Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Characterization of the Resistive Wall Mode in the Spherical Torus		
OP-XP-202	**Revision: v1.3**	Effective Date: 12/17/01 *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS	
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Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

<u>Title</u>: Characterization of the Resistive Wall Mode in the Spherical Torus

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1. Overview of planned experiment

Describe the scientific goals of the experiment.

Low toroidal mode number kink/ballooning instabilities have been a major obstacle to attaining high beta in tokamak experiments at conventional aspect ratio. Designs for optimized equilibrium configurations, including the low l_i, high β_t, high bootstrap fraction conceptual design target equilibrium for NSTX rely on wall stabilization of low-*n* kink/ballooning modes.

Temporary suppression of these modes using conducting wall stabilization has been documented on several devices, including PBX-M, HBT-EP, and DIII-D. Research over the past several years has focused on the behavior of these beta-driven instabilities in the presence of a conducting wall. At beta values above the theoretically computed ideal MHD beta limit assuming no stabilizing conducting structure (the so-called "no-wall" beta limit), the kink mode does not simply stabilize, but instead persists as a resistive wall mode (RWM). This mode has been observed in NSTX.[1] This observation was the first step toward understanding the physics of the mode in a low aspect ratio torus. Significant theoretical analysis was performed on reconstructed experimental data that shows the mode to follow the general picture of the RWM observed in the advanced tokamak, but with certain significant differences in mode structure, instability threshold, and stable operating window.

Further experimental data is required to document the full characteristics of the mode, and highly desired for the physics analysis that will lead to a design of an optimized active mode control system for NSTX.

The present experiment aims to fully document the characteristics of the resistive wall mode in low aspect ratio geometry and to utilize passive mode stabilization to being to operate significantly above the no-wall beta limit. The goals of this experiment are to:

1. Target development and setup:

- Generate a target plasma that exceeds the no-wall ideal MHD beta limit in NSTX as determined by ideal MHD stability analysis ($\beta_N > 6\ l_i$ if possible) for many (~ 10) times the conducting stabilizer plate time constant (τ_{wall} ~ 5 ms). (Several CY02 plasmas can serve this purpose with a small amount of development).
- Measure the rotation damping rate due to the RWM with the newly reduced error field, and compare this rate to what was observed in the CY 2001 run campaign.

[1]"Beta-limiting Instabilities and Global Mode Stabilization in NSTX", S.A. Sabbagh, R.E. Bell, M.G. Bell, *et al.*, submitted to *Physics of Plasmas*.

- Determine the critical rotation frequency for RWM growth, and examine its dependence on Alfven frequency.

2. Variations:

- Perform a plasma boundary / conducting wall gap scan to determine the dependence of toroidal rotation damping and critical rotation frequency on gap magnitude.
- Perform toroidal field scan to determine the dependence of critical rotation frequency on Alfven speed. If time permits, perform density scan at fixed toroidal field to make Alfven speed variation.

3. Measurements

- Measure critical rotation frequency for RWM growth in conditions outlined above.
- Measure δTe mode perturbation using unequal Thomson scattering pulse interval.
- Measure other mode structure as diagnostics (magnetics, SXR) allow.
- Attempt varying localization of toroidal rotation damping and correlate to the radial variation of mode amplitude (possible through equilibrium profile variation – CHERS toroidal rotation profiles required).

4. Analysis and accessory goals

- Compare expectations of mode structure, dynamics, and stability limits between theory and experiment.
- Make initial assessment of best configuration to be used for DIII-D/NSTX RWM similarity experiment.

2. Theoretical/ empirical justification

Brief justification of activity including supporting calculations as appropriate

The resistive wall mode has been observed in NSTX (reported at the 2001 APS DPP meeting). The theoretical stability threshold was also computed for reconstructed experimental NSTX plasmas and was shown to be in very good agreement with experiment (Figure 1). The theoretical mode
structure was also computed for these equilibria, and significant differences in wall coupling are expected due to the low aspect ratio and high q operation of the ST as compared to the advanced tokamak.

In the CY 2001 experiment (XP 17), plasmas that exhibited the RWM did so for a relatively short duration (up to 3.5 conducting plate wall times) compared to the duration observed in the DIII-D device. Both rapid toroidal rotation damping (-300 kHz/s) and the proximity of the NSTX plasma to the with-wall ideal stability limit play a role in the observed duration in NSTX.

