Activities of the MHD physics working group

Conveners - C. C. Hegna, UW and E. J. Strait, GA

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Working Group Members

- J. A.Breslau, PPPL
- D. P. Brennan, GA
- R. H. Bulmer, LLNL
- M. S. Chance, PPPL
- M. S. Chu, GA
- D. A. Gates, PPPL
- A. H. Glasser, LANL
- R. S. Granetz, MIT
- C. C. Hegna,† Wisconsin
- D. A. Humphreys, GA
- S. C. Jardin, PPPL
- R. J. LaHaye, GA
- L. L. Lao, GA
- J. Manickam, PPPL
- D. Mossessian, MIT
- M. Ono, PPPL
- L. D. Pearlstein, LLNL
- S. A. Sabbagh, Columbia
- J. S. Sarff, Wisconsin
- P. B. Snyder, GA
- E. J. Strait,† GA
- L. E. Sugiyama, MIT
- A. D. Turnbull, GA

Broad questions for the MHD working group

- What new MHD physics can we learn from a burning plasma, and to what extent will the proposed machines allow us to investigate those physics issues?
- What limitations will MHD instabilities impose on the ability of a burning plasma experiment to achieve its full range of scientific goals, and how can these instabilities be avoided or ameliorated?
- What impact will the MHD physics to be learned in a burning plasma experiment have on the development of future fusion devices - both tokamaks and other concepts?

Detailed physics issues

- Generation of equilibria - Lao, Manickam
- Ideal MHD stability - Glasser, Manickam, Turnbull
- Stability limits with resistive wall - Sabbagh, Chance, Chu, Sarff
- Neoclassical tearing modes - Gates, Brennan, Hegna, La Haye
- m = 1 stability - Strauss, Breslau, Jardin, Sugiyama
- Error fields - La Haye
- ELMs - Snyder, Mossessian
- Disruptions - Granetz, Humphreys, Ono
- Impact on fusion development - Sarff, Ono, Hegna

A variety of equilibria will be generated for stability studies

- Burning plasma science issue - integration of self-consistent MHD equilibrium including alpha-heating, transport, profile evolution, current evolution, edge properties, etc.
- Assessment - equilibria to be used are generated by using:
  - Reference equilibria for each device
  - Neighboring equilibria for sensitivity studies,
  - Equilibria from transport modeling.
- A variety of operational scenerios will be studied.
  - Available equilibria:
    - ITER - (EFIT, CalTrans, CORSICA) - conventional and AT scenarios
    - FIRE - (JSOLVER, TSC) - conventional
    - IGNITOR- (EFIT, CORSICA) -conventional

Ideal MHD instabilities provide an upper limit to plasma stability

- Burning plasma science issue - stability properties as part of an integrated study - proximity of operational points to stability boundaries.
- Assessment - There is a need to identify limiting instabilities and the proximity of operational points to stability limits as well as assessments of the sensitivity of the stability properties to modest variation in parameters (profiles, shaping, wall position, edge-q, etc.).
  - Initial ideal MHD calculations are being performed
    - DCON calculations of ideal ballooning, Mercier, n = 1 internal and external mode stability for reference equilibria for IGNITOR, FIRE and ITER
    - GATO calculations of n = 1, 2, 3 ideal kinks for an AT equilibria with L-mode edge for ITER-FEAT

The stability of m = 1 modes is a crucial issue for discharges with q(0) < 1

- Burning plasma science issue - Self-consistent modeling of m = 1 stability with isotropic alpha particle population. Alpha particle stabilization in burning plasmas? Scaling with various plasma parameters - collisionless reconnection.
- Assessment - A model for sawteeth in a burning plasma has been developed by Porcelli, et al, PPCF '96, which includes
    - δW for ideal internal kink
    - Kruskal-Oberman trapped thermal ions and alpha particles.
    - Non-ideal effects which allow for reconnection.
    - Sawtooth period and mixing radius are predicted when used with a transport code
  - – PEST in combination with TSC will be used to model this
  - – Possible use of M3D to account for hot ion and nonlinear effects.

Neoclassical tearing modes often limit long pulse discharges

- Burning plasma science issue - Observed $\beta_{crit} \sim \rho^*$ is not favorable for burning plasmas - Uncertainties in theoretical predictions for the island threshold and seed island formation. Theories point to key set of dimensionless parameters (ρ^*, S, $\nu_i/\varepsilon\omega^*$). Scaling in larger devices?
- Assessment
  - For IGNITOR, NTM's should not limit performance
  - NTMs are anticipated in ITER and FIRE plasmas.
  - ECCD stabilization techniques have been successful. Plans to use ECCD for NTM suppression on ITER are being considered.
  - The tentative plan for FIRE is to use LHCD as a suppression technique. This is an untested method. Current localization?
- A theoretical tool has developed to calculate relevant non-ideal MHD parameters, using PEST-3 for asymptotic matching data.

