Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**			
Title: Active Stabilization of the Resistive Wall Mode at Low Aspect Ratio			
OP-XP-615	**Revision: V1.0 (from Xp535 v1.2)**	Effective Date: 3/10/06 *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*	
PROPOSAL APPROVALS			
Author: S.A. Sabbagh, et al.			Date:
ATI – ET Group Leader: J. Menard			Date
RLM - Run Coordinator: R. Raman			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 Stabilization of the Resistive Wall Mode at Low Aspect Ratio OP-XP-615

1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

The overall goal of the experiment is to actively stabilize resistive wall modes (RWMs) in NSTX plasmas that are above the ideal no-wall beta limit and below the critical plasma rotation frequency for RWM stabilization. A milepost moving toward this goal is suppression of resonant field amplification (RFA) due to the stable RWM.

This experiment will be the first of its kind attempted on NSTX, so the specific goals of the experiment target subjects appropriate for the initial active feedback system:

1. Active stabilization of low rotation target plasmas at high normalized beta: NSTX plasmas that exceed the ideal no-wall beta limit are passively stabilized by plasma rotation. RWM XPs run this year have demonstrated the ability to reduce plasma rotation in a controlled manner, allowing the RWM to become unstable. These high beta, low rotation targets are reproducible, and are good candidates for active stabilization.
2. Initial investigation of feedback gain and phase: This initial investigation will concentrate on observing the plasma response to an applied $n = 1$ helical field produced by the RWM stabilization coil set. The applied field will be actuated dynamically by a real-time mode detection based on the measured RWM sensor data. The primary independent variables will be the feedback gain (G) and phase (δ).
3. Suppression of resonant field amplification: A corollary to the first goal is the suppression of RFA before the RWM becomes unstable. This suppression will be attempted as we move toward active stabilization of the RWM.
4. Comparison to theory: Both analytic (single mode model) and computational (VALEN) models of active RWM feedback performance have been used to determine the theoretical performance of active RWM stabilization in DIII-D. Data from the present experiment would be used to compare RWM stabilization theory to experiment for the first time in low aspect ratio geometry.

This experiment will also provide important results from a general standpoint. It will demonstrate significant new and important NSTX machine capability. Also, with the capability of NSTX to produce low rotation targets, it will immediately address the stabilization of plasmas in a regime of plasma rotation that is ITER relevant.

2. Theoretical/ empirical justification

Brief justification of activity including supporting calculations as appropriate

Active RWM stabilization has been envisioned for more than a decade to allow sustained high performance operation of plasmas above the ideal MHD no-wall beta limit. Recent experiments in DIII-D have observed active stabilization, with some initial investigation of stabilizing low rotation targets for short time periods. More attention has been placed experimentally on dynamic stabilization of error fields, since such correction is required in DIII-D to surpass the no-wall beta limit.

While theory and experiment on active RWM stabilization exist, the application is in its infancy, and the physics basis for optimal active feedback system parameters is still an area of active research. No results yet exist for low aspect ratio geometry. Results from more conventional aspect ratio tokamaks provide a good starting point for the investigation. DIII-D typically utilizes a feedback system with RWM sensor actuators fed to a controller using proportional gain, and the applied field response is typically set to a fixed phase shift from the measured field.

The initial NSTX experiment will use control system software written to provide basic feedback control. The system will allow n=3 fields for plasma rotation control, so that the RWM stability boundary can be crossed at a precise moment in the discharge, so that target conditions for stabilization can be reached relatively quickly. The NSTX RWM active stabilization system will be set to engage when RWM sensors surpass a threshold level of n=1 helical field amplitude. The response will be proportional to the measured field, with a given phase shift.

3. Experimental run plan

Describe experiment in detail, including decision points and processes

The experiment would be conducted in two parts. The first part will comprise the first RWM active stabilization experiments in NSTX, and so will focus on examining the impact of the stabilization system on the easier target to stabilize – plasmas near RWM marginal stability that are rotating sufficiently to provide a significant level of passive stabilization. With this experience, the more difficult task of stabilizing a low rotation target plasma will be examined in the second part.