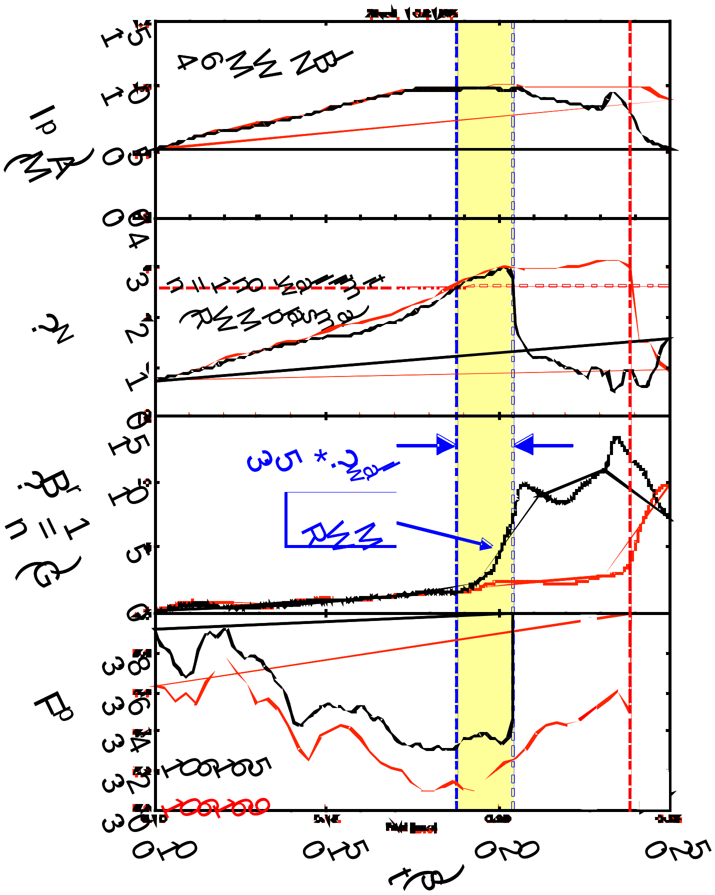

Figure 1 The resistive wall mode in NSTX observed in the locked mode detector (black, thick trace) is coincident with the violation of the ideal no-wall limit. The plasma illustrated by the red (thin) trace does not display the mode.

In the present XP, the first goal is to extend the period over which the ideal no-wall beta limit is violated. By operating in the CY 2002 NSTX coil configuration - with the corrected positioning of the PF5 coil – toroidal rotation damping might be greatly reduced if the rotation damping is related to the PF5 static error field. Also, using the present XP 17 RWM results and analysis as a guide, configurations will be operated to increase the gap in β_N between the no-wall and with wall β_N limits. This can be done by operating a plasma with reduced l_i and a broader pressure peaking factor.

Theoretically computed stability for target RWM configurations show that plasmas with relatively broad pressure profiles, F_p < 3, and q_0 ~ 2 (or at least significantly greater than 1) yield an unstable mode that has a large external component. This desired target, which originally was thought to be difficult to reach, has been created in NSTX at high toroidal field (4.5 kG) – shot 107499. Because this plasma also has a significantly extended pulse length and both high β_N and β_N / l_i, it serves as a good starting point.

Figure 2 illustrates the general approach of the experiment. First, a plasma will be created that is stable without the influence of the stabilizing conducting plates in the device. Once sufficiently large β_N is reached to allow the RWM to become significantly pressure-driven so that the mode amplitude becomes large at large major radius, the l_i will be clamped or reduced. This clamping or reduction of l_i has been demonstrated in NSTX in shots such as 107499 mentioned above most likely by bootstrap current effects at high β_p. Further reduction of l_i may be produced with gentle positive current ramping once the plasma is heated.

Operation above the ideal no-wall limit could be achieved by attempting to reduce the no-wall β_N limit through equilibrium modification, thereby producing a β_N limit lower than $\beta_N = 6\ l_i$ (for example, at higher pressure peaking). This technique is considered a contingency plan for the present experiment. The initial plan will be to operate at β_N significantly above 6 l_i if possible. Note that XP210 “Dependence of resistive wall stabilization on equilibrium configuration” by F. Paoletti, *et al.* (approved by and run through ISD Experimental Task Group) has also generated RWM plasmas with greater pressure peaking that could be used in this experiment (i.e. 107195).

