GMS Meeting Agenda – December 8, 2003

NSTX

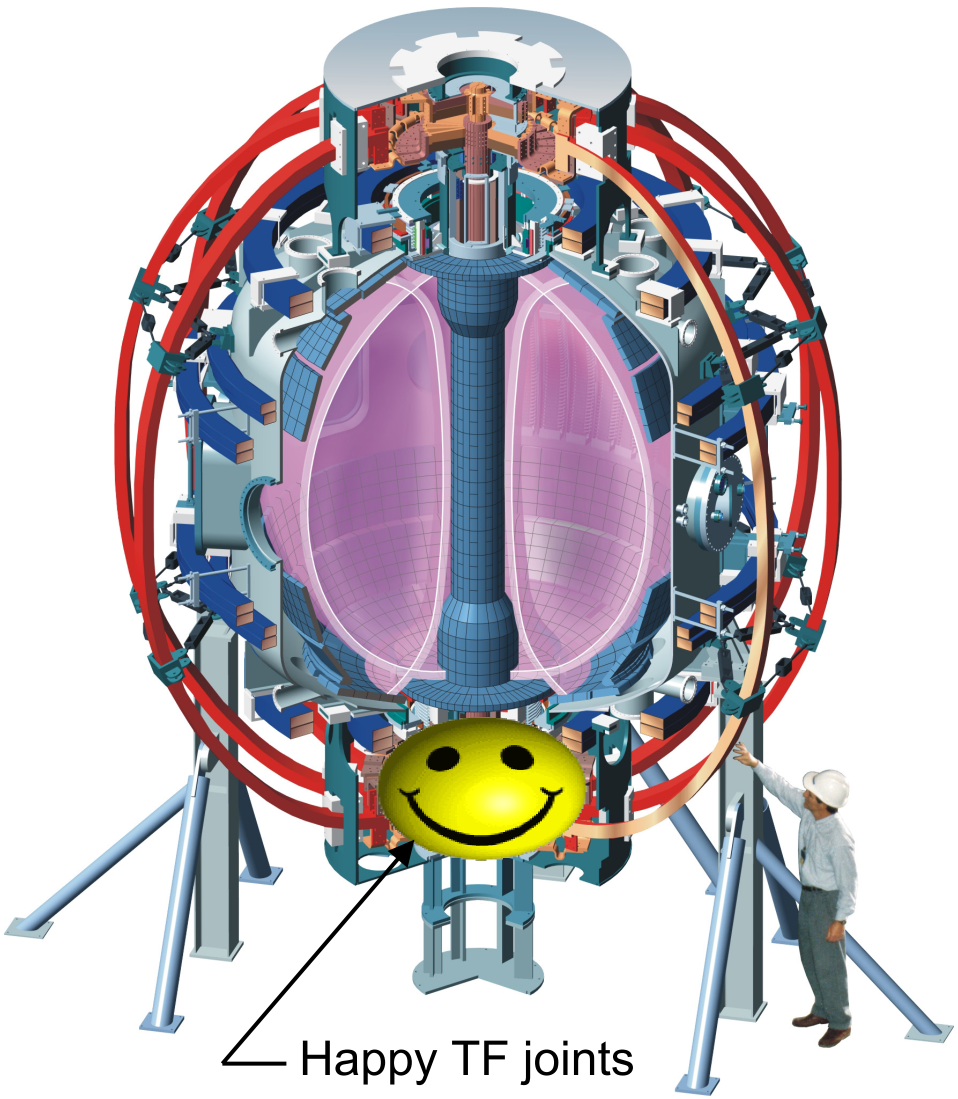
1) Review of RWM/EF system issues (Menard)

2) NSTX RWM Feedback Physics design recap (Sabbagh)

3) Recent VALEN analysis of NSTX RWM feedback system (Bialek)

4) Discussion of power system decision and requirements for control

Review of RWM/EF system issues



J. Menard, PPPL

for the NSTX GMS team

December 8, 2003

Desired specifications from GMS as of January 2003

(same performance characteristics still desired today)

NSTX

MEMO 72-030123-JM-01 "PRELIMINARY REQUIREMENTS FOR NSTX RESISTIVE WALL MODE AND ERROR FIELD FEEDBACK COILS AND POWER SUPPLIES"

*A **single** active control system would ideally be capable of the providing the following physics capabilities:*

1) *Resistive Wall Mode (RWM) control*
2) *PF coil and passive structure Error Field (EF) correction*
3) *Low frequency ($f \approx$ 1kHz) n=1 rotating tearing/kink mode suppression.*
4) *Rotation control via n=3 ripple field generation.*

As of last January, we had not decided between internal vs. external coils, and we were debating the merits of using TRANSREX vs. SPA

Note that external coils effectively eliminate capability (3) above

Several considerations motivated using external coils

Text from same MEMO 72-030123-JM-01:

1) **External coils are "good enough" for RWM control**

   "Because of the reduced relative influence of the image currents in the vessel wall, nearly ideal RWM stabilization up to 94% of the difference between the no-wall and with-wall beta limit can be achieved without toroidal rotation. With external coils, only 72% of this difference can be achieved."

