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Non-linear MHD modelling of Edge Localized Modes and their interaction with Resonant Magnetic Perturbations in rotating plasmas.

M.Bécoulet[1], F.Orain[1], J. Morales[1], X. Garbet[1], G. Dif-Pradalier[1], C.Passeron[1], G. Latu[1], E. Nardon[1], A. Fil[1], V. Grandgirard[1],

[1]*CEA, IRFM, 13108 Saint-Paul-Lez-Durance, France*

G.T.A.Huijsmans[2],

[2]*ITER Organization, Route de Vinon, 13067 Saint-Paul-Lez-Durance, France*

S. Pamela[3], A. Kirk[3],

[3]*CCFE, Culham Science Centre, Abingdon, UK*

P. Cahyna[4],

[4]*IPP.CR, Prague, Czech Republic*

M.Hoelzl[5], E. Franck[5], E. Sonnendrücker[5],

[5]*Max-Planck-Institute, Garching, Germany*

B. Nkonga[6]

[6] *Nice University, INRIA, Sophia Antipolis, Equipe CASTOR, France*

marina.becoulet@cea.fr

The intensive experimental and theoretical study of Edge Localized Modes (ELMs) and methods for their control has a great importance for ITER [1]. The application of small external Resonant Magnetic Perturbations (RMPs) has been demonstrated to be efficient in ELM suppression/mitigation in present day tokamaks [2]. RMPs are foreseen as one of the promising methods of ELM control in ITER [3]. However in order to make reliable predictions for ITER significant progress is still required in order to understand ELM dynamics and the interaction of ELMs with RMPs. In the present work the dynamics of the full ELM cycle including both the linear and non-linear stages of the crash and the possible explanation of the mechanism of ELM mitigation by RMPs are presented based on the results of the multi-harmonics non-linear resistive MHD modeling using the JOREK code [4]. These simulations are performed in the realistic tokamak geometry with the X-point and the Scrape-Off-Layer (SOL) with relevant plasma flows: toroidal rotation, the bi-fluid diamagnetic effects, and neoclassical poloidal friction, which have recently been included in the model [5]. The introduction of flows in the modelling demonstrated a large number of new features in the physics of ELMs and their interaction with RMPs compared to previous results.

The novelty of the present work consists firstly in the demonstration of non-linear MHD simulations of multi-cycle ELMy regimes. The role of the diamagnetic two fluid effects is found to be the most important factor in accessing multi-cycle regimes in modelling, since the MHD turbulence triggered during the non-linear stage of ELM crash is rapidly stabilized by the diamagnetic flows allowing pressure gradient to recover after an ELM crash, leading to the destabilization of the following ELM. Secondly, the ELM precursor's rotation on the linear stage and the rotation of the ELM filaments and "blobs" on the non-linear stage of an ELM were modeled. The third new result obtained in modelling is that the ELM powers deposited on the inner and outer divertors are almost symmetric with diamagnetic drifts, which is closer to the experimental observations [6], compared to the previous modelling of ELMs without flows [4], where contrary to the experimental observations, the outer divertor received almost all ELM power. Finally, the new modeling results of the interaction between ELMs and RMPs are presented. For the first time ELMs mitigation by RMPs was demonstrated in multi-harmonics modeling for realistic JET-like parameters and realistic RMP spectrum generated by EFCC coils with a dominant toroidal number n=2. The peak power reaching the divertor is found to be mitigated by almost a factor of ten by RMPs (Fig.1a-b). Mitigated ELMs represent small relaxations mainly due to the non-linearly driven modes coupled to the imposed n=2 RMPs. These modes have tearing-like structure and produce additional islands, (Fig.1c-d). The divertor footprints of the mitigated ELMs exhibit structures created by n=2 RMPs, however, slightly modulating them due to the presence of other harmonics, feature also observed in RMP experiments [7]. The proposed mitigation mechanism could be valid for the high collisionality ELM mitigation scheme where ELM crashes were replaced by magnetic turbulence sometimes called Type II-like ELMs [8].

