NSTX Five Year Plan Ideas Forum
MHD Group Summary

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NSTX

Outline

- Briefly outline MHD parallel session topics
- Re-state MHD charges for this meeting
- Attempt to answer charges using talks and discussion from our sessions

MHD meeting structure

- **5 separate sessions**
- **20+ individual presentations**
- Sessions under budget, often behind schedule, but “well-received”
  - Good discussions in each session

- **Started with description of group long-term ST vision – 3.1**
  - Discussed FESAC goals and implementation approaches – *S. Sabbagh*
  - Discussed present control capabilities and future requirements – *D. Gates*
  - Discussed optimal geometry for ST – *J. Menard*
  - Discussed cross-cutting boundary and MHD issues – *R. Maingi*

MHD meeting structure

- **Discussed needed measurement and theory advances – 4.1**
  - Inclusion of rotation/flow in equilibrium – *R. Betti*
  - Future plans for ion temperature and rotation measurements – *R. Bell*
  - Field line pitch, Er, and |B| diagnostics – *F. Levinton*
  - Expansion of between-shot equilibrium and stability capability – *Sabbagh*

- **Discussed Global Mode Stabilization (including RWM) – 5.1**
  - GMS sensors and control systems - *J. Menard*
  - 1-D and 2-D USXR for MHD modes and equilibrium, *D. Stutman*
  - Key issues in planning a mode control program in NSTX, *G. Navratil*
  - GMS present and future physics studies, *S. Sabbagh*
  - Use of PF4 for MHD studies, *S. Kaye*
  - RWM theory development, *A. Boozer*

MHD meeting structure

- **Resistive MHD (including EBW and NTM) – 6.1**
  - Research plans using M3D, *W. Park*
  - EBW CD for TM & NTM control, *G. Taylor*
  - GEM X-ray imaging, *D. Pacella*
  - X-ray Camera, *B. Stratton (presented by J. Menard)*
  - Use of pellet injector ablation cloud to measure field-line pitch, *D. Rasmussen*
  - Internal fluctuation and field diagnostics, *T. Peebles*

- **Fast Particle MHD (including TAE, CAE) and Astrophysics – 7.3**
  - Fast particle theory – status and future plans, *N. Gorelenkov*
  - TAE Experiments and Diagnostics, *B. Heidbrink*
  - Long-term Mirnov array upgrade plans, *J. Menard*
  - Study of Physics Issues Related to Astrophysics in NSTX, *H. Ji*

Meeting charges:

- Charge #1: *Identify the **scientific issues** that must be addressed to reach the **IPPA 5 and 10 year goals***
- Charge #2: *Identify the **major hardware issues** that must be considered to meet the **IPPA science goals***
- Charge #3: *Identify **inter-device research** opportunities and **advanced diagnostics** that will enable contributions to other fields*

Role of MHD research in the context of the IPPA ST goals:

- IPPA - ST 5 year goal: *Make a preliminary assessment of the attractiveness of the ST regarding confinement, **stability, and high beta operations**, and non-inductive operations (to be achieved early in the 2004 - 2008 time frame)*
- IPPA – ST 10 year goal: *Assess the attractiveness of extrapolable, **long-pulse operation** of the spherical torus for time scales much greater than the current penetration time scales (to be achieved in the 2009 timeframe)*
- IPPA science goal 1: *Advance the **fundamental understanding** of plasmas... and enhance predictive capabilities through **comparison of experiments, theory, and simulation***

Charge #1 – 5 and 10 year IPPA goals:

Scientific issues for high β, high f_{BS}, long pulse operation

- Some in group feel ST 5 year IPPA "assessment" goal already met
- **MHD group is already beginning to study stability physics related to 10 year goal – extrapolable long-pulse operation**
  - Peak β_N=6, β=16% - 700ms I_P flat-top, total pulse length = 1s
  - Long pulse, high β_N shots often suffer from internal disruption
    - q profile evolving to unstable state?
      - Double tearing modes?
    - Uncontrolled density rise
      - Loss of rotation due to fixed input torque
        - » Destabilization of RWM even without locked mode signature?
  - Need improved diagnostics and control tools in NSTX to fairly assess attractiveness of ST concept in near-term and 5-10 year time-frame

Charge #1 – 5 and 10 year IPPA goals:

Scientific issues for high β, high f_{BS}, long pulse operation

- Facility enhancements for MHD studies
  - PF4 commissioning *(Kaye – 5.1)*
    - Change outboard boundary shape, proximity to plates
      - Study RWM and kink physics
    - Introduce dimple to study impact on edge ballooning
      - **May be good way to control edge pressure gradient, control ELMS**
    - Additional flux (and neutral field index) for PF-only inductive startup
  - NBI *(Gates – 3.1)*
    - Feedback control of NBI power
      - Control proximity to beta limits
      - Control NBI current drive
    - Routine operation at higher voltage
      - At 1MA and above, no problem with 100kV absorption
      - Combined with power feedback, use for rotation modifications?

