Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: HHFW heating in high confinement NBI-heated NSTX plasmas

OP-XP-222	**Revision: 0**	Effective Date: 4/16/2002 *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Author: J. Menard	Date
ATI - Task Force Leader: D. Gates	Date
RLM - Run Coordinator: R. Maingi	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

HHFW heating in high confinement NBI-heated NSTX plasmas

1. Overview of planned experiment

The goal of this experiment is to use HHFW heating to modify and hopefully improve the performance of long-pulse high-β_P NBI-heated H-mode discharges by changing the current profile relaxation rate and bootstrap current via electron heating. HHFW heating during the current flat-top and current ramp-up phase will be attempted. Variations in the early outboard gap evolution and plasma shape, divertor timing and H-mode onset time, HHFW power and duration, toroidal field, and I_P value, will be utilized to optimize HHFW heating and plasma performance. It is expected that the relatively high stored energy (150kJ), high central T_e (1keV), and high density from the H-mode ($3\text{-}5\times10^{19}$ m^{-3} line-average density) in the target discharges will maximize the probability achieving significant HHFW plasma heating. Special attention will be paid to the outboard gap in optimizing heating efficiency.

2. Theoretical/ empirical justification

Improved conditions in NSTX have recently allowed the achievement of quasi-steady H-mode discharges of > 300ms duration with $\beta_p \sim 1$ and $\beta_N > 5$ in NBI heated discharges. The longest discharges (> 500ms) free of locked tearing modes and hard ideal disruptions have been achieved at $I_P \leq 800$kA and $B_T = 4.5$kG (ex: shots 107494-6). Lowering the toroidal field in such discharges (see results from XP-207, 202, etc.) often results in tearing mode formation and subsequent transient locking during the I_P flat-top. This is strongly suggestive of reduced safety factor playing a role in tearing-induced disruptions. Electron heating during the ramp-up and flat-top is potentially beneficial for several reasons. First, slowing the current profile relaxation and raising q prior to entrance into H-mode may make it possible to operate free of tearing mode disruptions at reduced toroidal field. This could potentially allow operation at higher β_t and β_N at $\beta_p \sim 1$. For instance, if the field could be dropped from 4.5kG to 3.75kG without loss of stored energy, β_t would increase from 14% to 20% and β_N from 5 to 6 at a collisionless bootstrap fraction approaching 50%. Second, even if very early HHFW injection proves difficult, HHFW heating during the flat-top ELMy H-mode phase might prove beneficial. If electron heating is efficient, the pulse may be significantly extended from a combination of increased conductivity and bootstrap current which is driven primarily by electron pressure gradient. Interestingly, thermal ion heating is also predicted for the HHFW for β values above 15% with Ti >> Te as typically found during the NBI heating phase of the aforementioned discharges. Theoretically, the deposition is off-axis in this regime and may result in a broadened kinetic pressure profile with improved ideal stability. At the very least, this experiment would lead to an improved understanding of the coupling of HHFW power to high-performance NBI-heated H-mode discharges – a new operating regime for NSTX.

3. Experimental run plan (1.5 run days)

Development of early large-bore and high triangularity LSN plasmas suitable for early HHFW heating (from XP221 in the MHD ET group) is a pre-requisite for execution of this XP.

1) DAY 1 – HHFW heating during I_P flat-top - 1 run day

a) Initial target development:

i) Reproduce early large-bore $\beta_p \sim 1$ reference shot discharge free of reconnections

(1) Use best target discharge from XP-221 derived from 107494 – **2 shots**

ii) Ideally, hold FireTIP line-density constant at $4\times10^{19}m^{-3}$ after t=400ms, but such control will be difficult with long-pulse H-mode. Vary HFS gas feed plenum pressure as needed to attempt control.

iii) Reduce power to 1 NBI source as needed to avoid ideal stability limits during XP.

b) Decrease outer gap during flat-top phase

i) The nominal outboard gap for the reference discharge is 8cm

ii) Reduce gap in 2cm decrements between t=150-500ms (or longer) until H-mode is lost or tearing modes disrupt plasma. Then, increase gap in 1cm increments until reproducible long-pulse target discharges are recovered – **6 shots**

c) HHFW loading/matching and power scan:

i) Use 350ms pulse starting at t=150ms at 200kW of HHFW power in heating phasing to adjust tuning to achieve good RF match – **6 shots**

ii) Once good match is achieved throughout long-pulse phase, begin increasing power to assess impact on H-mode and TM stability – **8 shots**

