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GENERAL ATOMICS

## DISCLAIMER

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# Experimental Demonstration of High Frequency ELM Pacing by Pellet Injection on DIII-D and Extrapolation to ITER

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Injection of small deuterium pellets at high repetition rate on the DIII-D tokamak has been used to successfully demonstrate for the first time the pacing of edge localized modes (ELMs) at a 10x higher frequency than the natural type I ELMs. This demonstration of ELM pacing was made by injecting slow (<200 m/s) 1.3 mm $D_2$ pellets at 60 Hz from the low field side in an ITER shaped plasma at $q_{95}$=3.5 with a low natural ELM frequency of 5 Hz, $\beta_N$=1.8, and normalized energy confinement factor $H_{98}$=1.1, with the input power only slightly above the H-mode threshold. The non-pellet similar discharges have ELM energy losses up to 50 kJ (~8% of total stored energy), while the case with pellets was able to demonstrate 60 Hz ELMs with an average ELM energy loss less than 5 kJ (<1% of the total). Total divertor energy deposited by the ELMs is reduced by an average factor greater than 10 as measured by an IR camera and peak particle flux to the divertor from ELMs is also greatly reduced. Central impurity accumulation of Ni is significantly reduced by the application of the 60 Hz pellets.

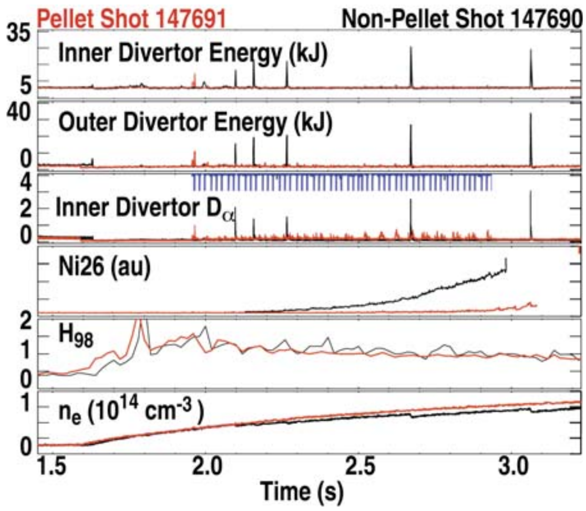


Fig. 1. Comparison of 60 Hz pellet case (red) and natural ELM plasmas with 5 Hz ELMs (black). Divertor deposited energies and divertor particle flux are shown with nominal pellet times marked by blue tick marks. Central Ni emission, normalized energy confinement $H_{98}$, and electron density are shown.

No significant increase in density or decrease in energy confinement with the pellets was observed as can been seen in Fig. 1. The individual pellets are not observable in the interferometer density measurements due to their small size and the small ELMs that are triggered within 0.5 ms of the pellet entering the plasma that eject the pellet mass. The plasma rotation is reduced at the edge from the pellets; however the central rotation is strongly increased without any increase in angular momentum input. Experimental details of the pellet ablation light and magnetic loop signals indicate that the ELMs are triggered before the pellet reaches the top of the H-mode pressure pedestal, implying that very small, shallow penetrating pellets are sufficient to trigger ELMs. Fast camera images of the pellet entering the plasma from the low field side show a local triggering phenomenon. A single plasma filament becomes visible near the pellet cloud and strikes the outer vessel wall within 200 μs. Additional ejected filaments are then observed to subsequently reach the wall. The plasma stored energy loss from the pellet triggered ELMs appears to be a function of the elapsed time after a previous ELM.

In these experiments, the pellets were injected from the low field side from both the midplane (Fig. 2, blue arrow) and newly installed lower port (Fig. 2, orange arrow) that mimics the injection geometry proposed for ITER. Both trajectories lead to ELM triggering for this size and speed of pellet, agreeing with previous observations for vertical low field side injection (Fig. 2, yellow arrow) [1,2]. No obvious difference is observed in the ELMs triggered from these three locations. The flux expansion in the plasma bottom enables a more precise measurement of the position of the pellet in the plasma at the ELM onset. The measurements there indicate that pellets of this size trigger ELMs when they reach the radial location that has approximately half of the peak pedestal pressure, which is ~2 cm inside the last closed flux surface along this trajectory. The pellet ELM pacing reduces the pedestal electron pressure before an ELM by approximately 20%, while maintaining the time average pressure.

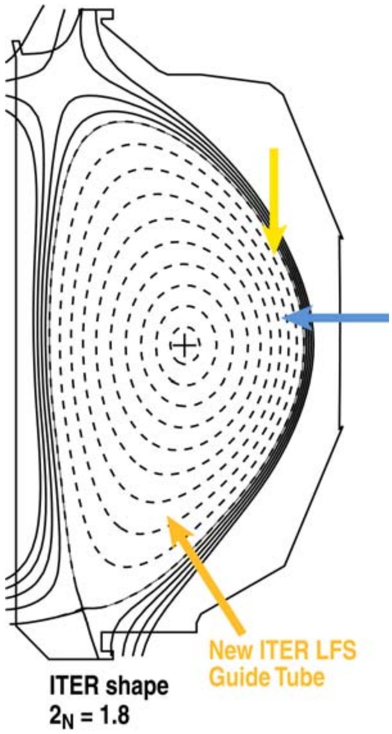


Fig. 2. Pellet injection geometry used for ELM pacing studies on DIII-D. The lower trajectory mimics the planned ITER low field side injection line for pellet ELM pacing.

Pellet ELM pacing has been proposed some time ago as a method to prevent large magnitude ELM events that can erode the ITER plasma facing components [3]. From these experiments it appears that the technique can be applied at pellet repetition rates approaching what ITER needs without deleterious effects while greatly reducing the spontaneous ELM generated divertor heat flux. ITER will require a reduced peak heat flux of more than a factor of 10 from the anticipated natural ELMs [4]. The technique is anticipated to be applicable in any plasma configuration without regard to edge q95 resonances; however this needs to be demonstrated. Issues that remain to be further investigated are the minimum size pellet perturbation that will reliably trigger ELMs and whether inner wall pellet fueling, as planned for ITER plasma fueling, in concert with pellet ELM pacing can work synergistically to maintain high plasma performance. Modeling of the pellet triggering of ELMs is being undertaken using the JOREK code [5] to compare with these experimental results and extrapolate to ITER. The heat flux in the divertor from pellet triggered ELMs has also been shown to be non-axisymmetric [6] and therefore better diagnostic coverage in the divertor will be needed to further study the impact on the divertor plasma facing components.

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