standard diagnostics like Thomson scattering, 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
- CHERS for ion temperature
- FIDA for energetic ion tails
- NPA and SS-NPA for energetic ion tail
- EDR for edge ion heating
- Neutron measurements for core ion heating
- Soft x-rays
- high-k scattering
- Visible brehmmstralung

5. Planned analysis

Expected results:

- Heating efficiency in vs wavenumber:
  - – 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, current profiles
- Plasma profiles, core and edge, for permitting predictions of wave propagation damping and CD characteristics

Planned analysis:

- Compare efficiencies vs wavenumber to those for deuterium L-mode
- Determine if stability with NB is dependent of antenna phase
- Benchmarking of RF codes that calculate high harmonic ion cyclotron damping on energetic beam ions

6. Planned publication of results

Results will be presented at 2008 IAEA (Geneva), 2008 APS (Dallas), and 2009 RF Power in Plasmas (Gent). Preliminary results may be presented at 2008 EPS (Herssonisos), depending on experimental run dates.

Journal publication will follow completion of experiment in the 2009 experimental campaign.

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **-65** Flattop start/stop (s): **-0.02 – 0.8**

I_P (MA): **0.65-0.8** Flattop start/stop (s): **0.1/0.6**

Configuration: **LSN**

Outer gap (m): **0.04-0.08** Inner gap (m): **~0.04**

Elongation κ: Upper/lower triangularity δ:

Z position (m):

Gas Species: Injector(s):

NBI Species: **D** Sources: **A,B,C** Voltage (kV): **90,70,70** Duration (s): **0.04-0.5**

ICRF Power (MW): **1.5-3** Phasing: **various** Duration (s): **0.15-0.5**

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

LITER: Off

Either: List previous shot numbers for setup: **128155**

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

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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 – ExB 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		√