Synchronous ELM Pacing at JET using the Vertical Stabilisation Controller

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** See the Appendix of M.L.Watkins et al., Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu, 2006) IAEA, (2006)*

1. INTRODUCTION

Although ELMs are a beneficial mechanism in controlling the plasma particle inventory and controlling plasma impurity content, the associated power to the plasma facing components can be unacceptable. Extrapolation based on experimental data from present tokamaks indicates that the transient heat loads in ITER could be high enough to lead to melting/erosion and hence strong reduction in component lifetime, if left unmitigated.

Several ELM mitigation techniques are presently being studied, some based on the application of static magnetic fields and other based on the shallow injection in the plasma edge of D2 pellets. In this paper we present the first JET experimental results of the application of rapid varying radial field as ELM pacing mechanism.

2. EXPERIMENTAL SETUP

JET [1] Vertical Stabilization (VS) controller has been modified to allow the application of a user defined voltage pulse (so called kick) at an adjustable frequency which can be synchronised to the ELM-event or applied asynchronously. The periodic pulse generation is implemented by introducing a count-down timer in the VS. When the counter reaches zero, the desired voltage pattern is generated and sent to the amplifier. If this mechanism is synchronised then the counter is restarted at every occurrence of an ELM, as detected by a rapid variation on one of the divertor Dα trace. With this technique the kicks are only applied if the natural ELM-free period is larger then the timer setting. In addition this means that the kick will never be applied just after a naturally occurring ELM thus compounding the disturbance to the VS system and potentially risking a VDE (Vertical Displacement Event) [1]

The experiments presented in this paper were performed on deuterium target plasmas with a low density H mode and low frequency type-I ELMs. Auxiliary heating was provided by neutral beam injection with a power of 6.5 MW (the power level was selected to generate low frequency natural ELMs) and by ion cyclotron resonance heating with a power of 1.6

MW. The magnetic configuration was a single null with Ip=1.9MA, Bt=2.35T, q95=3.7, elongation k=1.72.

3. RESULTS AND ANALYSIS

The first experimental observation is that in JET positive kicks (positive voltage pulses) do not trigger an ELM while negative pulses do (See Fig 1). This indicates that the plasma instability is excited only when the plasma is pushed down.

This has been demonstrated by the experiments 68310 and 68320 (Fig 2) where the kick frequency was progressively raised from 25Hz to 50Hz. Pulse 68320, where the negative pulse was used, shows a successful control of the ELM frequency while in pulse 68310 the natural ELM frequency is unchanged.

In order to demonstrate that the ELMs are actually triggered by the kicks and that the ELM frequency is not just naturally evolving in the desired direction, Fig 3 shows also the time relation between kicks and ELMs. From the data it is evident that the majority of successful kicks trigger an ELM within 3-5 ms while the natural ELMs occur at a random delay.

Experiment 68320 shows that it was possible to increase the ELM frequency from 25Hz up to almost 50Hz by progressively increasing the kicking frequency. This is an example of the first experimental trials which were performed under the assumption that the ELM pacing would affect the plasma pedestal itself and that there would be a slow response of the plasma frequency to the pacing. This was to be proven false by a second set of experiments where the ELM frequency was changed abruptly.

In shot 70426 the ELM frequency was increased by oscillating in steps the synchronous kick frequency between a base value of 10Hz and in sequence 25, 33, 40, 50 and 66 Hz (Fig 4). The 10 Hz phase was in fact meant as un-kicked reference windows but as it happened the natural ELM frequency was even lower. The experiment not only demonstrated a substantial change in natural ELM frequency (by a factor of 5) but more importantly proved that the plasma would immediately relax to a lower kick frequency with no memory of the previous kicks.

Taking also in consideration the fact that synchronous ELM pacing always kicks at a precise time after an ELM one can conclude that this pacing method acts by shortening the ELM-free phase. A further demonstration of this statement is provided by shot 70427 (Fig 5), where the initial ELM-free phase is effectively shortened by activating the pacing mechanism during the H mode transition.

