ITPA – Topical Group on MHD Stability

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Presented at the
16th Workshop on MHD Stability Control
San Diego, Nov. 22, 2011

GENERAL ATOMICS

The ITPA operates under the auspices of the ITER-IO

Purpose: provide a framework for coordinated physics research activities

- **Develop the physics basis for ITER operation**
- **Integrate the expertise of the international fusion community into ITER**
- **Provide a pathway to exploit the capabilities of existing fusion facilities in support of ITER**
- **Create a common international research programme organized around scientific issues**

Advisory role with respect to the ITER-IO

[excerpts from the ITPA charter]

Scope of the MHD Topical Group

- **MHD instabilities and active control**
  - Sawteeth, NTMs, RWMs
- **Disruptions and disruption mitigation**
  - disruption database, disruption characterisation
  - prediction, avoidance, and mitigation of disruptions
- **Plasma magnetic control**
  - control of plasma current, position and shape
  - control and reduction of error fields
- **Diagnostic issues related to the above**

MHD Stability Topical Group

- **Leaders (2008-2011):**

  A. Sen (chair)

  E. Strait (deputy)

  Y. Gribov (deputy)

- **US members:**

  E. Strait (coordinator)
  R. Granetz (deputy)
  J. Harris
  V. Izzo
  S. Jardin
  S. Sabbagh
  F. Waelbroeck
  J. Wesley

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- **Leaders (2012-2014):**
  - E. Strait (chair)
  - P. Martin (deputy)
  - Y. Gribov (deputy)

Post-IAEA Topical Group meeting

- **University of Padova, Italy, October 4-7, 2011**
  - Approximately 40 participants
- **The agenda included sessions on**
  - ITER needs (by Y. Gribov and M. Sugihara)
  - Contributed talks on a wide range of topics
  - Activities of joint experiments and working groups
- **Emphasis on disruptions and disruption mitigation**
  - Approx. 50% of presentations

The tangible output of the ITPA

- **Joint experiments**
  - Motivate research
  - Lead to joint publications on the results
- **Working groups**
  - Response to specific requests from ITER IO
  - Short time horizon for answers (1-2 years)

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

AUG, C-Mod, DIII-D, FTU, JET, MAST, NSTX, TEXTOR, Tore Supra

Goal: Determine optimal disruption mitigation schemes for ITER

- Determine minimum mass for heat load / halo current mitigation
- Scaling of thermal quench time vs. machine size injected mass
- Assess achievability of Rosenbluth density for runaway suppression

Status

- High field side injection in AUG indicates higher assimilation
- First experiments with rupture disc injection into current quench plasma (Tore Supra)
- Other fast valve experiments in AUG, T-10

Plans

- multi-valve injection (AUG, C-Mod, TEXTOR)
- current quench injection with rupture disc cartridges (Tore Supra)
- comparison of high field side vs. low field side injection (AUG)
- impurity-filled shell pellets and cryogenic pellets (DIII-D)

WG-8: Radiation asymmetry during massive gas injection *(M. Lehnen)*

Goal: **Determine minimum number of ports required for MGI in ITER**

- Avoid local melting of Be wall,
- Maintain redundancy and reliability

Status

- Single-valve asymmetry experiments in AUG, C-Mod, DIII-D, JET
  ➔ provisional estimate of upper limit to local radiation heat loads in ITER
- Systematic analysis of the dependence on parameters like plasma thermal energy, q95, gas species, and pressure remains to be done.

Plans

- A draft preliminary report has been written
- Anticipate that this working group will complete its analysis in 2012.

MDC-15: Disruption database development *(N. Eidietis)*

AUG, C-Mod, DIII-D, JET, JT-60U, MAST, NSTX, TCV, Tore Supra

Goal: Use cross-machine data to

- Develop disruption science: empirical scaling, model validation
- Extrapolate disruption parameters to ITER
- Provide input to detection and mitigation scenarios

Status

- Input of initial halo current data is essentially complete
  - Data contributions from AUG, C-Mod, DIII-D, JET, MAST, and NSTX
- Initial set of variables defined for massive impurity injection
  - Data submission in progress
- A new web-based interface to the database has been created

Plans

- Analysis of the recently collected halo current data
- Completion of data on shutdown by massive gas injection

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

ASDEX-Upgrade, C-Mod, DIII-D, FTU, JET, JT-60U, TEXTOR, Tore Supra

Goals:

- Characterize runaway electron generation and confinement
- Provide physics basis for runaway suppression and mitigation
  - Gas injection, magnetic perturbations, runaway beam control

Status

- Tore Supra experiments confirm deceleration by injection of helium
- Collisional suppression at E-field above the predicted threshold (FTU)
- Controlled rampdown of the runaway current (DIII-D)
- Experiments to deconfine a runaway electron beam, by injection of a high pressure gas jet to induce instabilities (Tore Supra, T-10)
  - Secondary disruption triggered only during slow current quench in T-10.

