Notes from US-Japan/ITPA MHD Meeting

March 6, 2012
NIFS, Japan

S. Jardin
CEMM Meeting
Madison, WI
June 12,13 2012

- Presentations from ITER IO
- Some interesting (new?) physics results
- Working Group and Machine Comparisons

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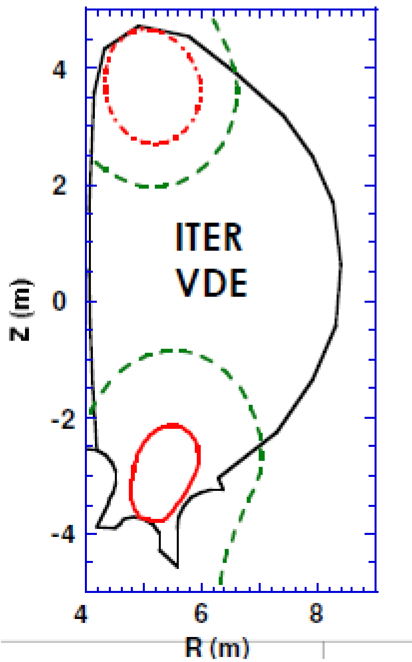
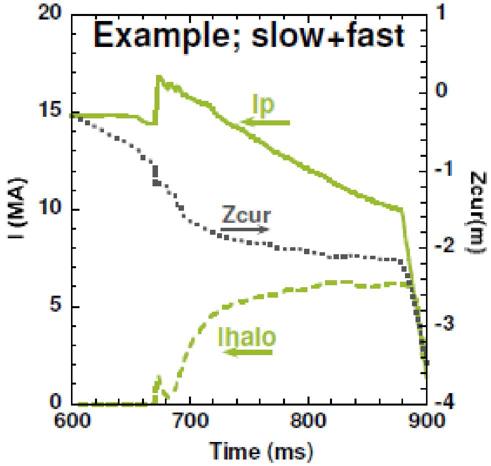
- Presentations from ITER IO
  - Sugihara.. Disruption related design issues
  - Putvinski .. Disruption mitigation in ITER
  - Gribov .. MHD stability and magnetic control

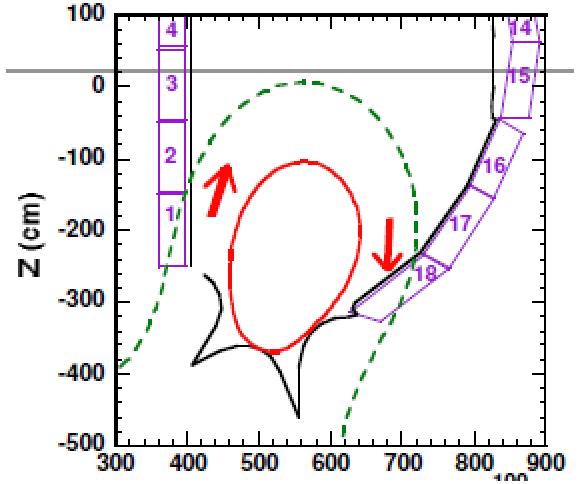
Disruption Related Design Issues in ITER

M. Sugihara, IO



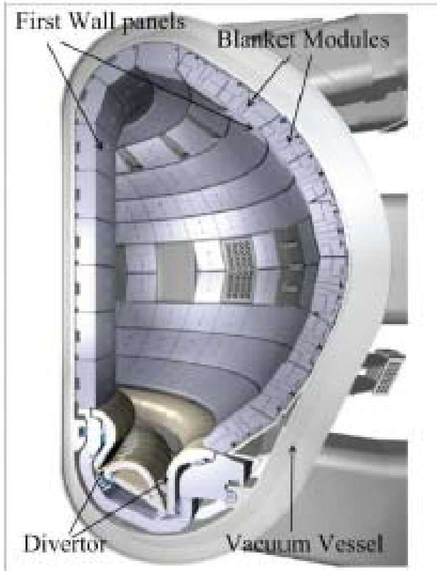
- EM loads caused by slow + fast current quench
    - overlap of large halo current with large eddy current
- Heat load during current quench
    - ITER has assumed that radiation energy dissipation dominates during the CQ
    - Requests heat load during the CQ phase
- Effects of asymmetry
    - is the effect of asymmetry that the halo current is more concentrated at some places or is it just wider?