2) **External coils are simpler, cheaper, can be installed w/o vessel access**

   "Initial calculations from C. Neumeyer indicate that external coils could be air cooled between shots, whereas internal coils would require active coiling of a copper inner conductor encased in polyamide or equivalent insulation, both of which would be encased in a stainless tube which may need differential pumping."

3) **Internal coils could interfere with in-vessel components**

   "Internal coils would potentially interfere with in-vessel components such as the HHFW antenna array, neutral beam dump, and possibly other diagnostics and sightlines. Diagnostic interference is also possibly an issue for ex-vessel coils, although the region occupied by the present locked-mode sensor coils would become available if the internal sensors can be used as a substitute."

Several considerations favored using SPA

Text from same MEMO 72-030123-JM-01:

1) **TRANSREX latency too large for fast RWM feedback control**
"Of particular concern for RWM and rotating mode control is the potential for phase instability due to latency and switching speed. The time lag between requesting and applying a voltage to a coil is as long as 4ms for the present TFTR supplies used on NSTX. This latency combined with the comparatively low switching frequency of the supplies, may make them unusable for RWM control."

2) **SPA is much faster, can supply enough current, but more expensive**
"Robicon switching power amplifiers have a significantly higher switching frequency (7kHz) and much lower latency. These supplies are not cheap ($150k-200k) and have a long procurement time (6 months). Some of the cost would be offset by eliminating the need for buswork from FCPC to NSTX."

SPA offers most research flexibility in single system

	TRANSREX	SPA	AUDIO
EF correction	Yes	Yes	No
Fast RWM Feedback	No	Yes	Yes
Ω_ϕ-braking	Yes	Yes	No

- TRANSREX latency too large for fast RWM feedback
  - 1.3ms minimum – need about 10× smaller for RWM feedback
- Audio amplifier DC current too small or absent for EF correction, braking
  - For instance, CROWN amps f_{min} (-3dB) = 5-30Hz
  - Output impedance ≈ 10× coil resistance
- Minimum SPA latency ≈ 1/7kHz = 140μs = 5° for 100Hz sine wave

Parameter comparison for various options

	TRANSREX	SPA	AUDIO
DC current / turn	5kA (coil limit)	3.3kA	0
Feedback Latency	> 1.3ms	> 0.14ms	0.01ms?
M&S	$150k	$350k	?

M&S cost differential between SPA and TRANSREX is approximately the cost of one SPA

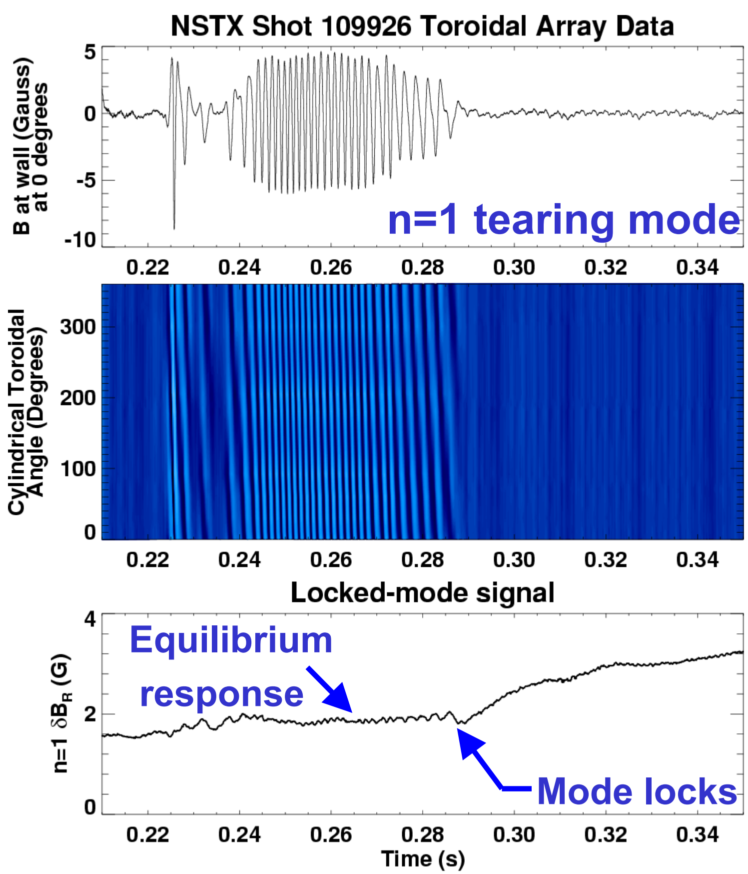
SPA direct cost increased $70k from original estimate ($150k) due to:

