# Report on the ITPA MHD stability topical group meeting and IEA Workshop on Key ITER Disruption Issues

6-9 October 2009
Culham, UK

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PPPL

CEMM Meeting
Nov 1 2009
Atlanta, GA

see: fusion.org.uk/itpa

# U.S. Attendees

- S. Sabbagh (CU,NSTX)
- E. Strait, J. Wesley, V. Izzo (DIII-D)
- R. Granetz (CMOD)
- J. Ramos (MIT)
- S. Jardin, L. Zakharov (PPPL)

# Major MHD topics of interest to ITER[1]

- Neoclassical tearing mode (NTM)
  - Avoidance by sawtooth control
  - Prevention and stabilization by current drive
  - Rotation effects
- Resistive wall mode (RWM)
- Other macroscopic stability
  - Saturated ideal mode in AT operation
- Disruption avoidance
- Disruption modeling
  - Effects of induced and halo (and Hiro) currents on vessel forces
  - Heat load and runaway electron prevention and mitigation

[1]ELMs and RMP are also of great interest to ITER, but they are not part of this ITPA group or meeting

# Neoclassical Tearing Mode (NTM)

- Avoidance by sawtooth control
  - Showed fast ion de-stabilization on JET. Decreased $\tau_{SAW}$ by 2.
    - Saw a correlation with reduced NTM triggering
  - Can control sawtooth period in TCV by EC deposition near q=1
  - Sawtooth period is increased by ICRH in Tore supra, and reduced by ECCD just inside the q=1 surface.

- Prevention and stabilization by current drive
  - Preemptive ECCD at q=2 effective in eliminating (2,1) mode in DIII-D
    - However, (4,3) and (3,2) modes can still appear

- Rotation effects
  - NSTX experiments show higher $\beta_N$ achievable with sheared rotation
    - Rotation itself is of little value

No modeling/simulation results were shown!

# Resistive Wall Mode

- MISK (Modifications to Ideal Stability by Kinetic Effects)
  - Linear perturbative code uses PEST eigenfunctions (Hu and Betti)
  - Includes both thermal and energetic ions
  - Resonances with bounce and precession frequencies important

- MARS-F (linear resistive MHD with feedback coils)
  - MARS-K (also includes bulk plasma bounce and precession drifts)
    - Non-perturbative: includes self-consistent eigenfunction
  - CarMA includes detailed 3D vessel model from Carridi code

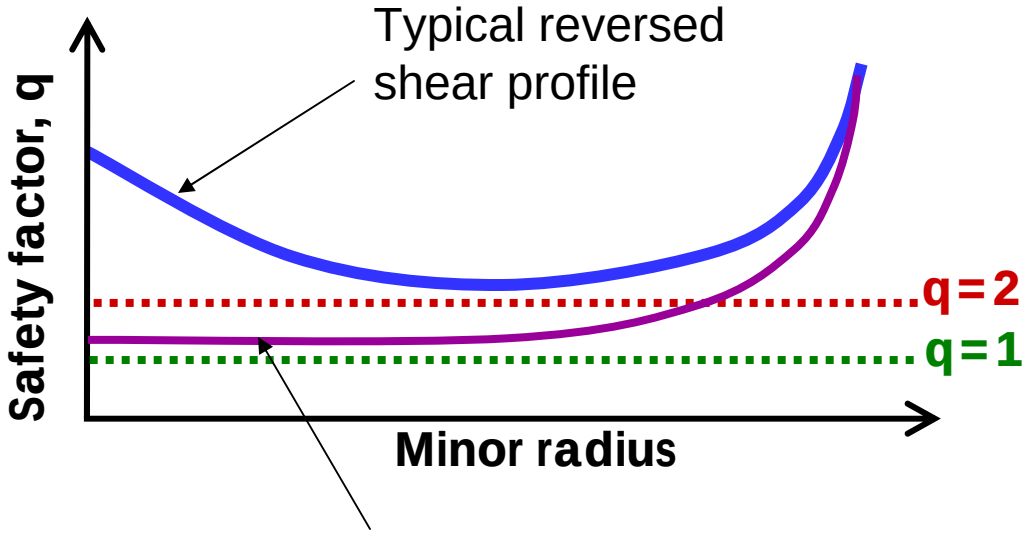
- IPEC – DCON linear stability with forcing boundary conditions

- mmVALEN – attempt to couple DCON with 3D vessel model

Various results were presented trying to interpret RWM experiments with one or more code. Results not very conclusive.

# Other Macroscopic stability

- Saturated ideal mode in AT operation
  - Several tokamaks have found a long lived, mostly m=n=1 non-resonant internal mode when q > 1 everwhere
  - Called Long-Lived Mode (LLM) in MAST
  - In NSTX this also drives m=2 islands




CEMM codes are uniquely qualified to study nonlinear saturation of these modes. See Breslau presentation

# Disruption Avoidance

- Active control of locked modes (ECCD)
- ECRH used to avoid density limit disruption
- When to give up on discharge and apply mitigation technique such as killer pellet or massive gas injection

Improved modeling could have an impact in learning how to avoid disruptions. Need to develop strategies toward disruption-free operation.

# Key ITER issues in disruptions and their mitigation

- Forces due to halo currents on supporting structures. $\mathrm{TPF} \times \frac{\langle I_h \rangle}{I_{p0}} < 0.75$
  - Dynamic amplification factor also important
  - Need to understand origin of “sideways force” in JET
  - Zakharov has a theory based on development of surface currents (that he calls Hiro currents after Hiro Takahashi)
- Heat load during thermal quench
  - Time scale of energy dump
  - How much does the divertor SOL expand during thermal quench
- Disruption and runaway electron mitigation
  - Massive gas injection and killer pellet both candidates
    - Helium, D2, Neon, Ar, Kr, Xe all under consideration
- Runaway electron characterization
  - Energy spectrum, current, beam energy, time evolution

# Disruption Modeling

- Effects of halo currents on vessel forces
  - Paccagnella, Strauss, and Breslau presented :

    "M3D nonlinear simulations of tokamak disruptions"
    - Benchmarked linear RWM growth rate with MARS
    - Initial results confirm $\mathrm{TPF} \times \langle I_h \rangle / I_{p0} < 0.75$
    - Will be applied to JET sidewise force data
  - Several presentations from DINA and TSC (2D) codes
    - Involved in detailed benchmark activity

- Runaway electron prevention and mitigation
  - V. Izzo, et al. presented:

    "Disruption mitigation and runaway electron modeling for DIII-D"
    - NIMROD modeling with KPRAD and single particle orbit RE modeling

Sugihara (ITER IO) is very receptive to this modeling. He is funding the 2D modeling with Dina and TSC, and will soon let out a contract for 3D modeling aimed at 3D toroidal peaking of halo currents (M3D)

# Summary

- Disruption modeling is the primary area the ITER IO is interested in
  - Forces due to inductive and halo currents
  - Mitigation and runaway electron production
  - It would be desirable if both NIMROD and M3D could model the thermal quench (with RE) and current quench (with resistive wall), and could compare with TSC in the n=0 limit

- Other opportunities to improve ITER operation
  - NTM stabilization by RF (one of the goals of the SWIM project)
  - NTM elimination by sawtooth modification
  - Nonlinear studies of RWM physics, mode locking, error field effects etc.
  - Interpret Long-Lived Mode (LLM) seen in NSTX, MAST, and JET

- ELM modification and prevention is also of high priority
  - Not part of this ITPA group

- Disruption avoidance studies are probably the #1 long term application