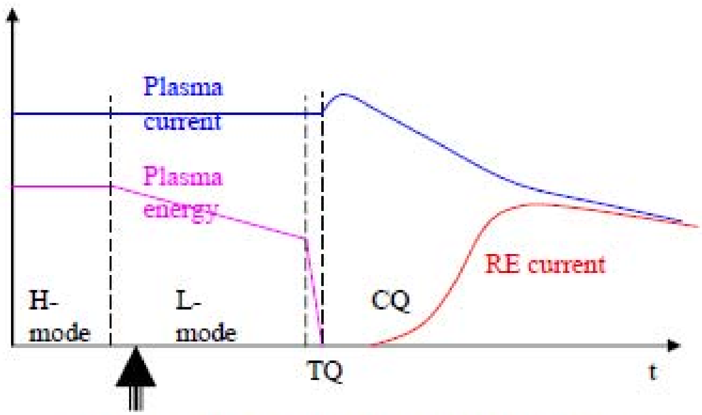




Disruption mitigation in ITER

S. Putvinski, ITER IO





Typical chain of events during plasma disruption

- The largest thermal loads occur during Thermal Quench (must be reduced by factor of 10 by preventive MGI)
- Major mechanical forces act on plasma facing components during Current Quench (CQ time shall be controlled by DMS within limits 50-150 ms)
- Runaway electrons can be generated during Current Quench (RE current must be suppressed to less than 2 MA)

Scheme for this yet to be developed

Issues of MHD stability and plasma magnetic control

Y. Gribov, IO

- Axisymmetric magnetic control
- Error field control
  - 3-mode error field likely < 15 x 10^{-5}
  - must be reduced to 5 x 10^{-5} by CC
  - Criteria based on "overlap criterion" of Menard & J-K Park will likely not be exceeded
- Resistive wall mode control
  - Analysis of RWM control by ELM coils being performed with CARMA code
- New working Groups on MHD control suggested:
  - Control of Locked Modes for disruption avoidance
  - 3D distortion of plasma boundary (Chapman to lead)

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- Some interesting (new?) physics results
  - Overview of DIII MHD activities
  - 3D structures and long-lived Modes
  - Nonlinear interactions of different modes (EP +….)
  - Control of runaway discharge in ITER ?

DIII-D MHD Research

E. Strait

DIII-D MHD Research (E. Strait)

- NTM stabilization by ECCD at low torque
  - replacement of missing bootstrap current in islands
  - modification of equilibrium current density profile
- Plasma becomes resistive unstable before kink unstable (Brennan)
- ELM suppression
  - Not a topic for this ITPA
- Locked Mode control (disruption avoidance)
  - rotating n=1 field prevents locking
  - modulated ECCD shrinks island size
- RWM stability
  - Off-axis NB injection improves stability
    - broader pressure?
    - stronger stabilizing from passing particles?
- Error Field correction and effects
  - What field spectrum is needed to correct for TBM in ITER?
- Disruption avoidance and mitigation
  - massive gas injection + control of runaway beam

