Princeton Plasma Physics Laboratory

NSTX-U Experimental Proposal

Title: **GAE/CAE Suppression Scaling with 2^{nd} Neutral Beam Line Sources (and affect on Te profile peaking).**		
OP-XP-	Revision: **0**	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: E. Fredrickson	Date **4/19/2016**
SG, TSG or TF Leader (assigned by RC): **M. Podestá**	Date
Run Coordinator (RC):	Date
Responsible Division: Experimental Research Operations	

RESTRICTIONS or MINOR MODIFICATIONS

(Approved by Experimental Research Operations)

NSTX-U EXPERIMENTAL PROPOSAL

TITLE: **GAE/CAE Suppression Scaling** No. **OP-XP-**
AUTHORS: **E. Fredrickson** DATE: **4/19/2016**

1. Overview of planned experiment

Robust suppression of GAE activity has been observed with injection of any of the three 2nd neutral beam line sources in the present 6.5 kG target plasmas. This experiment will study the scaling of the beam voltage and power thresholds for suppression of GAE activity. The experiment will also extend plasma conditions to 4.5 kG and 5.5 kG toroidal field levels to make contact with NSTX experiments where much stronger GAE/CAE activity was typically seen. In the course of the studies of GAE suppression, an effort will be made to document any correlation of core electron temperature peaking with GAE activity level.

2. Theoretical/ empirical justification

The beam driven current profile is an important tool for controlling stability of high-performance NSTX-U plasmas. Previous experiments have found direct evidence that strong GAE activity is redistributing fast ions in phase-space, thus potentially modifying the beam current drive profile. GAE activity is correlated with a core flattening of the electron temperature profile, either through and energy channeling mechanism involving kinetic Alfvén waves, or through direct diffusion of thermal electrons. The ability to suppress GAE activity gives a tool to advance understanding of drive mechanisms for fast-ion driven instabilities, for understanding our attempts to modify the current profile with neutral beams and improve understanding of possible electron energy transport *via* GAE activity.

3. Experimental run plan

The first part of this experiment will address the relative efficacy of the three outboard sources in suppressing GAE. Starting with a reference shot like (203587, 204000, 204112), the BL #1 power will be increased to all sources. Then on subsequent shots, BL #2, source A, source B and source C will be injected with 50 ms(?) modulation. If complete suppression is not seen for injection of any BL #2 source, BL #1 power will be reduced by 1 source (tbd based on source performance). Previous experiments suggest that it takes more BL#2 power to fully suppress the GAE later in the discharge.

The second part will address the question of voltage vs. power dependence of the suppression threshold. BL #2 source voltages will be reduced to about 70 kV (1MW). A full suppression case will be selected from part 1, and the shot run with the new lower voltage source. If full suppression is not seen, additional low voltage sources will be added. If full suppression is seen, low voltage source will be tried in any part 1 case where full suppression was not seen.

In the third part, the experiment will be extended to lower field, nominally 4 kG. Here, it is expected that much stronger GAE and CAE activity will be seen; possibly correlated with flattening of the core electron temperature profile. The decision as to whether to use an 0.65 MA or 0.9 MA, 4 kG target will be made later. An H-mode plasma target will be developed using beam heating profiles similar to those in the NSTX experiments. Assuming that there is strong GAE/CAE activity as was typical for these plasmas in NSTX, outboard sources will be added. For the 0.65MA target, their may be an issue with respect to beta limits and it is possible that at most one BL2 source could be added. Again, we will step through each outboard source from 2a to 2c, at the voltage deemed optimal from parts 1 & 2. Each source will again be modulated at 50ms period – assuming a sufficient flattop length is achieved. If suppression is not seen, we will try two modulated sources, and then three.