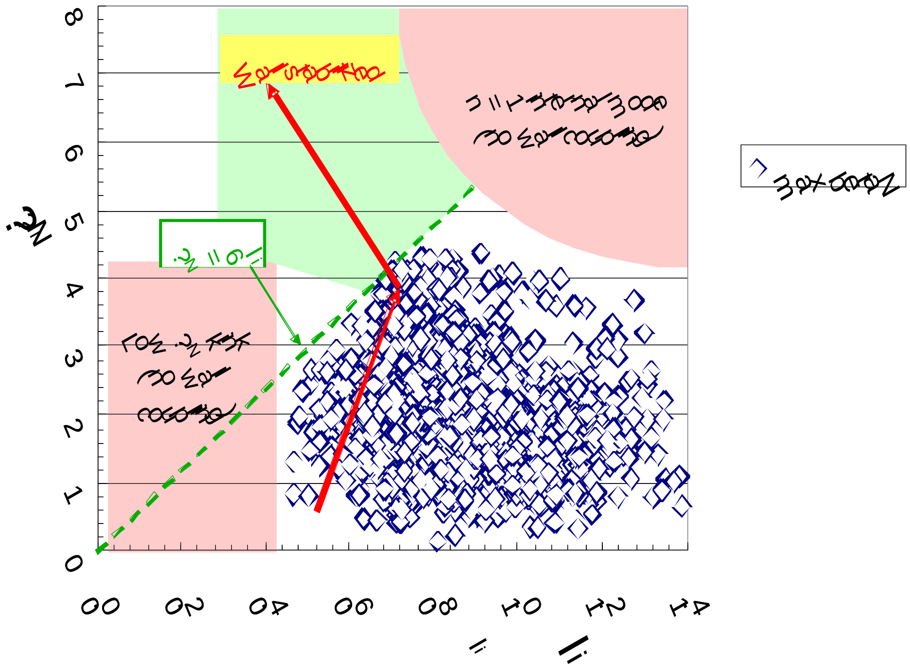

Figure 2 Primary approach of the present experiment in violating the ideal no-wall β_N limit and generating the resistive wall mode.

Once a target in (β_N, l_i) space above the no-wall β_N limit is established, and the RWM is observed, the duration of the high β_N phase will be increased to 10 wall times (about 50 ms) or greater, if possible. This plasma will allow a starting point for the determination of the mode characteristics. Critical rotation frequency will be determined. Toroidal field will be varied to deteremine the dependence of the critical rotation frequency on the Alfven frequency. Finally, as many diagnostics as possible will be brought to bear to determine the mode structure of the RWM in the low aspect ratio, high *q* operation of NSTX. These would include Thomson scattering with short intervals between lasers to determine the Te perturbation caused by the RWM, magnetics to determine toroidal mode number, and perhaps give an indication of the mode structure near the center column, USXR, and the locked mode detector.

If possible, the target plasma of this experiment would be configured so that a plasma with analogous cross-section could be created in DIII-D. This target plasma would be used as a starting point for the NSTX / DIII-D RWM similarity experiment, proposed by Sabbagh and Garofalo at the last NSTX forum for the NSTX CY 2002 run.

3. Experimental run plan

Describe experiment in detail, including decision points and processes

The run plan would proceed as follows:

FIRST Phase: (14 shots)

Generate configuration with maximum β_N/l_i and sustained RWM:

Task	Number of Shots
A) Create desired shape:	
- Reproduce LSN 107499, I_p = 0.8 MA, B_t = 4.5 kG (attain / maintain H-mode if possible)	2
- Alter configuration to reduce no-wall limit	4
- Reduce $\delta < 0.3$, increase $\kappa \sim 2.2$ (LSN or DND)	
B) Decrease l_i by increasing I_p slowly to ~ 1 MA after plasma is heated	3
C) If RWM is not observed, bring full power NBI early to increase pressure peaking (i.e. 107195)	2
D) Alter timings to sustain $\beta_N > \beta_{N\text{-no-wall}}$ for > 10 τ_{wall} (i.e. drop one NBI source after exceeding no-wall limit)	3
	Total: 14

SECOND Phase: (18 shots)

