Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: **Optimization of long-pulse high-β_T discharges**

OP-XP-948	Revision:	Effective Date: **7/1/09** *(Approval date unless otherwise stipulated)* Expiration Date: **7/1/11** *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: S.P. Gerhardt	Date 6/30/09
ATI – ET Group Leader: D. A. Gates	Date
RLM - Run Coordinator: R. Raman	Date 6/30/09
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Optimization of long-pulse high-β_T discharges** No. **OP-XP-948**

AUTHORS: **S.P. Gerhardt, D.A. Gates** DATE: **5/30/09**

1. Overview of planned experiment

The goal of this experiment is to expand the high-β_T operational space achieved in NSTX. This experiment will follow the traditional method for achieving high-β: the plasma current will be raised as the toroidal field is reduced, and high elongation will be used to keep q*>~2.2. More specifically, the recent high-β_P shot 133964, which operated at 700 kA and 0.47T, will be used as an initial target, though at 900 kA and 0.45 T. The toroidal field will then be dropped to 0.4 T and discharges made with I_P values of 700, 900,1000, 1100, and 1200 kA, all at the maximum NB power. This should result in a series of discharges at increasing values of β_T, but decreasing pulse duration; the scaling of confinement and NI fraction with plasma current could will be determined. If time permits one or two of these I_P values will be repeated at both lower (0.375 or 0.35 T) and higher (0.475 or 0.55 T) toroidal fields, in order to study the scaling of transport and NI fraction with B_T in these high-κ, low-l_i plasmas.

2. Theoretical/ empirical justification

Most designs that make use of the ST concept to make something useful (say, a CTF or a reactor) operate at substantially higher toroidal β than is common in NSTX: CTFs may operate at β_T in the rage of 18-28, while an ST reactor may need β_T=50%! Furthermore, the elongation in these studies typically is 3 or higher. It is the purpose of the present XP to push the present NSTX operating space to the longest available pulses at high-β_T and low-q*, using a high-κ discharge that should be optimal for increasing the NI fraction.

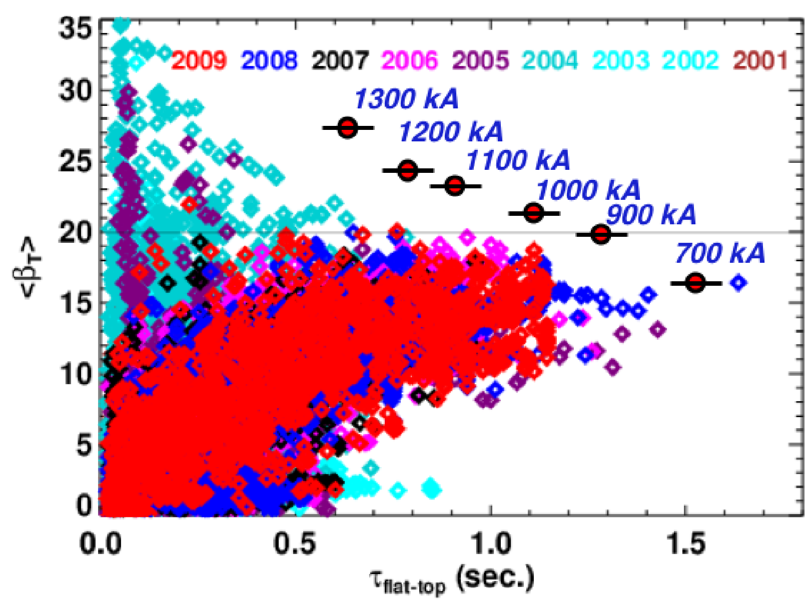

Fig 1: The NSTX database of flat-top average β_T values, sorted by year. Also shown in red circles are the target points for this XP at B_T=0.4T, assuming good confinement.

A further important topic for these equilibria is to understand how the transport and non-inductive current fraction scale with I_P and B_T in these high-κ, low-l_i discharges. Though these studies are not the primary goal of the XP, the subject will be addressed in the scans to be conducted.

In preparation for this XP, a series of target equilibrium were studied with the isolver code. The profiles and shape were taken from 133964, the value of β_N was fixed at 5.5, and I_P and B_T were scanned. The resulting equilibrium characteristics are shown in table 1. The lines in red indicate the equilibrium at B_T=0.4 T that are of primary interest for this XP.

