Current understanding of tokamak plasma eruptions and the consequences for ITER.

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1 Abstract

Here will lie the abstract

2 Background

Toroidal magnetic field devices looking to maximise power production must operate in the high confinement regime (H-mode), in which the central plasma density profile is raised up on a pedestal, providing enhanced confinement.[1] In H-mode, type I ELMs are initiated when the pressure increases such that it reaches the Peeling-Ballooning stability boundary

Despite the many negative effects of ELMs on reactor lifetime, they do drive some positive processes such as enhanced transport which reduces impurity fraction in the bulk plasma. As a result of this, a controlled amount of low power ELMs may be desired to keep the core clean and give the ability to control the plasma density.[2] The positive impact of this impurity removal is greater than the resulting drop in fusion performance due to loss of energy confinement.[3]

Edge-plasma eruptions can easily be viewed by measuring the corresponding peak in H_α emission at the eruption position.[2]

"Observations about ELMs:

1. They tend to limit energy confinement
2. they provide density control and limit the buildup of impurities in H-mode
3. they broaden the scrape-off layer density profile and modulate ICRH antenna coupling
4. they produce large heat pulses on the plasma facing components
5. they increase sputtering of first-wall materials

"Type 3 ELMs are observed when the power crossing the separatrix is just above the H-mode power threshold, and may result from resistive instabilities, since they occur at pressure gradients well below the ideal limit and can be stabilized by increasing the edge electron temperature"[2]

Hill 1997[2] says it is not understood why ELMs produce a large heat pulse at the inner divertor target than at the outer plates (in single-null divertors)

What changes ELM frequency: "The critical pressure gradient for the destabilization of the ideal ballooning mode [6] depends on the local flux-surface averaged magnetic shear, S, and the safety factor, q, which Gohil evaluated at the 95% flux surface in his study (S95/q295). Thus, anything which increases the rate that the pressure builds up reduces the time required to hit the stability limit and increases the ELM frequency, while anything that raises the limit, such as increasing the current (lowers q95) or triangularity (increases S), increases the time required to hit the stability limit and reduces the ELM frequency."[2]

Several tokamaks have corroborated the scaling of ELM frequency given in equation 1 [4][5], showing that is may be possible to externally decrease the time between ELMs in order to reduce their magnitude. P_{SOL} is essentially fixed for a given machine and is estimated to be approximately 100 MW.[6]

$$f_{ELM}\Delta W_{ELM} = 0.2 - 0.4P_{SOL} \tag{1}$$

3 Problems for ITER

ELMs R (mostly) Bad [3]

ITER will be able to tolerate ELM energies of under 1 MJ per eruption; given that a single ELM can release a small fraction of the entire plasma energy, a regular type I ELM in ITER could release 20 MJ in 500 μs[7].

A limit has been set on the maximum power fluxes allowed onto the PFCs, specifically half that which would melt these components.[8] Natural ELM frequency for ITER will be about 1 Hz and the resultant power load on the plasma facing components (PFCs) will cause them and the tungsten (W) divertor plates to melt[9]. ITER will not be able to stand even one ELM of this magnitude and so it must operate in a completely ELM-mitigated regime.[7]

There is a limit on the minimum ELM frequency necessary for ITER's operation due to the need to remove impurities (page5/6).[8]

4 Current methods for mitigation

4.1 Resonant Magnetic Perturbations (RMPs)

ELM magnitude scales as $f_{ELM}.\Delta W_{ELM}$ ~ constant[7], so influencing factors which decrease the time between ELMs will consequently decrease their power.

ITER's tungsten divertor introduces further requirements on ELM control[7] W build up in the plasma core could cause catastrophic energy losses; hence, additional methods to provide enhanced transport will need to be implemented, else low power ELMs must be allowed to occur to provide this enhancement.

Magnitude of field applied by RMP coils is 10^{-4}~10^{-3} T[10]

4.2 Vertical Kicks

Fractional shifts in the vertical position of the plasma, ~$1-3\%$ of the minor radius[7], executed rapidly augment the edge current to attempt to mitigate ELMs.[11]

4.3 Pellet Injection

ASDEX-U trialled the first usage of pellets to trigger ELMs in 2003.[12] Projectile pellets provoke type 1 ELMs when they penetrate into the pedestal.[7]

4.4 Evidence for these methods in practice

DIII-D experiment showing complete ELM suppression (DIII-D geometry is similar to ITER's)[13]

References on Slide 45 of A. Kirk's talk about ELM (I) suppression at low collisionality. ***What exactly is collisionality, how is it measured and how is it externally influenced?*** Lowering collisionality, ν^*, causes the pressure cycle to retreat from the unstable peeling-ballooning region and thus leads to complete type I ELM suppression.[14]

4.5 How they may work on ITER

ITER will utilise at least two major ELM control systems, RMP coils and pellet injectors.[15]

Vertical stability coils may be implemented as a fall back ELM control method.[8]

5 Necessary future work

lots

6 I-Mode

The I-mode is an operating regime that combines the desirable elements of H- and L-mode[16] and has automatic ELM suppression.[17] It is more easily available to higher-field machines and has been investigated most considerably on Alcator C-Mod. Core impurity levels are lowered in I-mode as it lacks an edge particle transport barrier, while retaining the edge energy transport barrier. Hence, I-mode can be distinguished by observing an H-mode like temperature pedestal along with an L-mode like density profile.[16]

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