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Magnetic ELM triggering on ASDEX Upgrade

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1. Introduction

Controlling the Edge Localised Mode (ELM) frequency and in turn their amplitude is one possible way to mitigate their impact on the divertor components in ITER. Since the ELM triggering mechanism depends on the edge current and pressure profiles, a modification of these parameters can lead to a variation of the ELM cycle. Different techniques exploiting this concept have already been reported [1]. Among those, ELM triggering by plasma vertical position modulation was performed on TCV [2]. In these experiments the vertical oscillation of the plasma generates edge current which, in turn, triggers or inhibits ELMs depending on the sign of the induced edge current. Similar experiments have now been performed on ASDEX Upgrade (AUG) to test this technique on an additionally heated H-mode with type I ELMs. This contribution presents the first results of these experiments.

2. Experimental set-up

The perturbation, a sine wave of given frequency and amplitude, was added to the reference in the vertical position feedback control loop. It resulted in an oscillation of the current flowing into the coils used for the vertical control, which in turn generated an oscillating vertical displacement of the plasma magnetic axis. Due to operational and machine constraints, the available perturbation frequency range lay between 30 and 90Hz. Plasmas with a natural ELM frequency in the low part of this range were chosen as targets.

The perturbation frequency was extracted from the acquired signal of the injected perturbation. The starting point of an individual perturbation was arbitrarily chosen at the upwards crossing of the unperturbed signal (phase=0 in a sine wave). The ELM frequency was estimated from the D_α emission signal as $1/\Delta t$ for each ELM pair. The time delay between the perturbation and the ELMs was then uniquely defined. The phase of the ELM occurrence in the oscillation cycle was also calculated. In a similar way, the phase of the ELMs in the coil current signal and in the plasma vertical position was also estimated.

In a series of discharges, the amplitude and the frequency of the perturbation, the NBI heating power, the plasma current and the plasma triangularity were scanned.

3. Results

A 56Hz magnetic perturbation was applied to an H-mode with type I ELMs during 0.5s. The plasma current was maintained at 1MA, the average density naturally evolved between 5 and 6 $10^{19}m^{-3}$ in the absence of feedback control and the neutral beam power was set to 5MW. The average natural ELM frequency, measured before the perturbation phase, was 44Hz. It rose to the perturbation frequency as soon as it was turned on as shown in Fig.1. The ELMs became more regular, the standard deviation of the ELM frequency was smaller during the perturbation and the time delay between the perturbation and the ELM occurrence remained approximately constant. All these observations show the synchronisation of the ELM cycle to the magnetic perturbation cycle. After the perturbation, the ELM frequency slightly decreases towards its natural value. It stayed at a larger value than before because of a decrease in plasma density.

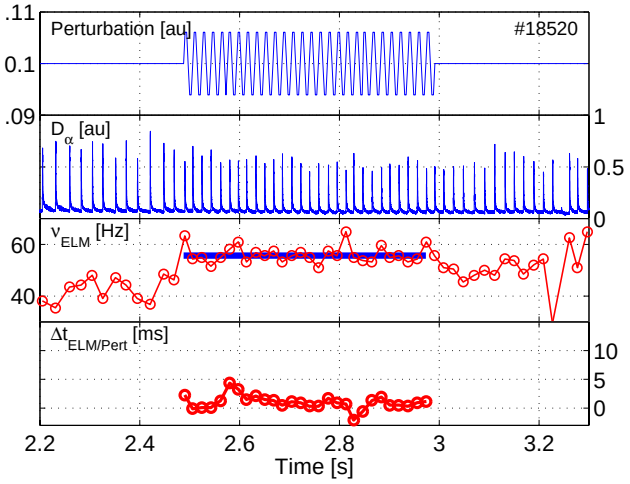

Figure 1: Evolution of the perturbation signal, D_α emission, ELM frequency, time delay between perturbation and ELM. The perturbation frequency is indicated as the straight line in third box.

Boxcar averaging was performed over all perturbation cycles shown in Fig.1. Signals were shifted in time to have t=0s at the beginning of each perturbation cycle. The average was then taken over all cycles. The averaged perturbation is shown in Fig.2, first box. Beneath it appear successively the sum of the coil currents used for plasma vertical position control, the vertical excursion of the plasma and the D_α emission. For this latter parameter the average was not taken, but we show individual ELMs. They are clearly grouped in a space of only a few milliseconds while the duration of the perturbation cycle is 18ms. The last box shows the histogram of the ELM occurrences in the perturbation cycle.

In TCV, the ELMs were triggered when the plasma moved away from the X-point. Figure 2 shows that, in AUG, the ELMs occur when the position moved down, i.e. when the plasma moved towards the X-point. The several differences between the TCV and AUG experiments are currently being investigated to explain this surprising difference.