Plans

- Test the predicted critical E for avalanche production of runaways
  - Use recent techniques of runaway position and current control
- Further experiments with rupture disc injection are also expected

WG-10: Halo current modeling *(S. Jardin)*
– newest working group

Goals:

- Assess and improve the existing halo current models,
- Develop other possible models,
- Recommend most reliable model for ITER use.

Status

- Goals and membership have been defined
- Validation of TSC halo current model vs. NSTX experiments
  ➔ improved model of the vacuum vessel and attached structures.

Plans

- Assessment of present models of the halo region is in progress
- A provisional recommendation is expected in early 2012

MDC-17: Active disruption avoidance (*M. Maraschek*)

AUG, C-Mod, DIII-D, FTU, JET, JT-60U, MAST, NSTX, TCV

Goals:

- Quantify requirements for postponement of disruptions with ECRH.
- Explore other means of disruption avoidance
- Investigate mode stabilization with fast current ramp-down

Status

- Postponement or avoidance of disruptions using localized ECH/ECCD demonstrated on several tokamaks (AUG, FTU, DIII-D)
- High β disruption rate significantly reduced by n=1 feedback (NSTX)

Plans

- Joint scaling of ECH power for postponement (AUG, FTU, DIII-D).
- New subtopic: Comparison of requirements and strategies for
  - prediction of disruption thresholds
  - avoidance of disruptions by avoiding operational limits
  - avoidance of disruptions by controlled rampdown (soft stop)
  - recovery of high-performance full operation

MDC-2: Joint experiments on RWM physics *(S. Sabbagh)*

DIII-D, JET, JT-60U, MAST, NSTX

Goal: Benchmark and validate kinetic RWM stability models

- Benchmark RWM stability theories, including kinetic models
- Validate these models against experiments

Status

- Benchmarking of MISK, MARS-K, MISHKA, and HAGIS is in progress
- Ongoing NSTX/DIII-D experiment to test kinetic stability models
  - off-axis NBI in DIII-D

Plans

- Benchmark kinetic models that include precession drift, fast ions
- Validate models using joint experimental data (RWM onset and resonant field amplification)
- Model RWM stability in ITER

WG-7: Resistive Wall Mode feedback control *(Y. Liu)*

Goal: **Assess capability of ITER ELM coils to stabilize RWMs**

- Inform requirements for machine, CODAC, diagnostics, actuators
- Provide validated control models

Status

- Sensor signal noise analyzed separately (AUG, JET, DIII-D, RFX-Mod)
- CarMa modeling in progress for an ITER 9 MA steady state scenario
- VALEN modeling with an "equivalent thin shell" model of the blankets shows less passive stabilizing effect than previous results
- Analytic model shows feedback cannot tolerate coil current saturation, but can tolerate some power supply voltage saturation
- Demonstrated the use of "dither injection" to analyze the RWM spectrum and the behavior of the feedback system (EXTRAP-T2R)

Plans

- A preliminary report anticipated by March 2012

MDC-5: Comparison of sawtooth control methods for NTM suppression *(I. Chapman)*

AUG, C-Mod, DIII-D, EAST, FTU, HL2A, JET, KSTAR, TCV, Tore Supra

Goal: Improve NTM β-limits by control of sawtooth seed instability

- Demonstrate sawtooth control by current drive in the presence of a significant population of fast ions.

Status

- Modification of the sawtooth period by ECCD near the q=1 surface in H-mode plasmas with ITER-relevant beta (DIII-D)
- Sawtooth pacing by modulated ECCD (TCV and FTU)
- Real-time control of the sawtooth period (TCV)
- A draft paper on DIII-D results has been written

Plans

- Emphasis on real-time control and input to ITER requirements
- Experiments on sawtooth control by localized ECCD, and sawtooth pacing by modulated ECCD (TCV, FTU, Tore Supra, and DIII-D)
  - Some using new capabilities for real-time mirror steering.
- Sawtooth control with ICRH (JET)

MDC-4: Neoclassical tearing mode physics – aspect ratio comparison *(M. Maraschek)*

AUG, MAST, NSTX, DIII-D

Goal: Determine the aspect ratio dependence of NTM stability

- Comparisons of MAST – AUG, NSTX – DIII-D

Status

- Data sets are substantially complete for both machine pairs.
- DIII-D/NSTX analysis shows:
  - marginal island size ~3 times the ion banana width in both devices.
  - stabilization by field curvature in NSTX, and negative Δ' in DIII-D.
- Paper submitted to Physics of Plasmas.