PART I: Active stabilization of rotating target plasma near RWM marginal stability

The run plan follows a logical sequence, demonstrating the result of the initial RWM active feedback system:

1. Create a plasma with maximum margin above the n=1 ideal MHD no-wall stability limit (the presented computed maximum margin over this limit is 50% - $\beta_N = 6$, $\beta_{N\text{ -nowall}} = 4$).

2 Apply pre-programmed n=3 helical field for plasma rotation control such that the RWM stability boundary is reproducibly crossed during a period in the discharge free of n=1 tearing mode activity. (This is the control shot).

3. Bring to bear the RWM active stabilization system on the control shot. Choose a phase that is 180 degrees from the measured n=1 RWM phase plus a phase shift to approximately compensate for the field penetration of the vacuum vessel and plasma rotation (based on XMP45, this value appears

to be 270 degrees, but the value may change based on further analysis, In any event, it is only an initial value.).

4. Vary phase shift of the applied field relative to the measured RWM field perturbation to determine the effect on unstable mode cancellation.

5. Vary proportional gain to produce a measurable effect of the feedback field on the plasma.

The specific shotlist is:

PART I Run plan: (24 shots)

Task	Number of Shots
1) Create target plasma with high margin over the ideal no-wall beta limit (control shot)	
(use 116861 as setup shot)	
A) Produce at least a 0.2s period free of n=1 tearing mode activity	2
2) Drive control shot over the RWM marginal stability boundary	
A) Apply pre-programmed n = 3 helical field to reduce plasma rotation below the RWM critical rotation frequency	
(ii) Vary n = 3 current to produce unstable RWM during n = 1 tearing mode free period	4
3) Observe effect of RWM active stabilization system	
A) Vary n = 1 AC feedback gain for a given phase shift between measured/applied field (set threshold of measured mode amplitude for feedback based on (2) above)	2
B) Vary n = 1 AC feedback relative phase between measured/applied field	10
C) Vary n = 1 AC feedback gain for most favorable phases	6
Total:	24

PART II: Active RWM stabilization of low rotation target plasmas

After establishing the best conditions and control system parameters for stabilization of the RWM marginally stable target, the experiment would determine the system's present capability of stabilizing the RWM in plasmas with reduced plasma rotation. The logic for the run plan is:

1. Create a plasma with maximum margin above the n=1 ideal MHD no-wall stability limit, reducing plasma rotation with n = 3 braking such that the RWM stability boundary is crossed in a reproducible manner during a period in the discharge free of n=1 tearing mode activity. (This is the control shot).

2. Stabilize the RWM in the control shot with the active feedback system set up with optimal parameters determined in Part I of the XP.

3. Reduce the plasma rotation in the feedback stabilized plasma by altering the current creating the n = 3 field used to slow the plasma rotation.

The specific shotlist is:

<u>PART II Run plan</u>: (18 shots)

Task	Number of Shots
1) Create target plasma with high margin over the ideal no-wall beta limit (control shot)	
(use target from Part I as setup shot)	
A) Produce at least a 0.2s period free of n=1 tearing mode activity	2
2) Drive control shot over the RWM marginal stability boundary	
A) Apply pre-programmed n=3 helical field to reduce plasma rotation below the RWM critical rotation frequency	
(ii) Vary n = 3 current to produce unstable RWM during n=1 tearing mode free period	2
3) Reduce plasma rotation profile toward zero / alter feedback system parameters as required	
A) Increase n = 3 DC field in increasing steps, 100 ms in duration	1
B) Vary n = 3 time evolution and magnitude to produce reduced plasma rotation	2
C) Vary n = 1 AC feedback relative phase shift for a given gain between measured/applied field about the baseline value to determine optimal stabilization	2
D) Vary n = 1 AC feedback relative phase between measured/applied field for a given gain about the baseline value to determine optimal stabilization	2
E) Alter n = 3 time evolution / magnitude to further reduce plasma rotation profile and repeat steps C and D as required/desired.	8
Total:	19

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

As usual, standard magnetic diagnostics are essential. Diamagnetic loop and Thomson scattering are required since partial kinetic EFIT reconstructions are needed for this experiment. CHERS is required for toroidal rotation and ion temperature profile evolution. MSE is highly desired for this experiment, but not absolutely required. The initial NSTX RWM feedback control system will be required. The internal RWM sensor set will be required for RWM detection and operation of the RWM active feedback system.