3.1 Perturbation amplitude scan

In discharge 18520, five 0.5 second bursts, separated by 0.5s, with 56Hz perturbations, were injected into the vertical position control system. The amplitude of the perturbation was then scanned, leading to vertical excursions from 6 to 12mm. In the case of small excursions, the synchronisation was excellent whereas it deteriorated when the amplitude was increased as shown in Fig.3. Between the perturbation pulses, the ELM frequency remained close to the perturbation frequency. Therefore the deterioration of the synchronisation at high amplitude cannot be attributed to a change in the natural ELM frequency.

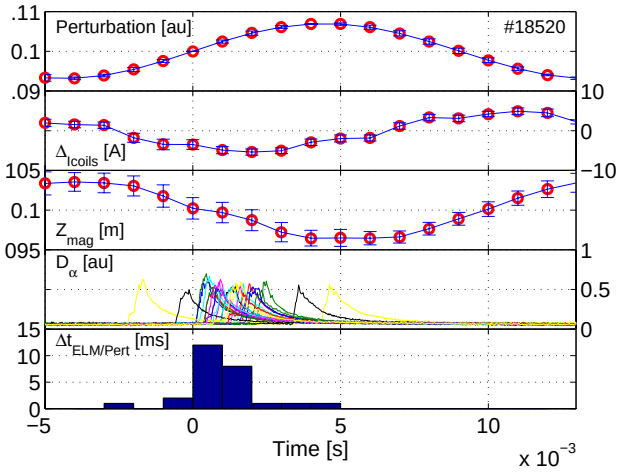

Figure 2: Boxcar average of the perturbation signal, current difference in plasma vertical position control coils and plasma vertical position. Overlay of D_α emission with time normalised to the perturbation time. Histogram of time delay between perturbation and ELM.

Nevertheless, all histograms are peaked, indicating significant synchronisation in all cases. This peak always coincides with the plasma moving downwards.

3.2 Perturbation frequency scan

A series of perturbations of different frequencies were injected into another discharge (#18524). In this case, the bursts were contiguous, lasting 0.3s each and the frequencies ranged between 33 and 80Hz. In the first phase, the ELM frequency increased due to the perturbation. The plasma density then decreased and small ELMs replaced the type I ELMs. Tracking was then lost for a few periods. When the perturbation frequency was low (43Hz) type I ELMs appeared and synchronisation was recovered, although not as precisely as in the previous case. The difference in the behaviour is attributed to the evolution of the plasma discharge.

3.3 Plasma parameter scan

The neutral beam power was scanned in discharge 18523. The level of additional power was maintained constant during the injection of each of the 0.5s perturbation bursts. In this experiment, the ELM synchronisation was significantly affected by the level of additional power. Only two perturbation bursts were applied to a plasma with type I ELMs, with a

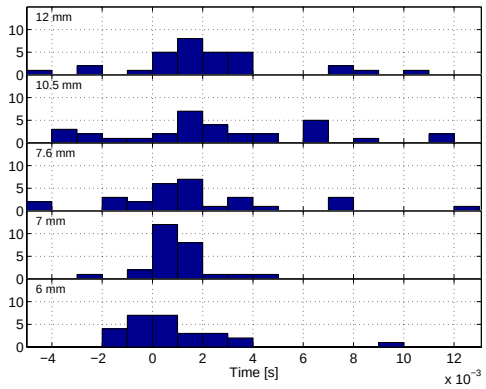

Figure 3: Histograms of ELM occurrences in different perturbation phases. The legend in each row is the vertical excursion.

power of 4 and 6.7MW. In these 2 phases, synchronisation of ELMs to the perturbation was observed. Once again the ELMs were triggered when the plasma moved downwards. In the high power case, the time delay between the perturbation and the ELM was smaller by 2 ms. It shows that less vertical movement is required to trigger an ELM at high power, attributable to an increased edge conductivity.

In a last discharge (#18525), the plasma current was ramped during 3 perturbation bursts and the triangularity scanned during 2 bursts. The synchronisation was still observed during the current ramps. However the time delay between perturbation and ELM reached 5ms. During the triangularity ramp, the natural ELM frequency rose. The perturbation was not able to prevent the ELMs from occurring and therefore no synchronisation was found.

4. Conclusion

The frequency of type I ELMs was successfully increased by a magnetic perturbation in ASDEX Upgrade, using the technique found on TCV. This perturbation, applied to the plasma vertical position control system, induces a current at the plasma edge, which affects the ELM cycle. Even small perturbations (7mm) already lead to significant synchronisation of the ELMs. The time delay between the perturbation and the ELM occurrence varied slightly when the perturbation or plasma parameters changed. Synchronisation always occurred when the plasma was moving downwards, contrary to the observation on TCV, the subject of ongoing modelling investigations.

5. Acknowledgement

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6. References

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[2] A.W.Degeling et al. Plasma Physics and Controlled Fusion (2003), 1837.