Correlation between ELMs and the Edge Plasma Profiles during the L-H Transition in JET

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CORRELATION BETWEEN ELMS AND THE EDGE PLASMA PROFILES DURING THE L-H TRANSITION IN JET

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Introduction

Edge Localised Modes (ELMs) are characterised by bursts of D_α radiation occurring in tokamak plasmas during H-mode. ELMs are associated with a temporary decrease in confinement resulting in increased particle losses from the edge region (here defined as the region of ρ=0.8-1.0, where ρ is the normalised minor radius). ELMs can thus be employed as a means of controlling the plasma density and impurity levels, prolonging the H-mode phase [1].

A series of highly repetitive ELMs of low D_α amplitude is often observed at the L-H mode transition. The repetition frequency of the ELMs can be as high as 2 kHz immediately after the L-H transition. This gradually slows down, until the ELMs disappear completely. The duration of the ELMy period decreases with increasing plasma heating power. At low power, close to the H-mode threshold, the ELMs may continue throughout the H-mode. In figure 1 the D_α emission is shown together with the electron temperature T_e in the edge region and the plasma centre. T_e increases in steps each time a heat pulse, generated by a sawtooth crash in the plasma centre, reaches the edge region. Each increase in T_e is accompanied by a visible decrease in the ELM repetition frequency. As these ELMs are localised to the edge region, it is clear that the change in ELM repetition rate is a result of the change in edge parameters caused by the sawtooth pulse.

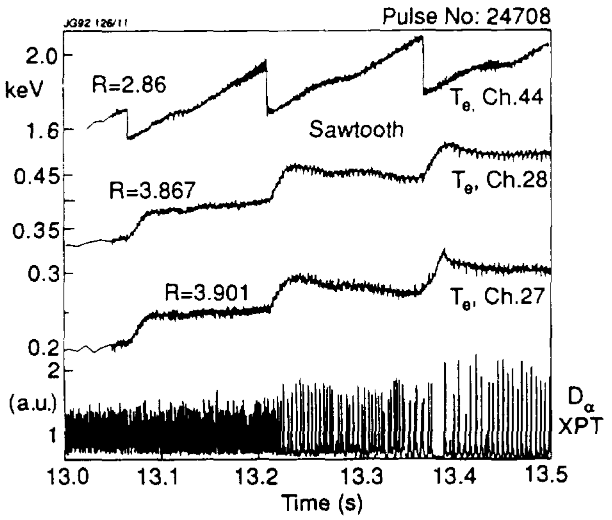

Figure 1. Electron temperature in the plasma edge and centre, and D_α emission, showing the change in ELM repetition frequency at each sawtooth heat pulse for #24708

Evolution of Edge Profiles

The temporal evolution of the edge T_e profile in the beginning of the H-mode has been investigated using the ECE heterodyne radiometer. The spatial resolution of this is ≈3 cm in the edge region, and the measurement points are separated by ≈4 cm [2]. During the H-mode the temperature gradient ∇T_e is significantly greater between the ρ=0.92-1.0 than in the rest of the edge plasma inside ρ=0.92. After the L-H transition T_e in the edge region at ρ=0.8-1.0 increases in steps at each sawtooth pulse. The steep ∇T_e in the outer edge region increases in steps at the sawteeth as well, while the gradient inside ρ=0.92 remains constant. The ECE spatial resolution is insufficient to fully resolve the edge gradient.

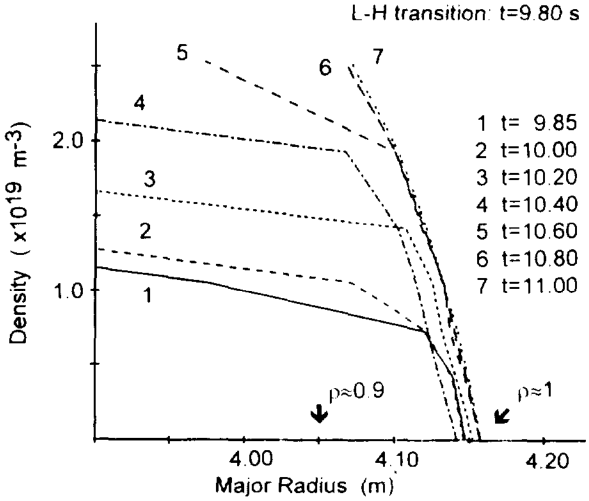

Figure 2. *Build up of the edge electron density profile in the beginning of the H-mode for discharge #27221.*

