Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: MHD spectroscopy of wall stabilized high β plasmas		
OP-XP-501	**Revision: V1.1**	Effective Date: 2/7/05 *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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ATI – ET Group Leader: D.A. Gates	Date
RLM - Run Coordinator: J. Menard, S. Sabbagh (Deputy)	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Title: MHD spectroscopy of wall stabilized high β plasmas **OP-XP-501**

1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

The overall goal of the experiment is to determine the response of high β ST plasmas to applied, rotating resonant fields with low toroidal mode number, primarily focusing on $n = 1$, with the option to investigate the effect of $n = 2$ applied fields. Specifically, the experiment would examine:

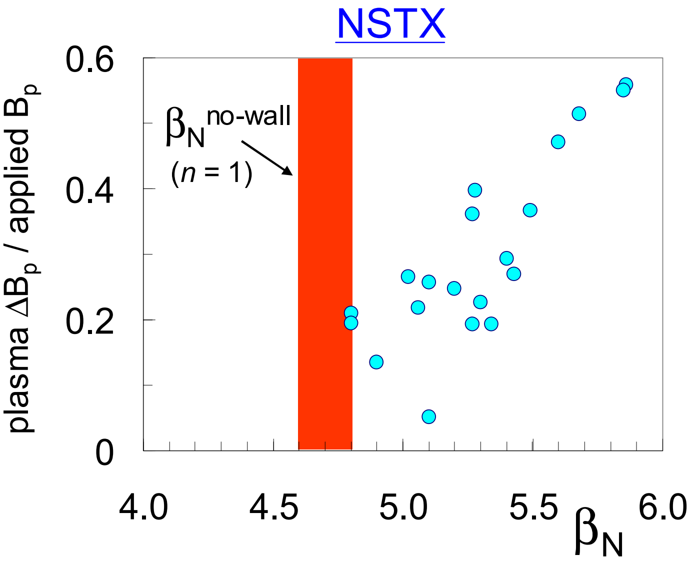
1. Resistive wall mode physics near marginal stability: Resonant field amplification by high β plasmas would be investigated as a function of applied field frequency. Precise plasma rotation control by the fully installed resistive wall mode (RWM) coil and matched switching power amplifier (SPA) would be used to control proximity to, and violation of, the RWM critical rotation frequency. RWM rotation would be measured at marginal stability, and RWM growth/damping rates would be measured and compared to theory. Phase coupling of the rotating RWM to the applied resonant field would be examined.
2. MHD spectroscopy of passively stabilized plasmas: The dependence of the resonant field amplification (RFA) amplitude and phase to the rotation frequency of the applied field would be examined. From this data, the RWM growth/damping rate and rotation rate will be determined by fitting to a single mode RWM model. These time-dependent computed values will be compared to the corresponding measured values. Comparison will be made to DCON and VALEN computations of mode stability and simpler analytic theory (e.g. Fitzpatrick-Aydemir (F-A) theory). Discharges with sufficient pulse length to allow beta variation over many resistive wall times will be used so that the RFA amplitude and phase shift can be examined as a function of β_N.
3. Search for low frequency resonances: Studies in DIII-D have successfully used the single mode model of the RWM to fit the RFA plasma response vs. frequency.[1] This single mode response is not guaranteed in high beta ST plasmas. One reason for this is the greater tendency for multiple toroidal mode numbers to couple at low aspect ratio. Also, in some single mode theories such as the F-A model, the dependence of RFA amplitude and phase vs. β_N can be more complex than the simpler single mode slab model. The possibility of greater complexity of the plasma RFA response in the ST will be explored. For example, once the marginal stability point is controlled by a pre-programmed applied resonant field pulse, other sources of potential resonance or instability drive can be varied to determine the affect on the plasma. One such possible source is the ripple on the shaping coil currents. Altering the frequency of this ripple can determine if the RFA resonance observed is sensitive to this frequency.

The present experiment would be the first attempt at RWM stability control by affecting plasma rotation in NSTX using full RWM coil capability. In addition, examining the plasma response to the pre-programmed, rotating resonant field is a necessary precursor study for future active RWM control experiments. Rotating RWM phase locking to the applied rotating field would be analyzed, and the behavior of the n > 1 RWM and/or RFA to n = 1 applied field would be examined in this experiment.

2. Theoretical/ empirical justification

Brief justification of activity including supporting calculations as appropriate

Magnetohydrodynamic modes near marginal stability have been shown to amplify the intrinsic error field of tokamak devices[1] and theory has been proposed to explain the phenomenon.[2] This effect, known as resonant field amplification, has been observed in high β NSTX plasmas. Both DIII-D[3] and NSTX[4] experiments have shown that RFA increases as β_N is increased above the ideal MHD no-wall beta limit. (Fig. 1) DIII-D has also shown that RFA can be generated from an applied resonant field and that the RFA amplitude and phase is dependent on the frequency of the applied resonant field.[5] Experiments in DIII-D have used this effect to compute the stability of the plasma by fitting the RFA amplitude and phase shift data to a single mode model of the RFA due to the resistive wall mode. (Fig. 2) The initial two-coil version of the RWM coil on NSTX was used in XP452 "RWM physics with initial global mode stabilization coil operation" in 2004 to test the dependence of RFA amplitude and phase shift on an applied, non-rotating n=1 resonant field.