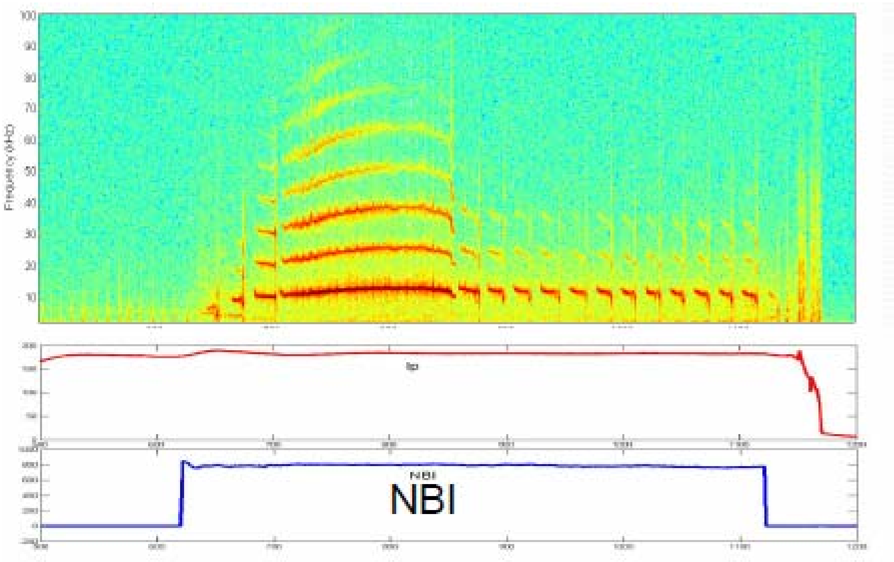
3D Stability Phenomena in MAST

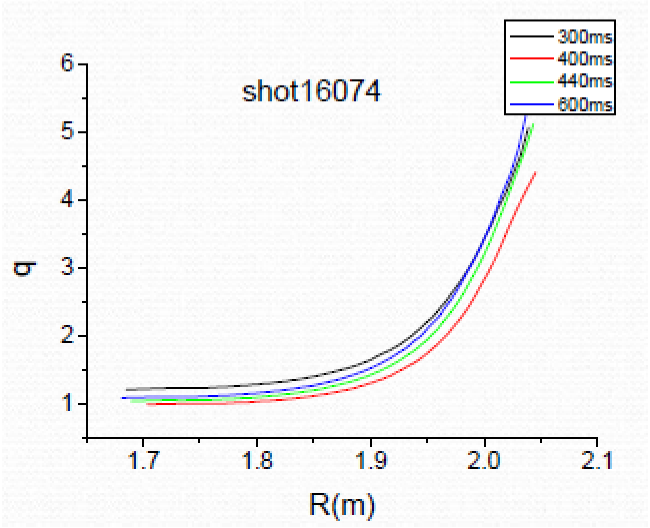
I. Chapman

- Ballooning instability due to 3D deformation during sawtooth
- Saturated ideal n=1 (Long-Lived) mode when q-profile is reversed shear or flat
  - Causes massive fast ion redistribution
  - Causes strong breaking of core rotation
- RMP coils (n=3) can cause ±2.5 cm distortion of boundary

Observation of Long-lived mode on HL-2A

Yi. Liu, et al (SWIP)





- LLM observed in both H-mode and L-mode…degrades confinement
- n=1,2,3 and higher order harmonics are present
- safety factor has broad weak shear region in center
- causes rotation flattening in core
- can co-exist with sawteeth !!

Helical Equilibrium Structures Embedded in a Tokamak

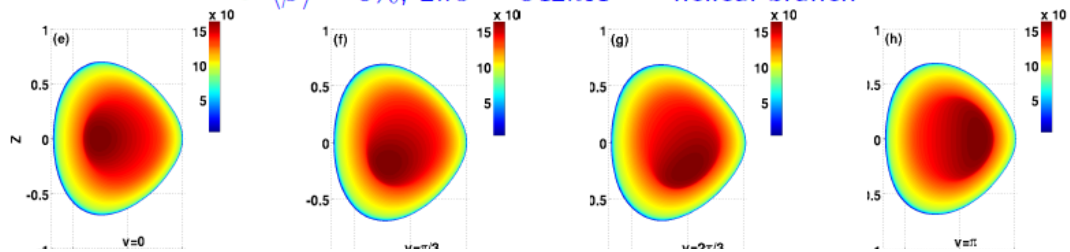
A. Cooper

Application of VMEC code to tokamak equilibria: $\nabla p = \mathbf{J} \times \mathbf{B}$

- Toroidal Magnetic Field Ripple (n = N_{TF})
- Test Blanket Modules, (n=1)
- ELM Control RMP coils (n=3-4)
- Spontaneous internal Helical Structure Formation (n=1)

