Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**			
Title: **Search for multiple RWM behavior at high β_N**			
OP-XP-935	Revision: **1.2**	Effective Date: **5/13/09** *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*	

PROPOSAL APPROVALS

Responsible Author: S.A. Sabbagh	Date: 5/13/09
ATI – ET Group Leader: S.A. Sabbagh / S.P. Gerhardt	Date 5/13/09
RLM - Run Coordinator: R. Raman	Date 5/13/09
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Search for multiple RWM behavior at high β_N** No. **OP-XP-935**
AUTHORS: **S.A. Sabbagh, R.E. Bell, J.W. Berkery, et al.** DATE: **5/9/09**

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1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

Determine if the observed unstable RWM is born from an observed, stable RWM (with frequency at peak resonant field amplification, as investigated in XP931), or is an independent (second) mode. Either result is important. If these are same mode, the conclusion supports the single mode physics model, assumed in most tokamak analysis. This would be a key conclusion for RFA control of NBI to limit β_N (a future NSTX milestone). If the unstable mode is a separate mode from the stable one, the conclusion supports multi-mode theory, showing the importance of this model for RWM control in ST, and RFA control of NBI. The experiment would determine the β_N dependence of RFA and the effect of ω_ϕ for these modes, and the effect on active n = 1 control as marginal stability is approached and surpassed.

2. Theoretical/ empirical justification

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

In tokamaks, analysis of resonant field amplification (RFA) and control of unstable resistive wall modes (RWM) typically assumes that the least stable mode dominates the measured dynamics. However, theory states that modes with the ideal stability functional $|\delta W|$ closest to no-wall marginal stability yield the greatest response for a given input applied field (or inherent error field). As the system becomes less stable, the second least stable, or higher eigenfunction may meet this criterion. At the high β_N values attained in NSTX, this criterion has been met, nominally at β_N greater than about 5.5. Figure 1 shows $|\delta W|$ for the two least stable modes in NSTX shot 120038 as an example. The yellow bands indicate where ideal theory would say that the second least stable eigenfunction would be expected to dominate the system dynamics.

3. Experimental run plan

Describe experiment in detail, including decision points and processes.

This experiment is designed to be supported by, and to run after XP931 "Effect of the active stabilization of RWMs on the background plasma" by L. Delgado-Aparicio, et al. In that experiment, the observed RFA will be diagnosed using the multi-energy SXR (ME-SXR). This result will be used to compare to unstable RWM generated in the present experiment.

A standard approach to an experiment of this kind is to determine ideal mode structure from theory and compare to measured external magnetics. In this experiment, we attempt to directly measure the stable RWM (RFA) and the unstable RWM to determine if they are distinct. The ME-SXR diagnostic (along with the SXR diagnostic) allows a direct approach to measuring the global extent of the mode, and the mode frequency. Diagnosing the stable RFA with the SXR diagnostics and external magnetics is the goal of XP931, and will be used as input here.

