Validation of ITER disruption mitigation physics on JET and ASDEX-Upgrade

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Developing strategies for effective disruption mitigation in ITER has been the focus of the recent campaigns on JET and ASDEX-Upgrade (AUG). The main aim of these experiments was the validation of the physics basis for disruption mitigation using Shattered Pellet Injection (SPI). The experimental setup and plasma discharges were tailored to cover all the various aspects, such as the material assimilation physics and thermal quench (TQ) dynamics, multiple SPI scenarios, the influence of q-profile, intrinsic impurities and plasma instabilities on the mitigation process, the evolution of radiation asymmetries, and the effect of fragment size and velocity distributions. To specifically address these questions, the three-barrel SPI at JET was significantly upgraded before the 2022-23 campaigns to allow injection of two identical size pellets and one smaller size pellet while controlling the velocities in the range of 200-650 m/s. Furthermore, a three-barrel SPI with three different shatter head geometries was installed in AUG to study the effect of different fragment sizes and injection velocities. The fragment penetration and effects on plasma density, temperature and radiation have been tracked by fast cameras at both tokamaks, the upgraded JET High Resolution Thomson Scattering diagnostic measuring down to temperatures in the low eV range, and new additional bolometer diagnostics at AUG.

At JET, injections of large fragments at low velocity appeared to be more effective than smaller fragments at high velocity. The AUG-SPI shatter head geometries were designed to disentangle the fragment size distribution from the injection velocity. The results indicate that there is an additional benefit if large fragments are injected at high velocities and penetrate deeper. These findings from the two devices demonstrate the importance of optimum fragment sizes for mitigation efficiency. It has been observed that the mass assimilation is limited by plasmoid drift, which could be overcome by neon (Ne) doping. The assimilation can be further increased by multiple injections. However, the density rise relative to the original pellet masses does not exceed 50%. Pure deuterium SPI has been explored as it is considered as a good candidate for runaway electron avoidance in ITER. It was seen at JET that timescales of the mitigation process can be significantly shortened when high impurity levels are present in the plasma, either intrinsic or deliberately seeded. Such constraints must be considered when employing advanced mitigation schemes such as staggered injection of H and Ne/H pellets in ITER. This scenario was tested on both devices and shows high mass assimilation, benign thermal quenches and good current quench (CQ) control. The robustness of SPI schemes was also tested on plasmas which were vertically unstable or were near stability limits provoked by density limits or tungsten accumulation. Even in such deteriorated plasmas, the fragments could be effectively assimilated and the CQ rate controlled. Radiation peaking during the TQ has been assessed using externally applied error fields and radiation localisation was found at JET to decrease with increasing thermal plasma energy.

In this talk, our findings from SPI experiments on the all-metal tokamaks, AUG and JET, with a large range of plasma parameters, will be presented. Implications of these results on the viability of disruption mitigation on ITER will be discussed.