The build-up of the edge electron density profile has been studied with the fixed frequency phase detectors of the multichannel reflectometer. This monitors the relative movements of 11 reflecting density layers in the range $n_e=0.4\text{x}10^{19}$-$7\text{x}10^{19}$ m^{-3} [3,4]. The uncertainty on the movement of the density layers in relation to each other is typically less than 0.5 mm. The evolution of the density profile in the beginning of the H-mode is illustrated in figure 2. In the outer edge region at ρ=0.95-1.0 a steep edge density gradient ∇n_e is observed. As n_e increases throughout the plasma, the steep ∇n_e in the edge region remains constant, but the top of the steep edge gradient extends radially to a higher density further inside the plasma.

Reflectometer data also shows that even large sawtooth pulses have no significant effect on the steep constant n_e profile in the edge region, so the stepwise decrease in the ELM repetition frequency at the sawtooth pulses can not be attributed to changes in n_e.

Profile Perturbations during ELMs.

The perturbation of the temperature and density profiles caused by the L-H transition ELMs is localised to ρ=0.90-1.0, with the centre ρ_{elm}=0.93-0.95. On the density profile the ELMs only affect the outer edge region where the underlying density profile is constant. When the n_e profile builds up and the steep constant ∇n_e extends to a higher n_e, ρ_{elm} moves inwards to a higher n_e as well, from $n=1.2\text{x}10^{19}$ m^{-3} to $n=2.2\text{x}10^{19}$ m^{-3} or from ρ_{elm}=0.95 to 0.93. On the T_e profile the ELMs are also localised to the steep edge ∇T_e region at ρ=0.92-1.0.

When the intervals between the ELMs are less than ≈4 ms, the next ELM occurs as soon as the density and temperature have recovered their pre-ELM values. Later in the ELMy period however, when the ELMs occurs 6 ms or more apart, the density and temperature recovers to their pre-ELM values 2 ms or more before the next ELM. This indicates that the ELMs are not triggered just by the edge n_e and T_e profiles recovering to an unstable value after each ELM, and that the ELM repetition frequency is not determined simply by the recovery time of the edge n_e and T_e.

Correlation between ELM Repetition Rate and Plasma Parameters

The ELM repetition frequency has been calculated by counting the ELMs in selected time intervals containing 10-30 ELMs. The intervals have been chosen so as not to cover any sudden changes in ELM repetition rate due to sawtooth pulses. The uncertainty of the repetition frequency is estimated to be 1-2% at 1 kHz increasing to 10% at 100 Hz.

The correlation coefficient between the ELM repetition frequency and ∇T_e has been calculated for nine discharges with long ELMy periods at the start of the H-mode. The discharges have a total magnetic field of either 2.0 T or 2.9 T, and the plasma current is 3.1 MA. The results show a very strong correlation for each individual discharge, >0.95 on a scale where a perfect correlation gives 1 and random data gives 0. The overall correlation between different discharges is still strong at 0.85. The correlation is independent of the magnetic field in the discharges. The correlation between ELM frequency and edge temperature is similarly strong for the individual discharges, but the overall correlation for different discharges is lower at 0.75. The lower corelation with T_e could however be instrumental, as the ρ of the T_e measurement points may vary 1-2 cm between discharges.

In figure 3 the ELM repetition frequency is plotted against the edge pressure gradient.