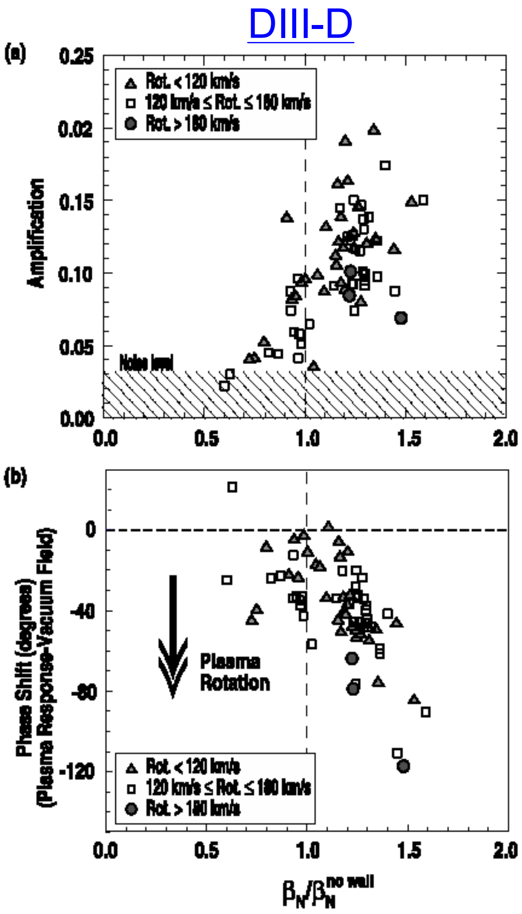


***Fig. 1**: Resonant field amplification as a function of β_N in NSTX (left) and DIII-D (right). The associated RFA phase shift is also shown for DIII-D.*

However, due to the large ripple amplitude of the applied field (switching power amplifier not available at that time) and the restriction of 0.3T toroidal field, the RFA experiments vs. applied frequency were inconclusive. Only standing wave perturbations could be applied using the initial RWM coil, which also limited the flexibility of the experiment. However the experiment did show that the applied AC field could be used to affect the stability of the RWM and generate an initially rotating, then growing RWM as the plasma rotation dropped below the critical rotation frequency. The experiments indicated that the RFA amplitude was dependent on the frequency of the applied resonant standing wave field. The RWM appeared to partially phase lock to the applied field as the mode became unstable.

