Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: **Improving $<\beta_N>_{pulse}$ vs. rotation under RWM control and beta feedback**		
OP-XP-934	Revision: **0**	Effective Date: **7/27/09** *(Approval date unless otherwise stipulated)* Expiration Date: **7/27/11** *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: S.A. Sabbagh	Date: 7/24/09
ATI – ET Group Leader: S.A. Sabbagh / S.P. Gerhardt	Date 7/27/09
RLM - Run Coordinator: R. Raman	Date 7/27/09
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Improving $<\beta_N>_{pulse}$ vs. rotation under RWM control and beta feedback** No. **OP-XP-934**

AUTHORS: **S.A. Sabbagh, R.E. Bell, S.P. Gerhardt, et al.** DATE: **7/24/09**

1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

Operation at high normalized beta with minimal fluctuation is highly desired for fusion energy applications. Combined n = 1 RWM and β_N feedback will be used to improve reliability of control at various plasma rotation levels, ω_ϕ. The experiment will attempt run at high levels of $<\beta_N>_{pulse}$ with a low level of β_N fluctuation. Limitation in reaching this goal will be determined, e.g. RWM triggering at different steady-state ω_ϕ levels. Characterization of success will be evaluated as a function of proximity to no-wall and with-wall beta limits, and ω_ϕ. RWM control will be re-optimized as a function of feedback phase angle in reversed B_t operation.

2. Theoretical/ empirical justification

Brief justification of activity, including supporting calculations as appropriate. Describe *briefly* any previous or related experiments.

Beta feedback control has been recently implemented on NSTX and was demonstrated to work. This XP would combine this new capability with the now widely used n = 3 error field correction and n = 1 active RWM control to best sustain β_N with minimal fluctuation as a function of plasma rotation. A key motivation to perform the experiment is to understand the interaction of the two control systems with rotation control, which will be afforded by n = 3 non-resonant magnetic braking. This braking mechanism has been shown in NSTX experiments to be consistent with a $T_i^{5/2}$ scaling. As NBI is controlled with increasing beta, NBI momentum input will decrease. This is expected to decrease T_i, and therefore non-resonant braking torques will increase as well. The dynamics of this system will be examined for feedback stability. The experiment will begin to address the NSTX Milestone R(10-1): "Assess disruptivity/sustained high β", and will add to results for ITPA joint experiment MDC-2 on RWM stabilization physics. Optimization of feedback phase angle has already been conducted in standard B_t operation, and so will simply be repeated in reversed B_t operation, with upper/lower RWM B_p sensor spatial phase mismatch set for the reversed field line helicity.

3. Experimental run plan

Describe experiment in detail, including decision points and processes.

For 2009, this experiment is set to run under tight time constraints at the end of the run period. The stated run plan would be applied from top-down in priority order. The approach is to operate at high β_N (from 4, to 6) in long pulse plasmas with I_p = 0.8 MA, using discharges from XP935 as initial targets. Lithium would be deposited using the LITER system. Quasi-steady-state plasma rotation levels would be established using guidance from XP933 (using n = 3 braking). Desired level(s) of β_N feedback would be set to demonstrate operation at these target levels, and to guard against confinement transients leading to secular increases in beta, and subsequent disruption. RWM control system settings would be changed if required. Once control is demonstrated, both beta feedback and n = 1 RWM control would be turned off in a plasma with an intermediate level of plasma rotation to compare to the stability of the two discharges. As time allows, a successful long-pulse shot with control would be repeated to assess reliability. The n = 1 RWM feedback phase scan would be performed in reversed B_t operation to support other reversed B_t experiments, and to assess any differences that might be found with reversed B_t.

The experimental procedure is given in the table below.

