Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: SCALING OF PERTURBED ELECTRON TRANSPORT WITH COLLISIONALITY, HEAT FLUX AND CURRENT IN NSTX

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PROPOSAL APPROVALS

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RLM - Run Coordinator: R. Raman	Date
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

SCALING OF PERTURBED ELECTRON TRANSPORT WITH COLLISIONALITY, HEAT FLUX AND CURRENT IN NSTX

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1. Overview of planned experiment

We propose to investigate the effects of changes in collisionality, heat flux and current on the propagation of cold pulses produced in the NSTX plasma periphery by pellet injection. The experiment will use ≈ 0.5 mg lithium pellets to create edge perturbations on the electron temperature and follow the evolution of these perturbations with the poloidal USXR arrays and the new tangential 'optical' array developed at JHU. Three basic single-parameter scans are proposed for the experiment:

a) A density scan from 2 to 5 10^{13} cm^{-3} (line average) in 1 MA, high field L-mode discharges

b) A NBI power scan from 2 to 6 MW in 1 MA, 4.5 kG H-mode discharges, trying to preserve the q-profile by preheating for a fixed time, then changing the power about one slowing-down time before the pellet perturbation

c) A plasma current scan at fixed q in 4 MW discharges, from 0.8 MA/0.36T to 1.25 MA/0.55T

Since good wall condition is important for the proposed XP, we will use lithium evaporator conditioned discharges if baseline shots (low n_e/power L-modes and high n_e/power, Type-I ELM-free H-modes) can be pre-developed within the ISD or boundary group. Conversely, we will use conventionally (GDC) conditioned baseline discharges from the 2005 run. Scan c) will likely require some development time for the lowest and highest current cases.

2. Theoretical/empirical justification

Electron transport still remains a puzzle on NSTX. During the 2005 NSTX run we performed an assessment of Li pellet injection as a tool for perturbative electron transport experiments, using the poloidal USXR diode system. Injection of a 0.5 mg pellet with 150 m/s velocity, in a low n_e/shear reversed L-mode (#117784) produced a quite large 'cold pulse' in the outer plasma. The pulse however stopped at mid radius, indicating the existence of a strong electron transport barrier around q=1. Moreover, the USXR data suggests 'polarity inversion' of the pulse (positive δT_e) inside the barrier, as occasionally seen with tokamak ITBs. The T_e profile in these 'L-modes' is therefore not stiff. However, reduced electron transport and strong shear reversal are so far seen only at low n_e and high T_e, suggesting that collisionality may also play an important role in the NSTX electron transport.

The perturbed electron transport in high density and power H-mode is radically different. The same small Li pellet produces a rapid, global collapse of the T_e profile, shortly after it penetrates the pedestal (e.g., #117793). Similar T_e crashes are observed following Type-I ELM perturbations. The perturbed χ_e values are very large and have radial dependence opposite to the equilibrium (power balance) χ_e. The largest χ_e^{pert} is found in the outer region of large T_e gradient, with a marked decrease in the central region where T_e tends to be flat and the equilibrium χ_e largest. This suggests that in the outer plasma of high power H-modes electron transport is well above a critical gradient.

We propose to investigate in more detail the above effects. For instance, if a strong dependence of electron transport on collisionality is confirmed though a density scan in L-modes, this might point to μ-tearing activity as turbulence drive (see work by M. Redi). Further on, we will try and estimate the critical gradient parameters of the NSTX H-mode, by measuring how the perturbed χ_e changes with heat flux during a beam power scan. Finally, we propose to study perturbed electron transport as a function of plasma current, at fixed q-profile. Current is supposed to be a main knob in the NSTX energy confinement, which in H-mode is largely determined by the electron transport. In addition, a reduction in ELM penetration at high current observed by K. Tritz may indicate that perturbative transport also changes with current. The current scan at fixed-q will also complement the ELM perturbative study at variable B_t planned in the boundary group by K. Tritz.

The proposed XP will also offer good opportunities for low and high-k scattering measurements. In all the above conditions it would be of interest to measure the change in fluctuation spectra from the unperturbed profiles to the perturbed ones, for a correlation with changes in transport. Finally, it will be also interesting to compare the changes computed by TRANSP in equilibrium transport before pellet perturbation, with those measured in the perturbed transport during the above scans. Pending good results, this XP will also be considered as the basis for an ITPA proposal.

