Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Error Field Threshold Study in High-beta Plasmas**

OP-XP-903	Revision: **3**	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: Jong-kyu Park	Date:
ATI – ET Group Leader: Steve A. Sabbagh Steven Sabbagh Digitally signed by Steven Sabbagh DN: cn=Steven Sabbagh, c=US, o=Columbia University, email=sabbagh@pppl.gov Date: 2009.03.11 12:55:02 -04'00'	Date: 3/11/09
RLM - Run Coordinator: Roger Raman	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

Note 1 – Determine the operating space, by finding the experimental RWM marginal stability point (in beta), then stay below it.

Note 2: If time permits, attempt to obtain data at various betaN in quasi-steady-state conditions. Rather than just collecting data during the natural betaN ramp-up, take separate shots with different levels of betaN with plasma rotation having reached quasi-steady-state.

NSTX EXPERIMENTAL PROPOSAL

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1. Overview of planned experiment

The goal of the experiment is to study *static locking (error field penetration)* phenomena driven by external non-axisymmetric field in high-β_N NSTX plasmas. This study will extend the parametric space of the present error field threshold database, which is concentrated mostly on low-β_N cases, and thus will increase the applicability of the database to the wider range of plasmas.

Another important point of physics in this experiment is the role of the plasma amplification to the resonant field driving magnetic islands in high-β_N plasmas. The static locking is known to be dangerous in low-β_N plasmas due to the linear correlation of the critical field with plasma density, but the field itself can be amplified in high-β_N plasmas and thus can become also destructive. In addition, more detailed dynamics can be studied by taking advantages of diagnostics available only in the high-β_N operations. For example, the evolution of the rotation or the opening of magnetic islands can be measured by facilitating CHERS and MPTS measurements.

2. Theoretical/ empirical justification

The static locking is believed to be the sudden opening of magnetic islands at the rational surfaces, when an external non-axisymmetric field is beyond a threshold and so plasma rotation can not shield the perturbation any more. The substantial degradation can be followed by enhanced transport across magnetic islands and rotational damping, and then islands can grow further until a plasma disruption. Since an external magnetic perturbation almost always exists, it is important to estimate the field threshold and to correct the field below the threshold during operation.

The method estimating the actual driving field at the rational surfaces has been significantly improved by Ideal Perturbed Equilibrium Code (IPEC), which calculates ideal plasma response, shielding currents and the total resonant field (δB_{mn}) at the rational surfaces q=m/n. The previous vacuum approximation used the external resonant field ($\delta B^{x}{}_{mn}$), which is very often inappropriate to measure the actual drive of magnetic islands. As Figure 1 shows for both NSTX and DIII-D, the known correlation between the resonant field and the locking density can be restored when the total resonant field is evaluated by IPEC even for the cases when the external resonant field does not show any relevant correlation. Note that DIII-D data in Figure 1 include a recent high-β_N locking experiment ($\beta_N \sim 1.5$) as seen at the high density.

As the recently attempted in DIII-D, our experiment will test the high-β_N locking in NSTX. If it is assumed that the linear correlation in low-β_N locking experiments from XP703 holds up to the high-β_N, the resonant field 5~7 Gauss is required to lock the high-β_N plasmas, which roughly have the line-averaged density $4 \sim 6\times10^{19} m^{-3}$. IPEC calculations show that the required resonant field is achievable through the plasma amplifications with n=1 SPA ~ 1kA in high-β_N plasmas.

