Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Optimized RWM control for high $<\beta_N>$pulse at low collisionality and l_i**

OP-XP-1023	Revision: **1.0**	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: S.A. Sabbagh	Date **4/8/10**
ATI – ET Group Leader: S.A. Sabbagh	Date
RLM - Run Coordinator: E. Fredrickson	Date

Responsible Division: Experimental Research Operations

RESTRICTIONS or MINOR MODIFICATIONS

(Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Optimized RWM control for high <β_N>pulse at low collisionality and l_i** No. **OP-XP-1023**

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1. Overview of planned experiment

Next-step ST devices (including the planned upgrade of NSTX) aim to operate at plasma collisionality and l_i below usual NSTX levels. For example, the near-term milestone application for the ST – a fusion component test facility (ST-CTF) – is envisioned to operate at a bit lower l_i and β_N than NSTX can reach at present (See Figure 1 in section 2). However, bridging the gap is non-trivial, as NSTX has not run with high reliability in this regime, and since this region of operational space makes a sharp transition to the purely current-driven kink mode. In 2009 XP948 (S.P. Gerhardt, et al.) showed significantly higher RWM activity in reduced l_i plasmas (l_i ~ 0.45 and below). The present experiment aims to improve reliability of RWM stabilization at low l_i, and to understand the impact of reduced plasma collisionality using the new LLD capability. Improved n = 1 RWM feedback control settings will be examined and the effectiveness of the new AC compensations in feedback for upper/lower RWM Bp, Br sensors will be assessed at low l_i (Br sensor feedback to provide RFA correction, Bp to provide RWM control). Superior control system settings could then be used in other NSTX XPs. Unfavorable ω_ϕ profiles for RWM stability would also be examined (and avoided) at low l_i. Differences in experimental vs. single mode vs. multi-mode RWM model expectation of the best spatial phase offset for lower / upper B_p sensors will be examined for low l_i mode eigenfunctions.

2. Theoretical/ empirical justification

Figure 1 gives a summary of the stability target for an ST-CTF along with results from XP948 that examined low l_i and high β_N operation in NSTX, and results of related stability calculations. NSTX has made steady progress toward the (l_i, β_N) target for CTF of ~ (0.35, 5.6), β_N/l_i = 16. A value of 11 was published for this parameter in 2006, and XP948 reached a value of 13 in 2009. However, the probability of RWM onset and significant beta collapses or disruptions occurred in about 50% of the shots taken, and many other shots terminated due to NTM onset and mode locking. In contrast, the ST-CTF target must be sustained indefinitely. Another critical consideration is that at these very low l_i values, a drastic change in ideal MHD stability can occur as the plasma reaches the purely current-driven kink limit. At this point, the plasma is kink unstable at any value of β_N in a non-rotating plasma. Computing ideal n = 1 stability for shot 135111 from XP948, using equilibria reconstructed with Thomson scattering electron pressure, CHERS ion pressure, and motional Stark effect pitch angle constraints, the plasma is shown to reach the no-wall limit at significantly reduced β_N = 2.8 (l_i = 0.38). This should be compared to the standard range of the n = 1 no-wall for NSTX H-mode plasmas of 4.0 – 4.6. This drastic reduction indicates a greatly increased instability drive due to the broader current density profile.