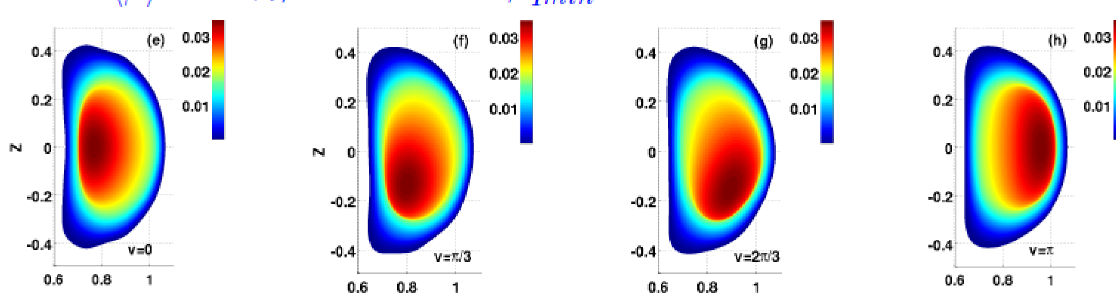
• $\langle\beta\rangle \sim 6\%,\ 2\pi J = 842kA$ —- helical branch

MAST



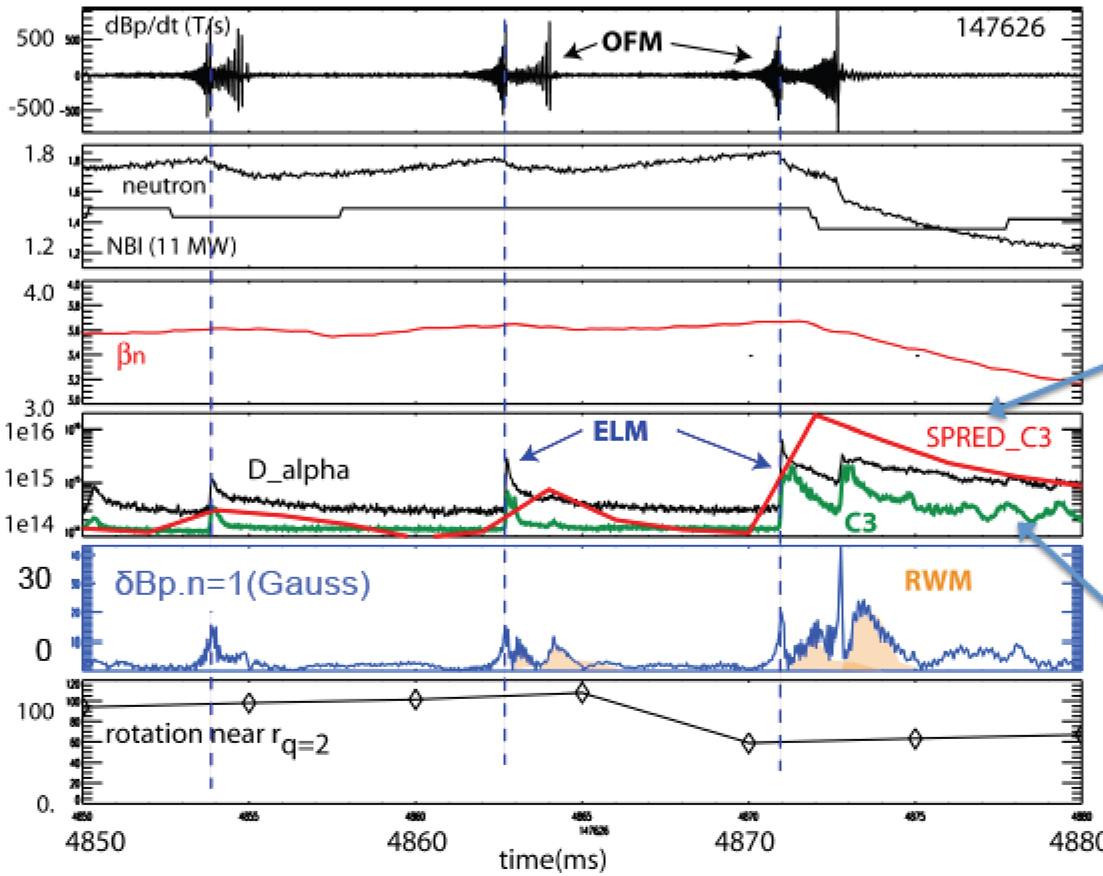
• $\langle\beta\rangle \sim 1.6\%,\ 2\pi J = 485kA,\ q_{min} = 0.995$ —- helical branch