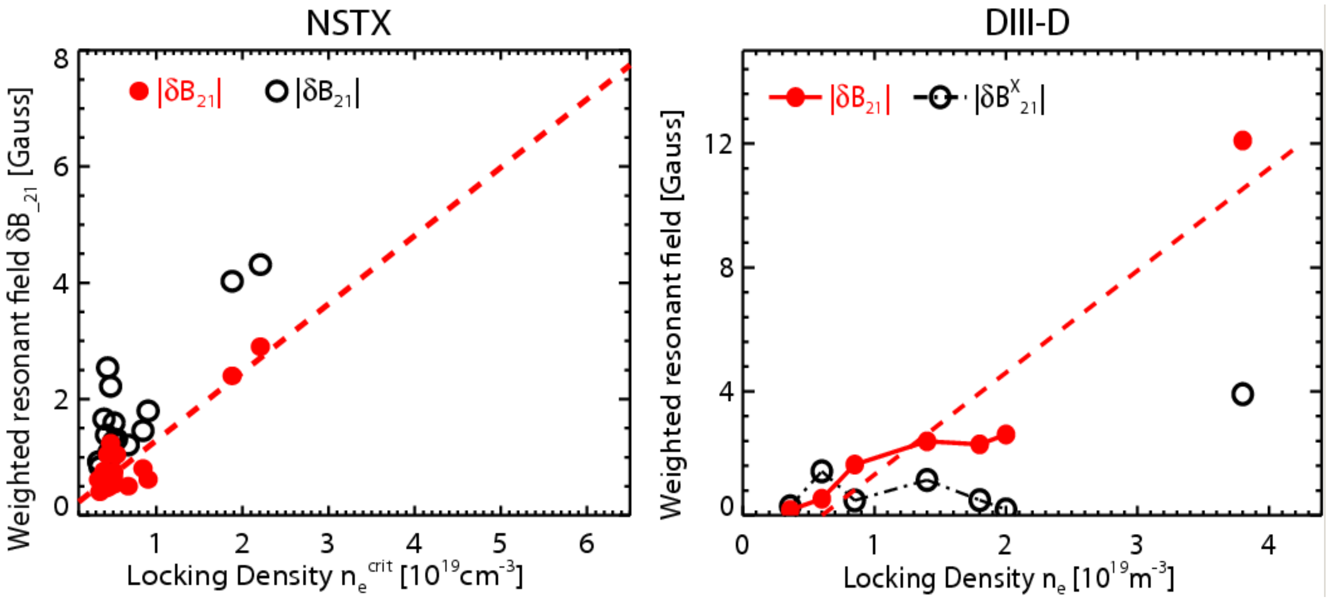

Figure1. The correlation between the critical resonant field (red) at q=2 surface and locking density for NSTX and DIII-D. The external resonant field (black) is shown for comparison, and often shows very poor correlation as can be seen. As the high density experiment on the rightmost data in DIII-D, this experiment will focus on the locking of the high density ($>3\times10^{19}\,m^{-3}$) NSTX plasmas.

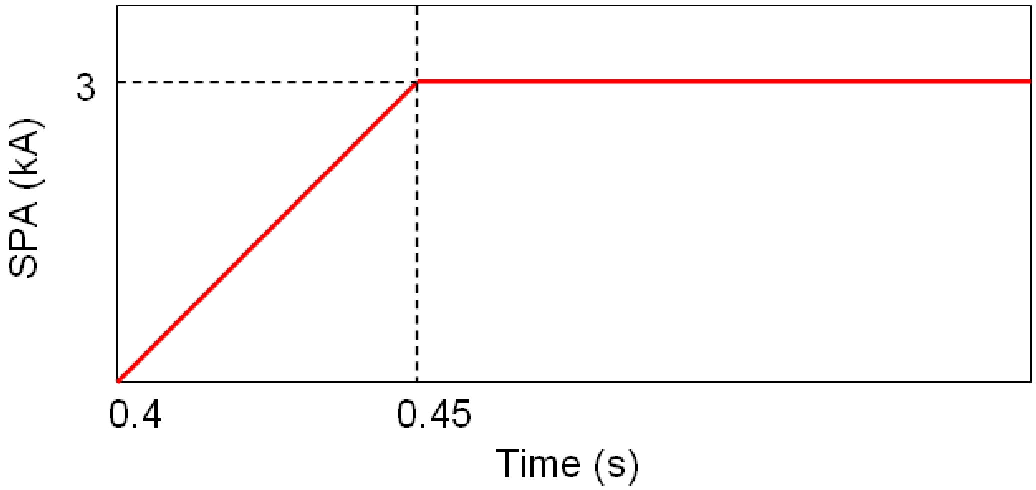

Figure 2. The desired SPA current waveform. For n=1 perturbation, one of three SPA currents will be uncharged and the other two will have the above proposed wave form. The start time =0.4s may be modified to account for the dynamics of the discharge.

