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ELM pacing by pellet injection on DIII-D and extrapolation to ITER

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1. Introduction

Deuterium pellet injection experiments have been performed on the DIII-D tokamak to investigate triggering of edge localized modes (ELMs) in reactor relevant plasma regimes. Previously, ELMs have been observed to be triggered from fueling pellets injected from all locations and under all H-mode operating scenarios in DIII-D [1]. Experimental details have shown that the ELMs are triggered before the pellets reach the top of the H-mode pedestal, implying that very small shallow penetrating pellets are sufficient to trigger ELMs. Pellet ELM pacing has been proposed as a method to prevent large ELMs that can damage the ITER plasma facing components [2]. As part of the experiment on ELM triggering, a demonstration of pellet ELM pacing has been achieved on DIII-D with a 5x increase in ELM frequency from the natural ELM frequency. Experimental details of the pellet ELM pacing demonstration are reported here.

2. Pellet ELM Triggering

The DIII-D pellet injector [3] was configured to inject deuterium pellets from the vertical low field side (V+3) and outside midplane (LFS) for these experiments as shown in Fig. 1. The low field side injection locations were chosen because of the higher sensitivity of these locations to trigger ELMs with fueling pellets and lower fueling efficiency [1]. The smallest available size

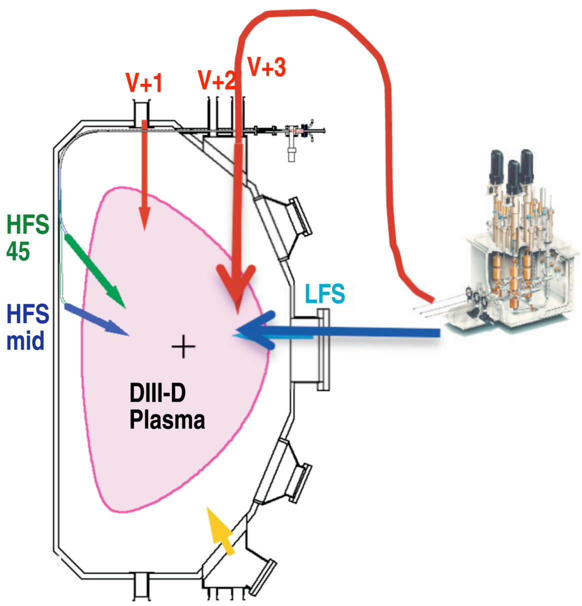

Fig. 1. Cross-section view of DIII-D showing the pellet injection locations.

pellet, 1.8 mm cylinders of equal length and diameter were injected from two barrels of the injector. One barrel was connected to each of the injection ports. The nominal pellet size contains 2x10^{20} atoms (4 mbar-L) of deuterium. All of the pellets injected were observed to trigger ELMs. A tangential viewing fast camera was available to image the vertically injected pellets [4]. Divertor D_α emission, divertor infrared (IR) camera, and fast magnetic probes are all used to diagnose the ELMs in these experiments.

Images from the fast camera of the pellet entering the plasma from the vertical low field side, as shown in Fig. 2, show the pellets becoming visible from ablation that occurs before the pellet reaches the separatrix. This is similar to what was observed from pellets dropped into the plasma in earlier experiments which was attributed to fast ion ablation in the scrape-off-layer. When the fueling pellet just reaches the separatrix (±1 cm), a single plasma filament becomes visible just in front of the pellet cloud. This filament is observed to strike the outer vessel wall within 200 μs of its formation. Additional ejected filaments near the pellet are then observed to subsequently reach the wall.

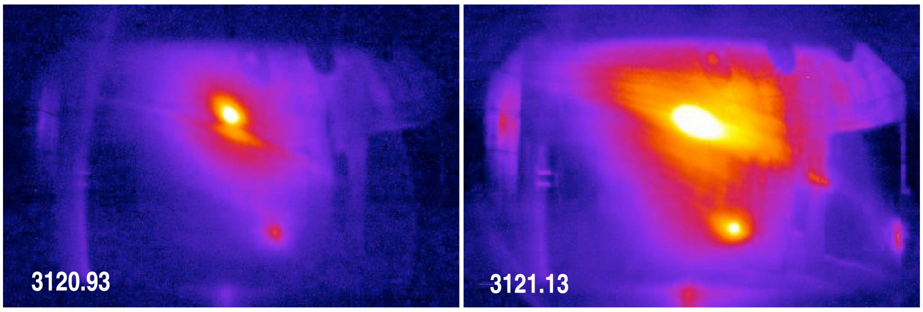

Fig. 2. Images from fast camera in D_α light showing a pellet just reaching the separatrix with a filament becoming visible just in front of the pellet. On the right image, 200 ms later, the filament can be seen to be striking the wall at the edges of the port. The bright spot below the pellet is a reflection from the wall.

3. Pellet ELM Pacing Demonstration

A demonstration of pacing of ELMs on DIII-D was made by injecting slow (100-150 m/s) D_2 pellets on the low field side in an ITER shape plasma with low natural ELM frequency and a normalized β of 1.8 with neutral beam injection heating. Both pellet injector barrels injected pellets at 7 Hz, alternating pellets between barrels, giving a total repetition rate of 14 Hz. A comparison of the density evolution and divertor D_α evolution in two similar discharges from this demonstration is shown in Fig. 3. The density is not observed to be increased by the shallow penetrating pellets compared to the non pellet discharge. The plasma energy loss from each ELM in the two discharges determined from high time resolution equilibrium analysis is shown in Fig. 4. The non-pellet discharge natural

ELM frequency was ~5 Hz with ELM energy losses up to 85 kJ (>10% of total stored energy) while the case with pellets was able to demonstrate ~25 Hz ELMs with an average ELM energy loss less than 22 kJ (<3% of the total). The resulting ELM frequency was larger than the pellet frequency indicating both a direct ELM trigger by each pellet and an indirect effect on the overall pedestal stability to ELMs from the multiple pellets. The energy confinement time as determined by the EFIT equilibrium code shows a modest ~10% lower average confinement time for the pellet paced ELM case compared to the non pellet case. The neutral beams were modulated in these discharges to maintain a constant β, which leads to a large uncertainty in the energy confinement determination.