- Doubling of previous output current from 1.7 to 3.3kA per phase
- Increase cap-bank voltage to 1kV operation to match TRANSREX feed
- Purchase of voltage control board to minimize latency (hopefully < 0.2ms)

Do we really need DC current capability?

Locked-mode sensors indicate some error field remains:

- Mode-locking observed at lower n_e, B_T
- Modes still lock to preferred locations



800kA, 2×10^{19} m^{-3}, 3.5kG

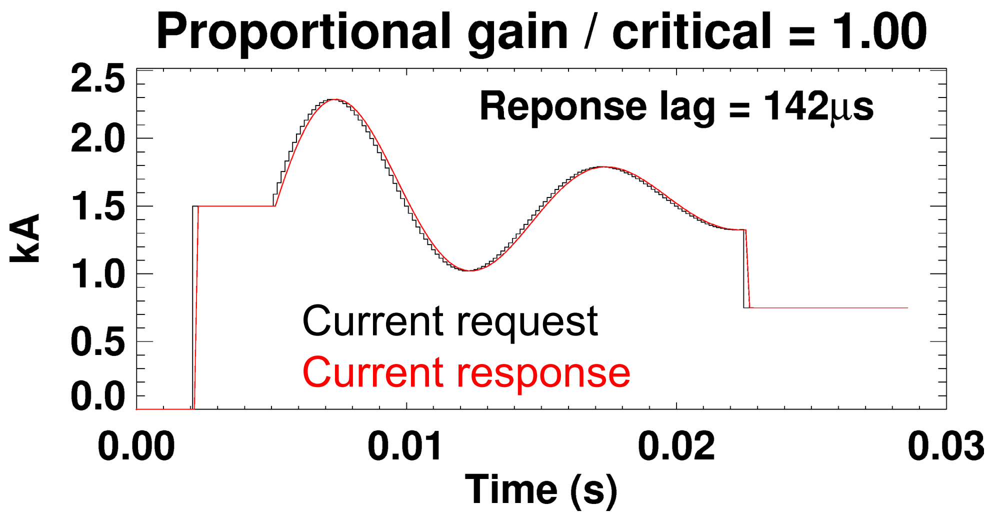
- n=1 B_R field with plasma present is 2-3 × vacuum value ⇒
  - 3D plasma response to remaining error field?
  - If true, EFA also likely present

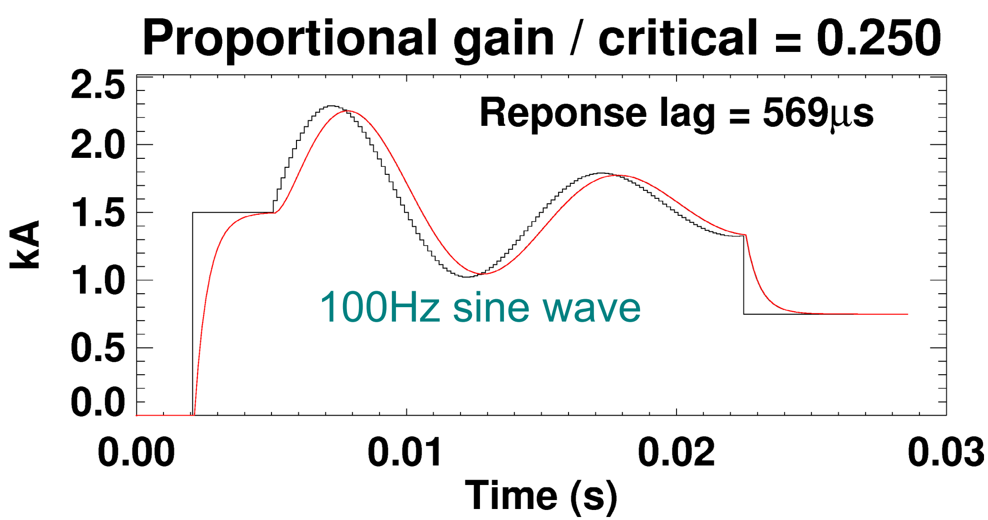
- 3kA/turn with 2 turn coil can provide approx. 10-15 Gauss n=1 resonant $B_\perp$ at q=2 surface
  - 10 × known PF5 error field
    - EF from other PFs undiagnosed

