Analysis of pellet ELM triggering potential in different ASDEX Upgrade plasma scenarios

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Cryogenic pellet edge localised mode (ELM) triggering was proposed decades ago to shorten the time elapsed between successive ELMs and therefore to reduce the ELM-caused heat loads on first wall elements. Pellet ELM pacemaking was successfully demonstrated on several tokamaks, increasing the ELM frequency substantially [1][2]. However, it has also been discovered that this technique cannot increase the ELM frequency arbitrarily. It was found that the probability of a pellet triggering an ELM is dependent on the time elapsed ("elapsed time") since the previous ELM, and even "lag times" were observed in all-metal wall ASDEX Upgrade (W AUG) discharges where this probability drops to zero [3].

Recently nonlinear MHD simulations (Jorek) including realistic ExB and diamagnetic background flows and time evolving bootstrap current were performed to simulate the ELM triggering by pellets (ASDEX Upgrade scenario: I_P=0.8MA, B_t=-2.5T q_{95}=5.2, P_{NI}=5MW). A full ELM cycle is modelled, and stability is probed by pellet injection at different elapsed times. The calculations confirmed the existence of the lag time, and it was shown that larger or slower pellets - both introducing larger local perturbation - shorten the lag time [4,5,6]. The simulation results offer a good opportunity to compare them with the experimental results, which is the aim of this contribution.

Since the discovery of ELM pacemaking, there have been several experiments on ASDEX Upgrade tokamak in which cryogenic pellets were shot into H-mode plasmas. Some of these were aimed at investigating the ELM triggering itself, some of them served a different purpose, but independently of the original aim, the efficiency of pellet ELM triggering can also be examined in these discharges. The data were processed as follows. Both the onset and the end of the pellet ablation was determined for every pellet from the ablation monitor signal by using a carefully selected threshold. Similar times were determined for the ELMs using the divertor shunt current signal (divertor Hα radiation for earlier discharges). The ELM-caused energy drops were also calculated from the plasma MHD energy content (W_{MHD} signal) for each ELM. Per definition the pellet triggered an ELM if an ELM onset time fell between the pellet ablation onset and end time. Usually the pellet life time is few hundreds of microseconds, which is shorter than the ELM collapse time (a few milliseconds). Therefore, this simple selection algorithm worked well. If the pellet ablation onset time was between the ELM onset and end time, the pellet was taken as arriving during an evolving ELM. All other cases were handled as the pellet ELM triggering failed.

Lag time can only be well studied in experiments where the pellet injection frequency is lower than the frequency of naturally occurring ELMs. This is because if the frequency of the pellet injection is higher than that of the ELMs, “pacemaking” will work, so there will be no elapsed times shorter than the provoked ELM cycle. This effect is well observed in Carbon wall ASDEX Upgrade (C AUG) discharges (see Fig.1.).

