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Simulations of Disruption Mitigation in ITER with Two-Stage Shattered Pellet Injection

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The currently envisaged method for disruption mitigation in ITER is to use massive material injection. One of the injection schemes considered is a two-stage shattered pellet injection (SPI), with a pre-disruption diluting deuterium injection followed by a neon injection aiming to radiatively dissipate the plasma energy content [1]. It was recently shown [1] that it will likely be possible to increase the plasma density by at least an order of magnitude, thus strongly reducing the plasma temperature, without unacceptably accelerating the onset of the thermal quench. In this work [2], we perform numerical simulations assessing the performance of such a mitigation scheme in an ITER-like setting, with a particular focus on runaway electron generation.

These studies are performed with the integrated tool DREAM [3,4], designed to evolve the 1D configuration space and 2D momentum space dynamics during tokamak disruptions. In this work, DREAM has been extended with the ability to simulate SPI based on a statistical model for the shattering [5], and the neutral gas shielding model for the ablation [6]. The effects of a finite spread and $E\times B$ drift of recently ablated material relative to the shards can also be studied using a depsition kernel with a finite width and shift. We determine, within this model, the degree of pellet shattering resulting in the most efficient use of the injected material for a given pellet size, and study the subsequent thermal quench, current quench and runaway electron dynamics over a wide range of pellet sizes. We also study the influence of impurity transport and drifts on the final density profile, and discuss the consequences for the two-stage SPI scheme.

Our studies indicate that the diluting deuterium injection can efficiently reduce the hot-tail runaway generation, by allowing for a moderate temperature equilibration of the superthermal electron population between the injections. During non-nuclear operation, in the absence of impurity transport, the maximum runaway current is found to be reduced to acceptable levels with realistic two-stage injection parameters. On the other hand, during nuclear operation, the unavoidable runaway seed from tritium decay and Compton scattering was found to be amplified to several mega-amperes by the avalanche mechanism for all investigated injection parameters. The reason is that the intense cooling from the injected material leads to a high induced electric field and a substantial recombination, resulting in an enhanced avalanche multiplication. The success of the two-stage injection scheme requires that the density increase reach the plasma core. Our initial studies suggest that the penetration depth might be significantly altered by impurity transport and drifts, as well as the interaction between the shards via their effect on the background plasma, indicating a need for further studies.

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