- **SPA should provide enough field and speed in 1 system to:**
  - Reduce error fields
  - Feedback on unstable RWM
  - Do some non-resonant braking

SPA phase lag will be sensitive to controller gain values

- Use very simple model of SPA where duty cycle per switching period is proportional to $V_{request}$
  - Duty cycle = $| V_{request} / V_{switch} |$
  - V applied at end of switch period
- Simple PI current controller:
  - $V_{request} = g_p \Delta I + g_i \int \Delta I \, dt$
  - Current error $\Delta I = I_{request} - I$
- Can find critical proportional gain based on R, L, and $\Delta t \equiv 1 / f_{switch}$
  - $g_p(\text{critical}) = R \times ((1 / \lambda \Delta t) - 1)$
  - Use $g_i = \lambda g_p$ where $\lambda \equiv R / L$





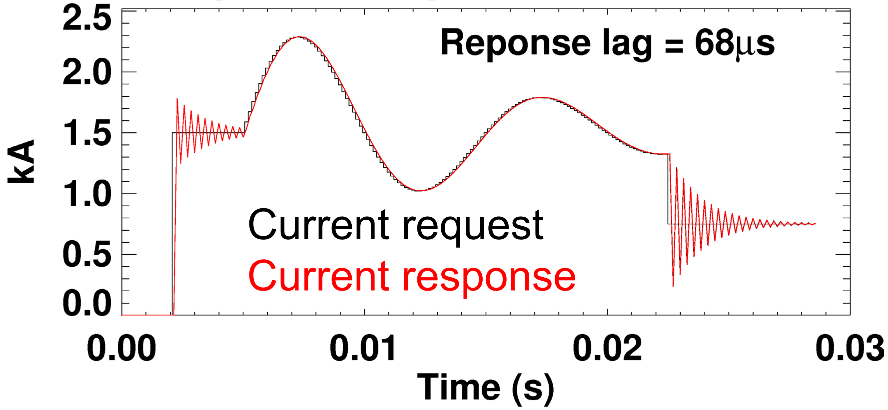
Gain parameters of SPA internal controller would need to be tuned *w.r.t. actual load* to minimize phase lag for optimal RWM control

PCS/control issues will also need consideration

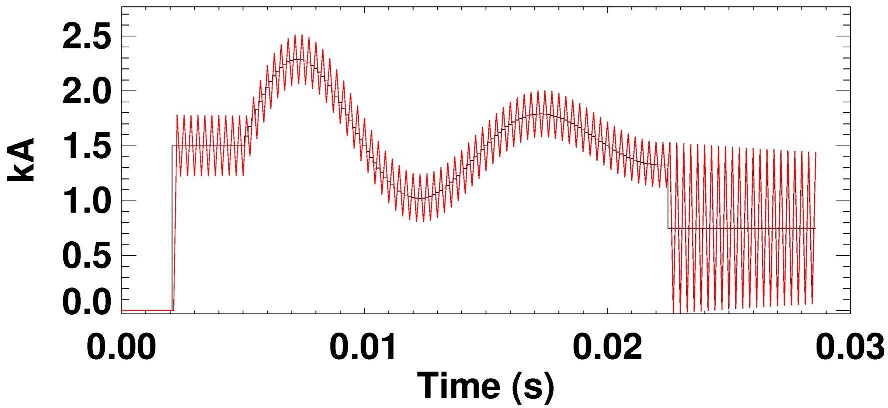
- Increasing the SPA gain introduces damped, and eventually undamped oscillation from step request
  - May need to live with SPA latency of 150-200μs to avoid oscillation
  - Reduce latency by living w/ damped oscillation using vessel as filter (?)
    - Undesirable high-f pickup on magnetic sensors, etc…

- Present PCS DAQ cycle period is at least 200μs (5kHz sampling) ⇒
  - Will need to increase overall DAQ sampling rate or have separate faster DAQ/control loop for latency < 200μs

Proportional gain / critical = 1.90



Proportional gain / critical = 2.00



Next step should be to purchase PCS <u>hardware</u> to control coil supplies

<u>FIRST, we need to know what supply we will use (SPA, audio, other)</u>