TCV



Off-axis-Fishbone Mode driven ELM-like behavior in DIII-D AT regime

M. Okabayshi



• 5-10% Neutron drop

Looking at large Plasma volume

• Massive Carbon influx With ELM

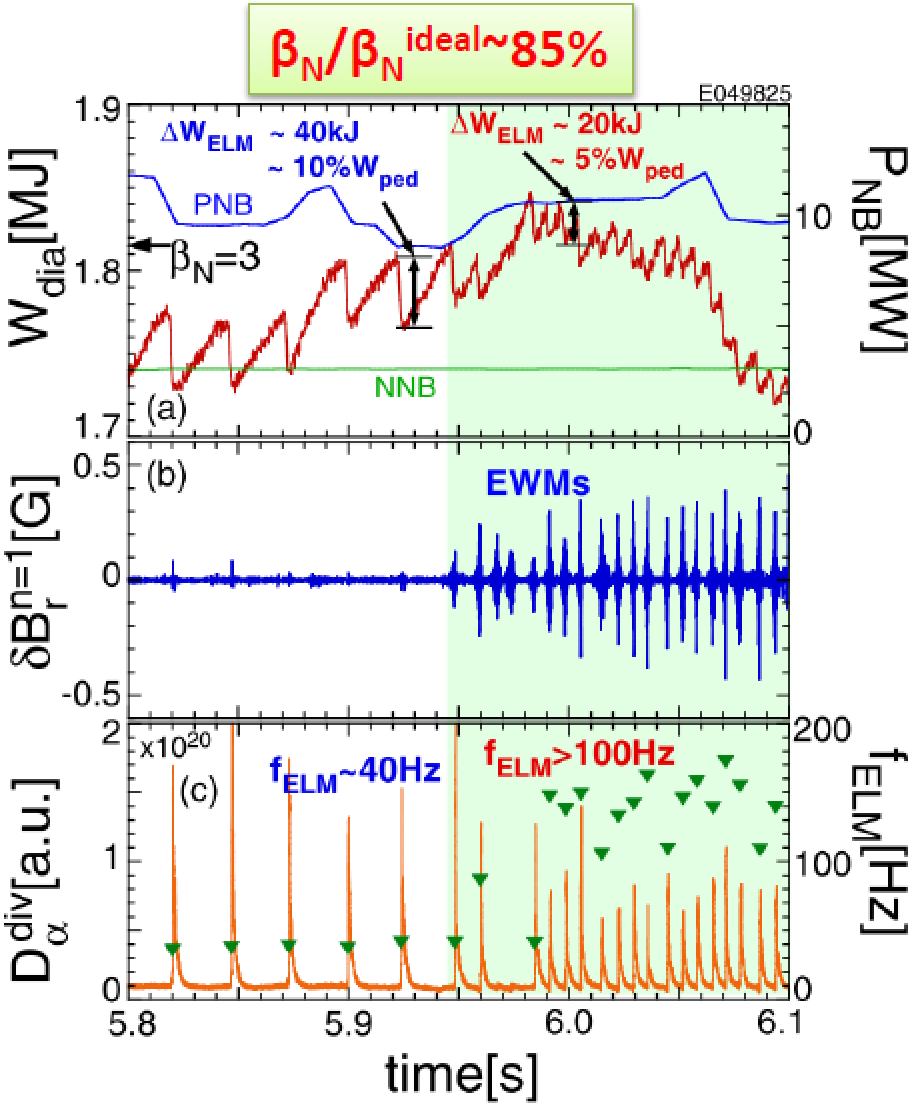
From divertor area

• n=1 RWM buildup even with high rotation

- Occurs when q ~ 2 in center
- Some data shows OFM related to n=1, m=2 density snake
- Shows importance of nonlinear interactions!