Charge #1 – 5 and 10 year IPPA goals:

Scientific issues for high β, high f_{BS}, long pulse operation

- Additional control tools
  - EBW CD for NTM control *(Taylor – 6.1)*
    - Theoretically possible to get CD localization for large islands
    - NSTX needs to identify current density needed for NTM suppression
    - Earliest date of 1MW EBW for CD is 2006
      - Earliest start of NTM work would be by end of 5 year period
  - RWM stabilization and feedback *(Menard, Sabbagh – 5.1)*
    - Near term goals (next 1-3 years)
      - Install and learn from internal sensors
        - » Assess error fields from PF coils, plates, etc.
        - » Measure RWM, locked mode structure
    - Assess need for either slow or fast active feedback
      - Is rotational stabilization alone enough to get us to target $\beta_N \geq 8$
      - GMS group already designing active coil options
      - Largest uncertainty probably in magnitude of feedback amplifier current

Charge #1 – 5 and 10 year IPPA goals:

Scientific issues for high β, high f_{BS}, long pulse operation

- **Entire NSTX team needs to discuss role/impact of CS upgrade**
  - **Diagnostics, NBI aiming, NBI power, divertor, etc. need to be considered**
- Optimal A and shape driven largely by MHD considerations
  - If ST vision is non-inductive sustainment using mostly BS current, then stability and BS scalings imply:
    - $\beta_t \sim \varepsilon^{1/2} (\kappa \beta_N)^2$ for κ large
  - High stable κ requires broad p and J profiles → H-mode operation
  - If fusion power production is the goal in this regime, A=1.6-1.8 is optimal
- A=1.6, κ_{95} = 2.5, $\delta \geq 0.6$ attractive w/ and w/o wall
- Probably impossible to access this shape with present CS & coils
- Group consensus that moving to this shape is not a large scientific leap provided NSTX studies higher A & κ with present CS

- If NSTX could routinely run long-pulse at high β at A=1.6, $\kappa \geq 2.5$, confidence in extrapolating to higher $\kappa \geq 3.0$ device is much higher

Charge #2 - IPPA Science goal 1:

Comparison of experiments, theory, and simulation

- **Predictive MHD modeling is highly dependent on accurate profile measurements**
  - Thermal pressure profiles and rotation *(Bell – 4.1)*
  - **q profile diagnostics are critical**
    - ***Multiple systems desired for cross-checking and redundancy***
    - ***Core q to distinguish RS from monotonic***
      - MSE-LIF-CIF *(Levinton – 4.1)*
        - » Core elongation from T_e contours
        - » SXR or GEM detector *(Stutman 5.1, Pacella – 6.1)*
    - ***Edge q shear, edge current density***
      - Edge q diagnostics
        - » MSE-LIF-CIF
        - » Pellet cloud pitch angle *(Rasmussen – 6.1)*
        - » Field line pitch from reflectometer array/correlation *(Peebles – 6.1)*
  - Incorporate profiles into reconstructions & stability *(Sabbagh – 4.1)*

Charge #2 - IPPA Science goal 1:

Comparison of experiments, theory, and simulation

- **Accurate comparison of experiment to simulation requires detailed measurement of MHD mode structure**
  - RWM sensors being installed *(Menard –5.1)*
  - Tearing mode diagnostics not yet sufficient
    - Need to measure poloidal mode numbers *(Menard – 4.1, 7.3)*
    - Develop EBW equivalent to ECE for island internal structure *(Taylor–6.1)*
    - Develop tomography for internal island width and m-number *(Stutman 5.1)*
  - TAE, fishbone, CAE
    - Present models will likely explain observed frequencies
    - Present models predict quite different internal structure *(Heidbrink – 7.3)*
      - Reflectometry?
      - Edge reciprocating Mirnov using Boedo probe? *(Menard - 7.3)*

Charge #2 - IPPA Science goal 1:

Comparison of experiments, theory, and simulation

- **Theory development needed in many areas to enhance modeling capabilities**
  - Inclusion of toroidal & poloidal flow in equilibrium *(Betti – 4.1, Park 6.1)*
  - Inclusion of rotation and multiple modes in RWM models *(Boozer – 5.1)*
  - Understand RWM damping mechanisms and critical Ω *(Navratil – 5.1)*
  - Intermediate-n kink and ELM stability *(Snyder – 7.2)*
  - Tearing mode modeling – role of low A, high β
  - Fast particle mode theory and modeling *(Gorelenkov – 7.3)*
    - Move away from perturbative theory (M3D)
    - Fully kinetic fast ions (no drift approx.) (HYM code)
    - Eventually follow orbits of all ions, model CAE stochastic heating
  - Experiments and analysis to support RWM modeling & theory *(Sabbagh – 5.1)*

Charge #3:
Inter-device research and advanced diagnostics

- **Inter-device research**
  - Toroidicity effects on TAE/CAE (DIII-D/NSTX) *(Heidbrink – 7.3)*
  - Aspect ratio, β, critical Ω effects on RWM (DIII-D/NSTX)
  - Develop collaborations to study plasma astrophysics *(Ji – 7.3)*
    - Magnetic reconnection
    - Angular momentum transport
    - Dynamo effect and helicity transport
  - Other possibilities
    - Stochastic heating in solar corona/NSTX

- **Advanced diagnostics to contribute to other fields**
  - No explicit discussion – doesn't mean they don't exist…

Summary

- Despite rapid construction of meeting, the MHD sessions were quite productive
  - Good discussions and outlines of theory, modeling, and diagnostic plans
  - We hope these discussions address the stated charges of the meeting

- NSTX has produced good results rapidly
  - To keep this pace up, internal profile and mode structure diagnostics must reach fruition
  - Enhanced control tools are also a must

- Thanks to S. Sabbagh for his efforts while I was away last week