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JOREK simulations of multiple type-I ELMs and small ELMs in ASDEX Upgrade

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Scalings of type-I ELM crash peak divertor energy fluency show a direct proportionality to pedestal top pressure. Extrapolating to the ITER H-mode baseline suggests an unacceptably short divertor lifetime [1]. Simulations of single ELM crashes have progressed significantly and are now actively validated against experimental data [2-5]. Said simulations have been initialised from unstable pedestal profiles (therefore are unable to answer how the pedestal reached the unstable state), and consider random seed perturbations out of which the ELM crash would evolve [6]. In experiments, however, the seed perturbations are set by the previous ELM. Therefore, in order to become self-consistent, ELM modelling requires the simulation of full ELM cycles. Promising first steps were shown in [7, 2], but full type-I ELM cycles had not been simulated so far.

Here, we show the first simulations of realistic type-I ELM cycles [8]. The simulations are performed with the JOREK code [9]. With an initially stable ASDEX Upgrade (AUG) plasma at low triangularity, the pedestal grows with *ad-hoc* diffusion profiles describing a stationary edge transport barrier. The pedestal height increases until peeling-ballooning (PB) precursor modes are excited (the magnetic energies of the precursors for the first ELM crash are present in fig.1(a) from 14 - 15 ms). Thereafter, a type-I ELM crash releases ~10% of the plasma stored energy. We observe a slight imbalance between stabilising and destabilising terms, caused by the precursors, to be directly responsible for the explosive growth (faster-than-exponential) of the ELM crash. This suggests that the violent nature of ELMs does not arise from linear MHD. The stabilisation from E×B and diamagnetic flows, which (together with the relaxed pedestal) causes the end of the type-I ELM is instrumental for the pedestal recovery and, therefore, for modelling realistic type-I ELM cycles. The different seed perturbations between the first and the second ELM crash is found to significantly affect ELM crash duration and size. The self-consistent seed perturbations lead to faster and more violent ELMs. We observe the ELM repetition frequency (f_{ELM}) to increase/decrease when the heating power is increased/reduced, as expected for type-I ELMs. An example of decreasing f_{ELM} as heating power is reduced is shown in fig. 1.

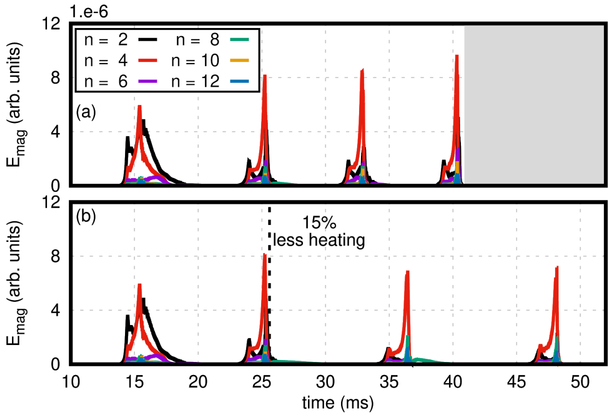

Figure 1: Magnetic energies of the non-axisymmetric perturbations of the simulated type-I ELMs. Reducing the heating power [after ~26 ms in panel (b)] shows a decrease in f_{ELM}, as expected for type-I ELMs.

Furthermore, using the same initial stable profiles with even lower heating power, type-I ELMs do not appear. Instead, PB modes similar to edge instabilities observed in small ELMs and density-limited discharges in AUG [10,11]. The simulated instabilities have a predominantly ballooning nature and keep the pressure gradient rapidly fluctuating around a mean value. These small ELMs become stabilised if the heating power is increased, thus giving rise to the type-I ELM regime. Finally, we recover the strong relationship between small ELMs and separatrix density [10]. Namely, reducing n_{sep} from $0.4n_{GW}$ to $0.3n_{GW}$ stabilises the small ELMs and gives way to type-I ELMs. The larger diamagnetic flow (~1/n) is found to be responsible for stabilising the small ELMs.

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