The empirical feasibility for this part of experiment can be also found, for instance, with the previous XP810 #130217~130221, where a mixed n=1+3 field was applied to NBI 4MW H-mode plasmas and SPA ~ 1kA actually locked the plasmas. The dataset can provide at least 4 data for high-β_N locking experiments, but this new experiment will use a pure n=1 rather than the field n=1+3, in order to avoid the additional degrading effects of n=3 field.

The high-β_N locking in XP810 is straightforward and is likely to be reproducible, but there are significant transitions from Ohmic L-mode plasmas to NBI H-mode plasmas in terms of various plasma parameters. So, the other part of the experiment will explore the intermediate-β_N regime starting from Ohmic L-mode in XP703 and adding only one source of NBI to keep L-mode, but increase the density and thus the plasma β_N. However, this plan of the experiment will be optional if only time permitting due to the uncertainties in target plasmas.

The density is the primary parameter to determine the error field threshold, but also the plasma β_N can become very important through the plasma response. The density and the plasma β_N are not well separable parameters in experiments, but the appropriate control of gas puffing and NBI timing can provide the interesting parametric dependency of the error field threshold.

3. Experimental run plan

Describe experiment in detail, including decision points and processes.

There are two major components in this experiment. The estimated number of shots is indicated by {}.

1. Study the static locking in NBI-heated H-mode plasmas from XP810
    a. Reproduce the reference shot #130217 (I_P = 900kA, B_T = 0.45T, NBI 4MW, Deuterium H-mode) or use the fiducial shot for a target. NBI 4MW is desired to stay below the no-wall limit. Make sure there are no rotating tearing modes (for about 100ms or more, ~250ms desired) and that there is sufficient β_N evolution (about 3 to 4) during the flat-top. {4}
    b. Apply the SPA waveform shown in Fig.2 for SPAs (1,2,3) from (0,0,0) to (3,-3,0)kA at different times during the flat-top. A suitable interval for the application of the SPA waveform is approximately ~50ms. After a sufficient number of scans at this level of β_N evolution, change the injected beam power to 3MW or to 5MW to scan for a different range in the beta evolution and to study effects due to different parameters. {~8}

#shot	T_{SPA} (start time)	β_N (T_{SPA})	NBI(MW)	Results

2. **(If step 1 is successful and time permitting)** Study the static locking in NBI-heated L-mode Plasmas
    a. Use the reference shot #126923 (I_P = 700kA, B_T = 0.40T, NBI 2MW), **but use D2 instead of He. Also, it may be necessary to increase outer-gap (up to 5-10cm). For some cases, small blips of source A for MSE data may be used.** {4} Note: This shot would likely have a beta-N ramp of about 1 to 2 during the MHD free (no rotating tearing modes) phase.
    b. Apply the SPA waveform shown in Fig.2 from (0,0,0) to (3,-3,0) kA at different times during the flat-top. If it is successful and if target shots with small blips of source A are reliable, try to reduce power by modulating source A (through beam modulation). {~6}
    c. Use the same reference shot, but with He to change gas puffing, as it may be easier to change the density in He discharges. Alternatively, it may be easier to add some has from the center stack gas injection system to increase the density and use the deuterium shot used in step 2b {~2}

#shot	T_{SPA} (start time)	β_N (T_{SPA})	NBI(MW) / GAS	Results

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 full magnetics/profile diagnostics are needed.

