Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Search For the n=3 Error Field Source in NSTX and Implementation of Improved n=3 EF Correction.**

OP-XP-902	Revision: **2**	Effective Date: *(Approval date unless otherwise stipulated)* 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)

NSTX EXPERIMENTAL PROPOSAL

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AUTHORS: **S.P. Gerhardt, et al.** DATE:

1. Overview of planned experiment

This experiment will have two steps. The first step is the most important, and the second step is "optional".

Step 1. This is a direct continuation of XP 701 & XP-823, where an asymmetry of the plasma rotation with respect to applied n=3 fields was observed and studied. Use the RWM/EFC coils to apply n=3 fields of various magnitudes and polarities, at the I_P,B_T, and κ values specified in Table #1. For each [I_P, B_T, κ] triplet, determine the applied n=3 field that maximizes the plasma rotation and/or angular momentum. (24 Shots)

Step 2. Previous analysis has indicated that the likeliest source of this error field is the PF-5 coil; it is the purpose of the preceding step to experimentally verify this. If this is found to be true, then a modification to the feedback code in PCS will be made, allowing the n=3 correction to be tied directly to the PF-5 coil current and yielding optimal correction for all values of the plasma current. A scan of the "gain" parameter will then be done, to verify that this proportional correction works as desired. (10 shots)

2. Theoretical/ empirical justification

Recent (2008) NSTX performance has been dramatically improved by the routine use of dynamic n=1 correction and static n=3 corrections. However, the n=3 correction has been fairly crude, with a value of ~300 A in the EFC coils in an n=3 configuration, regardless of plasma conditions (such as I_P or the current in the PF coils). It is the goal of the present experiment to determine which coil is the source of the n=3 EF, and implement an improved n=3 EF correction based on the knowledge of that source. This has the potential to improve NSTX operations.

Also note that very few (no?) other tokamak facilities routinely correct non-resonant error fields. The present EF correction techniques, which have lead to an improvement in NSTX high-β operations, are thus unique and quite possibly relevant for future larger tokamak facilities.

3. Experimental run plan

Reference Shot: The reference shot is standard 2008 fiducial; a typical example is 129072. It should go into H-mode reliably at t≈115ms, possibly with a "blip" of source C between 80 and 120 msec. The values of I_P and B_T will be changed in these experiments, as will the elongation in a single case.

Part 1: *Further efforts for determination of n=3 EF source.*

This experiment will attempt to find the optimal n=3 field for the [I_P, B_T, κ] combinations listed in Table 1. These three variables are of interest because they control either the currents in the coils, or the ratio of currents, as:

$I_P \rightarrow I_{PF5}, I_{PF3}$ $B_T \rightarrow I_{TF}$ $\kappa \rightarrow I_{PF5}/I_{PF3}$

Note that the κ change is listed as a third-priority. This is because it will change the plasma geometry, and hence coupling to error fields. This undesirable effect is offset by the need to change the ratio of the PF5 and PF3 coil currents, in order to determine which coil is the source of the EF. Hence, only a small change in κ is used.

For each condition, approximately 7-8 discharges will be taken with varying n=3 magnitudes and polarities. The n=3 fields will be ramped from 0 to the desired current over a period of 100msec, starting at ~300 msec, and will typically be left at that level for the remainder of the discharge (the exact start time may be adjusted depending on the early MHD in the discharge).

An idl code has been written to analyze all the shots in a scan of the n=3 field, in order to determine the optimal level of n=3 EF correction. This code will be run during the scan, to ensure that sufficient data is collected to localize the optional correction.

In some cases (particularly at higher values of I_P), the plasma can tolerate various levels of n=3 braking/correction without disruption. In these cases, two different values of the n=3 fields can be utilized. For instance: ramp to the first level of n=3 fields between t=0.300 and t=0.40, and then to a different level between t=0.550 and t=0.650.

