Princeton Plasma Physics Laboratory
NSTX Machine Proposal

Title: Optimization of β_N Control Gains

OP-XMP-65	Revision**: 0**	Effective Date: Expiration Date: *(2 yrs. unless otherwise stipulated)*

Procedure Approvals

Responsible author: **Stefan Gerhardt**	Date **3/11/2010**
ATI (NSTX Physics Ops):	Date
RLM (NSTX Expt. Research Ops):	Date

Responsible Division: **Experimental Research Operations**

Procedure Requirements

designated by RLM

	NSTX Work Permit		T-MOD (OP-AD-03)
	Independent Review		ES&H Review

RESTRICTIONS AND MINOR MODIFICATIONS

Approved by RLM

REVIEWERS (designated by RLM)		
Organization/Position	Name	Signature
ATI	D. Mueller	
Test Director		
Independent Reviewer		
NB system		
RF systems		
FCPC systems		
Diagnostics		

TRAINING (designated by RLM)

Training required: No ■ Yes ☐ Instructor ______________________

Personnel (group, job title or individual name)	Read Only	Instruction	Hands-On

RLM ________________________________

NSTX MACHINE PROPOSAL

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AUTHORS: Gerhardt, et al.	DATE: **3/11/2010**

1. Overview:

Beta control was first implemented in NSTX during the 2009 run, for a limited number of discharges. This system compares the present value of a request for the normalized β, to the value computed by rtEFIT, and then adjusts the NB power to reduce this difference to zero. The system performed well in the single instance of its use, but was not optimized. During the 2009 outage, some small changes woo the algorithm were made.

The "Beta Normal Feedback" (or bnf) algorithm for 2010 is based on the following PID equations.

$$e = \beta_{N,reqeust} - LPF\left(\beta_{N,RTEFIT};\tau_{LPF}\right)$$

$$P_{inj} = P_{\beta_N}\overline{C}_{\beta_N}e + I_{\beta_N}\overline{C}_{\beta_N}\int edt + D_{\beta_N}\overline{C}_{\beta_N}\frac{de}{dt}$$

$$\overline{C}_{\beta_N} = 1000\cdot\tau\cdot\frac{I_P V B_T}{200\mu_0 a}$$

Shots from 2008 with large steps in the beam power have been used to select reasonable value of P & I for the controller, using the Ziegler-Nichols "Process Reaction Method". The purpose of the present XMP is to test that the values of P and I so determined are reasonable, and make any necessary further adjustments. It is not clear that derivative gain is actually useful, given the noise on the β_N signal (the subscript β_N on the gains is dropped for the remainder of this document).

The PID scheme noted above produces an analog power request, with an additional block of code required to convert this power request to source modulations. There is also a direct analog power request capability built into the algorithm: the PIC specifies the requested power as a function of time as an input waveform, and PCS determines the beam modulations to match this power (on average). This block of code will be tested as part of the XMP.

If this XMP is successfully completed, the β_N control will be available for use as a general tool.

Note that the algorithm also has contingency for β_T and W_{MHD} control. However, these controls will not be tested as part of the present XMP.

2. Justification:

NSTX is known to have large fluctuations in the normalized beta and confinement transients that can cause stability limits to be exceeded (followed by disruption). Both of these problems can hopefully be mitigated by using beta control. If this is indeed successful, a large number of experiments in the MHD and ASC groups will benefit. Use of this system is also important for the FY-10 MHD milestone on techniques for reducing disruptivity

3. Plan:

3.0: ***Off-line testing of the code against idl equivalent code.***

The entire algorithm has been duplicated in idl, in order to provide a direct check of the outputs. The bnf algorithm will be run on the 2nd control computer during plasma operations, using the input data from the actual shot, and the outputs tested against those computed by the idl code.

3.1 ***Gain optimization***

3.1.1 Load 800 kA, B_T=0.45, with the shape from the 2009 high-delta morning fiducial. Establish discharge to reasonable long pulse.

> Note 1: Might be desirable to further lower I_P in order to stave off late rotating MHD. However, it is also desirable to maintain good absorption of source C, motivating the choice of 800 kA.
>
> Note 2: If there remain mhd problems, raising the TF to 0.48 T may be beneficial. A reasonable waveform to reload is from 133964. Be sure to ramp down I_P earlier in this case.

3.1.2: Notify the NBOS that beta feedback will be used, and that they must plug in the cable on the back of the chassis.

3.1.3: Turn on beta-control, with a waveform similar to that in Fig 3.1. Use gains P=2 and I=0, with 20 msec on/off times. Check that:

____ Gains are correct (P=0.75, D=0, I=0)

____ The batting order matrix is correct.

$$\textbf{Batting Order} = \begin{bmatrix} 1 & 2 & 3 \\ 1 & 3 & 2 \\ 2 & 3 & 1 \end{bmatrix}$$

____ The “Max Blocks Default” correct: [1,1,1]

____ The source power waveforms have the same values as the power of the actual sources.

____ That feedback is turned on at the correct time.

____ That source A is NOT allowed the modulate, but that B & C are specified as used for feedback.

____ That source A is asked to be on the entire time.

____ That the feedback window has the correct timing.

____ Beams enabled waveform set high

____ Deadband for β_N feedback set to zero.

____ Maximum number of blocks per source set to 18.

____Target filter time constant ramping between 0.2 and 0.25 seconds, from τ=0 to τ=0.01 sec.

Shots:________ __________ __________

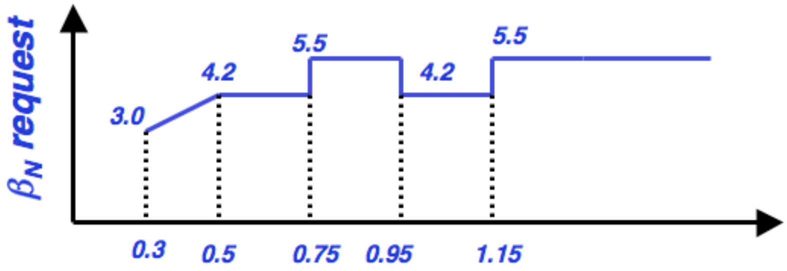

Fig 1: Proposed waveform for the β_N request during gain optimization.