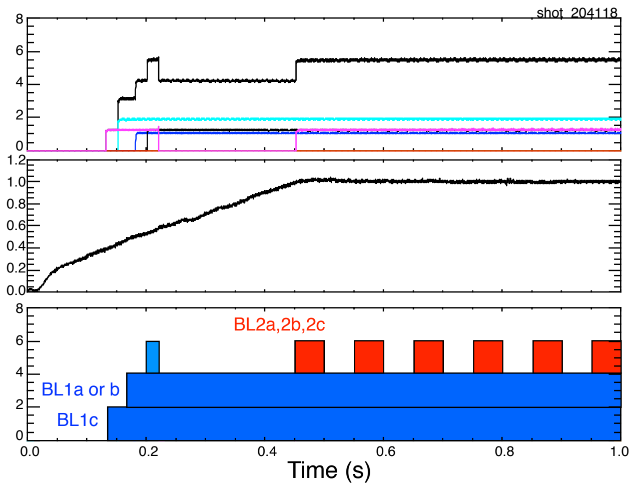

Fig. 1. a) Beam waveforms for shot 204118, b) plasma current waveform, c) proposed beam waveform.

The nominal target plasma is shown in Fig. 1 is based on shot 204118, a 1MA H-mode plasma. We could push the flattop longer than one second, but I don’t think there is that much to be gained. The 1 MA plasma should give a higher beta limit, which might be challenged in the lower toroidal field version of this shot. The ‘base’ heating power of about 4MW should come from BL1 and include source 1c. The red blocks indicate the timing of the 50 ms BL2 blips an represent either one or two BL2 sources. The 50 ms period should be long enough for the fast ion distribution to nearly relax, and long enough for Te flattening to occur, if that is the case?

The experiment should begin by reproducing shot 204118 with the new beam configuration, sans BL2 blips. Previous experiments suggest that 4 MW with BL2 should be adequate to excite GAE, but the base beam power can be adjusted to give good GAE activity. This target is then repeated three times with a scan of BL2 source blips. If satisfactory results are obtained, meaning at least some examples of complete GAE suppression and recovery, then move to Part 2. If not, either reduce BL#1 base power, or double up on BL2 blips, i.e., add two sources at a time starting with 2c&2b, then 2a&2c and finally 2a&2b.

With successful completion of Part 1, begin Part 2 which is a 2 point voltage scan of the BL2 sources. Exactly what this entails depends on the status of the BL2 sources, specifically whether any can operate at close to 90 kV. If there is not a significant range in available voltage, then move to Part 3. Otherwise, repeat Part 1 with lower voltage sources, including doubling up BL2 blips if necessary.

Part 3 takes the most successful GAE suppression configuration to a lower field target. Start by attempting the target with 4kG toroidal field and make changes as necessary. Confirm that strong GAE/CAE activity is present. Then, as time permits, begin with the most successful GAE suppression voltage and source(s), and see if the GAE can be suppressed. If so, based on results from Part 1&2, determine what the most likely successful scans (sources of voltage) and complete as much as possible.

Run Plan Shot List

0) Reproduce shot 204118 using only combination of sources 1a, 1b and 1c to total 4 MW. Ip flattop ends at 1s. Should be no kink mode.

If only weak GAE, increase power or try to lower density.

2-3 shots

Part 1. All BL2 sources at 90kV, if possible, else all at 70kV.

1.1) Run target shot and add source 2c with 50ms on, 50ms off starting at 0.45s.

1.2) Run target shot and add source 2b with 50ms on, 50ms off starting at 0.45s.

1.3) Run target shot and add source 2a with 50ms on, 50ms off starting at 0.45s.

3 shots

If full suppression is not seen in any of these shots lower base power and repeat.

1.1a) Run target shot and add source 2c with 50ms on, 50ms off starting at 0.45s.

1.2a) Run target shot and add source 2b with 50ms on, 50ms off starting at 0.45s.

1.3a) Run target shot and add source 2a with 50ms on, 50ms off starting at 0.45s.

+3 shots

If full suppression is seen, move to Part 2.

Part 2. Use sources with significant voltage operational range. If not available, move to Part 3.

2.1) Run target shot and add source 2c with 50ms on, 50ms off starting at 0.45s.

2.2) Run target shot and add source 2b with 50ms on, 50ms off starting at 0.45s.

