Session 1: Plasma Transients

(Organised by L. Baylor and H. Zohm)

Summary Session

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Plan for Session 1 - Transients

Introduction
(H. Zohm, IPP Garching)

Sudden Loss of Stored Energy from Tokamaks and Stellarators
(A. Dinklage, IPP Greifswald)

Prospects for Preventing Disruptions in DEMO
(N. Eidietis, GA)

Loads due to Disruptions and Prospects for Mitigation
(M. Lehnert, ITER)

Sudden Loss of Edge Transport Barrier in Tokamaks and Stellarators
(N. Aiba, QST)

Foreseeable Transient Phases in DEMO
(M. Siccinio, EUROfusion)

Discussion
(All)
Transients will occur in any DEMO design

Transients (defined as deviation from the steady state burn phase) will occur in any DEMO design (tokamak & stellarator)

• ‘foreseeable’ transients: ramp-up, ramp-down…

• transients induced by failure of technical systems (sensors, actuators, control system): loss of stored energy, disruption…

• these will lead to a change in the loading conditions and must be taken into account when designing the relevant components

The ‘stationary state’ may also exhibit some temporal variation (e.g. ‘breathing’, $P_{fus}$ variation due to sawteeth etc…)

• important to characterise these and ensure compatibility with relevant components (e.g. blanket, FW …)

• ELMs also in this category, but may not be acceptable (see later)

Note: traditionally, ‘loads’ are thermal loads and mechanical forces, but loads due to (thermal & fast) particle fluxes also need to be considered
Divertor reattachment – be prepared

For conventional divertor, DEMO will rely on detached divertor operation.

Due to the bifurcation character of detachment and the expected large fluctuations in $P_{sep}$ in DEMO, control is expected to be difficult.

- want to operate close to reattachment for performance reasons

Re-attachment is considered with finite probability in EU-DEMO.

- time to failure (LOCA) is so short (~seconds) that mitigation action is considered – strike point sweeping
- possible use of in-vessel coils has to be considered in the design from the beginning ($n$-resilience, AC-losses, maintainence…)

Risk of reattachment will have to be taken into account for any DEMO design relying on detached divertor operation.
Sudden energy loss triggered by a failure of technical subsystem and subsequent loss of the operational point

• very important to have an analysis tool (‘flight simulator’) that can predict how robust a plasma scenario is against such a failure
• will lead to technical specifications for the subsystems in turn

Discussion highlighted radiative losses triggered by ‘flakes’ (~ dust) entering the plasma

• need to characterise the expected frequency and magnitude
• need to understand ‘fuelling efficiency’ (how much ends up in plasma?)
• analysis must take into account nonlinear coupling the $\alpha$-heating (absent in present day experiments, need to introduce there?)
One of the big advantages of stellarators is the absence of disruptions

it is at present not clear if also the sudden energy loss events are more benign than in tokamaks

• similar to tokamaks, there are events that take place on a fraction (0.1-0.2) of the energy confinement time

• events on much faster (MHD) time scale, as in tokamak thermal quenches leading to disruptions, so far only observed in conjunction with β-limits in stellarators

  remember energy impact:  \( \eta = \frac{W_{th}}{S\sqrt{\tau_{loss}}} \)

This should be an area of intense research in future stellarator studies (what is the worst case thermal loading?)
Disruptions – a rare event in a tokamak DEMO?

Due to extreme loading conditions (> ITER) and impact on DEMO mission (reliable power production), disruptions have to be extremely rare events once DEMO goes into ‘production mode’ (airplane analogy).

This will require a different approach than in present day tokamaks:

• operational point has to be ‘passively safe’ as much as possible and have sufficient margin against component failure
• disruption avoidance starts from the monitoring of the operational point (onion skin approach)

This will need a structured programmatic approach for experiments and modelling (in competition with more academic physics studies).

Note: from licensing point of view, disruptions will be a threat to investment protection, but must not interfere with nuclear safety (in ITER, containment is ensured even for the worst disruption).
Disruptions – how far can we mitigate?

In view of the previous remarks, mitigation is a ‘last resort’

- at full DEMO parameters, even a mitigated disruption will lead to substantial damage, endangering the mission
- during commissioning, each step into new territory will increase risk of disruptions and mitigation will be essential for this process
- at higher performance, might anticipate some PFC damage already, make sure it is not critical for DEMO mission

The techniques qualified in ITER will be available for DEMO

- injection of matter ((shattered)pellets, massive gas injection etc.) may be sufficient to mitigate thermal and electromagnetic loads during the commissioning phase
- at present not clear if there is a solution to the Runaway Electron problem (expected to be even bigger than in ITER) and further research into avoidance/mitigation is strongly recommended
Analysis of impact of ELM heat loads in a DEMO suggests they have to be mitigated by large factors (> 40) or avoided at all.

Candidates for active suppression:
- RMPs best bet, but technical feasibility needs to be ensured and understanding (and hence predictability) is still incomplete.

Candidates for passive suppression:
- ELM free (Q)H-mode, I-mode (temperature pedestal only).
- Negative triangularity (will need dedicated devices, not in ITER!)

If divertor solution can be improved substantially (e.g. liquid metals), mitigation or small ELM regimes may become tolerable.
- Active: pellet pacing, vertical kicks, ECCD…
- Passive: grassy ELMs, type II ELMs (if applicable at low ν*)

Stellarator H-modes have ELMs as well, may be prudent to look for non H-mode regime from the beginning (H typically smaller than in tokamaks).
Some general remarks (not strictly Session 1 specific)

The discussions have clearly highlighted the need to develop a validated ‘flight simulator’ as the workhorse for

- designing the plasma scenario and analysing its robustness to unforeseen events (technical failures)
- reliable control of the plasma in DEMO (‘state space description’, ‘faster than real time prediction’…)

(note that this is in line with findings from previous DPW5, session on control)

More emphasis is needed on the investigation of component failure modes in order to achieve the required RAMI avoiding transients

- this will require dedicated test facilities (and also ‘in silico’ techniques)

In many areas, ITER will be crucial to guide the DEMO design

- important to make a systematic analysis of what ITER needs to demonstrate for DEMO (may not be 100% aligned with ITER goals)