3.1.4: Increase the proportional and integral gains as in the table below. Only one shot per condition is required, and the three shots per row are contingency for failures.

P	I	Shot #1	Shot #2	Shot #3
1	10			
1	20			
1	30			
2	20			

3.2 ***Test of more rapid modulations***

3.2.1 Repeat optimal case with 15 msec on/off modulations. May need to modify batting order.

Shots:________ __________ __________

3.3 ***Test of pre-programmed power ramps***

3.2.1 Turn off feedback and replace it with an injected power request of (approximately) the following shape. PCS should calculate modulations to achieve, on average, this power level.

Shots:________ __________ __________

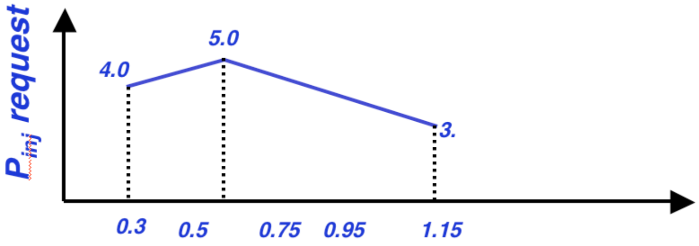

Fig. 2: Proposed waveform for the P_{inj} request test.

4. Required machine, beam, ICRF and diagnostic capabilities:

Standard profile diagnostics and operations magnetics. RWM control would be helpful in order to increase the discharge reliability. LITER operation at ~150-200 mg/shot is also requested.

5. Sign off at run time:

5.1 Permission to Proceed: ______________________________

Physics Operations Head

5.2 Documentation of results:

Documentation of the results completed, attached to proposal and sent to Ops. Center with copies to Cognizant Physicist and Head of Physics Operations.

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Cognizant Physicist/Test Director

PHYSICS OPERATIONS REQUEST

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Brief description of the most important operational plasma conditions required:

1: I_P flat-top of >800 msec without mhd. This allows a long period for testing the step response of the system.

2: RWM control available. This should improve the shot-to-shot reliability at higher values of β_N.

Previous shot(s) which can be repeated:

Previous shot(s) which can be modified: Any 2009 fiducial-like shot, say 135643

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

I_{TF} (kA): **0.45-0.48 kG** Flattop start/stop (s): **Standard front end, go to max. I^2t**

I_P (MA): **700-800** Flattop start/stop (s): **standard ramp rate, and use full OH and TF.**

Configuration: **2009 high-κ, high-δ shape, which is slightly biased down DN.**

rtEFIT controls: **Isoflux, no need for S.P. control at high-δ.**

Outer gap (m): **10-15cm** Inner gap (m): **few cm** Z position (m): **0<Z<-2 cm**

Elongation: **~2.3** Triangularity (U/L): **0.5/0.7** OSP radius (m): **high-δ**

Gas Species: **D_2** Injector(s): **Standard prefill + LFS + HFS (unless SGI becomes the working standard)**

NBI Species: **D** Voltage (kV) **A: 90** **B: 90** **C:** 90 Duration (s): **~1-1.1 sec.**

ICRF Power (MW): **0** Inter-strap phase (°): Duration (s):

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

LITERs: On Total deposition rate (mg/min): **rate to get ~200 mg/shot**

LLD: No Temperature (°C): **Room Temperature**

EFC/RWM coils: n=1 Feedback + n=3 correction
Configuration: **Odd**

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Beam Emission Spectroscopy		
Bolometer – divertor		
Bolometer – midplane array	√	
CHERS – poloidal		
CHERS – toroidal	√	
Dust detector		
Edge deposition monitors		
Edge neutral density diag.		
Edge pressure gauges		
Edge rotation diagnostic		√
Fast cameras – divertor/LLD	√	
Fast ion D_alpha - FIDA		
Fast lost ion probes - IFLIP		
Fast lost ion probes - SFLIP		
Filterscopes	√	
FIReTIP		
Gas puff imaging – divertor		
Gas puff imaging – midplane		
Hα camera - 1D		
High-k scattering		
Infrared cameras		
Interferometer - 1 mm		
Langmuir probes – divertor		
Langmuir probes – LLD		
Langmuir probes – bias tile		
Langmuir probes – RF ant.		
Magnetics – B coils	√	
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
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 detectors	√	
Plasma TV	√	
Reflectometer – 65GHz		
Reflectometer – correlation		
Reflectometer – FM/CW		
Reflectometer – fixed f		
Reflectometer – SOL		
RF edge probes		
Spectrometer – divertor		
Spectrometer – SPRED		
Spectrometer – VIPS		
Spectrometer – LOWEUS		
Spectrometer – XEUS		
SWIFT – 2D flow		
Thomson scattering	√	
Ultrasoft X-ray – pol. 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 tang. pinhole camera		