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Simulation and analysis of MHD response and radiation asymmetry after Shattered Pellet Injection in ITER plasmas

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Shattered pellet injection (SPI) is the baseline concept for disruption mitigation system (DMS) in ITER [1, 2]. The aim of SPI is to introduce huge amount of hydrogen isotopes or impurities into the plasma by injecting pellet fragments of corresponding species, thus depleting the large thermal and magnetic energy stored within the plasma homogeneously by radiative losses, so as to prevent localized energy deposition on the device which could cause substantial harm to the device [3]. The radiation asymmetry after the injection has a strong impact on the efficiency of thermal quench mitigation, since it determines the local radiative heat flux onto the Plasma Facing Components (PFC). In turn, the radiation cooling asymmetry itself is strongly influenced by the MHD activity after the injection, as the temperature and density profile evolution caused by the latter determine the behavior of the former.

However, the aforementioned MHD modes themselves are also driven by the cooling induced current redistribution [4, 5]. Such complicated nonlinear interaction between the MHD modes and the cooling necessitate numerical investigations in order to acquire a better understanding of the interplay between the former and the latter in ITER, and tokamaks in general.

In this study, we numerically investigate both pure neon and mixed neon/hydrogen SPI into ITER L-mode plasmas by the 3D nonlinear reduced MHD code JOREK, with the Neutral Gas Shielding (NGS) model to describe the ablation of each separate pellet fragments within the plasma [6]. Furthermore, the fragments size distribution is modelled using the Statistical Fragmentation model [7], which agrees well with laboratory observations [8]. We use the Coronal Equilibrium model [9] to estimate the radiative cooling of the impurities, which produces only negligible deviation from more detailed coronal models provided that the plasma is cooled down fast enough. The injection configuration and parameters are all chosen to conform with that of the real ITER system.

We demonstrate the two major MHD destabilization mechanism by injection induced cooling, namely the axis-symmetric current profile contraction and the helical current profile perturbation at rational surfaces, and we will show that the latter always dominate over the former so long as the timescale of resistive current contraction is longer than the fly time of the pellet fragments. Meanwhile, the MHD modes also have strong impact on the density profile evolution of injected materials, as the convective transport caused by the modes, especially that by 1/1 kink mode, contribute greatly to the core penetration of the injection.

On the other hand, the outgoing heat flux caused by the destabilized MHD modes is found to induce strong radiation asymmetry by sustaining an impurity density gradient along the field line as the local density source competes with the parallel convective relaxation of density. This asymmetry is most pronounced at the onset of the Thermal Quench, and gradually relax over its cause. The resultant asymmetry in PFC heat load will also be shown.

Last, we will compare the radiation asymmetry caused by single SPI and multiple simultaneous SPI at different toroidal angles, and show how the latter mitigates the aforementioned localized radiative heat load.

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