3. Experimental run plan

A) For an assessment of collisionality effects we will perform a density scan in L-mode discharges, where this parameter can be well controlled. Starting with 117783 as baseline ($\langle n_e \rangle \approx 2x10^{13}$ cm^{-3}, $P_{beam\ A}$= 2 MW) we will increase $\langle n_e \rangle$ to 3, 4, and 5 $x10^{13}$ cm^{-3} and inject 0.5 mg Li pellets at ≈ 330 ms. Being interested in the density effect, we will maintain moderate I_p ramp in order to minimize the drive for shear reversal.

An issue here is the likely change in q-profile with density. The TRANSP computations for previous L-mode experiments suggest that with increasing density, the shear reversal occurring at low n_e tends to diminish. While this could also be of interest for the proposed study, we will attempt to minimize the drive for q-profile change by moving the heating beam earlier in time as the density is increased (for instance, by always applying the beam when n_eL reaches 2 10^{15} cm^{-2}). This is motivated also by the TRANSP modeling which shows that early heating increases the drive for reversal, thus possibly compensating the decreased drive from the higher density.

For the L-mode study the pellet velocity will be reduced compared to that in the 2005 run (from 150 m/s to 75 m/s), in order to produce a somewhat smaller T_e perturbation in the outer plasma half.

This L-mode part of the XP will be performed at the highest allowable field in order to delay the onset of n=1 internal MHD activity. Also, the L-mode scan will be performed prior to the H-mode work, in order to keep the gas wall loading low.

B) In order to study the critical gradient behavior we will inject 0.5 mg Li pellets for controlled T_e perturbations during heat flux scans in ELM-free H-modes. The basic idea of these scans is to ‘freeze’ the q-profile characteristic for a given power, by pre-heating the plasma for 400 ms at that power, then changing the power and injecting the pellet, in order to see the effects of the heat flux change. The pellet will be injected at about one beam-slowing time after the power change (i.e., after $\approx$ 30 ms), in order to allow the electron heating to approach equilibrium at the new power level (the current diffusion time being much longer than the beam-slowing time).

The first heat flux scan will therefore consist in the following:

- constant heating at 4 MW throughout the shot, with pellet injection at 450 ms
- preheating at 4 MW for 420 ms, then increasing the power to 6 MW, and injection at 450 ms
- preheating at 4 MW for 420 ms, then decreasing the power to 2 MW, and injection at 450 ms

As baseline for this scan we will use a recent, high elongation and triangularity DN shot, exhibiting small ELMs and good confinement (#117818, 4 MW, 1 MA, 4.5 kG).

To understand the critical gradient behavior it will also be important to assess the effect of the initial ‘frozen-in’ q-profile on the perturbed electron transport. A first step in this direction can be taken in the present experiment. For instance, if we see a difference in transport between a discharge that was preheated at 6 MW and then the power dropped to 2 MW, and a discharge that was preheated at 4 MW and then the power dropped to 2 MW, the effect can be directly attributable to the different initial q-profiles.

To investigate this question we propose to compare in a second scan discharges preheated at 6 MW, with those preheated at 4 MW in the above. The second heat flux scan is as follows:

- constant heating at 6 MW throughout the shot, with pellet injection at 450 ms
- preheating at 6 MW for 420 ms, then decreasing the power to 4 MW, and injection at 450 ms
- preheating at 6 MW for 420 ms, then decreasing the power to 2 MW, and injection at 450 ms

As baseline for the second scan we will use the above #117818, with the third source C added at 200 ms, or the very similar small ELM shot #117814 (6 MW, 1 MA, 4.5 kG).

C) In a third part of the proposed XP we will investigate perturbed electron transport as a function of plasma current, at fixed q-profile. To this end, we will inject 0.5 mg Li pellets at t ≈ 450 ms in 0.8 MA/3.6 kG, 1 MA/4.5 kG, 1.1 MA/5 kG and 1.25 MA/5.5 kG discharges. The lowest and highest current conditions may require some development. As baseline shot we will also use the above intermediate power, high κ and δ shot #117818 (1 MA, 4.5 kG, 4 MW). The highest field condition will be executed separately, when 5.5 kG operation becomes available. To touch base with the lower field results, we will reproduce as reference the 1.1 MA/5.0 kG shot.