2.3) Run target shot and add source 2a with 50ms on, 50ms off starting at 0.45s.

3 shots

If full suppression is not seen in any of these shots lower base power and repeat with two sources per blip.

2.1a) Run target shot and add source 2b,2c with 50ms on, 50ms off starting at 0.45s.

2.2a) Run target shot and add source 2a,2c with 50ms on, 50ms off starting at 0.45s.

2.3a) Run target shot and add source 2a,2b with 50ms on, 50ms off starting at 0.45s.

+3 shots

If full suppression is seen, move to Part 3.

Part 3. Reproduce experiments at low field. Use BL2 sources at optimum voltage.

3.0) Develop 4kG, 1s version of target shot with strong GAE/CAE activity. Should be no kink mode.

4 shots

3.1) Run target shot and add source 2c with 50ms on, 50ms off starting at 0.45s.

3.2) Run target shot and add source 2c with 50ms on, 50ms off starting at 0.45s.

3.4) Run target shot and add source 2c with 50ms on, 50ms off starting at 0.45s.

3 shots

if suppression not seen, move directly to 3 source beam blips.

3.1a) Run target shot and add source 2c with 50ms on, 50ms off starting at 0.45s.

3.2a) Run target shot and add source 2c with 50ms on, 50ms off starting at 0.45s.

3.4a) Run target shot and add source 2c with 50ms on, 50ms off starting at 0.45s.

+3 shots

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

Reliable neutral beam operation of most of the sources is needed, including the ability to modulate beam heating. Plasma pulse lengths long enough to give quasi-steady fast-ion distribution conditions are required, ideally discharges with duration of order 1.5s. Beamline #1 sources a,b,c should be available at 90 kV to excite large amplitude GAE (experiment could probably be done with only 4 MW of BL#1 power, but it would be less than ideal). As many BL #2 sources as possible should be available. No RF or CHI is required. Fast Mirnov, Thomson scattering and neutron diagnostics are required. CHERs, ssNPA, FIDA, UCLA reflectometers are desired.

5. Planned analysis

LRDFIT and TRANSP analyses will be performed for assessing the classical fast ion distributions. Some moments of the fast ion distributions may be incorporated into a database indicating parameter ranges for suppression of GAE. For a select set of shot, it is envisioned that more extensive analysis with HYM will also be performed.

6. Planned publication of results

It is hoped that the first results can be shown at the APS 2016 meeting. The results will also probably be incorporated in an IAEA presentation/Nuc. Fusion paper. It is also expected that a number of other presentations and publications will come out of other TSGs making use of these discharges.

7. Estimated Neutron Production

Based on the number of shots, plasma current levels, and expected durations, estimate the maximum neutron production of this experiment. See calculator in Appendix #2 for this calculation.

# of Shots used in Estimate: 24   Estimated Total Neutron Production: 7.20E+15

PHYSICS OPERATIONS REQUEST

TITLE: No. **OP-XP-**
AUTHORS: DATE:

(use additional sheets and attach waveform diagrams if necessary)

Brief description of the most important operational plasma conditions required and any special hardware requirement:

Previous shot(s) which can be repeated:

Previous shot(s) which can be modified:

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

B_T Range (T): **0.4-0.65** Flattop Duration (s): **1s**

I_P Range (MA): **1.0** Flattop Duration (s): **1s**

Configuration: **Limiter / DN / LSN / USN**

Equilibrium Control: **Outer gap / Isoflux** (rtEFIT) **/ Strike-point control** (rtEFIT)

Outer gap (m): Inner gap (m): Z position (m):

Elongation: Triangularity (U/L): OSP radius (m):

Gas Species: Injector(s):

NBI Species: **D** Heating Duration (s): **0.9s**

Voltage (kV) 50 cm (1C): 60 cm (1B): 70 cm (1A):

Voltage (kV) 110 cm (2C): 120 cm (2B): 130 cm (2A):

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

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

LITERs: Off Total deposition rate (mg/min) or dose per discharge (mg):

EFC coils: Off

DIAGNOSTIC CHECKLIST [1]