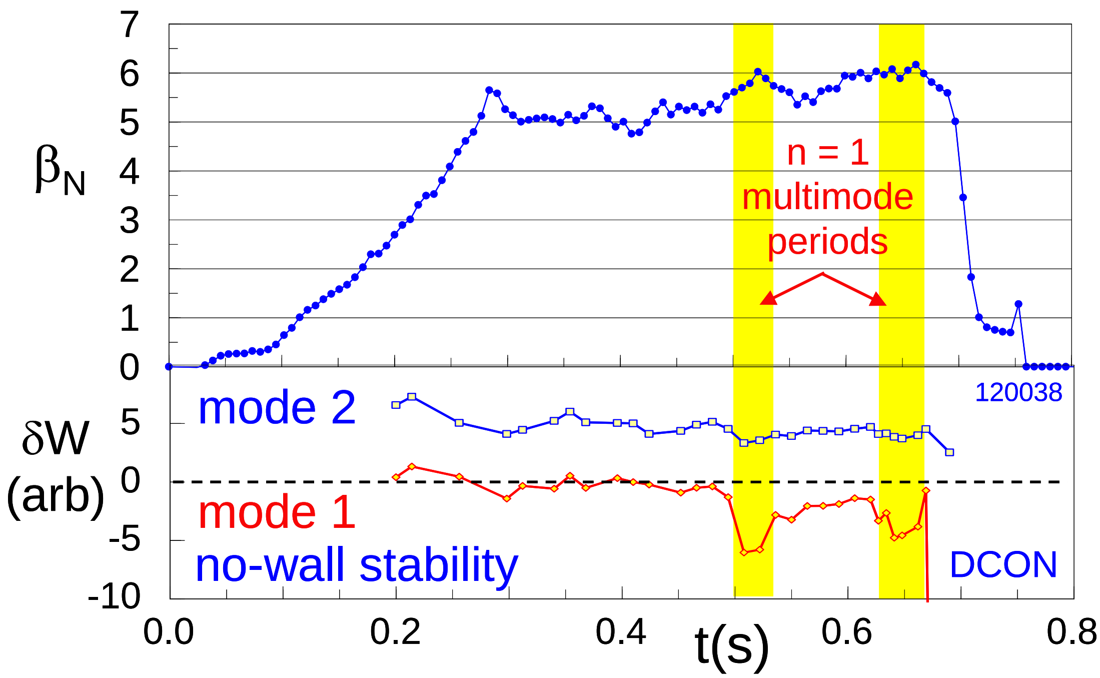

Figure 1: Ideal MHD stability for the two least stable n = 1 modes (NSTX discharge 120038). The vertical bands indicate where the 2^{nd} least stable mode is expected to have a greater response to external stimulus than the least stable mode.

In the present experiment, attention will be placed on running the plasma at β_N values among the highest in the NSTX, and bringing the plasma to marginal RWM stability via high β_N and plasma rotation variation. The unstable RWM will either grow from the stable, rotating RFA as marginal stability is approached, or the observed mode growth will be independent of stable RFA as the instability threshold is crossed. The modes will be distinguished by comparing mode frequencies and the global extent of the modes. The RFA has been observed with ME-SXR at ~ +30 Hz (co-rotation) and the radial extent has been determined from signal inversion. XP931 will diagnose this activity in a controlled experiment at moderate β_N below n = 1 RWM marginal stability and correlate it with output from RWM magnetic sensors, which measure mode amplitude and phase/mode rotation. Measurements using magnetic RWM sensor in experiments approaching the RWM marginal stability point show that the unstable RWM can be born rotating, “wobbling” (restricted oscillation in toroidal angle), or more typically grows locked. Mode growth and rotation for n = 1,2, and 3 modes are typically measured by the RWM sensors. This information will be supplemented with the ME-SXR and USXR measurements to determine of the RFA and unstable RWM are distinct modes, or not.

The experimental procedure is given in the table below.

Run plan:

Task	Number of Shots
1) Create target plasma (use Li conditioning)	
A) Start from high performance fiducial w/n=1 FB (133078), adjust I_p for maximum β_N	4
B) Ramp n = 3 from correction to braking to reach RWM marginal stability, n = 1 FB off	2
C) Add n = 1 AC pre-programmed +30Hz to quasi-steady-state, n = 1 FB off	2
2) Vary ω_ϕ and β_N	
A) Reduce ω_ϕ with n = 3 braking at highest β_N (full NBI power)	4
B) Reduce ω_ϕ with n = 3 braking at reduced $\beta_N > \beta_N^{\text{no-wall}}$ (reduced NBI power)	4
3) Compare results under active n = 1 RWM control	
A) Repeat conditions from (2a) with AC pre-programmed +30 Hz off, n = 1 FB on	3
B) Repeat conditions from (2a) with AC pre-programmed +30 Hz on, slow n = 1 EFC on	3
4) Control shots	
A) Magnetics only shot with n = 3 waveform and n = 1 AC pre-programmed field	1
	Total: 23

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

- SXR filters set for optimal RWM and RFA detection (based on results from XP931).

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. The new multi-mode VALEN code will be tested using equilibria from this experiment. Kinetic modification to ideal kink/ballooning stability analysis will be evaluated using the MISK code.

6. Planned publication of results

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

As stated in the Overview section, as long as a clear conclusion can be made as to whether the observed RFA and RWM are of single or multi-mode origin, the result will be important regardless of the specific conclusion. Either case may warrant publication in Phys. Rev. Lett., especially if multiple modes are found. If the conclusion shows the RFA and RWM as a single mode, the result may be more suitable for Phys. Plasmas or Nuclear Fusion. Either result would be shown at the APS DPP and MHD Mode Control meetings in 2009, and at the next ITPA MHD stability group meeting.

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
- SXR filters set for optimal RWM and RFA detection (based on results from XP931).

List any pre-existing shots:

- 133340 ($\beta_N = 6.6$), 133078 (fiducial); 132558 (1 MA, $\beta_N = 6.5$)

- 133311, 133313 (n = 1 AC RFA seed field)

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 – 1.3 Flattop start/stop (s):

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

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

Elongation κ: **2.1 – 2.6** 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: **<u>Off</u> / On** Bank capacitance (mF):

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

EFC coils: Off/<u>On</u> Configuration: **<u>Odd</u> / 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**