

NSTX Working Group 3 - Magnetism and Stability Limits

NSTX Forum 12/3-5/97 - S.A. Sabbagh
DRAFT version 1.2

A research forum was held for the NSTX project on December 3-5, 1997 at PPPL. Following the plenary sessions and Working Group (WG) introductory talks, parallel WG sessions were held to discuss NSTX stability issues.

The NSTX stability working group has been charged to report the near-term goals of the group in support of NSTX. An update to the key scientific goals of WG3 for NSTX follows. Diagnostic needs are also summarized. The summary of the complete discussion held during the two WG3 "parallel" sessions complete this document.

Summary of WG3 parallel session 2 (Summaries and Recommendations):

A list of desired diagnostics, as well as scientific goals were prioritized.

Note that chits were handed out to the group, so that individuals could provide a list of action items. The subtitles were:

- diagnostic needs
- theory/modeling needs
- experimental operations needs
- infrastructure (and other) needs

The following summary includes the discussion held at the forum. Input from chits, if any, has not been incorporated to these lists.

Working Group 3 (Magnetism and Stability Limits) Scientific Goals and Tasks:

The working groups have been charged to provide updated information on the (1) scientific goals for the stability research area for the initial 3 years of NSTX experimentation, emphasizing the unique ST plasma properties. We are also charged to describe the (2) elements of research to achieve these goals, including for each element (where appropriate):

- anticipated scientific results
- relevance to the research goals
- needed plasma operating conditions
- necessary measurements and accuracy

A recommended time order for developing diagnostics has also been requested. Priorities as research topics are listed as high, medium, and low.

The NSTX research forum WG3 sessions addressed the first (1) charge given. The additional detail desired in (2) was not addressed at the forum.

Priority Stability Physics for NSTX:

Key Topics in MHD Theory/Modelling:

- Ideal stability
 - Low-n, ballooning, infernal, interchange...modes
 - Idealized profiles: **priority - low** (it's been done)
 - Experimental profiles: **high**
 - OH (tokamak experiments, START)
 - RF (Alcator, HHFW modeling code)
 - NBI (tokamak experiments, START)
 - CHI induced
 - Role of discrete coils on achievable β - limit: **high**
 - Wall stabilization: **high**
 - Determine optimal NBI footprint: **high**
 - Rotational shear stabilization of modes: **low**
 - Rotation and torque balance in MHD codes: **low**
- Resistive MHD
 - Tearing modes (Δ' - linear, non-linear) - FAR: **medium**
 - Neoclassical tearing modes: **medium**
- Kinetic MHD
 - Alfvén eigenmodes: **low**
 - Kinetic stabilization of sawteeth (RF/NBI): **high**
 - FLR effects: High τ_E at low B: **medium**
(important, but longer term)

Key Experimental Issues: all high priority:

- Equilibrium reconstruction modeling
- Plasma start-up and operational issues:
 - Resistive current penetration and stability during startup
 - Axial stability
 - Current and density limits
 - Role of resistive MHD instabilities in CHI for current drive
- Mode detection, identification, and structure
 - Poloidal and radial structures; comparisons with theory
 - Locked modes / stationary magnetic perturbations
 - Error field measurements
 - Structure of Alfvén eigenmodes
- β -limiting phenomena

- ☐ Low-n, ballooning, infernal modes and coupling
- ☐ Tearing / neoclassical tearing modes
- ☐ Sawteeth, ELMs: effects of toroidal coupling
- Disruptions
 - ☐ IREs vs. disruptions, beta-collapses
 - ☐ Halo currents, runaways
- Wall stabilization
 - ☐ Resistive wall modes
 - ☐ Design issues with potential feedback system needs
 - ☐ Maintain flexibility of passive plate design
 - ☐ Effects on β -limit
- Additional recommendations / comments
 - ☐ Establish experimentally accessible reference coordinates within the machine
 - ☐ Investigate a momentum injection source
 - ☐ Plans for a reflectometer?

Priority Measurement Needs - Baseline

- Poloidal soft X-ray imaging systems
 - ☐ Measurement of low m/n islands
 - ☐ Can the present system resolve high m ? ($m = 7$ shown)
- Rotation profile measurement
- Measurements on passive plates
 - ☐ "Smart shell" sensors
 - ☐ Eddy currents
- Halo current measurements
- Locked mode detectors

Priority Measurement Needs - Advanced

- Current profile measurement diagnostic
 - ☐ ASAP!, or consider alternatives to MSE before NBI is available
- Toroidal imaging system (soft X-ray)
- Well-resolved edge measurements
 - ☐ Edge islands
 - ☐ Sharp edge gradients in density, temperature
- High-speed visual camera (i.e. START system)
 - ☐ Fast global instability evolution; disruptions

Summary of WG3 parallel session 1:

Manickam:

The suggestion was made to list the research needs or topics to be addressed in the next few years. We should also prioritize topics as urgent, high, and medium, and

suggests that they equate to short, medium and long-term needs. However, Navratil and others disagree with this mapping. The suggestion is to weigh the ultimate importance against time and resources needed to be investigated.

