Nonlinear Evolution of the Mode Structure of Edge-Localized Modes in Realistic ASDEX Upgrade Geometry

I. Krebs[1], M. Hölzl[1], K. Lackner[1], S. Günter[1], ASDEX Upgrade Team[1]
[1]Max-Planck-Institut für Plasmaphysik, EURATOM Association, Boltzmannstraße 2, 85748 Garching, Germany

Edge-localized modes (ELMs) are relaxation-oscillation instabilities, which eject particles and energy from the plasma, occurring at the edge of tokamak plasmas in the regime of enhanced confinement (H-mode). The suitability of the H-mode as operational regime for ITER and future fusion reactors depends crucially on the exact dynamics of the occurring ELMs as on the one hand they enable stationary H-mode operation by removing impurities from the plasma and on the other hand they can damage the plasma facing components if they become too large.

We have simulated edge-localized modes in realistic ASDEX Upgrade geometry using the nonlinear reduced MHD code JOREK [1,2]. Emphasis has been put on the analysis of the evolution of the toroidal mode structure in the early phase of an ELM event. The evolution is characterized by the exponential growth of the unstable toroidal Fourier harmonics with different growth rates followed by a phase of saturation of the growth. In the linear phase at the beginning of the phase of exponential growth, the toroidal harmonics grow independently from each other, whereas at larger mode amplitudes, the nonlinear interaction between the different toroidal harmonics influences their growth rates and mode structure. In our simulations the saturation of the mode is determined by two mechanisms: One is the reduction of the drive of the instability due to changes in the equilibrium edge profiles and the other one is related to the stabilizing effect of the ideally conducting wall boundary conditions applied in the simulations becoming stronger at large radial displacement.

In the phase of nonlinear mode interaction, the time evolution of the toroidal mode structure in the simulations can be reproduced to a large extent by a simple model describing the linear growth of the different harmonics and the quadratic mode coupling among them. This model yields a possible explanation for the strong n=1 component of type-I ELMs observed in ASDEX Upgrade [3]. In the linear phase of the simulations, intermediate toroidal mode numbers ($n \sim 6 - 14$) are the most unstable as predicted by the peeling-ballooning model, but in the course of the phase of nonlinear interaction, the n=1 component becomes important [4]. In the framework of quadratic mode coupling, this can be explained by an energy transfer from pairs of linearly dominant toroidal harmonics with neighboring mode numbers to the n=1 toroidal harmonic. It is analyzed, how the radial structure and phase of the n=1 are changed by this coupling in the simulations.

References:

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