For improved statistics, in all the above conditions we will run one reference and two pellet shots.

For fast T_e profile measurements the proposed XP will use the new 'three-color' tangential SXR array developed by JHU, as well as the USXR poloidal arrays in a 'two-color' configuration. The technique of measurement of the cold pulse propagation consists in modeling the emissivity profiles in multiple energy ranges *before the perturbation*, using the MPTS T_e and n_e profile, as well as the CHERS C profile and the relative fractions of low Z-impurities from spectroscopy. The temporal evolution of the ratio of these profiles is then used to constrain the evolution of the perturbed T_e profile. To improve the accuracy of the procedure we will use two consecutive MPTS time points spaced about 5 ms apart. The first provides the start point for the SXR modeling right before the pellet arrival, while the second measures the T_e profile a few ms into the cold pulse evolution, thus providing a stringent test of the SXR modeling.

Since a fast T_i diagnostic is not available, changes in ion confinement following pellet perturbations will be estimated by subtracting the electron stored energy from the total stored energy, as well as by using the NPA in fast T_i mode.

Tangential fast cameras equipped with Li I filters, as well as the tangential bolometer array will be used to monitor the depth of neutral pellet penetration, while the JHU Li III telescope will be used to monitor with μs time resolution the edge and beam excited Ly Ly_α emission at 135 Å. In addition, fiber optics with beam splitters for D_α, Li I and C II at Bay K window, for assessment of pellet ablation profiles, are highly desirable. High resolution spectra in the 10-150 Å range, such as those provided by the LLNL spectrometers are also highly desirable.

All the routine transport diagnostics (MPTS, CHERS, MSE and fast EFIT) must be operational for the proposed XP.

Finally, due to the relevance of this XP to the high-k scattering diagnostic assessment, this system must be operational and taking data.

As above mentioned, lithium conditioned baseline discharges will be used if they can be developed within preparatory work. Conversely, good machine condition will be obtained using helium GDC, as has been done in the 2005 run.

In addition, since the initial experiments of pellet injection in H-mode were performed in LSN shots, it would be desirable to test the effects of switching to DN baseline shots, by injecting prior to the XP a few Li pellets at the end of a target baseline shot.

The proposed shot matrix is presented below, **in order of priority**. We estimate that the first two scans can be accomplished in a long run day, while the third one in a regular day.

Density scan in L-mode (1 MA #117783 baseline, but using maximum B_t available)

$\langle n_e \rangle$ at t_{pellet} = 0.33 s ($x10^{13}$ cm^{-3})	Baseline shots/ Li pellet shots	P_{beam} (MW) Source A	t_{beam} (s) (approx.)
2	1/2	2	0.2
3	1/2	2	0.175
4	1/2	2	0.15
5	1/2	2	0.1
			Total=12 shots

Beam power scan in H-mode (1 MA, 4 MW, 4.5 kG, #117818, or 6 MW, #117814 as baseline)

Preheat P_{beam} till 0.42 s (MW)	P_{beam} at t_{pellet} = 0.45 s (MW)	Baseline shots/ Li pellet shots
4 (A+B)	4 (A+B)	1/2
4 (A+B)	6 (A+B+C)	1/2
4 (A+B)	2 (A)	1/2
6 (A+B+C)	4 (A+B)	1/2
6 (A+B+C)	6 (A+B+C)	1/2
6 (A+B+C)	2 (A)	1/2
		Total=18 shots

Current scan at fixed-q in H-mode (4 MW, #117818 as baseline, t_{pellet}=0.45 s)

I_p/B_t	Baseline shots/ Li pellet shots
1 MA / 4.5 kG	1/2
1.1 MA /5.0 kG	1/2
0.8 MA /3.6 kG	1/2
1.25 MA /5.5 kG	1/2
	Total=12 shots

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

(1) All neutral beams operational at 90 kV; **required**

(2) LPI loaded with 0.5 mg Li pellets for an estimated 40-50 shots; inject at 75 m/s in L-modes and 150 m/s in H-modes; **required**

(3) Three-color tangential optical SXR array (Be 10, Be 100, Be 500 filters); **required**

(4) USXR arrays in two-color configuration: Hor. Up – Be10, Hor. Down - Be100, Re-entrant Be-100; **required**