Bell:

Among the issues mentioned is the role of FLR in NSTX. This may be stabilizing, so extrapolation to higher T and B needs to be assessed quantitatively.

The question was raised about the need for good reference points to the actual field configuration.

Theoretical considerations: equilibrium reconstruction, ideal MHD stability, resistive MHD, and kinetic MHD. We should consider a set of codes that are “optimal” for NSTX. The

Experimental considerations: include start up, mode detection, β -limiting phenomena, disruptions, wall stabilization, and active feedback.

The discussion included diagnostic considerations at low field, deciding upon standard computational tools for NSTX. The key issue here is accuracy at low aspect ratio.

Kaita:

Magnetics and X-ray emission diagnostics become even more important due to the loss of important diagnostics like ECE at the low NSTX toroidal field. Bob showed the present poloidal soft X-ray array diagnostic for NSTX (collaboration with Johns Hopkins group). Details of the sensitivity of the soft X-ray detectors were discussed. Mike Bell suggested a “multi-layered” detector system of different sensitivities, which is straightforward, but the constraint becomes budget.

Manickam illustrated an $m=7$ perturbation and questions whether the soft X-ray diagnostic has sufficient resolution to measure such a perturbation. The method of signal inversion will also be important in measuring such a high m perturbation. Bob mentions that we may have to re-think the sight-lines to optimize the measurement in the NSTX field geometry.

Tangential ports will exist at all locations not used by the RF antenna and the NBI port.

Manickam brings up the subject of coils on the front and backside of the passive plates. Bob shows a diagram illustrating pickup coil positions for such a system on the present plate design.

Ramos:

Jesus discusses resistive stability issues for NSTX. Equilibrium calculations are shown, preparing a model for MARS analysis ($n = 1$). Growth rate depends more

strongly on resistivity than expected ($3/2$ power is found). The perturbed current for the $n = 1$ resistive mode is shown. (for $S = 5e6$ and $2e6$). Jesus remarks that numerical considerations are non-trivial at the high q values considered.

Navratil:

Summary of the feedback control workshop. Most important modes to consider are $n=1$ ideal kink, resistive wall mode, tearing modes and neoclassical modes, higher n kink mode.

Discussion of fusion power in ST shows a scaling to the 4th power with beta-N for fixed toroidal field. There's a clear need to access the maximum ideal stability limits (those computed with the influence of conducting wall). To attain this, feedback stabilization is required.

Conceptual ideas to stabilize the modes mentioned were discussed. These include a passive, close fitting wall, smart shell, $n = 0$ style direct feedback, plasma rotation, active feedback control of island amplitude, asynchronous dynamic stabilization; ion inertia damping, profile control at the plasma edge; edge ergodization, and driven halo currents.

Manickam suggests that RF stabilization of islands should also be considered for NSTX.

Active mode control implementation issues for NSTX include the degree of gaps available between the passive plates. Smart shell considerations include the location of the sensors with respect to the passive plates. The sensor coils should be placed immediately behind the passive stabilizer. Tearing mode control at audio frequencies has problems JET reported vibrational dust release to the plasma and also coil shorting.

Takahashi:

Halo currents, locked modes, and Stationary Magnetic Perturbations (SMPs) should be studied on NSTX. The study would include the causality between the SMP, transport (stability), and edge phenomena. Subjects to be addressed include disruptions and confinement loss.

Sawtooth "suppression" is often reported in plasma that have SMPs (TFTR data shown for a plasma with a plasma current ramp-down - detail of the sawtooth evolution is shown). The re-heating phase of the sawtooth disappears, and the conclusion is that SMPs appear to have an effect on the transport in the plasma interior.

Diagnostics include a halo current measurement (complete and partial Rogowski loops on the center stack), instrumented tiles on the center stack, large number of pickup coils for mapping halo currents, SMP sensors inside the vacuum vessel. Also want diagnostic to directly detect low m/n islands, and islands near the plasma edge. Edge diagnostics also include edge and scrape-off plasma densities, $H\alpha$ and carbon light.

Paoletti:

EFIT modeling of NSTX was shown. Results obtained to date plus studies for the near future were shown. The studies include the impact of the free-boundary plasma shape on stability, the implementation of experimental profiles, robustness of the stability of NSTX target equilibria, and modeling of the control system.

The 40% beta case of Menard was reproduced. When the free-boundary is used instead of the parameterized boundary, the beta limit is reduced to 33%.

DIII-D H-mode and L-mode pressure profiles were implemented in the study. Compared to the optimized pressure profile of Menard, these profiles are more peaked. The DIII-D L-mode profile gives an equilibrium at about 18% which is near marginal stability to the high-n mode, and stable to the $n=1$ kink. This value of beta is consistent with the expectations of L-mode scaling.

Continuing efforts include implementation of START pressure profiles, and optimization of beta limits by varying q profiles with fixed, experimental pressure profile shapes.