MHD behavior in JT-60U high-β plasmas

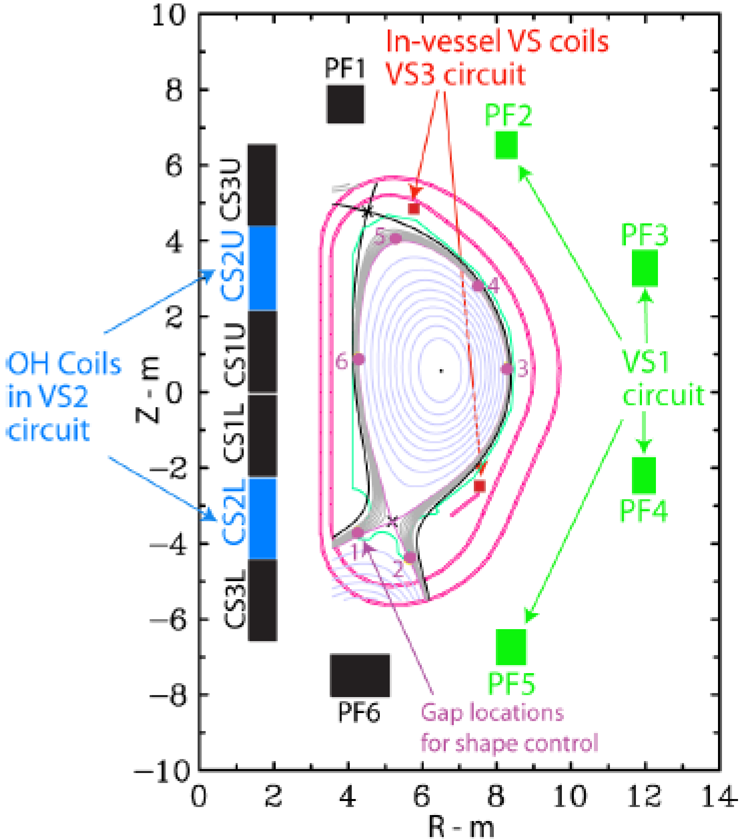
G. Matsunaga, et al.

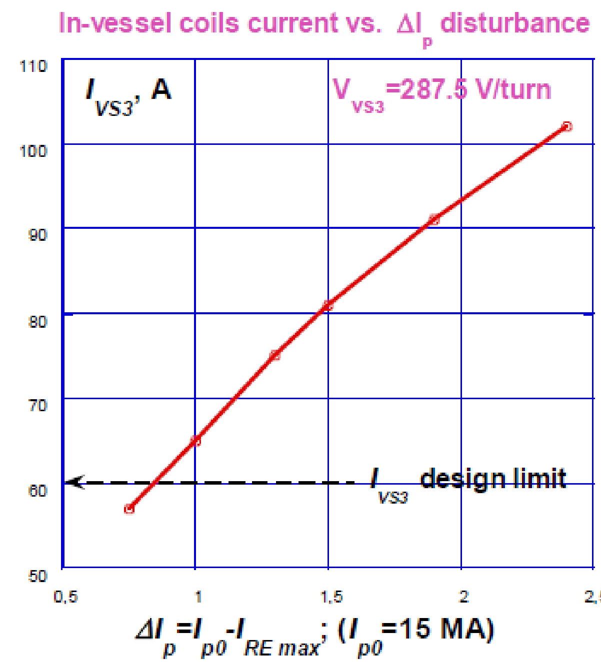


- Energetic particle modes can drive ELMs
- ELMs can drive RWMs at high beta
- Again, shows importance of nonlinear interactions!

Study of ITER plasma position control during disruptions with formation of Runaway Electrons

V. Lukash





If $\Delta I_P = I_{p0} - I_{RA}$ is less than 0.8 MA, then control system cannot control runaway discharge after disruption!

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Discussion of Joint Expts and Working Groups

- What are Joint Experiments and Working Groups?
- Status of Joint Experiments
- Status of Working Groups
- Proposed new Working Groups and Joint Activities

What is a joint experiment?

- Analysis of existing multi-machine data
- Coordinated multi-machine experiments on a common topic
- "Identity" experiments to determine scaling vs. size, aspect ratio, …

Key features:

– Common scientific personnel, analysis tools

– Scientific results beyond what is possible on a single machine

<u>IEA / ITPA Coordinating Committee Meeting (December)</u>

- Reports of progress on joint experiments
- Proposals to close joint experiments or open new ones
- Lab directors agree to support joint experiments

What is a Working Group?

