Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **ELM Pacing Via Vertical Jogs**

OP-XP-945	Revision: **0**	Effective Date: **9/28/09** *(Approval date unless otherwise stipulated)* Expiration Date: **9/28/11** *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: S.P. Gerhardt	Date 9/28/09
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RLM - Run Coordinator: R. Raman	Date 9/28/09

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **ELM Pacing via Vertical Jogs** No. **OP-XP-945**
AUTHORS: **J.M. Canik, D. Gates, R. Goldston, R. Hawryluk, R. Maingi, J. Menard, S. Sabbagh, A. Sontag** DATE: **9/28/09**

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1. Overview of planned experiment

The goal of this XP is to apply small oscillations in the plasma vertical position, in order to trigger ELMs. The vertical oscillations will be generated in one of two ways i) by requesting rapid variations in the plasma vertical position, or ii) explicitly adding a "kick" voltage to the PF-3 coil, and then allowing the vertical position control system to return the plasma to its equilibrium location (some simple modifications to PCS algorithms must be made for this step to be possible). If ELMs are successfully paced, scans of the ELM frequency, and over the target shot up/down balance, will be conducted.

2. Theoretical/ empirical justification

Future large tokamak experiments will almost surely need to run in H-mode in order to achieve sufficient confinement. One consequence of H-mode is the presence of periodic expulsions of energy from the steep gradient regions at the plasma edge; the expulsions are generally thought to be peeling/ballooning instabilities at the plasma boundary, and are called ELMs (Edge Localized Modes). These energy expulsions are sufficiently large that serious divertor erosion due to impulsive heat loading can occur. For this reason, ITER requires that each ELM expel <0.5% of the total plasma stored energy; DEMO requirements reduce this fraction by another order of magnitude. Typical (type-I) ELMs in NSTX and other H-mode tokamaks expel ~10% of the plasma energy.

For these reasons, it is necessary to find ways to decrease the size of (mitigate), or eliminate entirely, these impulsive heat-loading events. At DIII-D, ELMs have been eliminated via certain configurations of (non)resonant magnetic perturbations, and in a specific type of discharge known as the "Quiescent H-mode". Options for mitigation include:

- small ELM regimes (for instance, Type-V ELMs in NSTX)
- pellet pacing to increase the ELM frequency
- magnetic triggering to increase the ELM frequency (XP-943 in NSTX)
- vertical "jogs" to increase the ELM frequency

It is the purpose of this XP to study the final possibility. Vertical jogs were first used to trigger type-III ELMs in TCV [A. W. Degeling, et al., Plasma Phys. Control. Fusion **45**, 16367 (2003)]; it was thought that the edge current modulations due to the plasma motion lead to instability. Subsequent studies in AUG were also able to trigger Type-I ELMs [P.T. Lang, et al., Plasma Phys. Control. Fusion **46**, L31 (2004)], through the characteristics of the triggering were quite different than in TCV. More recently, ELM pacing via vertical jogs has been demonstrated on JET [F. Sartori, et al., 35th EPS Conference on Plasma Physics], where it is being studied as a potential ELM mitigation method for ITER.

The physical mechanism by which ELMs are triggered by vertical kicks remains obscure. One likely explanation is that the perturbation to the edge current cause the plasma to transiently cross the boundary of peeling mode stability, and an ELM occurs. Alternatively, changes in the plasma shape during a jog could reduce the stability of the edge, resulting in an ELM being triggered. If ELMs are successfully paced with this method in NSTX, scans will done in order to understand this physics.

3. Experimental run plan

3.1: **Establish target discharge.** **(3 shots)**

Reference shot is 132543. No lithium evaporation is required. The shot should have 30-40 Hz ELMs. A brief passivation of the first wall via 1 minute D_2 glow will likely be necessary in order to eliminate the effects of previously applied lithium. It is likely that the XP will (at least initially) be done on a 15 minute cycle with 7 minutes of He glow and 8 minutes of pump-out.

3.2: Establish triggering:

This may be a two-step process. Part a) uses rapid variations in the requested plasma position to try to pace ELMs. Part b) uses a new PCS capability to explicitly place voltage pulses on the radial field coils. If part 1 works, then part 2 will not be necessary.

3.2a) Jogging via rapid Variations in z_{axis} (7 shots)

____ Add a square pulse-train to the z_{axis} request in isoflux, with the following parameters:

Amplitude A_{kick}=-2cm,

Frequency f_{kick}=60 Hz (period =1/60=17 msec)

Duration τ_{kick}=3 msec

This pulse train has the kicks all going in the downward direction, so that the risk of diverting onto the more poorly conditioned divertor is reduced. The train of pulses should start at t=0.35 sec, and persist through t=1.0 sec.

If this triggers ELMs, then reduce $|A_{kick}|$ and τ_{kick}, in increments of ~30% of those values, until triggering is not observed.