Priority	XP	I_P (kA)	B_T (T), I_{TF} (kA)	κ
Done	701	800	0.44,	2.3
Done (questionable data)	823	750	0.4,	2.25
Done	823	1100	0.44,	2.35
1	902	1100	0.55,	2.3
2	902	750	0.44	2.3
3	902	1100	0.44	2.1
4	902	900	0.54	2.3
5	902	900	0.44	2.3

Table 1: [I_P, B_t,κ] combinations for this XP, as well as previous companion XPs*. The goal is to complete steps 1-3 during a single run day; these three points, in addition to the previous data, should be sufficient to resolve the EF source.*

Each table below corresponds to a given [I_P, B_t, κ] combination, and is to be used for recording shot numbers and SPA currents. Note that not all of these tables, or lines within the tables, will be used.

I_P (kA)	B_T (T), I_{TF} (kA)	SPA 1 Current	SPA 2 Current	SPA 3 Current	Shot Number
1100	0.54, 66	0	0	0	
1100	0.54, 66	-250	-250	250	
1100	0.54, 66	250	250	-250	
1100	0.54, 66	-500	-500	500	
1100	0.54, 66	500	500	-500	
1100	0.54, 66	-750	-750	750	
1100	0.54, 66				
1100	0.54, 66				
1100	0.54, 66				

Table 2.1: Shot record for [I_P, B_t,κ]=[1100,0.55,2.3]*. Note that "double" steps in the SPA current are likely possible in this case.*

I_P (kA)	B_T (T), I_{TF} (kA)	SPA 1 Current	SPA 2 Current	SPA 3 Current	Shot Number
750	0.44, 54	0	0	0	
750	0.44, 54	-250	-250	250	
750	0.44, 54	250	250	-250	
750	0.44, 54	-500	-500	500	
750	0.44, 54	500	500	-500	
750	0.44, 54	-750	-750	750	
750	0.44, 54				
750	0.44, 54				
750	0.44, 54				

Table 2.2: Shot Record For [I_P, B_t,κ]= [750,0.44,2.3]

I_P (kA)	B_T (T), I_{TF} (kA)	SPA 1 Current	SPA 2 Current	SPA 3 Current	Shot Number
1100	0.44, 54	0	0	0	
1100	0.44, 54	-250	-250	250	
1100	0.44, 54	250	250	-250	
1100	0.44, 54	-500	-500	500	
1100	0.44, 54	500	500	-500	
1100	0.44, 54	-750	-750	750	
1100	0.44, 54				
1100	0.44, 54				
1100	0.44, 54				

Table 2.3: Shot Record For [I_P, B_t,κ]=[1100,0.44,2.1]. *Note, this elongation change will be accomplished by reducing the upper and lower outer squareness values by ~0.1. Note that "double" steps in the SPA current are likely possible in this case.*

I_P (kA)	B_T (T), I_{TF} (kA)	SPA 1 Current	SPA 2 Current	SPA 3 Current	Shot Number
900	0.54, 66	0	0	0	
900	0.54, 66	-250	-250	250	
900	0.54, 66	250	250	-250	
900	0.54, 66	-500	-500	500	
900	0.54, 66	500	500	-500	
900	0.54, 66	-750	-750	750	
900	0.54, 66				
900	0.54, 66				
900	0.54, 66				

Table 2.4: Shot Record For [I_P, B_t,κ] =[900,0.54,2.3]

I_P (kA)	B_T (T), I_{TF} (kA)	SPA 1 Current	SPA 2 Current	SPA 3 Current	Shot Number
900	0.44, 54	0	0	0	
900	0.44, 54	-250	-250	250	
900	0.44, 54	250	250	-250	
900	0.44, 54	-500	-500	500	
900	0.44, 54	500	500	-500	
900	0.44, 54	-750	-750	750	
900	0.44, 54				
900	0.44, 54				
900	0.44, 54				

Table 2.4: Shot Record For [I_P, B_t,κ] =[900,0.44,2.3]

Part 2: *Optimal Correction of n=3 EF Using Modified PCS code.*

Present evidence indicates that the likeliest source of the n=3 EF is the PF-5 coil; it is the purpose of step 1 to verify that this is the case. If this hypothesis is confirmed, then go on to this step.