Case	Ip (MA)	BT (T)	betaN	betaT (%)	q*	q95	WMHD (kJ)
1	0.7	0.5	5.5	13.6	4.78	14	260
2	0.7	0.45	5.5	14.8	4.4	12.5	234
3	***0.7***	***0.4***	***5.5***	***16.4***	***4***	***11.1***	***208***
4	0.7	0.375	5.5	17.4	3.8	10.4	195
5	0.7	0.35	5.5	18.5	3.57	9.7	183
6	0.9	0.5	5.5	17	3.9	10.7	330
7	0.9	0.45	5.5	18.5	3.57	9.7	300
8	***0.9***	***0.4***	***5.5***	***20.5***	***3.23***	***8.6***	***270***
9	0.9	0.375	5.5	21.8	3.05	8.1	252
10	0.9	0.35	5.5	23	2.87	7.5	235
11	1	0.55	5.5	17	3.9	10.7	410
12	1	0.5	5.5	18.5	3.6	9.7	373
13	1	0.45	5.5	20.3	3.3	8.7	337
14	***1***	***0.4***	***5.5***	***22.5***	***2.9***	***7.7***	***300***
15	1	0.375	5.5	23.9	2.7	7.3	281
16	1	0.35	5.5	25.3	2.6	6.8	263
17	1.1	0.55	5.5	18.5	3.6	9.7	452
18	1.1	0.5	5.5	20	3.3	8.8	411
19	1.1	0.45	5.5	22	3	7.9	371
20	***1.1***	***0.4***	***5.5***	***24.6***	***2.7***	***7.1***	***330***
21	1.1	0.375	5.5	26.2	2.6	6.63	310
22	1.1	0.35	5.5	28	2.4	6.2	289
23	1.2	0.55	5.5	19.5	3.3	8.88	493
24	1.2	0.5	5.5	21	3.1	8.1	449
25	1.2	0.45	5.5	24	2.8	7.3	405
26	***1.2***	***0.4***	***5.5***	***26.7***	***2.5***	***6.5***	***361***
27	0.2	0.375	5.5	28.4	2.4	6.1	339
28	1.2	0.35	5.5	30	2.2	5.7	317
29	1.3	0.5	5.5	21.4	-3.1	8.2	537
30	1.3	0.5	5.5	23.4	2.8	7.5	487
31	1.3	0.45	5.5	25.8	2.6	6.7	439
32	***1.3***	***0.4***	***5.5***	***28.8***	***2.3***	***6***	***391***
33	1.3	0.375	5.5	30.6	2.2	5.6	367
34	1.3	0.35	5.5	32	2.05	5.2	343

Table #1: Characteristics of the high-κ discharge at different I_P and B_T.

3. Experimental run plan

For reference, here is a table of possible B_T waveforms and a figure showing their durations:

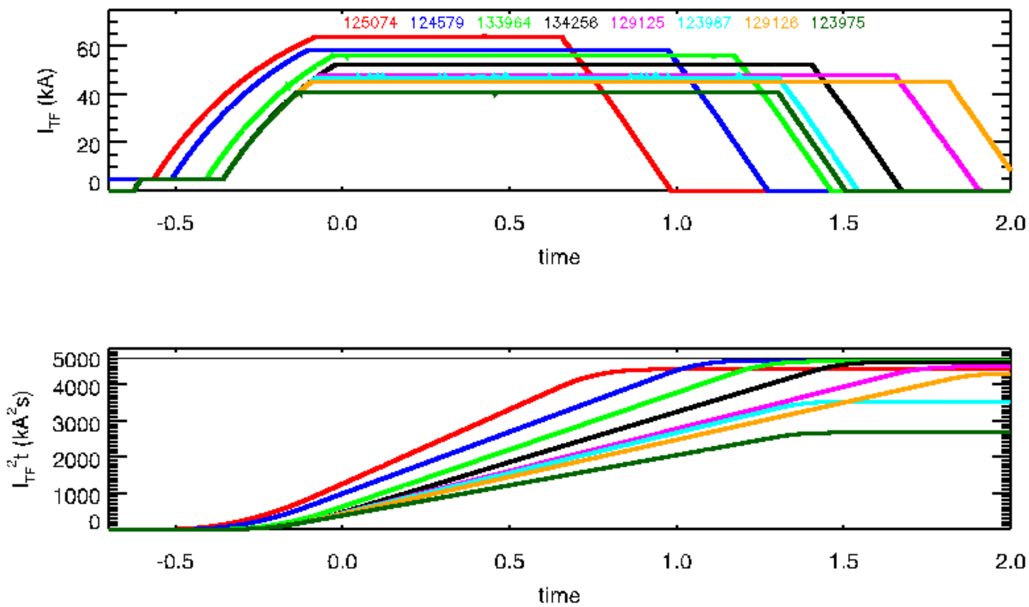

Figure #2: Example TF waveforms, along with their approach to the I^2t limit of the coil.