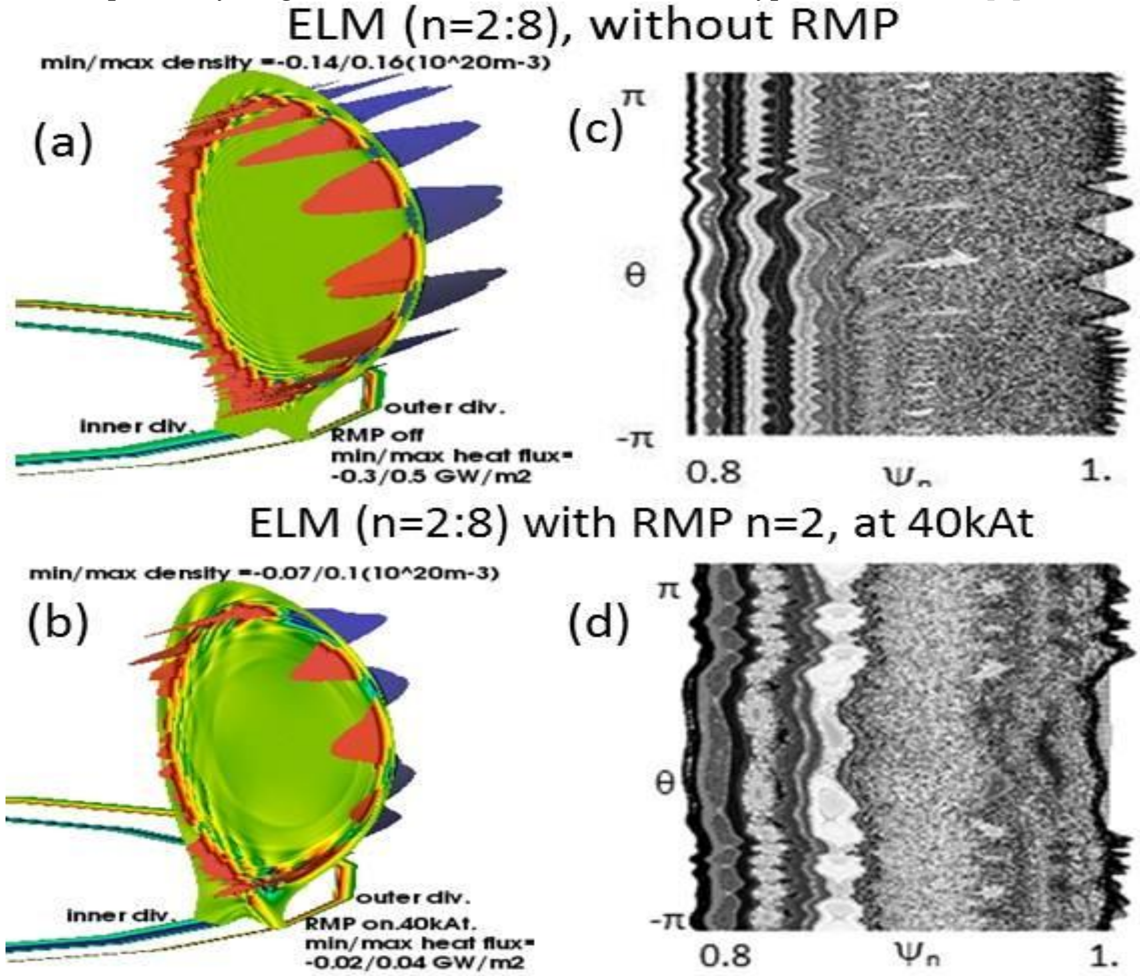

Fig.1. *Density perturbation and maximum divertor heat flux in unmitigated ELM (a) and in ELMs mitigated by application of EFCC n=2; 40kAt (b); edge magnetic topology (Poincare plot) at the time of maximum magnetic perturbation in unmitigated ELM (c) and with RMPs n=2, 40kAt EFCC current (d)*

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