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MHD activity during disruptions and disruption mitigation: Recent insights from JOREK

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Mitigation as last line of defense against disruptions needs to simultaneously mitigate electromagnetic forces, heat loads, and runaway electrons (REs) for a safe operation of ITER like tokamaks. Simulations help to prepare robust mitigation scenarios and need to capture various non-linearly interacting physics processes simultaneously in a self-consistent way.

JOREK is an extended non-linear MHD code designed for this purpose in realistic tokamak geometry. It features models for pellet ablation, fluid and kinetic impurities, fluid and kinetic neutrals, fluid and kinetic REs as well as resistive walls and coils. This allows for a comprehensive treatment of disruption physics. A focus lies on validation against experiments; in particular, we aim to quantitatively reproduce bifurcating dynamics, e.g., RE beam formation changing discontinuously as function of plasma parameters. ITER predictions are being continuously refined as more advanced models become available. In this contribution, we review recent developments and results and provide a brief outlook.

Halo currents and wall forces of mitigated and unmitigated disruptions are compared against dedicated experiments; first results show good agreement regarding key parameters. 3D ITER predictions focus on a complete modelling of the current quench including vertical plasma motion, wall forces and the interplay with MHD activity. Direct coupling to the CARIDDI code is progressing for self-consistent modelling of 3D plasma dynamics with accurate 3D conducting structures.

We compare the assimilation of material during deuterium/mixed/impurity shattered pellet injection (SPI) and the resulting radiation patterns to experiments and perform predictions for ITER. For deuterium injection, we introduce an ad-hoc model to capture the drift of small-scale plasmoids that cannot be resolved in simulations otherwise. The effect of pre-existing islands onto the MHD activity triggered by SPI is studied. Radiative collapse and current spike formation during the thermal quench are explored. A fully kinetic impurity model is being established that does not assume a Maxwellian energy distribution.
Using a self-consistently coupled RE fluid model that has been benchmarked against other codes, RE mitigation by multiple material injections is studied predictively for ITER axisymmetrically and the inclusion of 3D MHD activity is progressing. Test particle simulations in stochastic MHD fields provide insights into loss mechanisms for passing and trapped REs. A self-consistent coupling of the kinetic REs to the MHD fluid is planned for the future.

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