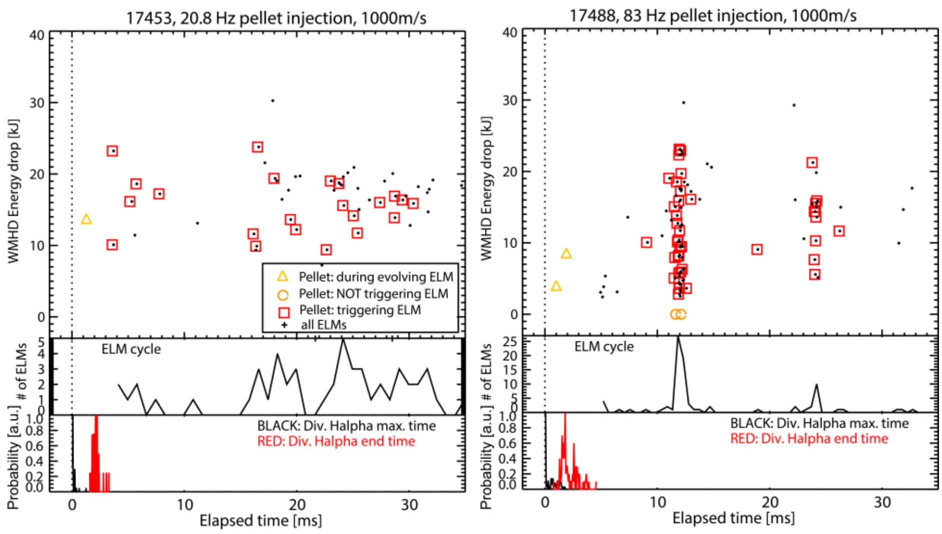

Fig. 1. Pellet ELM triggering in C AUG discharges. The upper figures show the ELM-provoked plasma energy drop as a function of the time elapsed after the previous ELM both for spontaneous and pellet triggered ELMs for the pellet injection time window (+). The coloured symbols represent the energy drops followed by the pellet injection for the three triggering cases (ELM triggered, ELM not triggered, pellet arrived during an already evolving ELM). To characterise the ELM cycle, the number of the ELMs are plotted as a function of the time elapsed after the previous ELM on the middle plots. To visualise the ELM crash dynamics the lower plots show the histogram of the time of the divertor Hα radiation maximum as a function of the time elapsed after the ELM onset (black curve). The histogram of the ELM crash end time derived from the divertor Hα radiation is also over plotted on the figure (red curve). The left column shows 20Hz pellet injection rate, while the right one the 80.3Hz case. Almost all pellets trigger an ELM independently of the elapsed time and pellet speed.

For C AUG almost all pellets trigger an ELM independently of the pellet speed and size and plasma scenario, and lag time was never observed. On the contrary, in W AUG discharges the lag time always exists. As an example, Fig.2 shows the ITER baseline scenario with three different plasma currents (1.2MA (B_t=-1.9T), 1MA (B_t=-2T), 0.8MA (B_t=-1.8T)): a lag time of ca. 15ms - about the half of the natural ELM cycle - appears.

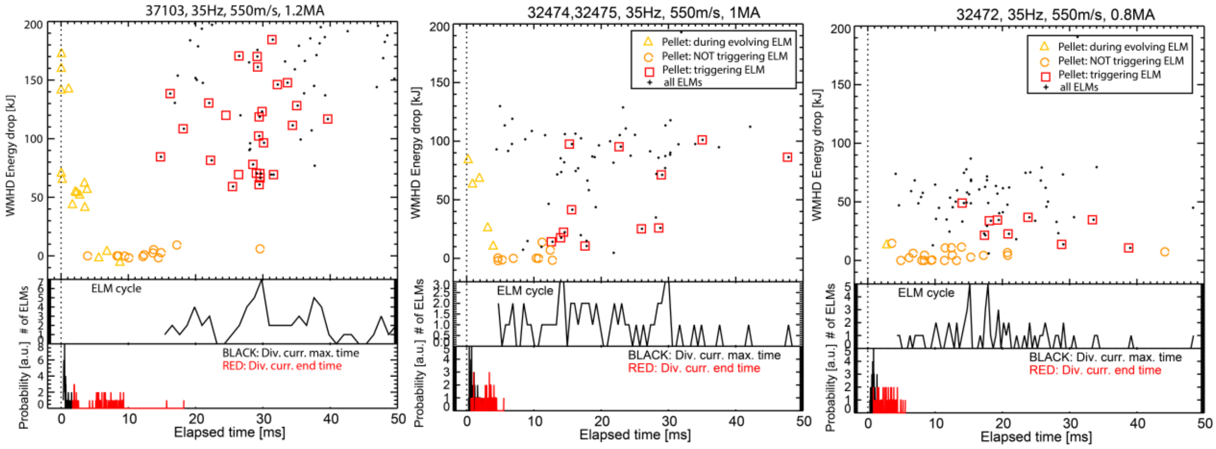

Fig. 2. ITER baseline scenario (W AUG) for different plasma currents: left 1.2MA (B_t=-1.9T), middle 1MA (B_t=-2T), right 0.8MA (B_t=-1.8T). See Fig.1. for the figure details, but here the ELM crash dynamics is characterised using the divertor shunt current.

A pellet perturbation scan is presented on Fig.3. in standard H-mode discharges (W AUG: I_P=1MA, B_t=-2.5T, q_{95}=4.5, P_{NI}=5MW), where both the pellet size and speed were varied. No significant lag time change is observed, maybe the largest and slowest pellet case (highest particle deposition rate) reveals some lag time reduction, but the amount of available data is too low for making a solid conclusion.

In edge-optimized configuration (EOC, W AUG, I_P=0.8MA, B_t=-2.5T, q_{95}=4.7, P_{NI}=2.5MW) the effect of the pellet speed and Nitrogen seeding was investigated. It seems that by changing the pellet speed the lag time does not change much. However, Nitrogen seeding ($2.5x10^{21}$ e/s) reduces lag time, but also causes shorter ELM cycle and smaller ELMs.