TITLE: No. **OP-XP-**

AUTHORS: DATE:

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Beam Emission Spectroscopy		
Bolometer – midplane array		
CHERS – poloidal		
CHERS – toroidal		x
Divertor Bolometer (LADA)		
Divertor visible cameras		
Dust detector		
Edge deposition monitors [2]		
Edge neutral density diag.		
Edge MIGs [2]		
Penning Gauges [2]		
Edge rotation diagnostic		
Fast cameras – divertor [2]		
Fast ion D_alpha - poloidal		
Fast ion D_alpha - toroidal		
Fast lost ion probes - IFLIP		
Fast lost ion probes - SFLIP		
Filterscopes [2]		
FIReTIP		
Gas puff imaging – divertor		
Gas puff imaging – midplane		
Hα cameras - 1D [2]		
Infrared cameras [2]		
Langmuir probes – divertor		
Langmuir probes – RF		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism		
Magnetics – Halo currents		
Magnetics – RWM sensors		x

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
MAPP		
Mirnov coils – high f.	x	
Mirnov coils – toroidal array		
MSE-CIF		
MSE-LIF		
Neutron detectors [2]		
Plasma TV		
Reflectometer – 65GHz		x
Reflectometer – correlation		
Reflectometer – FM/CW		
Reflectometer – fixed f		x
Reflectometer – SOL		
SSNPA [2]		
RF edge probes		
Spectrometer – divertor		
Spectrometer – MonaLisa		
Spectrometer – VIPS		
Spectrometer – LOWEUS		
Spectrometer – XEUS		
TAE Antenna		
Thomson scattering	x	
USXR – pol. Arrays		
USXR – multi-energy		
USXR – TG spectr.		
Visible Brems. det. [2]		

Notes:

[1] Check marks in this table do not guarantee diagnostic availability. Check with diagnostic physicists or research operations management to ensure diagnostic coverage.

[2] In some cases, a given line represents multiple diagnostics. For instance, there are multiple SSNPAs, multiple IR cameras, multiple neutron detectors, and multiple Langmuir probe arrays.

Appendix #1: Allowed Neutral Beam Power vs. Pulse Duration

Heating of the primary energy ion dump limits the beam duration to that given in the following table[1]:

Acceleration Voltage [kV]	MW per Source	MW per Beamline	Pulse Length [s]
65	1.1	3.2	8
70	1.3	3.8	7
75	1.5	4.5	6
80	1.7	5.1	5
85	1.9	5.8	4
90	2.1	6.4	3
95	2.4	7.1	2
100	2.6	7.7	1.5
105	2.8	8.4	1.25
110	3.0	9.0	1

Table A1: Beam power and pulse length as a function of acceleration voltage

Appendix #2: Table for neutron rate estimations:

Change only the blue cells					
I_p Range [kA]	Center of I_p Range [kA]	Number of Discharges	Typical Discharge Time [s]	Assumed Neutron Rate [N/s]	Fluence at this I_p [N]
$0<I_p\leq400$	200	0	0	0.00E+00	0.00E+00
$400<I_p\leq600$	500	0	0	1.00E+14	0.00E+00
$600<I_p\leq800$	700	0	0	2.00E+14	0.00E+00
$800<I_p\leq1000$	900	24	1	3.00E+14	7.20E+15
$1000<I_p\leq1200$	1100	0	0	4.00E+14	0.00E+00
$1200<I_p\leq1400$	1300	0	0	5.00E+14	0.00E+00
$1400<I_p\leq1600$	1500	0	0	8.00E+14	0.00E+00
$1600<I_p\leq1800$	1700	0	0	1.30E+15	0.00E+00
$1800<I_p\leq2000$	1900	0	0	2.00E+15	0.00E+00
Total # of Discharges		24	Total Fluence		7.20E+15

Table A2: Neutron Emission Rate Calculator. Double click to open in excel for automatic calculation. Change only the blue cells.

[1] J.E. Menard, et al., Nuclear Fusion **52**, 2012 (83015)