Perform gap scan and diagnosis of RWM

Task	Number of Shots
A) Vary plasma / conducting wall gap on most favorable configuration above	6
B) Vary B_t to determine dependence of critical rotation frequency on Alfven frequency	4
C) Vary Thomson laser pulse timing to diagnose δT_e before / after RWM onset	4
D) Vary B_t, n_e together to determine effect of combined alteration on critical rotation frequency	4
	Total: 18

Total number of shots: 32

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

The list of diagnostics:

- Flux loop and plasma current data are required.
- Integrated poloidal Mirnov coil data is required.
- CHERS toroidal rotation measurement is required.
- Locked mode detector is required.
- Thomson scattering is required.
- Measurement of the shaping and OH coil currents are required.
- Toroidal Mirnov coil data is highly desired.
- USXR is highly desired.
- The diamagnetic loop is required for partial kinetic EFIT reconstruction.
- Fast camera is highly desired.
- Measurements of currents in passive conducting plates is highly desired.
- D_α , C_{III} measurements are highly desired.

5. Planned analysis

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

Partial kinetic EFIT analysis is crucial to not only the final publication of the data, but also for stability analysis during the run. PHOENIX EFIT is essential for determining the equilibrium configuration, and also for input to ideal stability analysis codes. DCON and GATO will be used to determine the ideal stability analysis for the configurations generated. Having DCON run automatically shot-to-shot through PHOENIX is desired but not required for the experiment to be run. The VALEN code will be used for both designing optimal plasma configurations for RWM study, and to design optimal RWM feedback systems for a future active mode control system on NSTX.

6. Planned publication of results

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

Diagnosing the RWM in a spherical torus with the plasma lasting above the no-wall limit for 10 τ_{wall} would be appropriate for publication in Physical Review Letters. If the existing RWM data and analysis is published in PRL before this experiment, the combined data set might be more appropriately published in a longer journal article. Also, this data and analysis would be presented at the 2002 IAEA meeting on the subject of RWM observation and stabilization in the spherical torus if such an abstract is accepted.

PHYSICS OPERATIONS REQUEST

Title: Characterization of the Resistive Wall Mode in the ST **XP No.: 202**

Machine conditions (indicate range where appropriate):

TF: Flattop (T) ≤ 0.45T__ Flattop start/stop (s) ________

$\mathbf{I_p}$:Flattop (kA) ≥ 0.7 - 1.0 MA Flattop start/stop (s) _REQUIRED: ability to perform I_p ramps

Position: R (m) ______ Z (m) ______ Boundary shape: CS, LSN, DND__

Gas: Prefill D___ Puff ______

NBI:Power (MW) _full (5MW)_ Start / stop (s) ________ Voltage (kV) ______

RF:Power (MW) _< 6 MW__ Start / stop (s) ________ Frequency (MHz) ______

CHI: (Off) Off / Start-up / Ramp-up / Sustainment

If this is a continuation of a previous run or if shots from a previous run are similar to those needed, provide shot numbers for setup

107499, 107195

If shots are new and unique, sketch desired time profiles and shapes. Accurately label the sketch so there is no confusion about times or values. Attach additional sheets as required.

DIAGNOSTIC CHECKLIST

Title: Characterization of the Resistive Wall Mode in the ST **No. 202**

Diagnostic system	**Need**	**Desire**	**Requirements** (timing, view, etc.)
Magnetics	✓		
Fast visible camera		✓	
VIPS-1		✓	
VIPS-2			
SPRED			
GRITS			
Visible filterscopes		✓	
VB detector			
Midplane bolometer		✓	
Diamagnetic flux	✓		
Density interferometer (1mm)		✓	
FIReTIP interf'r/polarimeter		✓	
Thomson scattering	✓		
CHERS	✓		
NPA		✓	
X-ray crystal spectrometer			
X-ray PHA			
EBW radiometer			
Mirnov arrays		✓	
Locked-mode detectors		✓	
USXR arrays		✓	
2-D x-ray detector (GEM)			
X-ray tangential camera			
Reflectometer (4 ch.)			
Neutron detectors		✓	
Neutron fluctuations			
Fast ion loss probe			
Reciprocating edge probe			
Tile Langmuir probes			
Edge fluctuation imaging			
H-alpha cameras (1-D)		✓	
Divertor camera (2-D)			
Divertor bolometer (4 ch.)			
IR cameras (2)			
Tile thermocouples			

SOL reflectometer			