Chapter 5: MHD, Disruptions and Control (MDC)

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General comments

- Work on MDC is to a large extent in support of the general DTT Research Plan rather than one of its main drivers
- In many areas, techniques planned to be applied in DTT will be the same as in ITER → DTT = Companion to ITER
- Also, there are a few original/important topics that DTT might address → Will be highlighted in magenta
- Quite a few modelling activities ongoing/planned/to be planned → Tried to summarize status in blue

Chapter outline

5.1 Important features of DTT related to MDC

5.2 MHD stability and control

- 5.2.a Assessment of ‘basic’ MHD stability for DTT scenarios
- 5.2.b Sawteeth
- 5.2.c Neoclassical Tearing Modes (NTMs)
- 5.2.d Edge Localized Modes (ELMs)
- 5.2.e Error fields

5.3 Disruptions

- 5.3.a Disruption monitoring and mitigation
- 5.3.b Runaway Electrons (REs)
  - 5.3.b.1 RE avoidance
  - 5.3.b.2 RE mitigation
- 5.3.c Disruption prediction and avoidance

5.4 Other control aspects

5.1 Important features of DTT related to MDC

- Large nominal B_t and I_p → β_N relatively modest but potentially large disruption loads
- 'Exotic' magnetic configurations (X Divertor, Negative Triangularity, Double Null)
- Powerful ECRH system
- 3D in-vessel coils (3x9)

5.2 MHD stability and control

5.2.a Assessment of 'basic' MHD stability for DTT scenarios

- Ideal and classical resistive MHD studies to check stability for low-n modes of the foreseen scenarios
  - Ideal internal and external modes, infernal modes, tearing modes, and RWM in specific high β_N scenarios
  - Was already carried out on the full power Reference Scenario E1

Status of simulations:

- Existing: Study using CHEASE and MARS-F for Scenario E1 (G. Vlad et al. DTT RP workshop July 2022 + V. Fusco EPS 2022)
- Ongoing/planned for near future: Analysis of scenario A (half-field, half-current, reduced heating, Day 0 scenario)
- To be done: All scenarios

5.2.b Sawteeth

- JETTO simulations for Scenario E1 (full power) → large $r_{q=1}/a$ (≈0.5) and large sawteeth according to Kadomtsev model, which may trigger NTMs
- However, smaller sawteeth would probably be found with an incomplete reconnection model → Should be investigated
- Sawtooth control using EC or IC waves should also be developed

Status of simulations:

- Existing: JETTO simulations (F. Porcelli, T. Barberis, S. Nowak, C. Piron, see report MHD-TEC-04601-A3)
- To be done:
  - JETTO simulations with incomplete reconnection model
  - JETTO and/or ETS/JINTRAC simulations of sawtooth control with EC or IC waves

5.2.c Neoclassical Tearing Modes (NTMs)

- Modelling to assess NTM stability
- Development of NTM control using EC waves + possibly Resonant Magnetic Perturbations (RMPs) for NTM unlocking

Status of simulations:

- Existing: ETS simulations of natural 3/2 and 2/1 NTM evolution by S. Nowak and E. Alessi (see report MHD-TEC-04601-A2)
- Ongoing/planned for near future: ETS simulations of NTM stabilization by EC waves
- To be done: Modelling of NTM unlocking with RMPs?

5.2.d Edge Localized Modes (ELMs)

- This topic is also mentioned in Chapter 3 → Need to discuss consistency
- Peeling-ballooning stability modelling to predict pedestal properties
- ELM control with RMPs: prepare with modelling and apply

Status of simulations:

- Existing:
  - Preliminary study on pedestal stability with JALPHA (G. Vlad and V. Fusco with help from R. Coelho)
  - MARS-F modelling for ELM control with RMPs (T. Bolzonella et al., EPS 2022)
- Ongoing/planned for near future:
  - Continuation of above MARS-F study with MARS-F, paper in preparation by L. Pigatto et al.
  - Study on pedestal stability with EUROPED (ideal) and MARS (resistive) (PhD student with L. Pigatto and N. Vianello)
- To be done: Non-linear MHD simulations of ELMs and their control by RMPs (JOREK?)?

5.2.e Error fields

- Error Fields correction with the 3D in-vessel coils should be developed, following the techniques discussed in the ITPA MDC group and adopted for ITER:
  - Modelling workflow based on the plasma response
  - Compass scan experiments

Status of simulations:

- Existing: Vacuum field statistical study of the error field and its and correction (R. Martone, R. Albanese, FED 2023)
- Ongoing/planned for near future: Plasma response modelling with MARS-F and GPEC (L. Pigatto, L. Piron, T. Bolzonella)
- To be done in support to experiments: Comparison of model-based and empirical (compass scan) correction

5.3 Disruptions

5.3.a Disruption monitoring and mitigation

- Monitor disruptions and their loads and update disruption budget as operation progresses
- Mitigate disruptions with Shattered Pellet Injection (SPI)
  - DTT as a 'companion' to ITER
- Study disruptions and their mitigation
  - At high I_p and B_t
  - In 'exotic' magnetic configurations, in particular at negative triangularity
  - With a liquid metal divertor (may be much less sensitive to heat loads)
- Test innovative disruption mitigation methods (e.g. shell pellets, granule injection, faster injectors, runaway killer coil)?
  - Testbed for options for possible ITER disruption mitigation system upgrade

Status of simulations:

- Existing: MAXFEA simulations to assess disruption loads (G. Ramogida)
- Planned: More MAXFEA/CREATE sims. to assess loads, SPI simulations with JOREK (D. Bonfiglio, A. Kryzhanovskyy)

5.3.b Runaway Electrons (REs)

Most serious disruption issue for ITER and DEMO: expect multi-MA RE beam in any disruption in activated phase!

5.3.b.1 RE avoidance

- Apply SPI (likely to work but demands confirmation by modelling)
- Also consider using the 3D in-vessel coils or waves / kinetic instabilities (exploratory)
- A 'RE killer' passive helical coil should be considered
  - Most promising idea to avoid REs in future reactors
  - First tests will take place on DIII-D and SPARC
  - Would need dedicated design work ASAP!

Simulations to be done:

- Simulations of RE generation/avoidance following SPI with DREAM (manpower?) and/or JOREK (L. Singh)
- Assessment with ORBIT of the possible use of 3D in-vessel coils to avoid RE generation
- Study on the effect of waves and kinetic instabilities?

5.3.b.2 RE mitigation

- Study RE beam mitigation by H_2/D_2 SPI into the beam
  - Best hope for the activated phase in ITER ('benign termination')
- Design and use dedicated sacrificial limiters like planned for DEMO

Simulations to be done:

- Simulations of RE loads with JOREK (PhD student E. Emanuelli supervised by F. Subba)
- Simulations of RE beam mitigation, in particular by H_2/D_2 SPI into the beam, with JOREK

5.3.c Disruption prediction and avoidance

- Act as a companion to ITER by deploying and testing disruption prediction and avoidance tools envisaged for ITER from the early operation

5.4 Other control aspects

- Position and shape control for 'exotic' shapes and divertor configurations

Important contributions to the Fusion Roadmap?

- Characterization, avoidance, prediction and mitigation of disruptions and REs
  - Companion to ITER (avoidance and prediction, SPI, testbed for ITER DMS upgrade options)
  - Sacrificial limiters for REs (DEMO relevant)
  - RE killer passive coil
  - Disruptions on liquid metal divertor