Second Technical Meeting on Plasma Disruptions and their Mitigation

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Self-Consistent Kinetic Simulations of Runaway Electron Termination Schemes

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Benign termination of mega-ampere level runaway current has been convincingly demonstrated in JET [1] and DIII-D [2], establishing it as a leading candidate for runaway mitigation on ITER. This comes in the form of a runaway flush by parallel streaming loss along stochastic magnetic field lines formed by global magnetohydrodynamic (MHD) instabilities, which are found to correlate with a low-Z (deuterium) injection that purges the high-Z impurities from a post-thermal-quench plasma. After the runaway flush, there are two scenarios determining whether the runaway current reforms.

The scenario of no-runaway-reconstitution is enabled by (1) high degree of high-Z impurity purge by massive deuterium injection and (2) limited assimilation of deuterium in the post-purge plasma. Both conditions are conducive to reduce radiative losses that would have otherwise prevented electron reheating by Ohmic dissipation of the plasma current, which is critical to establish and sustain a parallel electric field below the runaway avalanche threshold. Although electron reheating is most efficient at vanishing impurity density and low deuterium density, the current ITER target for current quench duration demands effective electron cooling to cap the electron temperature to a few tens of eV. This translates into a limit on how high the deuterium density must be, the exact magnitude of which is controlled by the residue impurity content.

In the likely scenario of insufficient electron reheating, the parallel electric field stays above the runaway avalanche threshold and runaway current can be reconstituted. Here the quantity of interest is the plasma current drop before the Ohmic-to-runaway conversion is completed. This critically depends on runaway seeding, which is dramatically different for a post-flush plasma. Specifically, the trapped “runaways” dominate the seeding for runaway reconstitution, in sharp contrast to that in a post-thermal-quench plasma where much lower energy hot tail, Dreicer mechanism, and tritium decay/Compton scattering are at play. The high-Z impurities previously injected to mitigate the thermal quench can greatly enhance such a trapped “runaway” population, which remains well confined in the presence of stochastic magnetic fields, and thus survives the 3D MHD flush. Furthermore, their relatively high energy, around 1 MeV, ensures a low collisional detrapping rate while the magnetic surfaces reheal at low electron temperature. Most interestingly, the incomplete purge of high-Z impurities helps drain the seed but produces a more efficient avalanche, two of which compete to produce a 2-3˜MA step in current drop before runaway reconstitution of the plasma current.

The different post-flush scenarios and the corresponding plasma parameter regimes demarcated here, help place the existing experiments in perspective in relation to ITER requirements. The present work will also elucidate strategies through which the phase space distribution of runaways during the current plateau can be tailored to minimize this trapped population of electrons, along with determining critical parameters for expediting the decay of the remnant electron population before the magnetic flux surfaces are able to reform. This work was supported by DOE OFES and OASCR.

[1] Reux et al., Phys. Rev. Lett. (2021), [2] Paz-Soldan et al. Nucl. Fusion (2021)

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