A modification to the PCS software will be implemented, such that the n=3 correction is directly tied to the PF5 current. The description of this algorithm specification will be developed elsewhere, but the general idea will be to generate SPA requests proportional to the PF-5 coil current as:

$$I_{RWM\,1} = -15 \times I_{PF5}$$
$$I_{RWM\,2} = -15 \times I_{PF5}$$
$$I_{RWM\,3} = 15 \times I_{PF5}$$

Based on the data from XPs 701 and 823, it appears that the optimal proportionality constant between the EFC coil current and the PF5 current in 15 A/kA. The purpose of this step is to verify this optimal value of this constant, and to verify that this correction improves performance.

So, when this PCS modification is complete, take one of the [I_P,B_T, κ] combinations from Part 1, and use it for the following scan of the proportionality constant for a fixed equilibrium.

SPA 1 Optimal Gain	SPA 2 Optimal Gain	SPA 3 Optimal Gain	Gain Multiplier	SPA 1 Gain	SPA 2 Gain	SPA 3 Gain	Shot Number
-15	-15	15	**-1**	15	15	-15	
-15	-15	15	**-0.5**	7.5	7.5	-7.5	
-15	-15	15	**0**	0	0	0	
-15	-15	15	**0.5**	-7.5	-7.5	7.5	
-15	-15	15	**1**	-15	-15	15	
-15	-15	15	**1.5**	-22.5	-22.5	22.5	
-15	-15	15	**2**	-30	-30	30	
-15	-15	15	**2.5**	-37.5	-37.5	37.5	

4. Required machine, NBI, RF, CHI and diagnostic capabilities

This target discharge is essentially the fiducial. Need the EFC coil system to be working and configured for anti-series connections, and three NB sources. CHI & RF are not wanted. Machine conditions should be such that 900kA fiducial shots with n=1+3 correction last longer than 1sec. Li evaporation would certainly aid in achieving these conditions, but is not strictly necessary.

5. Planned analysis

These will be analyzed with EFIT and LRDFIT. A simple idl code is used to determine the optimal EF correction for a given [I_P, B_T, κ] pair, given a number of shots with different n=3 fields. Additionally, some analysis of the n=3 EF from the PF-5 non-circularity will be done, to correlate it with the applied fields.

6. Planned publication of results

The subject of non-resonant EF correction is not well established in the present literature. Hence, these results, when conclusive, will make a fine contribution in a journal such as Nuclear Fusion.

PHYSICS OPERATIONS REQUEST

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(use additional sheets and attach waveform diagrams if necessary)

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

This XP will use the standard 2008 fiducial shot (κ~2.3, δ_l~0.6, dr_{sep}~-.01). The machine needs to have conditions such that the fiducial is lasting about 1 second. H-mode transitions should be occurring at about 115msec, possibly assisted by a “blip” of source C from 80-120 msec.

Previous shot(s) which can be repeated: 128895 (1100kA), 129075 (900kA)

Previous shot(s) which can be modified: These two above.

Machine conditions *(specify ranges as appropriate, strike out inapplicable cases)*

I_{TF} (kA): See table 1 Flattop start/stop (s): standard TF waveform

I_P (MA): See table 1 Flattop start/stop (s): standard fiducial waveform

Configuration: **LSN (kinda). This XP will run the 2008 fiducial shape.**

Equilibrium Control: **Isoflux**

Outer gap (m): **12cm** Inner gap (m): **6cm** Z position (m): **-.02m**

Elongation κ: 2.1-2.3 Upper/lower triangularity δ: ~0.6-0.75

Gas Species: **D** Injector(s): Standard early gas + HFS

NBI Species: **D** Voltage (kV) **A: 90** **B: 90** **C:** 90 Duration (s):

ICRF Power (MW): 0 Phase between straps (°): Duration (s):

CHI: **Off** Bank capacitance (mF):

LITERs: On if available Total deposition rate (mg/min): **25**

EFC coils: On Configuration: **Odd**

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 – E‖B 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		