Plans

- Analysis of MAST↔AUG comparison for the field curvature effects
- Joint analysis of the two machine pairs is also planned
- Expect to close the joint experiment in 2012

MDC-8: Current drive prevention/stabilisation of NTMs *(R. La Haye)*

AUG, DIII-D, FTU, HL-2A, JET, JT-60U/SA, NSTX, TEXTOR, TCV

Goal: **Benchmark Rutherford equation for NTM evolution**

- Pre-emptive current drive to prevent or mitigate 2/1 NTMs.
- Influence of ECCD modulation, and ECCD width

Status

- Integrated real-time control prevents 3/2 NTMs (TCV)
  - sawtooth pacing with modulated ECCD
  - pre-emptive ECCD at the q=3/2 surface following each sawtooth crash
- New results on 2/1 mode suppression with localized ECCD (HL-2A)
- Initial tests of real-time mirror steering in progress (AUG, DIII-D, FTU)

Plans

- Emphasis on input to ITER requirements for real-time NTM control
  - Strategies for minimizing EC power and power modulation
  - Benefits of ECCD modulation and pre-emptive ECCD
  - Real-time mirror steering expected at several facilities

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

AUG, C-Mod, DIII-D, JET, JT-60U, MAST, NSTX

Goal: Study key dependencies to extrapolate NTM β limits for ITER

- Dependence of NTM onset on plasma rotation,
- Increased error field sensitivity at low rotation

Status

- A joint publication (DIII-D, JET, JT-60U, and NSTX) on the role of rotation in tearing mode thresholds is nearing publication.
- A joint DIII-D/NSTX paper published in Nuclear Fusion on the mechanism by which error fields induce tearing modes
- New scaling for error field thresholds in H mode plasmas

Plans

- Error field sensitivity of medium β_N low rotation plasmas.
- Resolving other governing physics for the 2/1 NTM β_N limit
- Resolve theory of rotation effects on NTM
- Cross-machine hybrid beta limit scaling with rotation

WG-9: Requirements for error field control *(R. Buttery)*

Goal: **Criteria on low *n* resonant and non-resonant error fields for avoidance of locked modes, at low and high beta**

- Algorithms for analysis of error fields expected in ITER
- Capability of ELM coils and correction coils to reduce error fields

Status

- A new scaling for error field thresholds in torque-free H-modes
- Spectrum of the correction field is important,
- Single-mode error field correction may have limited benefits.
- Updated ITER error field estimates suggest that the error field correction coils must be able to reduce the error field by 50-75%.

Plans

- Near term analysis will focus on the error correction capabilities of ITER's EFCC and ELM coils

MDC-18: Evaluation of Axisymmetric Control Aspects *(D. Humphreys)* – Proposed

AUG, C-Mod, DIII-D, EAST, JET, JT-60U, KSTAR, MAST, NSTX, TCV, TEXTOR, Tore Supra

Goals:

- Address ongoing need for axisymmetric control physics results to inform requirements for machine, CODAC, diagnostics, actuators
- Provide validated control models

Status

- Successor to MDC-13, which was completed in 2009.
  - Determined the maximum controllable growth rate and displacement for robust operation in several machines
  - Guidance to ITER design, based on machine-independent metrics

Plans

- Test high order controllers: benefits/issues for ITER scenarios)
- Assess runaway current control: capabilities in ITER
- Validate models of axisymmetric plasma response, disturbances
- Develop ITER-specific control algorithms

Please participate!

- **Help needed with joint experiments, working groups, etc.**
- **You do not need to be an "official" member to attend meetings and participate in other ways**
- **Next MHD group meetings:**

  March 5-9, 2012 → **Toki, Japan**
  – with US/Japan MHD workshop & ITPA Energetic Particles group

  October 15-17, 2012 → **San Diego**
  – after IAEA conference

- **Web sites**

  http://www.iter.org/org/team/fst/itpa/ **(need passwd)**
  http://itpa.ipp.mpg.de/ **(2003 - 2010)**
  https://fusion.gat.com/itpa-ddb/Home **(disruption db)**