- Addresses a specific question or issue – generally Initiated by a request from the IO
- Limited duration: typically 1 to 2 years
- Relies on analysis and modeling efforts, using existing experimental data
  - New experiments not expected because of the short duration
- Output: a written report to the IO
  - Distributed to members of the MHD Topical Group before sending to the IO

Joint Experiments

MDC-1: Disruption mitigation by massive gas jets – ***M. Lehnen***

MDC-2: Joint experiments on resistive wall mode physics – ***S. Sabbagh***

MDC-4: NTM physics - aspect ratio comparison – ***M. Maraschek***

MDC-5: Sawtooth control methods for NTM suppression – ***I. Chapman***

MDC-8: Current drive prevention/stabilization of NTMs – ***R. La Haye***

MDC-14: Rotation effects on neoclassical tearing modes – ***R. Buttery***

MDC-15: Disruption database development – ***N. Eidietis***

MDC-16: Runaway electron generation, confinement, loss – ***R. Granetz***

MDC-17: Active disruption avoidance – ***M. Maraschek***

MDC-18: Evaluation of axisymmetric control aspects for ITER – ***D. Humphreys***

Working Groups

WG-7: Resistive Wall Mode feedback control – ***Y.Q. Liu***

WG-8: Radiation asymmetry during MGI – ***M. Lehnen***

WG-9: Criteria for error field correction – ***R. Buttery***

WG-10: Halo current modeling – ***S. Jardin***

(WG-1 to WG-6 are completed – or nearly so)

Additional comments

- Please look for ways to enhance the “joint” character of the joint experiments
  - Coordinated experiments
  - Joint analysis of data
- If you want to contribute to a joint experiment or working group, please contact:
  - Group leader
  - Topical group chairs

Status of joint experiments (I)

MDC-1: Disruption mitigation by massive gas jets – *M. Lehnen*

- Results from C-Mod, MAST, JET, TEXTOR, DIII-D

Medium term goals:

  - Injected mass requirement for heat load & halo current mitigation
  - Scaling of cooling, TQ, CQ times with gas injection (see MDC-15)
  - Radiation asymmetry & multi-valve injection (WG-8, new C-Mod results)

MDC-2: Joint experiments on resistive wall mode physics – *S. Sabbagh*

- Significant progress benchmarking MARS-K and MISK (Goal: complete by Oct.)
- ITER modeling with kinetic effects is in progress. Finite orbit width important.
- Analysis of DIII-D off-axis NBI effects is in progress.

MDC-4: NTM physics - aspect ratio comparison- *M. Maraschek*

- AUG/MAST: Analysis of 3/2 (AUG) and 2/1 (MAST) onset and marginal island
- DIII-D/NSTX: Analysis of island rotation
- Goal complete 4-machine comparison and close MDC-4 by end of 2012.

Status of joint experiments (II)

MDC-5: Sawtooth control methods for NTM suppression – *I. Chapman*

- ECCD control with mirror steering planned in AUG and DIII-D
- ICRH control planned in JET and EAST
- Expect to close ECCD and ICRH control items this year

MDC-8: Current drive prevention/stabilization of NTMs – *R. La Haye*

- Progress at several facilities: EC power, mirrors, controllers
- 2012 experiments planned for real time control with mirror steering, role of ECCD modulation

MDC-14: Rotation effects on neoclassical tearing modes – *R. Buttery*

- DIII-D database, MAST island evolution show role of Δ'
- Hybrid plasma beta limit scaling extended to multiple devices
- Need identity scaling experiments between devices

Status of joint experiments (II)

MDC-15: Disruption database development – *N. Eidietis*

- MGI data is being submitted
- New web page and data interface – live demo!
- Goal: Initial publication of database by end of 2012

MDC-16: Runaway electron generation, confinement, and loss – *R. Granetz*

- Evaluating RE position control
- Plan multi-machine experiment to test the theoretical E_{crit} for avalanche.

