Non-linear MHD modeling of multi-ELM cycles and mitigation by RMPs

F.Orain,[1] M.Bécoulet,[1] G.T.A.Huijsmans,[2] M.Hoelzl,[3] G.Dif-Pradalier,[1] J.Morales,[1] E.Nardon,[1] S.Pamela,[4] I.Chapman,[4] P.Cahyna,[5] A.Fil,[1] V.Grandgirard,[1] G.Latu,[1] C.Passeron,[1] and A.Ratnani[1]

[1]CEA, IRFM, Centre de Cadarache, 13108 Saint-Paul-Lez-Durance, France

[2]ITER Organization, route de Vinon, 13115 St-Paul-Lez-Durance, France

[3]EURATOM/Max-Planck-Institut für Plasmaphysik, Garching, Germany

[4]EURATOM/CCFE Association, Culham Science Centre, OX14 3DB, UK

[5]EURATOM/IPP.CR Association, Prague, Czech Republic

The study of the Edge Localized Modes (ELMs) and their possible control methods is a subject of great focus for current and future tokamaks. One of the promising control methods planned in ITER and tested in current tokamaks is the application of external resonant magnetic perturbations (RMPs). However a significant progress in understanding ELM dynamics and ELM interaction with RMPs is needed to explain the experimental results and make reliable predictions for ITER.

In this perspective, non-linear MHD simulations of the full ELM cycle dynamics, including linear and non-linear stages, and simulations of the ELM mitigation by RMPs, are presented. Both are done using the non-linear resistive MHD code JOREK in realistic tokamak geometries including the X-point and the Scrape-Off-Layer. Since the plasma flows are expected to affect the ELM dynamics as well as the penetration of RMPs, the code was recently extended to include the poloidal neoclassical friction, a source of toroidal rotation and the bi-fluid diamagnetic rotation.

So far, only a single ELM crash was simulated by MHD codes in full toroidal X-point geometry, which made it possibly quite dependent on the choice of the initialized state. The novelty of the present work consists in obtaining a multi-ELM multi-harmonic cycle in simulation. The diamagnetic rotation is found to be instrumental in accessing this cycle. After a few transient ELMs, a quasiperiodic ELMy state is obtained, each ELM occurring when a fixed threshold in pressure gradient is reached; the non-linear generation of a poloidal flow has the effect of shearing ELM filaments, expelling them out of the pedestal. The power deposition of the filaments on the divertor is near symmetric, which is closer to the experimental observations, compared to the previous modeling without diamagnetic drift where the outer divertor almost received the whole ELM power.

The new modeling results of the interaction between ELMs and RMPs are also presented. For the first time ELM mitigation by RMPs was demonstrated in multi-harmonic modeling for realistic JET parameters. The peak power reaching the divertor is found to be reduced by a factor of 10 in presence of RMPs with main toroidal number $n = 2$, generated by EFCC coils ($I_{coil} = 40kAt$). Externally imposed low-n RMPs (here $n = 2$) provide strong non-linear drive for lower-n numbers compared to "natural" ELMs usually triggered by high-n unstable modes. The redistribution of the energy of the most unstable high-n ELMs towards low-n modes – coupled with $n = 2$ RMPs – results in a more continuous MHD activity replacing large ELM crashes.