Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Active RWM stabilization system optimization and ITER support

OP-XP-802	Revision: **1.1**	Effective Date: **4/2/08** Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: S.A. Sabbagh	Date:
ATI – ET Group Leader: S.A. Sabbagh	Date
RLM - Run Coordinator: M.G. Bell	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Active RWM stabilization system optimization and ITER support** No. **OP-XP-802**
AUTHORS: **S.A. Sabbagh, R.E. Bell, S. Gerhardt, J.E. Menard, J.W. Berkery, J.M. Bialek, et al.** DATE: **4/2/08**

1. Overview of planned experiment

The key goal of the experiment is to alter the active n = 1 feedback control system configuration and parameters to achieve reliable RWM stabilization at various plasma rotation, ω_ϕ, levels, with emphasis on reduced rotation states more appropriate for comparison to ITER. Both radial and poloidal RWM sensors will be used, and feedback phase and gain for each type of sensor will be varied. New control system software allows superior specification of these gains, and also allows smoothing of the requested feedback control current waveforms which will be used to emulate shielding effects due to conducting material between the control coils and the plasma in ITER. Finally, to investigate the impact of a malfunctioning control coil, n = 1 feedback will be attempted with one coil disabled. In particular, the potential for the destabilization of n > 1 modes will be investigated under these conditions.

2. Theoretical/ empirical justification

This experiment continues the development of determining favorable n = 1 feedback system settings to achieve the highest reliability and to understand how the system provides stabilization. Active RWM stabilization was initially demonstrated in NSTX at reduced plasma rotation via n = 3 magnetic braking first using the upper poloidal field sensor set in NSTX.[1] While feedback performance was matched well by VALEN code calculations, instabilities were observed to arise in certain shots, with significant mode amplitude observed in lower Bp and/or radial field RWM sensors. Subsequent experiments followed in 2007 (XP729) that began to utilize both upper and lower arrays of RWM radial (B_r) and poloidal (B_p) field sensors. Some optimization of feedback system parameters was conducted in these experiments. For example, initial experiments using upper and lower B_p sensors found favorable settings for the feedback phase: RWM growth rates were reduced and discharge duration was extended (Fig. 1). An apparent "threshold" for instability was found in these experiments for the n = 1 B_r amplitude. This suggested using B_r sensors for feedback, and this was attempted in XP728 using B_r sensors alone. While the n = 1 B_r amplitude was reduced, the slower response of the radial field sensors due to the passive plates allowed faster growing modes measured by the B_p sensors to terminate the discharge. Further development in XP702 using plasmas with higher rotation included a spatial phase offset between upper and lower sensor sets. Optimizations of the feedback phase with this spatial phase offset, and the addition of n = 3 DC error field correction to best maintain plasma rotation yielded record pulse length at I_p = 0.9 MA in NSTX (Fig. 2).

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[1] S.A. Sabbagh, R.E. Bell, J.E. Menard, et al., Phys. Rev. Lett. **97** (2006) 045004.