Neil Pomphrey comments that the reduction of the beta limit to 33% is important. The remark is that a small change in the outer boundary shape reduced the beta by a significant amount. The robustness of the solution is important. NSTX management should be careful in touting just high numbers in beta.

Strong comment by Neil was that the PF coil design might not be robust enough. The present coil set and position was determined by cost-saving measures. We need to carefully examine the robustness of the free-boundary equilibria and be careful to state what we expect what beta limits can be reached with the existing coils set, instead of higher, optimized values.

Menard:

CDX-U reconnection events (IREs) were shown (1/1 and 2/1 coupled modes). No detectable spike in plasma current was observed in the case shown. Electron density and temperature in the island from probe measurements were shown. Remark is made of the stronger coupling of $q=1$ and 2 surfaces in this high li plasma. A strong overlap of the islands is observed, the islands being locked to each other.

Results from a probe scan are shown (scan in major radius). A coherent, 10 kHz 2/1 mode is observed. Before the reconnection phase, the 1/1 island is observed also, and overlaps with the 2/1. Overlap occurs both in frequency and space at the time of the reconnection. Both modes disappear after the reconnection (not much left!). Much later in the discharge, both modes are observed once more - not shown to overlap.

Sabbagh:

The analysis topics for NSTX that are being worked on by the Columbia U. collaboration were summarized: free-boundary equilibrium and stability analysis was

discussed in detail by Paoletti earlier in the session. Navratil touched upon active feedback and resistive wall mode studies in the talk. One slide was shown summarizing the initial studies now being conducted for NSTX. They include determining the effects of the low aspect ratio geometry on the free-boundary equilibria stability limits for kinks and resistive wall modes, and the impact on feedback coil design. Conducting shell effects will be included, SPARK code analysis of the eddy currents will be performed. These studies are extensions of the present EFIT studies on NSTX and experimental and theoretical work on the HBT-EP device at Columbia.

The initial goal of this work will be to sketch out possible feedback schemes for NSTX. Asynchronous frequency modulation will also be considered as a longer term goal for resistive mode stabilization in NSTX, again guided by the recent positive results on HBT-EP.

The final physics study shown comprised the heart of the presentation. A study of optimizing the NBI footprint in NSTX was proposed. The question is quite focussed and tractable. The goal of the study is to optimize the NBI geometry for both confinement and stability, determine a practical modification that would produce this footprint, and work with engineers to implement the changes on the NSTX NBI system.

The logic proposed is straightforward. Published results from TFTR (which was applied to other machines as well) show that energy confinement increases with increasing neutral beam deposition peakedness. However, the global MHD beta limit is observed to decrease with increasing pressure profile peakedness. Therefore, an optimal NBI footprint should exist which nominally maximizes both confinement and stability.

The tools envisioned to perform the study all exist. Three of the four tools are already functioning in the suite of codes that this group uses. The only remaining decision is whether TRANSP or BALDUR would be superior to perform the NBI deposition / pressure profile peaking study.

Okabayashi:

Resistive wall stabilization is considered by implementing both the "smart shell" and "fake rotating shell" ideas. Michio, et al. have developed a lumped circuit equation formulation to study RWM control ($n > 1$ is a modified version of $n = 0$ control - the control schemes are analogous). Equations for growth rate * wall time were shown. Schematic diagrams illustrating the smart shell and fake rotating shell concepts were also shown. Smart shell tries to cancel the detected eddy currents in the shell, while the fake rotating shell allows a phase shift between the detected and applied signals.

The best sensor is the eddy current pattern itself (measured in PBX-M). The eddy current pattern is shown for a DIII-D simulation. Michio also distinguishes the difference between the mode pattern induced in the shell versus that on the actual plasma, and makes the point that we want to influence the mode in the plasma. Delta Bn patterns from the coil and PEST simulations were shown, and were well phase-matched.

Pribyl:

LCT studies - kink stabilization by rotation was discussed. Disruptions due to $q=3$ surface were stabilized by rotation. The hypothesis is that sheared rotation stabilization is the cause. The 2/1 mode quench was shown - the mode is rotated such that the maximum rotation shear is near the $q = 2$ surface. An internal probe, 10 cm in the plasma, causes the rotation. Manickam suggests that this might be Rutherford stabilization - driving current on the island.

Relevance for NSTX was discussed. Driven poloidal rotation can potentially stabilize both resistive and ideal modes. RF could be used to produce a tail ion population for this. The low aspect ratio poses problems in that the damping is large, but this might be overcome.

Manickam suggests that this scheme might be used to stabilize the ballooning mode, which seems to be posing the strictest constraint on the beta limit in NSTX.

Yamada:

Extending NSTX operation to the low- q , spheromak regime in NSTX is discussed. Connection is made to the START results, particularly disruptions. Masaaki suggests that $n=1$ tilt/external kink mode are important, and might be the mode that causes the high beta disruption in START.

Radial profiles of B_p and B_t were shown, illustrating how ST and spheromak field profiles are very similar.

Stabilization schemes for the tilt mode (driving a current along the major axis of the spheromak) was presented.