Another important characteristic of this ELM pacing method is the fact that it does not seem to affect the plasma stored energy baseline (Fig 6). This is a preliminary observation that needs further experimental evidence for a confirmation.

JET kick system has two important technical limits. The amplifier current limit not only poses a ceiling to the duration of the pulse but also indirectly limits the frequency. The train of pulses acts as a one-directional disturbance to the VS system: by repetitively pushing the plasma down it forces the VS controller to raise the average amplifier current thus reducing the current available to recover the plasma stability (Fig 3). Because of this the practical maximum kick frequency is about 50Hz as shown in shot 70427 where a 66 Hz kick frequency lead to the VS amplifier over current and, consequently, to a plasma VDE.

4. CONCLUSIONS AND PROSPECTS

After these experimental trials there is no doubt that VS kicks can act as a very effective ELM triggering mechanism. It was possible to change the natural frequency by at least a factor of 5, and the initial large ELM in an H mode discharge was effectively moderated.

The experiment data have also taught us that ELMs can be triggered only by moving the plasma downwards and that the baseline plasma energy does not change as a result of the kicks.

The magnetic ELM pacing mechanism already has experimental application at JET: it can be applied as a safety net against large ELMs, and as a tool for obtaining the desired ELM frequency, and the ability to trigger ELMs at a precise time can be used to synchronise diagnostics or actuators.

These initial results are very promising, but the method needs further development and accurate documentation. On the physics side one needs to have a full diagnostic coverage to document the effects of the kicks on the edge transport barrier and on the ELM structure, as well as to measure the changes in the ELM power loads to the divertor and first wall.

New experiments of ELM pacing with kicks are now in progress, and their results will hopefully provide the missing experimental data and help in the understanding of the mechanism of ELM triggering.

ACKNOWLEDGEMENTS

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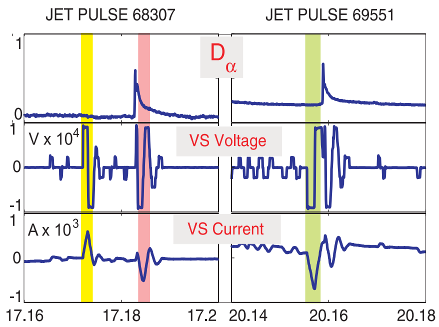

Fig 1: Voltage response to a natural ELM (pink bar), a positive kick (yellow bar), and a negative kick (green bar). The kick direction (positive/negative) is determined by the initial sign of the voltage. The following counter-kick is the VS trying to recover plasma vertical control. Note that in the natural ELM the VS applies a positive voltage briefly. This is caused by a measurement problem.

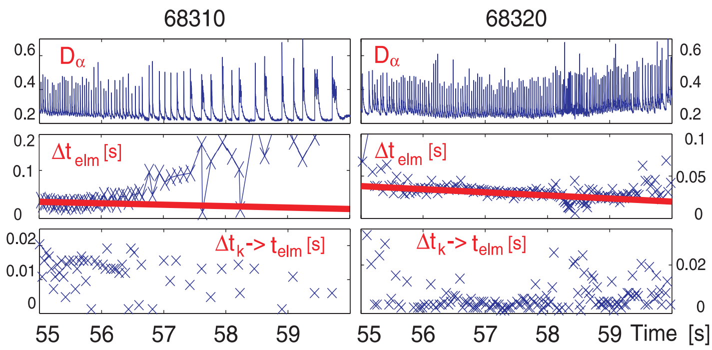

Fig 2: Comparison of pulses #68310 and 68320: (a) Dα signal; (b) ELM period vs reference (red); (d) time delay from each perturbation to the next ELM. In pulse 68310, where the positive kick is used, the ELMs pattern is not correlated to the kicks while in shot 68320 a large number of the ELMs occur 3-5ms after the start of the kick.