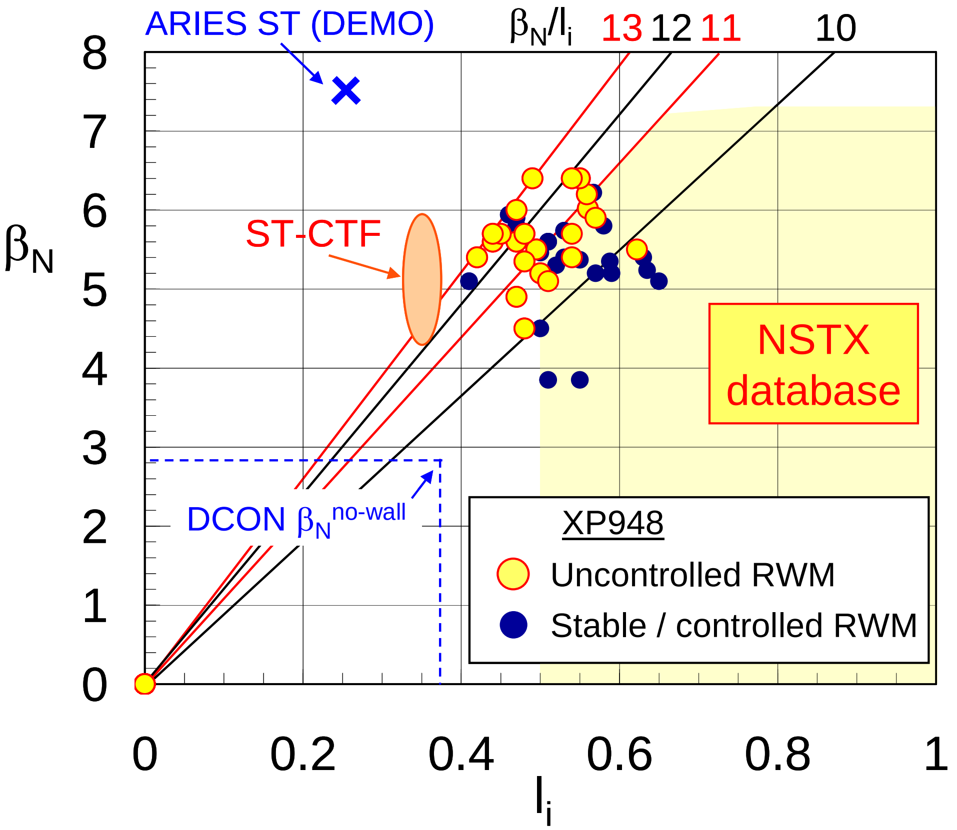

Figure 1: NSTX XP948 operational space in (l_i, β_N), which targeted low l_i and high β_N. Also shown is a schematic representation of the larger NSTX database, and the ST-CTF and ARIES-ST targets.

In addition to n = 1 active feedback, recent experiments and analysis have provided new tools and understanding to bring to bear on these low l_i plasmas. Plasma rotation profiles that lead to reduced RWM passive stabilization can be avoided using small levels of n = 3 magnetic braking. Real-time feedback on β_N was made available in 2009 and can be used to minimize fluctuation of this quantity and help avoid high pressure disruptions due to transient confinement improvements.

3. Experimental run plan

The experiment will focus on creating long pulse plasmas at low l_i and high β_N with minimal fluctuation of β_N over the pulse. The primary focus will be on finding superior settings for n = 1 RWM control, focusing mostly on feedback control phase, but also understanding the effect of new AC compensations to the RWM sensor input used in real-time control. The XP will rely on other XPs for target development where possible (e.g. XP1066 “LLD Survey”, S. Gerhardt, et al.). Real-time feedback on β_N will be used, along with modification of plasma rotation to avoid weakened RWM passive stabilization. In addition, operation with reduced plasma rotation will be examined to determine the importance of rotation in maintaining control at low l_i, as well as in RF plasmas, as requested by the NSTX PAC in 2010. A provision for performing similar n = 1 control optimization in RF plasmas is included for this purpose.

Task	Number of Shots	
0) Piggyback / pre-analysis		
A) Determine best upper/lower RWM sensor spatial offset from experiment (with new compensations), compare to single, multi-mode VALEN expectations; (choose settings for following runs)	-	
1) Generate low l_i and low collisionality targets (estimate ~ ½ day under revised schedule, no n scan w/LLD)		
(use low l_i, ν target from LLD survey XP, optionally fall back on low l_i, long pulse target from 2009 (shot 135111)		
A) Establish target plasma (2 or 3 NBI sources)	2	
B) Generate unstable RWM (by low l_i, and/or reduce plasma rotation / alter profile by n = 3 braking)	4	
C) Vary l_i and/ or collisionality, and/or edge pressure gradient	4	
2) Assess optimal settings for n = 1 feedback; add other tools for control/stabilization		
A) Feedback phase scan, Bp sensors with new AC compensation; +best setting w/ AC comp. off	6	
B) Feedback phase scan, Br sensors, new OHxTF, AC compensation; +best setting w/ AC comp. off	6	
C) Introduce β_N feedback to run steady, high $< \beta_N >_{pulse}$; use n = 3 braking if at unstable ω_ϕ for RWM	4	
3) Generate high <bN>pulse at low wE		
A) Generate lowest possible ω_ϕ at high β_N with n = 1 FB on; also with AC field and no FB for Xp1020	4	
B) Introduce β_N feedback to (A) to run steady, high $<\beta_N>_{pulse}$	2	
C) RF Approach: Apply best FB settings above to RF target with $\beta_N > \beta_N^{no-wall}$ (PAC recommendation)		8
(target established in other XPs (e.g. XP1012: LeBlanc RF H-mode XP, etc.)		
Total:	32;	8

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

Although this XP can run stand-alone, it can take significant advantage of plasma target and control system development from other XPs: XP 1066 “LLD Survey”, XP1019 “Optimized β_N feedback”, and XP1060 “RFA Suppression with Different Sensors/Time Scales in NSTX” (S. Gerhardt, et al.). The new RWM feedback algorithm “miu” available must be available and operational in the PCS, and the RWM coils must be in the standard odd parity n = 1, 3 configuration. Normalized beta feedback is also required. LITER operation is required. Warm LLD capability will be needed for alteration of collisionality if LLD demonstrates density pumping in 2010.

