Modeling and Simulation of Pedestal Control Techniques for NSTX-U

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In this paper we present high level simulations and modeling of pedestal control for NSTX-U. Real-time pedestal control is a crucial topic for future fusion reactors and ITER where pedestal has to be kept Edge-Localized-Modes (or ELMs) free for heat flux management purposes as well as stationary against many perturbations while keeping high plasma performance. We developed and tested many different control schemes to adjust and regulate the pedestal at DIII-D and we plan to test them on NSTX-U. But to do this it is important to understand the physics bases for how the control actuators affect the pedestal. It has been observed many times that a control scheme that work for a specific machine or a regime might not be applicable to other machines and regimes. This is especially the case for future reactors such as ITER.

Thus, we do high-level numerical simulations with the M3D-C1 code, which is a state-of-the-art 3D full-MHD code with realistic geometry. M3D-C1 [1] has been developed to study the plasma response when several actuators are triggered (gas puffing, 3D magnetic perturbations and LGI). Gas puffing [2] injects impurities at the plasma edge to control the plasma pedestal density, 3D magnetic perturbations [3] creates an edge stochastic layer increasing the transport (which lowers the pedestal pressure gradient), Lithium Granule Injections (LGI) [4] induce pressure perturbations triggering ELMs and can thus change the ELM frequency and their impact on the Plasma Facing Components (PFCs). The aim is to combine all these methods to get an adaptive and automatic pedestal control in tokamaks. These control capabilities could allow one to explore new innovative scenarios such as the Super H-Mode [5] or Lithium induced ELM-free regimes.

In this paper, we simulate and model the effects of these control ideas and based on this insight we suggest new optimized pedestal control schemes. We particularly focus on the effect of each actuators on the ELM frequency and amplitude. For LGI, experiments have been carried out on DIII-D [6] and are planned on NSTX-U. This method is essential if one want to decouple ELM control and plasma fueling. Experiments have demonstrated a robust ELM-pacing and an efficiency close to 100% for 0.9 mm Lithium granules but some concern exists because of the variability of ELM sizes obtained during these experiments. Moreover, the injection of smaller granules (0.4 mm) has not been able to increase the ELM frequency above 3-5 times the natural one.

First modeling results of ELM-triggering by LGI have been obtained with M3D-C1. Mesh adaptation techniques and high-order 3D finite elements allow simulation of sub-mm granules, without constraints on the granule toroidal width. This unique capability of M3D-C1 allows the simulation of realistic pellet sizes. For this study, two models for LGI are implemented in M3D-C1. The first one [7] [8] is a Neutral Gas Shielding Model (NGS) calibrated on DIII-D experimental measurements of the Lithium granule ablation rates. The second one [9] is valid for small size granules (sub-mm) where the contribution of plasma

ions to the ablation of the granule is not negligible.
In the simulation, it takes about 1 ms for the pellet to totally being ablated, which is comparable to experiments. Density increase is twice higher in simulation than in the experiment. We also found that H-mode high gradient pedestal makes simulation harder and typically requires high resolution meshes around the pedestal region. We thus started by a simulation in NSTX-U L-mode as shown in Figure 1, before moving to H-mode cases. Figure 1 is showing the plasma density at the equilibrium (left) and the increase caused by the Lithium Granule Injection in the simulations (right). Figure 2 shows plasma density profiles at different times after the injection of a small granule on a H-mode plasma. The resulting pressure gradient increase tends to destabilize peeling-ballooning instabilities. Among the parameters of most important are the type of element in the pellet, pellet speed, size angle of attack, and the equilibrium plasma conditions at which the pellet is launched.
M3D-C1 has its own stability calculations. They are in line with the ELITE code. To visualize the effect of the pellet penetration in the plasma the best is to look at the progression of the plasma stability on a stability plot. The stability from ELITE and M3D-C1 during the penetration process will be presented, as well as comparison with the EPED [10] code.
ELM-triggering simulations will finally be compared to NSTX-U experimental data.

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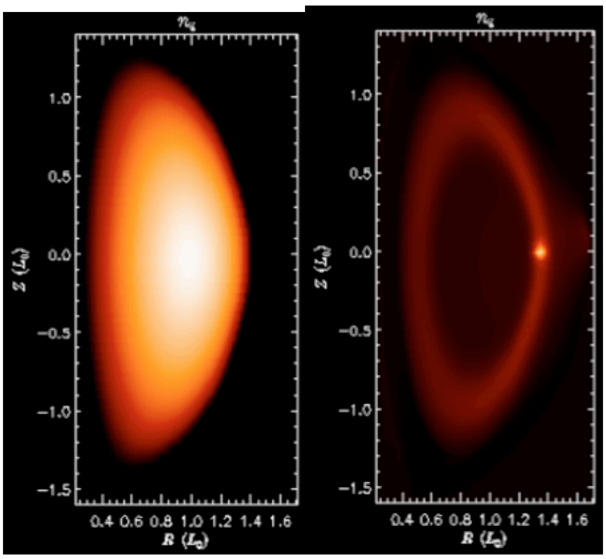

Figure 1: Density increase due to Lithium Granule Injection in NSTX-U

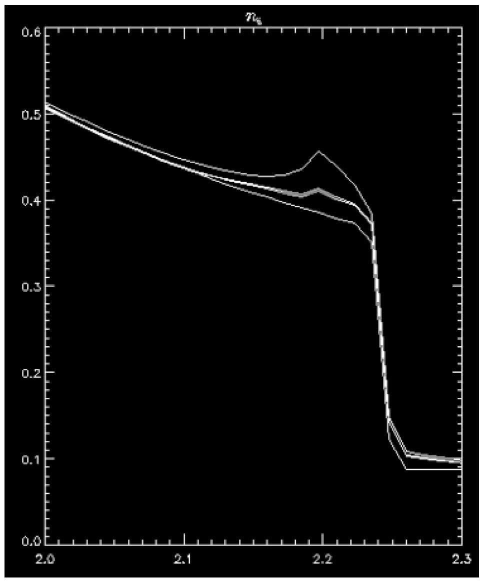

Figure 2: Density profile evolution for small size granules