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Mitigation of runaway electron heat loads by deuterium SPI injection and kink activity

Runaway electrons (RE) are a major threat for a reliable operation of future tokamaks including ITER. Avoiding or dissipating them is therefore essential. Shattered Pellet Injection (SPI) is the disruption mitigation and RE avoidance method currently planned for ITER [1]. However, if this first line of defence is not efficient enough to prevent the formation of REs, SPI must also be able to dissipate a fully formed RE beam. Recent experiments on JET [2] and DIII-D [3,4] using deuterium SPI showed complete dissipation of RE beams up to 1.2 MA. No measurable localized impact and damage on plasma facing components is observed in the JET cases. The runaway current is converted into ohmic current which then decays as a "standard"plasma current quench. Conversely, past experiments using Massive Gas Injection (MGI) or SPI had shown that beam mitigation using neon, argon or krypton was at best incomplete [5,6]. The RE current could be decreased in selected situations (low density companion plasma) but the final RE impact on the wall could not be avoided, leading to localized melting with currents as low as 200 kA [7].

The mechanisms leading to complete RE loss using deuterium SPI are twofold: a large MHD instability and a low-impurity content companion plasma. The companion plasma following D2 SPI is purged out of its remaining high-Z impurities, with electron temperature less than a few eV and electron density lower than 10^{18} m^{-3}. Current is allowed to grow again due to the voltage from the central solenoid, ultimately leading to a low-q MHD instability, most likely a kink [7]. MHD simulations with MARS-F and JOREK show that such a large amplitude kink leads to enhanced RE losses and increased wetted area. The reason why the instability is stronger with D2 SPI is not yet fully understood, but may be related to a more hollow RE current profile following the deuterium SPI. Such a profile can exhibit current-driven kink instability at any integer qedge. Once the instability has dissipated the RE plateau, no magnetic energy is converted back to RE kinetic energy thanks to the low impurity content: the current quench is slow enough and its bound electron density low enough to prevent re-avalanching of RE. The conversion mechanism is much stronger in high-Z SPI mitigation cases compared to D2 SPI cases, thus explaining why high-Z runaway mitigation is incomplete.

These experiments and simulations show that D2 SPI is a promising RE mitigation mechanism for ITER in case a RE beam appears. Simulations are underway to quantify the degree of high-Z purging which is needed to achieve a sufficiently low conversion rate from magnetic to kinetic energy following the MHD instability.

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