Spatio-temporal investigations on the triggering of pellet induced ELMs

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Outline

Introduction: Edge Localised Mode (ELM)
ELM dilemma in tokamaks

Strategy: ELM triggering without any global plasma perturbation
pellet velocity scan

Experiments: Pellet localisation
Determination of the ELM onset time

Results: ELM trigger localisation

Outlook: investigation of HFS-LFS asymmetry with the new
Leidenfrost blower gun
Introduction: the ELM problem

ELM (Edge Localised Mode): periodic energy pulses deposited on first wall components

Type-I ELMs can cause critically high transient power load on plasma facing components.

Solving the ELM problem: mitigation by frequency enhancement

Energy content \( \sim \) Volume \( \sim R^3 \)
Impact area \( \sim 2\pi R \, dR \)
Energy density \( \sim R^2 / dR \)

Large tokamak, severe problem

Envisaged solution:
Mitigate ELMs below damage threshold

\[ \frac{\Delta W_{ELM}}{W_{mhd}} = 0.2 \]

ASDEX Upgrade
- low triangularity (H)
- low triangularity (D)
- medium triangularity (D)

JET
- low triangularity
- medium triangularity

Observation:
\[ \Delta W_{ELM} \sim \frac{P_{heat}}{f_{ELM}} \]
for many scenarios with "natural" ELMs

Approach:
"Split" few large ELMs into many small ones

A. Herrmann, PPCF 44 (2002) 883
Injection of frequent small and shallow penetrating cryogenic pellets has been found at ASDEX Upgrade tokamak a promising techniques to mitigate the ELM effect.

The technique works but the underlying physical processes of the ELM triggering are not well understood. Therefore our aim is to study how a pellet triggers an ELM.

The investigations presented in this talk were devoted to answer the questions:

**At which magnetic surface does the perturbation of the ablating pellet finally cause the ELM?**

To answer the questions the dynamics of the triggered ELMs has to be linked to the time history of the pellet position in the plasma.
Earlier observations:

- Every pellet injected into ELMy H-mode plasma of ASDEX Upgrade triggered an ELM.

- This ELM was observed only if the pellet entered into the confined plasma crossing the separatrix: $dt_{ELM \text{ ONSET}} = t_{ELM \text{ ONSET}} - t_{\text{pellet @ separatrix}} > 0$

**Assumption:** to trigger an ELM, the pellet has to reach a certain magnetic surface ($Z_{\text{seed}}$) independently of the pellet mass and velocity.

Perturbation spreads and finally an instability starts to grow which develops into an ELM.

$$dt_{ELM \text{ ONSET}} = \frac{(z_{\text{seed}} - z_{\text{separatrix}})}{V_p} + t_0$$

Pellet velocity scan: $t_0$, $Z_{\text{seed}}$ can be determined.
The experiments have been performed on the ASDEX Upgrade tokamak injecting pellets from the high field side of the torus into the type-I ELM regime of an H-mode discharge.

Stable and robust operation in the type-I ELM regime with low natural ELM frequency (25 - 45 Hz) was achieved by keeping the auxiliary heating power just above the L-H transition power threshold.

To avoid the disturbance of the natural ELM cycle and parasitic plasma fueling, perturbative ELM triggering with driving frequency (6Hz) small compared to the natural ELM frequency was used.

Low pellet injection frequency: trigger events occur at different times in the ELM cycle that is we perform the analysis as a function of the time elapsed after the previous naturally occurring ELM.

\[ t_{\text{ELM ONSET}} - t_{\text{pellet @ separatrix}} \]

are measured as a function of

- time elapsed after the previous ELM
- pellet mass
- pellet velocity

MHD energy loss
Pellet injection system at ASDEX Upgrade

- Pellet velocity 240 - 1000 m/s
- Repetition rate up to 100 Hz
- Pellet mass 0.5 - 1.4 mg
- Reservoir up to 120 pellets

240 m/s, r=0.71mm, N=9 \cdot 10^{19}
600 m/s, r=0.67mm, N=7.4 \times 10^{19}
880 m/s, r=0.58mm, N=5.8 \times 10^{19}
1000 m/s, r=0.51mm, N=3.3 \times 10^{19}
Pellet localisation

- Pellet injection
- Separatrix
- Camera exposures
- Ablation monitor signal

- Trajectory reconstruction
- Short multiple exposures:
  - On time: 10µs
  - Off time: 90µs

- Tangential view
- Long exposure

- Vide angle view
- Photodiode
ELM onset determination

Dynamics of the ELMs is monitored by magnetic coils:

**Poloidal pick-up coil set**
- About 600 coils
- 180°, 5 coils

**Toroidal pick-up coil set**
- About 1800 coils
- 5 coils

**Mirnov coil set**
- 360°, 30 coils

**Poloidal pick-up coil set**
- About 60°, 7 coils

Magnetic pick-up coils signals:
- Strong quasi periodic oscillation at the very beginning of the ELM event

For every ELM, the Hilbert-Huang spectrogram was calculated and integrated in the typical 100-300kHz range (magnitude of the ELM related MHD activity)

**t_{ELM_OSET}**: magnitude exceeds a predefined threshold

The ELM onset appears on every coil signal at the same time: poloidal coil set is used.
Results: ELM onset delay

Low pellet injection frequency: trigger events occur at different times in the ELM cycle that is we perform the analysis as a function of the time elapsed after the previous ELM.

Pellets can trigger ELMs at any time in the ELM cycle: plasma edge is not stable against a pellet induced seed perturbation.

\[ \text{dt}_{\text{ELM\_ONSET}} \text{ saturates with increasing } \text{dt}_{\text{elapsed}} \]

\[ \text{dt}_{\text{elapsed}} > 8\text{ms}: \quad \text{dt}_{\text{ELM\_ONSET}} \sim \text{constant} \]
Results: ELM onset delay

\[ dt_{\text{ELM \, ONSET}} = t_0 + \frac{(z_{\text{seed}} - z_{\text{separatrix}})}{V_p} \]

\[ t_0 = 50 \mu s \]

\[ z_{\text{seed}} = 2.7 \text{cm} \]

Location of the seed perturbation: at the middle of the pedestal
Pellet triggering of ELMs was investigated by probing the natural ELM cycle injecting pellets with much lower frequency than the natural ELM frequency.

Every injected pellet can trigger an ELM independently of its velocity and mass and the time elapsed after the previous natural ELM.

Only 5-15% of the expected pellet mass is ablated until the position of the seed perturbation.

Assumption: to trigger an ELM a pellet has to reach a certain closed magnetic surface independently of its mass and velocity, location of the seed perturbation: at the middle of the pedestal where the plasma pressure gradient reaches its maximum.

Consistently with peeling-ballooning model of the ELM predicting instability onset localized to the pedestal steep gradient region
Leonard et al, PPCF (48) 2006 A149 , Snyder et al, PoP (12) 2005 056115

Origin of 50μs intrinsic delay time (perturbation spread time + instability growth time) is unclear → HFS - LFS symmetry?
Outlook

Two different injection directions:

- nearly tangential to the separatrix combined with hor/ver shifting of the plasma → mapping the location of the seed perturbation.

- nearly perpendicular to the magnetic surfaces intrinsic delay measurement → investigation of HFS/LFS asymmetry of the ELM triggering if it exists et al.

To further investigate the trigger mechanism and validate our present observations ELMs will be triggered by LFS pellet injection

New Leidenfrost gun type pellet injector was developed