5. Planned analysis

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

OP-XP-903

EFIT and LRDFIT will be used to reconstruct the 2D MHD equilibrium, and IPEC will be used to reconstruct the 3D MHD equilibrium. The non-resonant braking by n=1 NTV will be also analyzed to study the non-resonant field effects on locking.

6. Planned publication of results

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

The results will be added to the locking database for tokamaks. Depending on the level of physics that the total dataset indicates, the results will be published in Nuclear Fusion or Physics of Plasmas during 2009.

PHYSICS OPERATIONS REQUEST

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Describe briefly the most important plasma conditions required for the XP:

(1) High-β_N plasma : β_N = 3.0~4.5 (ramping up during the MHD-free phase), H-mode

(2) Intermediate-β_N plasma : β_N = 1.0~3.0 (ramping up during the MHD-free phase) and NBI-heated L-mode

Both are desired to have the flat-top period > 250ms without a rotating tearing mode

List any pre-existing shots: 130217, 126923

Equilibrium Control: [✓ Gap Control] / [✓ rtEFIT(isoflux control)]: 130217 is isoflux, 126923 is a Helium shot under gap control.

Machine conditions *(specify ranges as appropriate, use more than one sheet if necessary)*

I_{TF} (kA): 53kA~58kA Flattop start/stop (s):

I_P (MA): 0.7~0.9MA Flattop start/stop (s):

Configuration: **Double Null (DN)** *(strike out inapplicable cases)*

Outer gap (m): **0.06~0.15** Inner gap (m): **0~0.04**

Z position (m): ~0

Elongation κ: **2.0~2.2** Upper/lower triangularity δ: 0.45~0.75

Gas Species: **D, He** injector(s):

NBI Species: **D** Voltages (kV or off) **A: 0~90 B: 90 C: 0** Duration (s):

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

CHI: **[✓ Off] / On** Bank capacitance (mF):

LITERs: [✓ Off] / On Total deposition rate (mg/min):

EFC coils: Off/[✓ On] Configuration: **[✓ Odd] / Even / Other** *(attach detailed sheet)*

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Bolometer – tangential array	√	
Bolometer – divertor		√
CHERS – toroidal	√	
CHERS – poloidal	√	
Divertor fast camera		√
Dust detector		√
EBW radiometers		√
Edge deposition monitors		√
Edge neutral density diag.		√
Edge pressure gauges		√
Edge rotation diagnostic		√
Fast ion D_alpha - FIDA		√
Fast lost ion probes - IFLIP		√
Fast lost ion probes - SFLIP		√
Filterscopes	√	
FIReTIP		√
Gas puff imaging		√
Hα camera - 1D		√
High-k scattering		√
Infrared cameras		√
Interferometer - 1 mm		√
Langmuir probes – divertor		√
Langmuir probes – BEaP		√
Langmuir probes – RF ant.		√
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
Magnetics – Pickup coils	√	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		√
Magnetics – RWM sensors	√	
Mirnov coils – high f.	√	
Mirnov coils – poloidal array	√	
Mirnov coils – toroidal array	√	
Mirnov coils – 3-axis proto.	√	

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
MSE	√	
NPA – ExB scanning		√
NPA – solid state		√
Neutron measurements	√	
Plasma TV	√	
Reciprocating probe		√
Reflectometer – 65GHz		√
Reflectometer – correlation		√
Reflectometer – FM/CW		√
Reflectometer – fixed f		√
Reflectometer – SOL		√
RF edge probes		√
Spectrometer – SPRED		√
Spectrometer – VIPS		√
SWIFT – 2D flow		√
Thomson scattering	√	
Ultrasoft X-ray arrays	√	
Ultrasoft X-rays – bicolor		√
Ultrasoft X-rays – TG spectr.		√
Visible bremsstrahlung det.		√
X-ray crystal spectrom. - H		√
X-ray crystal spectrom. - V		√
X-ray fast pinhole camera		√
X-ray spectrometer - XEUS		√