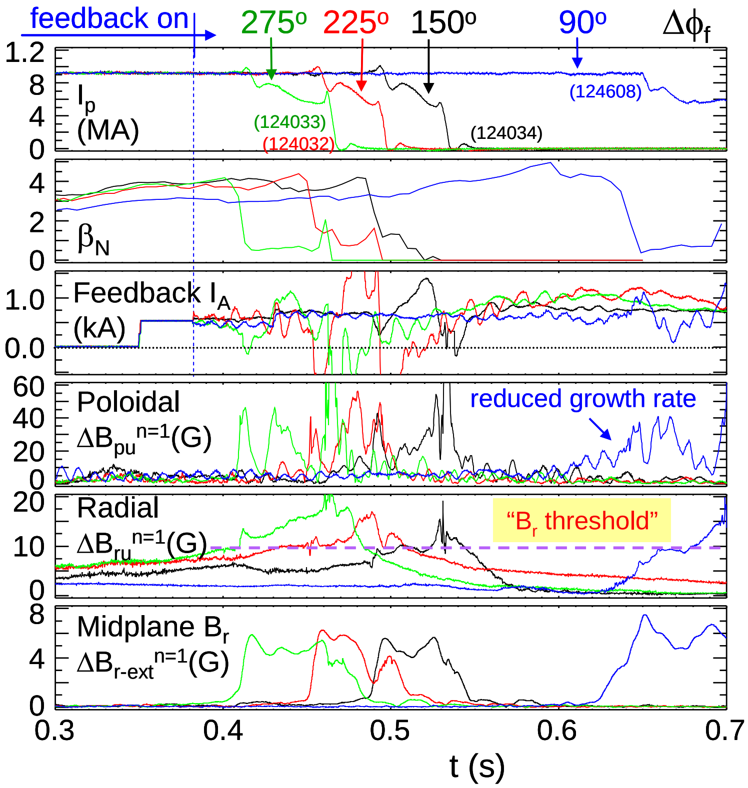

Figure 1: Reduction of RWM growth rate and increase in discharge duration for n = 1 feedback using upper and lower B_p sensors with zero spatial phase offset.

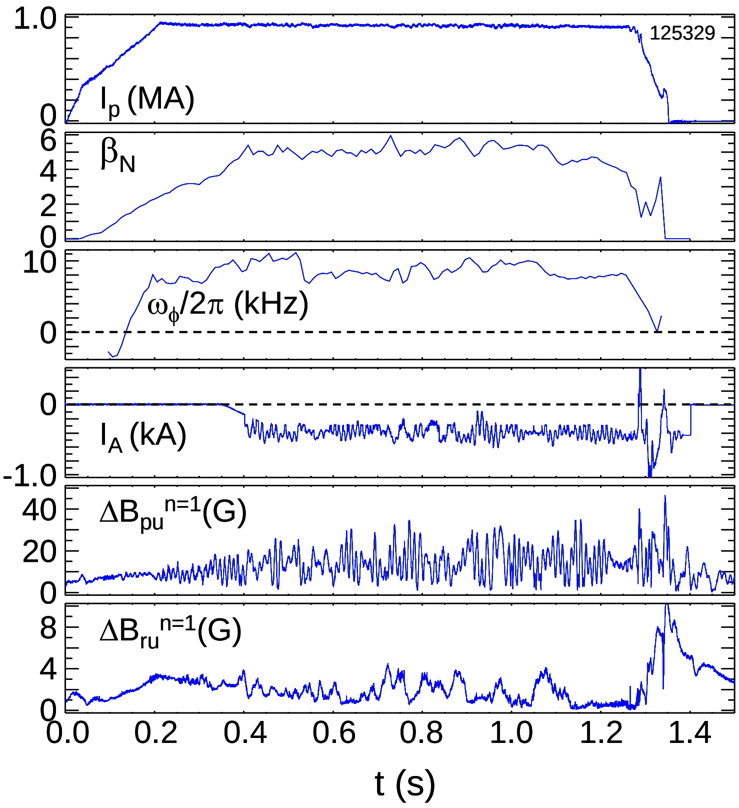

Figure 2: Record NSTX pulse lengths at I_p = 0.9 MA when n = 1 feedback was combined with n = 3 error field correction to sustain plasma rotation.

3. Experimental run plan

The background briefly discussed in Section 2 suggests that combining both B_r and B_p sensors for n = 1 feedback will be most effective at stabilizing the RWM at low plasma rotation. Feedback on the B_r sensors is meant to keep this field component low to avoid n = 1 resonant surfaces from locking. This should also help to maintain a broader plasma rotation profile that was observed in XP702, which might be favorable for stability. The addition of feedback on the n = 1 B_p sensor signal will be added in an attempt to control modes growing on RWM timescales. Experience from XP728 showed that separate gain settings for the B_r and B_p n = 1 feedback would be necessary for best performance. The control system software has been updated to easily allow the physics operator to set these gains separately.

In addition to emphasizing plasmas with reduced plasma rotation, other details of the experiment have been suggested to provide information for ITER. First, filtering of the feedback current request with a specified time constant will determine feedback performance as a function system response speed. This is meant to emulate filtering of feedback control currents by conducting structure in ITER, especially the blanket shield modules. Second, the potential effect of higher n modes will be examined in a scenario where one of the control coils is eliminated from the feedback loop. This is meant to simulate a situation where a single control coil of the presently envisioned ITER design would malfunction. The recently upgraded NSTX control system software allows both of these tests to be made. Note that the second task will require a special patch panel setting for the RWM control coil set, so this portion of the experiment will have to be conducted on a separate run day.