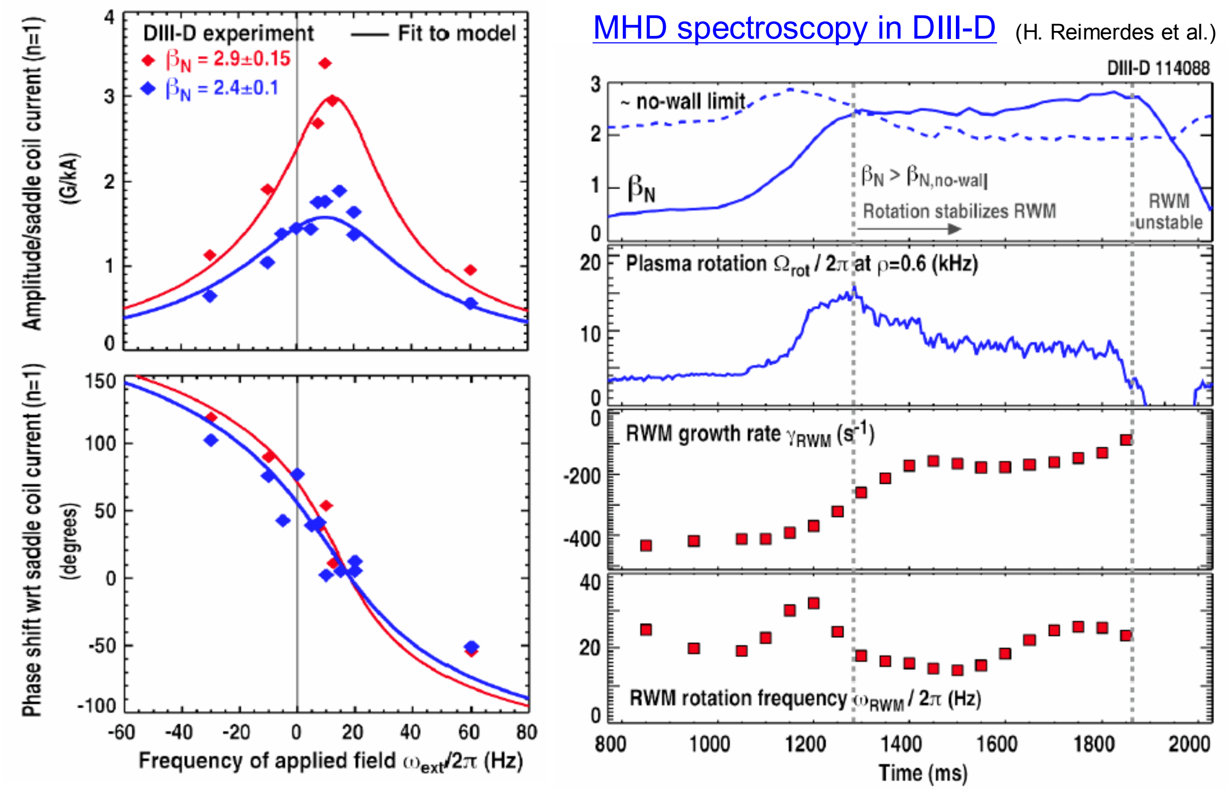


Fig. 2: *(left) Resonant field amplification and associated RFA phase shift as a function applied resonant field frequency in DIII-D; (right) Time-dependent calculation of RWM growth rate and natural rotation frequency using fitted data.*

3. Experimental run plan

Describe experiment in detail, including decision points and processes

The present run plan is a natural continuation of NSTX XP452, now utilizing the full RWM coil and SPA capability to apply a rotating n = 1 field to high beta plasmas near marginal RWM stability to determine the plasma response. Scan would be performed to investigate the physics outlined in Section 1. The specific run plan is given below. The primary experiment would determine the effects of an applied n = 1 field. However, a similar, reduced run plan could be re-run using an n = 2 perturbation after n = 1 is investigated. Using an n = 2 field in this manner would be the first such use in a tokamak, so there is considerable interest in performing this experiment.

<u>Run plan</u>: (30 shots - for GMS coil producing odd parity perturbation)

Task	Number of Shots
1) Determine marginal stability point vs. applied DC field (toroidal rotation dropping below critical rotation frequency)	
A) Vary applied current, zero rotation of applied field, DC square wave pulse:	
(i) 2 to 3 NBI sources (step up or down), longest possible pulse with $\beta_N/\beta_{Nno\text{-}wall} > 1$	1
(ii) Apply RWM coil current in steps until RWM is destabilized (gives Ω_{crit} scan)	4
(iii) 1.5 or 2 NBI sources ($\beta_N/\beta_{Nno\text{-}wall} < 1$) in above to compare	1
2) Determine RFA dependence on applied field rotation frequency and β_N	
A) Vary applied field rotation frequency:	
(Apply rotating field early ($\beta_N/\beta_{Nno\text{-}wall} < 1$) through planned end of discharge)	
(i) 2 - 3 NBI sources, vary applied field frequency -60, 60, -40, 40, -10, 10 Hz	6
(ii) 2 - 3 NBI sources, vary applied field frequency to best fill in data above	6
B) 1 NBI source at GMS frequency that produced maximum RFA amplitude	1
3) Determine RFA behavior and mode dynamics near marginal stability	
A) Vary applied current, applied field rotating at max. RFA from step (2) + DC offset:	
(Apply rotating field early ($\beta_N/\beta_{Nno\text{-}wall} < 1$) through end of discharge)	
(i) Vary applied field DC offset in steps until RWM is destabilized	3
(ii) Finer applied field frequency scan (3 more points)	3
B) Decrease RWM coil current to below marginal stability, vary PF MG set frequency	4
4) Vacuum field shots for each frequency used (if necessary)	3
5) (Optional) repeat the most successful trials above with n = 2 applied field	(optional 20)
Total (base):	32
Total (with optional n=2):	52

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 internal RWM sensor set will be required for general RWM detection and measurement of RFA magnitude and phase. The RWM coil system must be operating with at least pre-programmed current capability. The ability to program AC current in the RWM coils is required, as well as the ability to vary to the phase between the three coil pairs to generate an applied field that is rotating toroidally. The first experiments will be conducted with odd parity resonant fields, with the option of running even parity on a different run day if run time is available. USXR data taken at two toroidal positions is very highly desired for this experiment.

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 mode structure. VALEN will be used to model effects of the initial GMS coil pair as well as mode stability. MARS-F runs will be requested from Dr. Liu 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?

MHD spectroscopy of low frequency MHD modes is a newly found capability and the physics associated with it is relatively unexplored. 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. However, significant new experimental findings and the associated theoretical understanding could warrant more rapid publication in Physical Review Letters.

