What non-linear simulations can teach about ELM physics

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Edge localized modes (ELMs) are repetitive instabilities observed close to the boundary of H-mode plasmas in the region of large pressure gradients and current densities leading to a fast collapse of pedestal density and temperature profiles. During an ELM crash, parallel transport along open magnetic field lines leads to strong localized heat fluxes onto divertor targets expected to be beyond engineering limits for future machines like ITER. In the present contribution we emphasize the role of non-linear simulations for advancing the understanding of ELM physics as well as of methods for ELM mitigation, suppression, or avoidance.

The results are obtained with the fully implicit finite element code JOREK [1] which solves extended magneto-hydrodynamic equations in realistic tokamak X-point geometry including main plasma, scrape off layer, and private flux region. The model includes divertor boundary conditions [2], two-fluid and neoclassical effects [3] and a resistive wall model [4].

Simulations are approaching the stage where good quantitative agreement can be obtained for existing experiments in many respects. It is shown how modeling advances insights into ELM physics in a complementary manner to experiments by allowing to study aspects not accessible otherwise or enabling additional analysis. Reliable predictive simulations become more and more feasible. Nevertheless, remaining limitations are discussed as well – essentially the work plan for further modeling enhancements.

Simulations of ELM crashes are compared to various experimental diagnostics to gain confidence in the modeling and complement experimental approaches. The role of plasma flows and of non-linear coupling of toroidal harmonics for the spatial and temporal structure of ELMs is emphasized in particular. The penetration of error-fields produced by external 3D coils is discussed, and the means by which these perturbation fields can lead to ELM mitigation or suppression. ELM triggering by "vertical magnetic kicks" and pellet injection as well as natural ELM-free states are addressed as well.

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[3] F Orain et al, PoP 20, 102510 (2013)
[4] M Hoelzl et al, JPCS 401, 012010 (2012)