Field errors can have a significant deleterious effect on slowly rotating plasmas

- Burning plasma science issue - Relatively small non-axisymmetric fields ($\delta B/B \sim 10^{-4}$) can slow plasma rotation and produce locked modes, seeds for NTMs, etc. Sufficient rotation to inhibit mode locking? Scaling in larger devices?
- Assessment
  - Slowly rotating plasmas with q = 1 are sensitive to mode locking.
  - Increasing sensitivity as β approaches n = 1 ideal kink limits.
  - In ATs with q > 2, n = 1 ideal kink eigenmodes have m/n = 2/1 which interact with m/n = 2/1 field errors and slow rotation.
  - Observations of the discharges with q =1 can be understood by the 'induction motor' (Fitzpatrick, `95) and 'error field amplification' (Boozer, `01) models. However, these models are not applicable to the q > 2 discharges.

The ability to survive and/or mitigate disruptions is required for a burning plasma

- Burning plasma science issue - runaway electron population increases dramatically with current. Scaling in larger devices?
- Assessment - The three machines differ with respect to issues associated with vertical displacement, halo currents and the resulting EM forces.
  - ITER is to have a standard single null and has been engineered to survive halo current disruptions in the divertor.
  - Little data on double-null up-down symmetric systems, like FIRE. Enhanced vertical stability due to operation at its “neutral point”?
  - Since IGNITOR is a limiter plasma, it may not have much of a problem with post-quench vertical motion.
- High pressure injection of low-Z gas jets have been shown to be effective in forcing a fast shutdown and/or prevent runaways.

ELM size and MHD constraints on the pedestal are key issues for burning plasmas

- Burning plasma science issue - ELMs can limit performance through large transient heat loads on divertors and impact global confinement through strong dependence on β_{ped}. Scaling of edge parameters is not well understood.
- Assessment - Present theoretical efforts for understanding edge MHD properties address intermediate-n ballooning/peeling modes due to steep edge gradients and the associated edge bootstrap current .
  - Development of the ELITE code allows one to study n ~ 5-60 ballooning/peeling stability in shaped tokamak geometry.
    - H-mode like profiles; current consistent with bootstrap current
    - MHD stability calculated for n = 8,10,15,20,30 with systematic variation on pedestal width
    - Yields MHD constraints on pedestal height (T_{ped}, β_{ped}) as a function of width, shape, density. Structure of most unstable mode expected to be correlated to ELM depth.

Impact of MHD learned in a tokamak BPX on non-tokamak fusion development

- Varied magnetic configurations share some issues: resistive wall modes, neoclassical effects, kinetic effects, flow-stabilization, profile control, etc.
  - Good likelihood for valuable knowledge transfer from tokamak BPX to non-tokamak configurations (dependent on similarity to tokamak?)
  - Alpha-kinetic effects and integration issues special opportunity for BPX, which all configurations face in some way
- Knowledge transfer will probably depend strongly on basic understanding which provides predictive capability
  - For example, small configuration changes might require very different integration formulas (even within tokamak variation!)
  - Basic understanding will penetrate best into fusion portfolio
- Not every important MHD issue is found in a tokamak BPX. Often the most pressing MHD questions for various magnetic configurations will not be found in a tokamak (e.g., magnetic relaxation, 3-D shaping, sonic/Alfvenic flow shear etc.)

Post-Sherwood Snowmass MHD Working Group Meeting

Strathallan Hotel

Berkeley Room

Wednesday April 24, 2:00-6:00 pm

Thursday, April 25, 8:30-12:30

The meeting is to assess preliminary studies, obtain community input, and plan further group activities.

MHD science issues in a Burning Plasma

- MHD issues which require burning plasma parameters
  - NTM threshold and seed island scaling (ρ^*, S, $\nu_i/\varepsilon\omega_e*$, etc.)
  - Resistive wall stabilization, error field penetration, mode locking
  - Edge driven instabilities
  - Disruption scaling (runaway avalanche)
- MHD issues related to strong alpha-particle heating
  - Energetic particle interacting with MHD modes (m = 1, TAE, etc.)
  - MHD stability with self heated profiles
  - MHD stability with self-heating and relaxed current profiles
- Integration issues - self-consistent interaction of alpha heating, transport, stability, current, pressure, and rotation profile evolution.