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[1] A.M. Garofalo, T.H. Jensen, L.C. Johnson, *et al.*, Phys. Plasmas **9** (2002) 1997.

[2] A.H. Boozer, Phys. Rev. Lett. **86** (2001) 1176.

[3] A.M. Garofalo, T.H. Jensen, and E.J. Strait, Phys. Plasmas **10** (2003) 4776.

[4] S.A. Sabbagh, A.C. Sontag, J.M. Bialek, 20th IAEA Fusion Energy Conference, Vilamoura, Portugal, paper IAEA-CN-116/EX/3-2 (to be published in Proc. 20th International FEC Conference, 2004) IAEA, Vienna (2004).

[5] H. Reimerdes, M.S. Chu, A.M. Garofalo, *et al.*, "Measurement of the resistive wall mode stability in a rotating plasma using active MHD spectroscopy", submitted to *Phys. Rev. Lett.*

PHYSICS OPERATIONS REQUEST

Title: <u>MHD spectroscopy of wall stabilized high β plasmas</u> **OP-XP-501**

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**

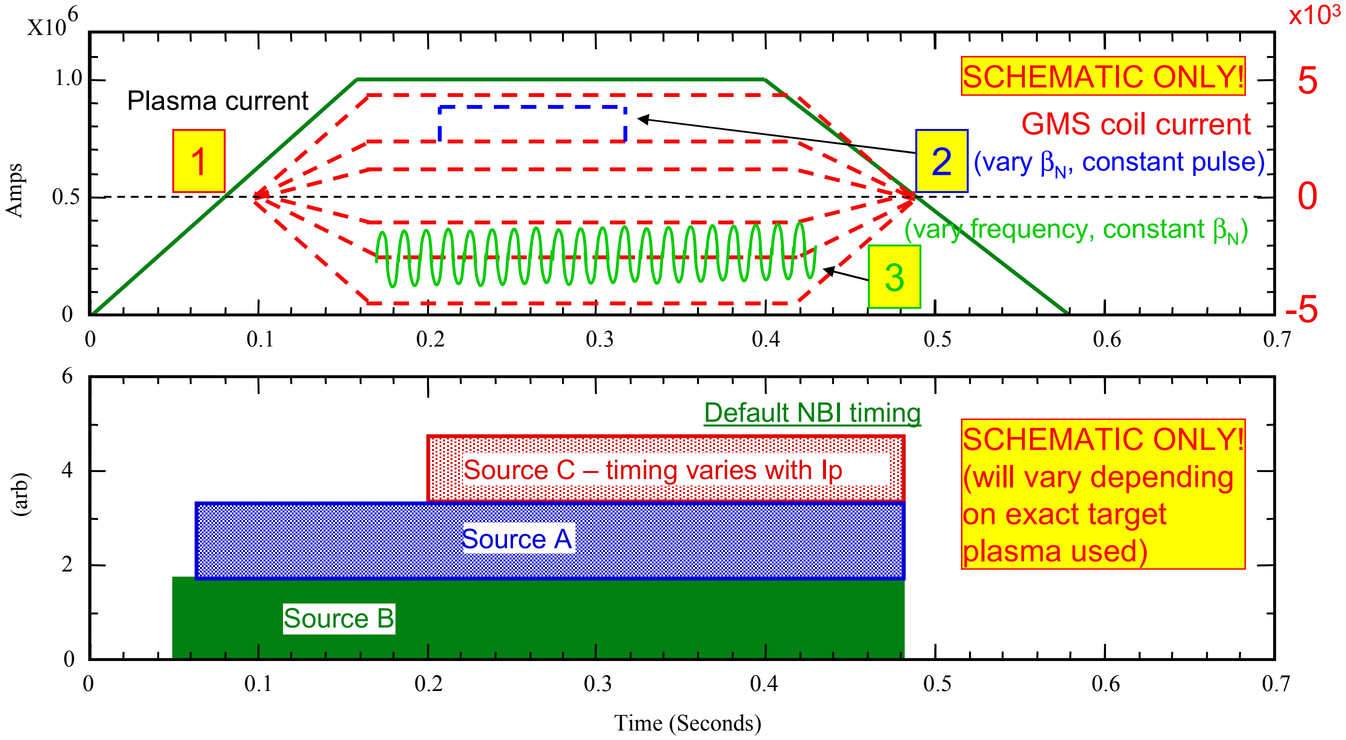
NBI - Species: **D,** Sources: **A/B/C,** Voltage (kV): **max**; A at 90kV, Duration (s):

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

CHI: **Off**

Either: List previous shot numbers: **<u>(Use new targets shots developed 2005 - TBD)</u>**

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: MHD spectroscopy of wall stabilized high β plasmas OP-XP-501

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	Two toroidal positions with edge channels (large R position)
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			