If this does NOT trigger ELMs, than increase $|A_{kick}|$ and τ_{kick} until either vertical position control is lost, or ELMs are generated. The values can be placed in the following table:

Case	Shot	A_{kick} (cm)	f_{kick} (Hz)	τ_{kick} (msec)	Result
1		-2	60	3	
2		-4	60	3	
3		-6	60	3	
4		-4	60	6	
5		-4	60	9	
6					

7					
8					

If step 3.2a) is successful in triggering ELMs, then it is not necessary to do step 3.2b)

3.2b) Jogging via explicit voltage requests on the PF-3 coil.

This step assumes that the changes to the PF-3 control software have been made in order to explicitly request voltage on the PF-3 coil.

___ Apply f_V=60 Hz voltage pulses, amplitude of A_V=200V, duration τ_V=3 msec. Given the limited slew-rate of the PF-3 rectifier, the voltage should not have time to go to it's maximum value in this time.

If this case is unable to trigger ELMs, increase the voltage and duration of the pulse as per the following table. Stop the increase when either the ELMs are reliably triggered, or the vertical position control of the plasma is compromised. The train of pulses should start at t=0.35 sec.

Case	Shot	A_V (V)	f_V (Hz)	τ_V (msec)	Result
1		200	60	3	
2		400	60	3	
3		800	60	3	
4		1200	60	3	
5			60	6	
6			60	9	
7					
8					

3.3) Upward Kicks **(4 shots)**

Take the best case from section 3.2, and reverse the direction of the kicks, so that they are upward.

Case	Shot	A_V (V) or A_{kick} (cm)	f_V (Hz)	τ_V (msec)	Result
1			60		
2			60		
3			60		
4			60		
5			60		

The next steps are used to document the triggering, and understand it better, assuming that it was established in section 3.2 & 3.3.

3.4) Gate triggering on/off. (2 shots)

_____ Take the best shot from step 3.2, and gate off the kick request from 500-700 msec, demonstrating the difference between random and paced ELMs.

3.5) Test ability to trigger ELMs over a range of kick frequencies. (5 shots)

For best case in section 3.2, modify the kick frequency to test the range of frequencies that can paced in NSTX.

Case	Shots	f_{kick} or f_V	A_{kick} or A_V

3.6) Isolate Transient vs. Equilibrium Effects (4 shots)

____ Repeat the reference discharge without the kicks.

____ Each kick will (presumably) have driven the plasma down, with a resulting modification to dr_{sep}. Modify the dr_{sep} request to achieve a steady plasma discharge with these values of dr_{sep}/z_{axis}. Take that shot without the kicks.

3.7) Determine range of dr_{sep} for which pacing/triggering works. (5 shots)

____ Repeat the best discharge from section 3.2 with the equilibrium dr_{sep} modified as in the following table.

Case	dr_{sep}	Shot
1	-1.5	
2	-1.0	
3	-0.5	
4	-2.	
5		

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

A modification to the NSTX PCS will be necessary to complete section 3.2b). This modification, which will allow an explicit voltage pulse to be added to the PF-3 coil voltage request, will be described in a separate specification.

5. Planned analysis

EFIT/lrdfit analysis will certainly be performed. It may be necessary to use a code such as TRANSP or TSC to predict oscillations in the edge current, as the purely experimental reconstructions may not be able to isolate this effect. Pedestal tanh fits and stability analysis will also likely be performed.

6. Planned publication of results

If successful, these results would easily merit presentation at a meting such as IAEA FEC. Publication in a journal such as Nuclear Fusion would be assured.

PHYSICS OPERATIONS REQUEST

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(use additional sheets and attach waveform diagrams if necessary)

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

This experiment will not use lithium in its initial manifestation. The target shot (132543) was chosen because it had i)~30 Hz ELMs, ii) was biased down, and iii) was closely based in the fiducial.

This shot (132543) is essentially the fiducial, with I_P raised to 1 MA and dr_{sep} reduced to -1.5 cm during the flat top.

Previous shot(s) which can be repeated: 132543

Previous shot(s) which can be modified:

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

I_{TF} (kA): 4.5 kG Flattop start/stop (s): Standard 0.45 T waveform

I_P (MA): 1MA Flattop start/stop (s): 0/1.0

Configuration: **LSN**

Equilibrium Control: **Isoflux**

Outer gap (m): **.1** Inner gap (m): Z position (m): **-10 cm**

Elongation κ: 2.1 Upper/lower triangularity δ: 0.7/~0.5

Gas Species: **D_2** Injector(s): Standard D_2 injection for fiducial.

NBI Species: **D** Voltage (kV) **A: 90** **B: 90** **C: 80** Duration (s): ~1 sec

ICRF Power (MW): 0 Phase between straps (°): NA Duration (s): NA

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

LITERs: Off / On Total deposition rate (mg/min):

EFC coils: On Configuration: **Odd**

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		