(5) High-k scattering operational and taking data; **required**

(6) MPTS pulses at 5 ms spacing, with timing synchronized for a measurement at ≈ 3ms after pellet deposition, as indicated by the lower energy USXR arrays; **required**

(7) CHERS operational and synchronized for measurement before and after the pellet arrival; **required**

(8) MSE operational and synchronized for measurement before and after the pellet arrival; **required**

(9) Plasma TV camera with Li I filter and FO bundle monitoring the pellet; **required**

(10) Bolometer array; **required**

(11) NPA in fast T_i mode, for estimate of relative T_i change following injection; **requested**

(12) Fiber optics with beam splitters for D_α, Li I and C II at Bay K ; **highly desirable**

(13) SPRED; **highly desirable**

(14) X-ray pinhole camera; **highly desirable**

(15) High resolution SXR spectroscopy (LLNL); **highly desirable**

5. Planned analysis

Cold pulse propagation and pellet deposition profile from analysis of USXR data. Fast EFIT for equilibrium changes. Routines for χ_e^{pert} estimate from LHD cold pulse model (Inagaki et al, PPCF 2004) and also E. Fredrickson. Fast TRANSP analysis, using USXR T_e profiles and assuming T_i profiles measured by CHERS, modulated with the relative change measured by NPA could be possible. Correlation with high and low-k scattering measurements and GS2 linear stability analysis before and after pellet injection are of interest.

6. Planned publication of results

EPS 06, APS/DPP 2006, publication in a refereed journal.

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **max. available** Flattop start/stop (s): **-0.02/1.0 s**

I_P (MA): **0.8-1.25** Flattop start/stop (s): **0.12-0.22/0.8 s**

Configuration: **DN (117783), DN (117818 or 117814)**

Outer gap (m): **5-10 cm**, Inner gap (m): **1-6 cm**

Elongation κ: **2-2.5**, Triangularity δ: **0.5-0.7**

Z position (m): **0.00**

Gas Species: **D / He**, Injector: **CS Midplane, Outer Midplane**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **90/90/90 kV**, Duration (s): **1s**

ICRF – Power (MW): **____**, Phasing: **Heating / CD**, Duration (s): **_____**

CHI: **On / Off**

Either: Previous shot numbers for setup: **117790 and 115872 as H-mode baseline and 117783 as L-mode baseline**

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

Diagnostic	Need	Desire	Instructions
Bolometer - tangential array	✓		
Bolometer array - divertor			
CHERS	✓		
Divertor fast camera		✓	
Dust detector			
EBW radiometers			
Edge deposition monitor			
Edge pressure gauges		✓	
Edge rotation spectroscopy			Only available by special request of T. Biewer @ MIT
Fast lost ion probes – IFLIP		✓	
Fast lost ion probes – SFLIP		✓	
Filtered 1D cameras			
Filterscopes		✓	Li filters
FIReTIP		✓	Pellet density perturbation
Gas puff imaging			
High-k scattering	✓		
Infrared cameras			
Interferometer – 1 mm		✓	
Langmuir probes - PFC tiles		✓	
Langmuir probes - RF antenna		✓	
Magnetics – Diamagnetism	✓		
Magnetics – Flux loops	✓		
Magnetics – Locked modes		✓	
Magnetics – Pickup coils	✓		
Magnetics - Rogowski coils	✓		
Magnetics - RWM sensors		✓	
Mirnov coils – high frequency	✓		
Mirnov coils – poloidal array		✓	
Mirnov coils – toroidal array	✓		
MSE	✓		
Neutral particle analyzer	✓		Fast Ti mode
Neutron Rate (2 fission, 4 scint)	✓		
Neutron collimator			
Plasma TV	✓		Li and B filter
Reciprocating probe			
Reflectometer - FM/CW			
Reflectometer - fixed frequency homodyne		✓	
Reflectometer - homodyne correlation		✓	
Reflectometer - HHFW/SOL			
RF antenna camera			
RF antenna probe			
Solid State NPA			
SPRED		✓	
Thomson scattering - 20 channel	✓		
Thomson scattering - 30 channel		✓	
Ultrasoft X-ray arrays poloidal -2 color	✓		
Visible bremsstrahlung det.	✓		
Visible spectrometers (VIPS)		✓	
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray pinhole camera		✓	
Tangential Optical SXR Array (OSXR)	✓		
Fiber optics with beam splitters for D_α, LiI and C II		✓	