Conclusions

Pellet ELM triggering potential was investigated for different pellet and plasma parameters. Almost 100% pellet ELM triggering was shown for Carbon wall discharges, almost all pellets trigger an ELM regardless of the speed and mass. Accordingly, no lag time was observed. In contrast, the pellet ELM triggering potential is clearly reduced in all-metal wall ASDEX Upgrade. Any kind of discharge shows the existence of lag time. Pellet speed and size scan shows no significant lag time reduction/changes. Nitrogen seeding reduces lag time, but also causes shorter ELM cycle and smaller ELMs. The ITER baseline scenario gives the longest lag time, which does not depend on the plasma current. In the light of these observations, Jorek simulation for Carbon wall ASDEX Upgrade scenario would be useful for the better understanding of the pellet ELM triggering mechanism, and would give a prospect for the first experimental phase of JT60-SA which is also Carbon armored.

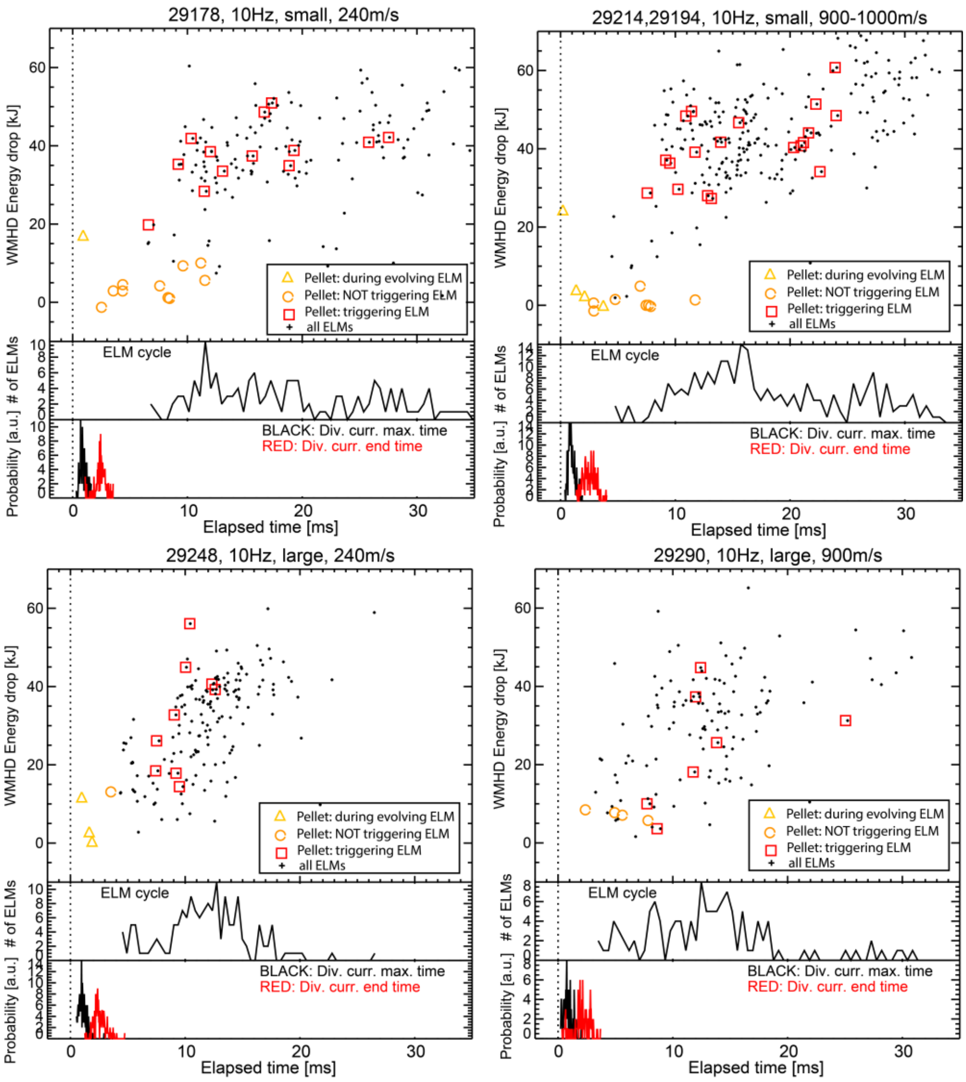

Fig. 3. A pellet perturbation scan in standard H-mode discharges (W AUG: I_P=1MA, B_t=-2.5T q_{95}=4.5, P_{NI}=5MW). See Fig.1. for the figure details, but here the ELM crash dynamics is characterised using the divertor shunt current. The left column shows slower pellet cases (240 m/s), while the right one the faster pellet cases (900, 1000 m/s). The upper figures are for small pellets while the lower ones for large pellets. The lag time seems to be shorter for the large and slow pellets, probably because they introduce the largest local pressure perturbation.

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