MDC-17: Active disruption avoidance – *M. Maraschek*

- Localization of ECH and role of ECCD are being investigated
- EC power threshold data expected this year
- Progress in other techniques: active feedback, soft stop, MGI triggering, …

MDC-18: Evaluation of axisymmetric control aspects for ITER – *D. Humphreys*

- Goals: model based control, effects of noise and disturbances, runaway electron contro
- Develop current status and plans by end of June

Status of working groups

WG-7: Resistive Wall Mode feedback control – *Y.Q. Liu*

- Sensor noise and disturbances: progress toward cross-machine analysis
- RWM control with equivalent thin shell blanket module is being assessed
- Preliminary report anticipated by October 2012

WG-8: Radiation asymmetry during MGI – *M. Lehnen*

- Asymmetry data from single-valve experiments in AUG, C-Mod, DIII-D, JET
  ➔ provisional estimate of upper limit heat loads in ITER
- Draft report written – to be finalized by end of March.

WG-9: Criteria for error field correction – *R. Buttery*

- Modeling → both resonant and non-resonant error fields are important
- Need calculation of non-resonant effects in ITER
- Preliminary report by October 2010?

WG-10: Halo current modeling – *S. Jardin*

- DINA and TSC compared. Sheath model added to DINA.
- ITER prediction may require modeling a range of parameters, with some physics constraints, for “worst case”
- Goal: preliminary report by October 2012 (?)

Proposed New Joint Activities

(WG-11 ?) Working Group on Locked Mode Control

(WG-12 ?) Working Group on 3D Distortion of Plasma Boundary

(JA-1 ?) Joint Theoretical Activity on Shear Flow Effects for NTMs

WG-?: Control of Locked Modes

- Control of Locked Mode for disruption avoidance using in-vessel coils and modulated ECCD has been demonstrated in DIII-D (*presentation by E.J.Strait at this meeting*).

- What are requirements to frequency and amplitude of currents in ELM coils and EFCC for Locked Mode control in ITER? (Input for design of the coils power supplies.)

- Should we form a new Working Group to address this question?

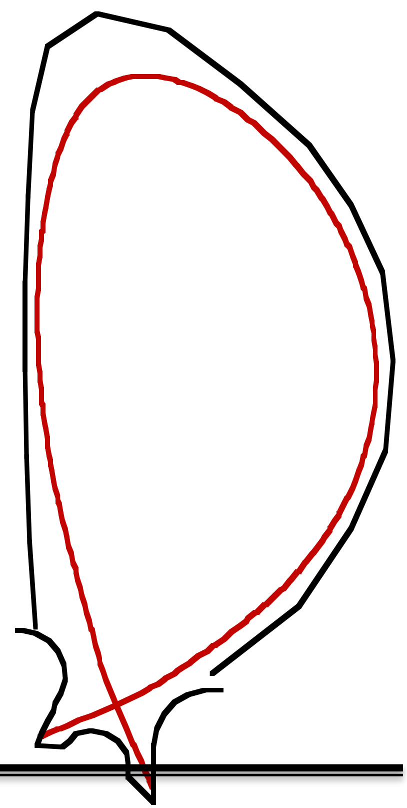
- Leader?
- Members?

WG-?: 3D distortion of plasma boundary

- Significant 3D distortion of plasma boundary caused by MHD activity happens in tokamaks in some regimes (*see presentation by I.Chapman at this meeting*).

- How high could be 3D distortion of ITER plasma boundary in these regimes? How high should be minimum value of plasma-wall gaps for reliable ITER operation? How can we avoid regimes with significant 3D distortion of plasma boundary?

- Should we form a new Working Group to address these questions?



- Leader ?
- Members ?

Proposal for a ~~Working Group~~ Joint Activity to advance theoretical understanding of shear flow effects on NTMs

Objectives:

- Assess relative contributions of various flow induced physical effects through:
  - Modeling of tearing stability in presence of flows using advanced numerical codes such as M3D, NIMROD…….
  - Obtaining better analytic estimates of $\Delta^{/}$ in toroidal geometry and in presence of flows
  - Doing comparative analysis of existing experimental data from various machines – collaborative effort with MDC-14
- Use above knowledge to provide realistic estimates of flow effects for ITER scenarios and their implications for ITER

Members:

Leader: ?

Theory/ Modeling:

Experiments: R.J. La Haye, R. Buttery (DIII-D); ? (MAST); ?(NSTX); ?JET; ?(AUG)

ITER: Y. Gribov

All presentations can be found at:

http://dg1.nifs.ac.jp/itpa2012/presentations.html

id: itpa2012

pw: nifs_japan