(1) From 200kW, increase RF power from 500kW to 3MW in 500kW increments. During power scan, stop increasing power if H-mode is lost, locked modes are observed, or antenna trips/arcs are observed. Note maximum "useful" power.

iii) Assuming heating is observed, compare flux consumption and stored energy with NBI only by taking 2 shots with HHFW turned off. – **2 shots**

d) DECISION POINT:

i) If no noticeable improvement in heating and flux consumption is observed, skip toroidal field scan in 1.e) below and begin early heating development in Day 2.

e) Toroidal field scan to assess impact of modified current profile – **6 shots**

i) Starting from optimized HHFW discharge, add TF ramp-down between t=200ms and 400ms. Decrease from 4.5kG to 4.25kG, 4.0kG, and 3.75kG if possible. Perform NBI-only comparison to assess influence of HHFW on discharge evolution of lowest field shot which is TM disruption free.

2) **DAY 2 – Addition of HHFW heating during I_P ramp-up - 0.5 run day**
   a) Modify very early gap evolution of optimized shot from previous run day – **5 shots**
      i) Reach 5cm gap by 50ms if possible, 100ms at latest, then hold fixed
      ii) Use smallest gap which retains H-mode w/o MHD with HHFW on after 150ms
   b) Attempt heating – **up to 10 shots**
      i) Decrease time of HHFW turn-on from 150ms to 50ms in 25ms decrements.
      ii) If H-mode is lost or tearing mode becomes unstable, decrease early heating power in 500kW decrements until good performance is recovered.
      iii) If arcing occurs or loading is weak, re-match antenna prior to 150ms as necessary.
      iv) Compare performance with early HHFW heating to NBI-only, time permitting.
   c) Repeat toroidal field scan from 1.e) above, time permitting – **6 shots**

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

This XP requires an operational NBI system and full HHFW capability, as well as the capability of generating lower-single null diverted and double-null diverted discharges with the plasma control system. No CHI will be used during this experiment.

5. Planned analysis

Stability and confinement analysis will be performed utilizing EFIT and TRANSP output and ray-tracing analysis will be performed using HPRT.

6. Planned publication of results

The results will be presented at the EPS conference, IAEA conference and/or in APS talks and published in a suitable journal within 1 year.

PHYSICS OPERATIONS REQUEST

Title: HHFW heating in high confinement NBI-heated NSTX plasmas XP No. 222

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **24-52** Flattop start/stop (s): **-0.05/0.9s**

I_P (MA): **0.8** Flattop start/stop (s): **0.15/0.8**

Configuration: **SND, almost DND**

Outer gap (m): **2-10cm** Inner gap (m): **1-5 cm**

Elongation κ: **1.8-2.1** Triangularity δ: **0.7**

Z position (m): **0.00**

Gas Species: **D_2**, Injector: **Inner Wall and Outer Midplane**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **80**, Duration (s): **< 1.0s**

ICRF – Power (MW): **0-6MW**, Phasing: **heating and/or CD** Duration (s): **< 1.0s**

CHI: **Off**

Either: List previous shot numbers for setup: **Shot from XP-221 based on 107494**
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

Title: HHFW heating in high confinement NBI-heated NSTX plasmas No. 222

Diagnostic system	**Need**	**Desire**	**Requirements** (timing, view, etc.)
Magnetics	✔		
Fast visible camera	✔		
VIPS-1		✔	
VIPS-2		✔	
SPRED		✔	
GRITS		✔	
Visible filterscopes	✔		
VB detector	✔		
Midplane bolometer		✔	
Diamagnetic flux	✔		
Density interferometer (1mm)		✔	
FIReTIP interf'r/polarimeter	✔		
Thomson scattering	✔		
CHERS	✔		
NPA	✔		
X-ray crystal spectrometer		✔	
X-ray PHA		✔	
EBW radiometer		✔	
Mirnov arrays	✔		
Locked-mode detectors	✔		
USXR arrays	✔		
2-D x-ray detector (GEM)		✔	
X-ray tangential camera		✔	
Reflectometer (4 ch.)		✔	
Neutron detectors	✔		
Neutron fluctuations	✔		
Fast ion loss probe	✔		
Reciprocating edge probe			
Tile Langmuir probes			
Edge fluctuation imaging		✔	
H-alpha cameras (1-D)		✔	
Divertor camera (2-D)		✔	
Divertor bolometer (4 ch.)		✔	
IR cameras (2)		✔	
Tile thermocouples			
SOL reflectometer		✔	