5. Planned analysis

NSTX EFIT reconstructions using MSE data will be used for ideal MHD stability analysis using DCON and as input to the VALEN code for RWM feedback analysis. Kinetic modification to ideal kink/ballooning stability analysis will be evaluated using the MISK code if the proximity to RWM marginal stability is needed.

6. Planned publication of results

The results are expected to be published as part of a 2010 IAEA Fusion Energy Conference submission. If the results show a clear demarcation of the current-driven kink limit in NSTX, these results may stand-alone as a separate publication as well. In addition, it is expected that the results will be presented at the APS DPP 2010 meeting in at least an oral contributed submission, and also at the 2010 MHD Mode Control meeting and ITPA MHD meeting.

PHYSICS OPERATIONS REQUEST

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Brief description of the most important operational plasma conditions required:

- RWM coils configured for $n = 1, 3$ operation
- $n = 1$ RWM active feedback required (using the new “miu” algorithm)
- β_N feedback system required
- LITER required
- LLD desired for density (collisionality) control if available

Previous shot(s) which can be repeated: 135111 and similar from XP948

Previous shot(s) which can be modified: 135111 and similar from XP948

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

I_{TF} (kA): **0.4 – 0.5T** Flattop start/stop (s):

I_P (MA): **0.9 – 1.2** Flattop start/stop (s):

Configuration: **Limiter / [✓ DN / LSN] / USN**

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

Outer gap (m): **0.06-0.10** Inner gap (m): 0.04 Z position (m):

Elongation: **2.1 – 2.5** Triangularity (U/L): **0.45-0.75** OSP radius (m): **< 0.5m**

Gas Species: **D** Injector(s):

NBI Species: **D** Voltage (kV) **A: 90** **B: 90** **C:** 80-90 Duration (s): ~ **1.3**

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

CHI: **[✓ Off] / On** Bank capacitance (mF):

LITERs: Off / [✓ On] Total deposition rate (mg/min): **30 (same as in XP948)**

LLD: Temperature (°C): **optimal for density pumping**

EFC coils: Off/[✓ On] Configuration: **[✓ Odd] / Even / Other** *(attach detailed sheet)*

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Beam Emission Spectroscopy		
Bolometer – divertor		**X**
Bolometer – midplane array		**X**
CHERS – poloidal		**X**
CHERS – toroidal	**X**	
Dust detector		**X**
Edge deposition monitors		
Edge neutral density diag.		**X**
Edge pressure gauges		**X**
Edge rotation diagnostic		**X**
Fast cameras – divertor/LLD		**X**
Fast ion D_alpha - FIDA		**X**
Fast lost ion probes - IFLIP		**X**
Fast lost ion probes - SFLIP		**X**
Filterscopes		**X**
FIReTIP		**X**
Gas puff imaging – divertor		**X**
Gas puff imaging – midplane		**X**
Hα camera - 1D		**X**
High-k scattering		**X**
Infrared cameras		**X**
Interferometer - 1 mm		**X**
Langmuir probes – divertor		**X**
Langmuir probes – LLD		**X**
Langmuir probes – bias tile		**X**
Langmuir probes – RF ant.		
Magnetics – B coils	√	
Magnetics – Diamagnetism	**X**	
Magnetics – Flux loops	√	
Magnetics – Locked modes	**X**	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		**X**
Magnetics – RWM sensors	**X**	
Mirnov coils – high f.		**X**
Mirnov coils – poloidal array		**X**
Mirnov coils – toroidal array	**X**	
Mirnov coils – 3-axis proto.		

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
MSE	**X**	
NPA – E‖B scanning		**X**
NPA – solid state		**X**
Neutron detectors		**X**
Plasma TV		**X**
Reflectometer – 65GHz		**X**
Reflectometer – correlation		**X**
Reflectometer – FM/CW		**X**
Reflectometer – fixed f		**X**
Reflectometer – SOL		**X**
RF edge probes		
Spectrometer – divertor		
Spectrometer – SPRED		**X**
Spectrometer – VIPS		**X**
Spectrometer – LOWEUS		**X**
Spectrometer – XEUS		**X**
SWIFT – 2D flow		
Thomson scattering	**X**	
Ultrasoft X-ray – pol. arrays		**X**
Ultrasoft X-rays – bicolor		**X**
Ultrasoft X-rays – TG spectr.		**X**
Visible bremsstrahlung det.		**X**
X-ray crystal spectrom. - H		**X**
X-ray crystal spectrom. - V		**X**
X-ray tang. pinhole camera		**X**