Shot	I_{TF} (kA)	B_T (T)	I^2t (kA^2s)	SOFT (msec)
125074	-64.2	-0.534	4437	-92
124579	-58.5	-0.49	5684	-116
133964	-56.2	-0.47	4657	-39
134256	-52.7	-0.44	4639	-29
129125	-48.3	-0.4	4513	-71
123987	-47.3	-0.395	3548	-81
129126	-45.3	-0.38	4331	-98
123975	-40.9	-0.34	2683	-138

Table #2: Selected TF waveforms to reload; some will require modification. The I^2t limit on the OH coil is 4750 kA^2s. SOFT is the start of flat top, and should be about -40 msec. In a few cases (125074,124579), the TF waveform should be delayed in order to maximize the flat-top after t=0.

Regarding Fueling: LITER rate appropriate for 300 mg/shot, using two evaporators. Use 12.5 minute shot cycle, no GDC. For the LFS gas, can use waveforms from 133964 (700kA), 132592 (1MA), or 132912 (1.3 MA). For the HFS gas, the approximate scaling of plenum fill pressure in torr, with I_P (MA) is

1050+400*I_P. However, this is for guidance only, and the actual required amount may vary depending on conditions at the time.

3.1) Reload shot 133964. Reduce the outer gap to ~13 cm, from 16 cm. Reduce B_T to 0.45 Tesla and increase I_P to 900 kA (can simply use the waveforms for the fiducial). May need a few shots to get the fuelling right.

3.2) Reduce B_T to 0.4 Tesla (TF waveform from 129125) and extend the I_P flat-top duration such that the current is ramped all the way down by 1.6 seconds. Fill in the following table of shots at this toroidal field.

The plasma current ramp rate is to be left unchanged as I_P is raised; shots with higher I_P will simply reach flat-top that much later.

To first order, the center-stack gas should be increased/decreased in a proportion to I_P, as noted above. Care should be taken to track changing fuelling requirements through the day.

It may be desirable to increase the NB power to 95kV on sources B and C.

Once the desired condition is reached, the shot should be repeated at least once.

I_P	B_T	Shots
900	0.4	
1000	0.4	
1100	0.4	
1200	0.4	
1300	0.4	
700	0.4	

3.3) Pick a value of plasma current from table #1 and scan the toroidal field.

I_P	B_T	Shots
	0.55	
	0.475	
	0.375	
	0.35	

3.4) Pick a value of plasma current from table #1 and scan the toroidal field

I_P	B_T	Shots
	0.55	
	0.475	
	0.375	
	0.35	

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

May request sources B & C to be run at 95 kV. Would use β-feedback if it is available, but it is not a requirement. However, all three NB sources are required. RWM feedback is a requirement. Dual LITER operations and 30mg/min total rate is a requirement.

5. Planned analysis

EFIT/LRDFIT equilibrium analysis, TRANSP for non-inductive current and transport analysis, DCON for ideal stability limit calculations

6. Planned publication of results

These results will be part of the report for the ASC milestone for 2009. They will be presented at the 2009 APS meeting, and likely go into a NF paper.

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 does not require any special conditions. Need 2 LITER units to be functional, all three NB sources working, and RWM feedback on-line.

Previous shot(s) which can be repeated:

Previous shot(s) which can be modified: 133964

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

I_{TF} (kA): 40-65 Flattop start/stop (s): See table #2

I_P (MA): 700-1.3 Flattop start/stop (s): Variable

Configuration: **LSN**, though dr_{sep} is so small that it is almost DN

Equilibrium Control: **Isoflux** (rtEFIT)

Outer gap (m): **12** Inner gap (m): **6** Z position (m): **-0.02**

Elongation κ: 2.5 Upper/lower triangularity δ: PF1A shot

Gas Species: **D_2** Injector(s): 1& 2

NBI Species: **D** Voltage (kV) **A: 90** **B: 90 (95?)** **C:** 90 (95?) Duration (s): 1.6

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

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

LITERs: On Total deposition rate (mg/min): **30**

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	√	