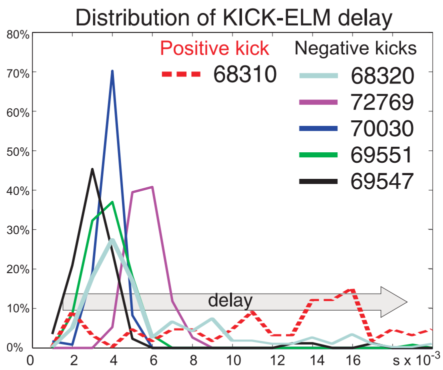

Fig 3: The graph shows the distribution of the delay between a kick and the following ELM. When the kicks are successful the majority of ELMs follow a kick after 3-5 ms. In shot 68310, where the positive kick was applied the distribution does not show a clear peak indicating no correlation between kicks and ELMs.

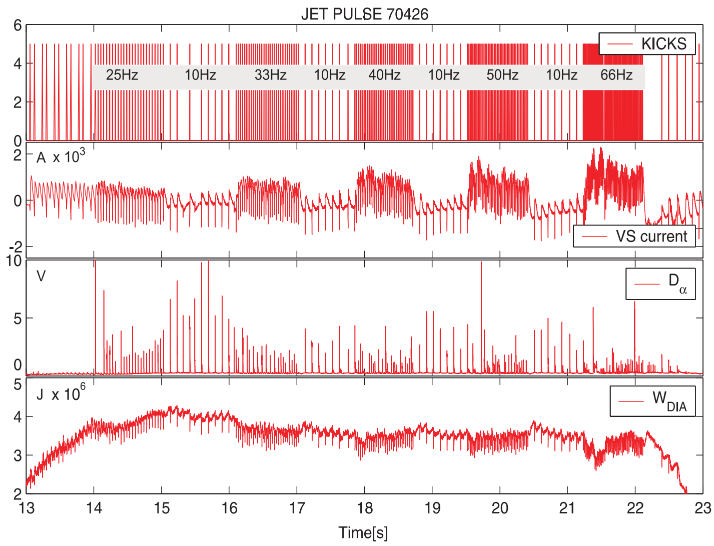

Fig 4: Pulse 70426: rapid variation of kick frequency corresponds immediate plasma change in frequency. This proves that the plasma has no memory of the kick. Note how the VS current grows with the increase of the frequency.

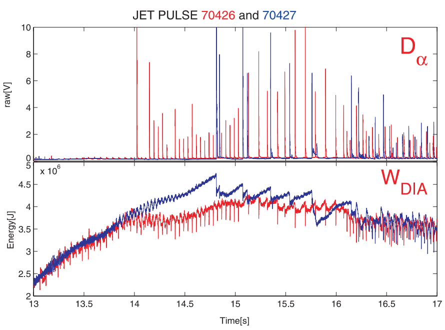

Fig 5: A comparison of kicked (70426) and unkicked (70427) ELM-free phase at the transition to H mode. Despite the lower fuelling in shot 70427 the initial ELM-free phase is effectively shortened by .7s and the initial large ELM is removed.

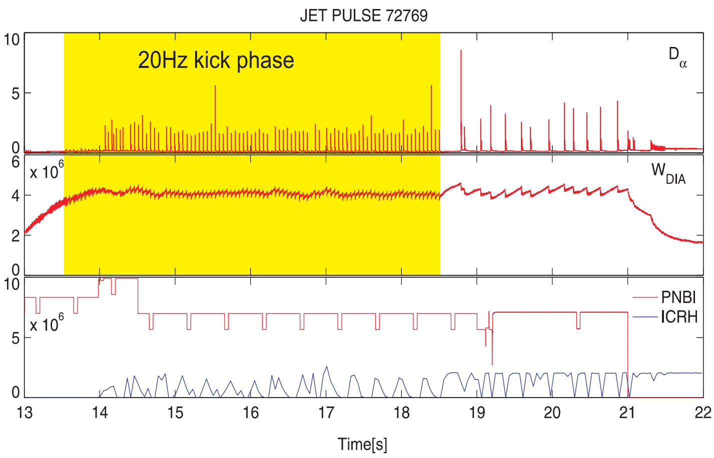

Fig 6: Pulse 72769 provides a convincing demonstration that the kicks do not strongly affect the plasma stored energy baseline. This fact was partially visible in other tests, but the natural evolution of the plasma was complicating the analysis.