Experience from XP702 suggests that access to the lowest possible plasma rotation is best achieved using a broad plasma rotation profile. This was demonstrated using n = 3 DC error field correction (e.g. shot 125329). This experiment plans to utilize this technique to create target plasmas with the broadest possible rotation profile, then evolve the applied field away from n = 3 field correction to n = 3 field anti-correction, leading to standard non-resonant magnetic braking to slow the rotation.

Run plan: (feedback optimization at reduced ω_ϕ)

Task	Number of Shots
1) Create target plasma	
A) Run active feedback in piggyback mode in prior experiments to verify operation	-
B) 3 NBI, $\kappa > 2.2$, $\beta_N > \beta_N^{\text{no-wall}}$ (control shot) - 125329 as setup shot (n=3 correction)	2
C) moderate n = 3 braking once core ω_ϕ is reduced; generate RWM	3
2) Optimize n = 1 feedback sensors at intermediate wf	
A) Upper/lower B_r sensor feedback (start with past "best" FB phase; vary phase)	4
B) Vary B_r gain	2
C) Add upper/lower B_p sensors to feedback circuit, vary FB and u/l spatial phase	6
D) Vary B_p gain	2
3) Active RWM stabilization at low ω_ϕ	
A) vary onset time, ramp rate, magnitude of n = 3 braking	4
B) gate off feedback at low ω_ϕ	2
4) Reliability testing	
A) Repeat best low rotation stabilized shot in repeated shots (feedback gated off - add neon for SXR tomography)	4
	Total: 29

Run plan: (ITER support tasks)

Task	Number of Shots
5) Examine feedback performance vs. feedback system latency	
A) Increase feedback system latency from optimized settings to find critical latency for mode stabilization	4
6) $n = 1$ RWM stabilization with one RWM coil omitted	
A) Create low rotation target plasma with “$n = 3$” braking; generate RWM	2
B) As (A), but with neon for SXR tomography	3
C) Upper/lower Br sensor feedback; vary phase	4
D) Add upper/lower Bp sensor feedback ; vary phase	2
E) Vary feedback gain	3
	Total: 18

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 the ideal kink/ballooning stability analysis will be evaluated using the Hu-Betti-Manickam code (HBM) presently being developed and tested for NSTX.

6. Planned publication of results

Conclusions from this experiment that address the stabilization physics during active $n = 1$ feedback could justify publication in PRL. Results of the experiment, analysis of the feedback performance, and implications for ITER would be published at the 2008 EPS meeting if the experiment is conducted in time. In addition, the results should warrant publication in Nuclear Fusion and are expected to be presented at the 2008 IAEA Fusion Energy Conference.

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

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

I_P (MA): 0.8 – 1.1 Flattop start/stop (s):

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

Outer gap (m): **0.06 – 0.10** Inner gap (m): **0.04**

Elongation κ: **2.1 – 2.5** Upper/lower triangularity δ: 0.45 – 0.75

Z position (m):

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

NBI Species: **D** Sources: Voltage (kV): 80 - 100 Duration (s): 0.8

(Source A at 90 kV for MSE)

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

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

LITER: On / Off (XP can run with or without LITER)

Shot numbers for setup: **125329 (for plasma and n = 3 DC correction field), n = 3 DC field programming will be specified based on target plasma duration.**

DIAGNOSTIC CHECKLIST

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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 – RF ant.		
Magnetics – Diamagnetism	**X**	
Magnetics - Flux loops	**X**	
Magnetics - Locked modes	**X**	
Magnetics - Pickup coils	**X**	
Magnetics - Rogowski coils	**X**	
Magnetics - RWM sensors	**X**	

Diagnostic	**Need**	**Want**
Mirnov coils – high f.		**X**
Mirnov coils – poloidal array	**X**	
Mirnov coils – toroidal array	**X**	
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’r - H		**X**
X-ray crystal spectrom’r - V		**X**
X-ray fast pinhole camera		**X**
X-ray spectrometer - XEUS		**X**