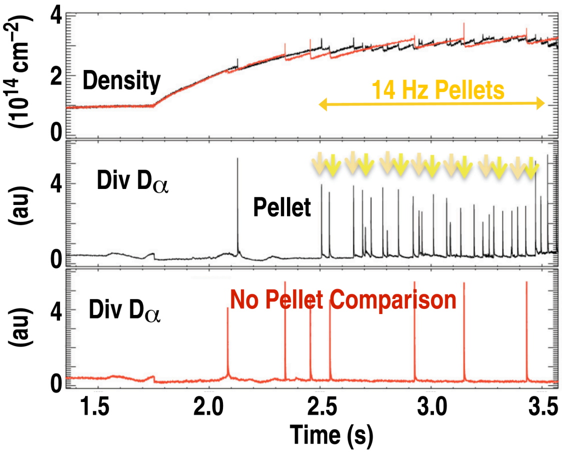

Fig. 3. Temporal evolution of line integral density and divertor D_α emission in two similar discharges, one with 14 Hz pellets and other with no pellets. Pellet injection times are shown with arrows in the divertor D_α plot.

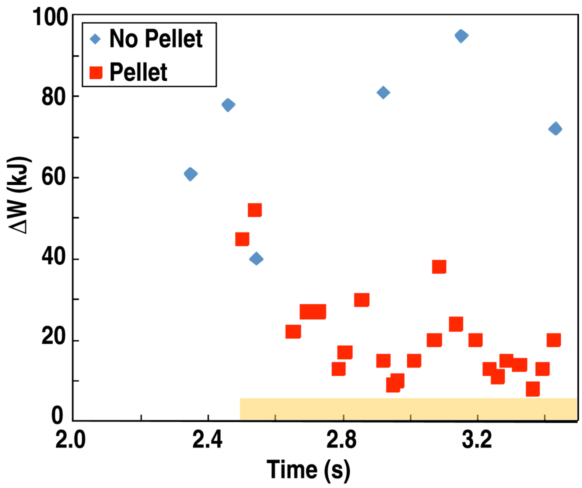

Fig. 4. The decrease in stored energy for each ELM in both the non-pellet natural ELM case (blue circles) and the pellet ELM pacing discharge (red squares). The period of the pellet injection is shown by the yellow bar from 2500-3500 ms.

Determination of the divertor heat flux at one toroidal location from the IR camera data was made during these discharges [5,6]. The inner divertor peak heat flux (at the one toroidal location where it is measured) was reduced by an average of ~50% and the outer divertor by 66% when the pellets were injected as compared to the non-pellet discharge. The average total energy deposited per ELM to the inner divertor was reduced by a factor of 3 and to the outer divertor by a factor of 4. The total energy deposited on the outer divertor is larger than on the inner divertor by a factor of 4. Detailed analysis of how the heat flux footprint in the divertor changes with pellet injection is underway.

The rotation of carbon ions in the plasma was measured by a charge exchange recombination emission diagnostic. The toroidal rotation speed near the top of the pedestal was observed to decrease from 55 km/s in the non-pellet discharge to 35 km/s when the pellets were pacing the ELMs. The role of the rotation change in the resulting ELM frequency is under study.

4. Summary and Discussion

The low field side injected pellets in DIII-D have been found to begin the ELM crash process within ±1 cm of the pellet crossing the separatrix. This is somewhat shallower than was observed on AUG [7] with HFS injection. The top of the pedestal in this vertical injection configuration is >5 cm inside of the separatrix. This implies that the ITER requirement for low field side injected ELM pacing pellets to reach the top of the pedestal may be overly conservative. Pellets may need to penetrate just inside the separatrix in ITER in order to guarantee triggering of an ELM. Future studies with smaller pellets are planned to elucidate just how far inside the separatrix the pellets need to penetrate. The filaments that are released during the ELM crash triggered by the pellet are observed to hit the wall locally near the pellet injection location. While most of the stored energy loss can be accounted for by extrapolating the heat flux measured in the divertor by the IR camera, it is clear that some level of heat flux yet to be quantified will impinge on the outer wall. It may be necessary to provide some high heat flux tolerance capability to the wall surfaces near the pellet ELM pacing injection location. Further optimization and extension to higher frequency pellet ELM pacing technique is needed to be able to fully extrapolate this ELM mitigation technique for application to ITER.

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[1] L.R. Baylor, *et al.,* Nucl. Fusion **47** 1598 (2007).
[2] P.T. Lang, *et al.,* Nucl Fusion **44** 665 (2004).
[3] S.K. Combs, *et al.*, J. Vac. Sci. Tech. **A 6** 1901 (1988).
[4] J. H. Yu, *et al.,* Phys. Plasmas **15** 032504 (2008).
[5] D.N. Hill, *et al*, Rev. Sci. Instrum. **59** 1878 (1988).
[6] A. Hermann, J. Nucl. Mater. **337-339**, 907 (2005).
[7] G. Kocsis, *et al.,* Nucl. Fusion **47** 1166 (2007).