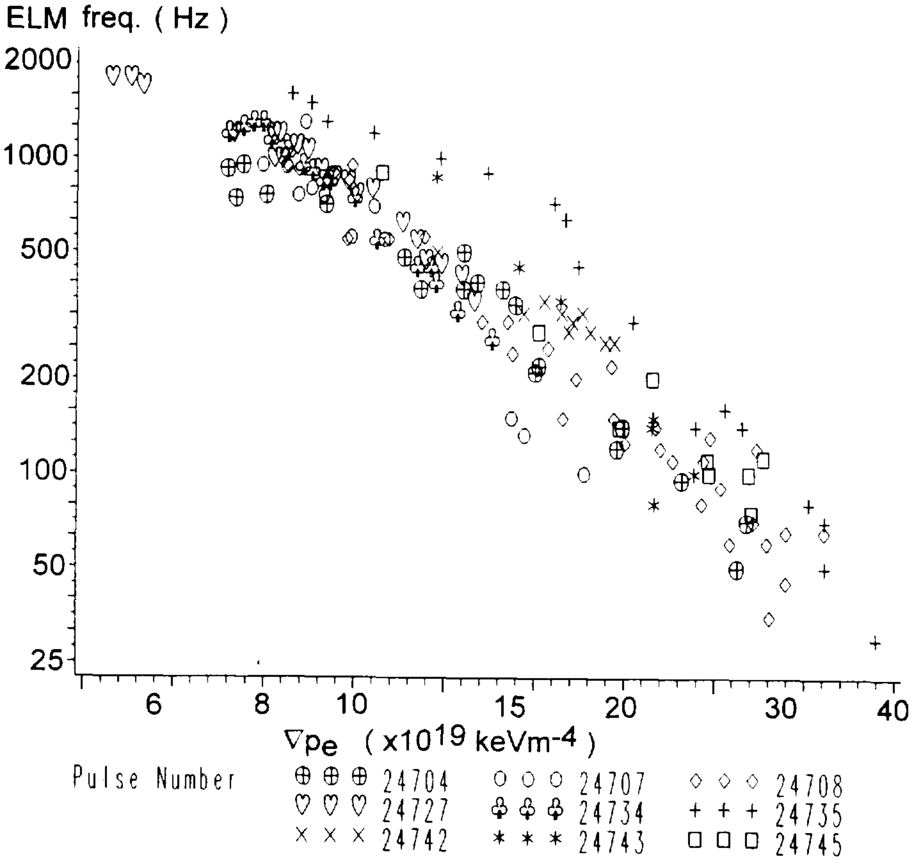

Figure 3. Plot of log(ELMfreq.) against log(dT/dR) at the ELM inversion radius for nine discharges with long ELMy periods at the beginning of the H-mode. The total magnetic field is 2.0 T for discharge #24704, #24707 and #24708, and 2.9 T for the rest.

A very strong correlation is observed for the individual discharges, with a strong overall correlation for different discharges as well. The correlation coefficients confirm the observations; the correlation value for each discharge is >0.97. The overall correlation for different discharges is 0.94, significantly better than for T_e and ∇T_e. The proportionality constant has been calculated by linear regression, giving a expression for the ELM repetition frequency of $F \propto (\nabla p_e)^{-2.1}$.

The increase in n_e at the ELM radius during the ELMy period is around 20-50%, and the corresponding increase in T_e is typically of the order of 100%. It has been shown that the density gradient in the region of the ELMs remains constant, whereas the ELM inversion radius move inwards. The increase in ∇p_e is therefore driven primarily by the increase in either T_e or ∇T_e, and secondarily by the increase in n_e at the ELM inversion radius as this moves inwards to a higher density. The spatial resolution of the T_e data is insufficient to establish whether the ELM repetition frequency decrease is driven by p_e and T_e, or ∇p_e and ∇T_e, but the localisation of the ELMs in the region of the steep edge gradients suggests that the latter is significant.

Conclusions

After the L-H transition the edge T_e and ∇T_e increases rapidly, whereas ∇n_e remains constant in the edge region.

The small repetitive ELMs occurring after the L-H transition are localised to the region of steep edge temperature gradient, and of steep constant density gradient. As the n_e profile builds up the ELM radius moves inwards to a higher n_e. This indicates that the ELMs are linked to the point of maximum pressure gradient, at ρ=0.92-0.95.

The ELM repetition frequency shows a strong inverse correlation with the square of ∇p_e during the ELMy period after the L-H transition. The increase in ∇p_e is primarily driven by the increase in ∇T_e and secondarily by the increase in n_e at the ELM radius.

The decrease of the ELM repetition frequency with increasing ∇p_e suggests that the ELMs are stabilised by ∇p_e. This rules out ideal ballooning modes and other ideal MHD instabilities driven by ∇p_e as candidates for the cause of ELMs. However the decrease in ELM frequency is driven primarily by T_e or ∇T_e. It is thus possible that ELMs could be caused by resistive ∇p_e driven modes, if the stabilising effect on the ELM repetition rate of the increasing T_e is larger than the destabilising effect of the increase in ∇p_e.

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