Run plan:

Task	Number of Shots
1) Create high β_N target plasma with lithium (150 - 250mg/shot – continue evaporation all run)	
- 3 NBI, $\kappa > 2.2$, $\beta_N > 6 > \beta_N^{no-wall}$, 133775 as setup / comparison shot; 135134 for β_N FB	
(i) n = 3 EFC, n = 1 Bp feedback alone, standard 2009 feedback parameters	1
(ii) β_N feedback with proportional gain - add β_N derivative gain ramp; retake shot with favorable β_N derivative gain based on ramped shot	2
(ii) β_N feedback set to high β_N levels (4, 5, 6) to test/demonstrate system	3
2) Add n = 3 braking to reduce ω_ϕ level – demonstrate stability at varied steady-state ω_ϕ	
- Use braking current guidance from XP933 – generate 2 - 3 different rotation levels	6
(note: τ_E drops with ω_ϕ transiently, need to assess in steady-state conditions)	
- change β_N feedback to 5 or 6 during this scan depending on $\omega_\phi(\tau_E)$	
- add n = 3 braking pulses (50 – 100 ms) to examine effect on β_N control	2
3) Eliminate control in unstable case	
- n = 1 FB and β_N control turned off, or gated off later in the shot (at reduced ω_ϕ)	2
4) Optimize n = 1 feedback if needed at varied wf	
- Vary B_p sensor FB phase at fixed gain about present "optimal" setting	2
5) Reproduce highest reliable $<\beta_N>_{pulse}$ in several repeated shots	2
6) n = 1 feedback phase scan (B_p sensors) in desired target plasma with reversed B_t	8
Total:	20
reversed Bt:	8

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

Describe any prerequisite conditions, development, XPs or XMPs needed.
Attach completed Physics Operations Request and Diagnostic Checklist.

- RWM coils configured for $n = 1, 3$ operation

- $n = 1$ RWM active feedback required

- β_N feedback system required

- LITER required

5. Planned analysis

What analysis of the data will be required: EFIT, TRANSP, etc.?

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. NTV torque profiles will be evaluated using analysis similar to past analyses performed separately by W. Zhu and J.-K. Park, but supplemented with recent modifications by K. Shaing. 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

What will be the final disposition of the results; where will results be published and when?

For the abbreviated run considered for 2009, the results would be expected to be shown at the APS DPP 2009 meeting (including in J.W. Berkery's invited talk), at the next ITPA MHD stability group meeting (contributes to joint experiment MDC-2), and at the MHD Mode Control meeting in 2009. The results may also appear in J. Berkery's Phys. Fluids paper associated with the APS invited talk, or if the results are extensive enough, in a separate publication.

PHYSICS OPERATIONS REQUEST

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

- RWM coils configured for n = 1, 3 operation
- n = 1 RWM active feedback required
- β_N feedback system required
- LITER required

List any pre-existing shots:

- 133775 (β_N > 6) to use as initial target shot

- 135134 for initial β_N feedback settings

Equilibrium Control: Gap Control / rtEFIT(isoflux control):

Machine conditions *(specify ranges as appropriate, use more than one sheet if necessary)*

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

I_P (MA): 0.8 – 1.0 Flattop start/stop (s):

Configuration: **Limiter / DN / LSN / USN** *(strike out inapplicable cases)*

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

Elongation κ: **2.1 – 2.4** Upper/lower triangularity δ: 0.45 – 0.75

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

NBI Species: **D** Voltages (kV or off) **A: 90** **B: 90** **C: 80-90** Duration (s): ~ 1.0

ICRF Power (MW): Phasing: Duration (s):

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

LITERs: Off / On Total deposition rate (mg/min): **10 - 20**

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
Bolometer – tangential array		X
Bolometer – divertor		X
CHERS – toroidal	X	
CHERS – poloidal		X
Divertor fast camera		X
Dust detector		X
EBW radiometers		X
Edge deposition monitors		X
Edge neutral density diag.		X
Edge pressure gauges		X
Edge rotation diagnostic		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		X
Hα camera - 1D		X
High-k scattering		X
Infrared cameras		X
Interferometer - 1 mm		X
Langmuir probes – divertor		X
Langmuir probes – BEaP		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism	X	
Magnetics – Flux loops	X	
Magnetics – Locked modes	X	
Magnetics – Pickup coils	X	
Magnetics – Rogowski coils	X	
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 – ExB scanning		X
NPA – solid state		X
Neutron measurements		X
Plasma TV		X
Reciprocating probe		
Reflectometer – 65GHz		X
Reflectometer – correlation		X
Reflectometer – FM/CW		X
Reflectometer – fixed f		X
Reflectometer – SOL		X
RF edge probes		
Spectrometer – SPRED		X
Spectrometer – VIPS		X
SWIFT – 2D flow		
Thomson scattering	X	
Ultrasoft X-ray 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 fast pinhole camera		X
X-ray spectrometer - XEUS		X