5. Planned analysis

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

EFIT at all run levels, including toroidal rotation and flux isosurface constraint (level 3), will be important for this experiment, and will be run for each shot of interest. If MSE data is available for this run, it will also be incorporated into the reconstructions. DCON will be used to determine no-wall and with wall β_N limits and RWM mode structure. VALEN, including the effect of RWM mode rotation, will be used to model the performance of the feedback system and compared to the experimental results. MARS-F runs will be run to determine RWM stability with rotation and to test present code dissipation models for NSTX data.

6. Planned publication of results

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

Active stabilization of the resistive wall mode, especially in low rotation target plasmas, is of major interest in the fusion community today, and important to the ITER and future burning plasma devices. If performed successfully early in the 2006 experimental run, the result would be the first stabilization of the RWM in a low rotation target plasma. RWM stabilization in the ST could also expose nuances of the stabilization technique. In either case, the significant new experimental findings and the associated theoretical understanding would warrant rapid publication in Physical Review Letters. If the technique and the relevant physics turn out to be similar to that found in tokamaks, then the publication of the present experiment results would be appropriate for Physics of Plasmas, or Nuclear Fusion.

PHYSICS OPERATIONS REQUEST

Title: Active stabilization of the resistive wall mode at low aspect ratio OP-XP-615

Machine conditions (specify ranges as appropriate)

I_{TF} (T): **0.35 – 0.45T** Flattop start/stop (s): _____/_____

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

Configuration: **Lower Single Null (minimize no-wall limit)**

Outer gap (m): 5+/**- 3 cm**, Inner gap (m): **5 +/-3 cm**

Elongation κ: **2.1 – 2.5**, Triangularity δ: **0.4 – 0.5**

Z position (m): **0.00**

Gas Species: **D / He**, Injector: **Midplane / Inner wall / Lower Dome**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **max**; A at 90kV, Duration (s):

ICRF – Power (MW): ____, Phasing: **Heating / CD**, Duration (s): _____

CHI: **Off**

Either: List previous shot numbers: **119565, applied field WFs TBD from XMP45**

Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

Title: Active stabilization of the resistive wall mode at low aspect ratio OP-XP-615

Diagnostic	Need	Desire	Instructions
Bolometer – tangential array			
Bolometer array - divertor			
CHERS	X		
Divertor fast camera			
Dust detector			
EBW radiometers			
Edge deposition monitor			
Edge pressure gauges			
Edge rotation spectroscopy			
Fast lost ion probes - IFLIP		X	
Fast lost ion probes - SFLIP		X	
Filtered 1D cameras			
Filterscopes			
FIReTIP		X	
Gas puff imaging			
Infrared cameras			
Interferometer - 1 mm			
Langmuir probe array			
Magnetics - Diamagnetism	X		
Magnetics - Flux loops	X		
Magnetics - Locked modes	X		
Magnetics - Pickup coils	X		
Magnetics - Rogowski coils	X		
Magnetics - RWM sensors	X		
Mirnov coils – high frequency		X	
Mirnov coils – poloidal array		X	
Mirnov coils – toroidal array		X	
MSE		X	
Neutral particle analyzer		X	
Neutron measurements		X	
Plasma TV	X		
Reciprocating probe			
Reflectometer – core			
Reflectometer - SOL			
RF antenna camera			
RF antenna probe			
SPRED			
Thomson scattering	X		
Ultrasoft X-ray arrays		X	
Visible bremsstrahlung det.			
Visible spectrometers (VIPS)			
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray PIXCS (GEM) camera			
X-ray pinhole camera			
X-ray TG spectrometer			