Pedestal destabilization by magnetic perturbation fields in tokamak plasmas

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The achievable pressure-gradient in H-mode tokamak plasmas is typically limited by type-I edge localized modes (ELMs). ELMs are projected to cause severe damage to the wall components of future fusion devices. For this reason, it is important to study methods to mitigate or suppress them, such as the application of magnetic perturbation (MP) fields. In this work, we use the CASTOR3D code [1], which is the only linear extended MHD stability code that includes full 3D equilibrium geometry, for the numerical stability analysis of magnetically perturbed, i.e. non-axisymmetric (3D), tokamak plasmas corresponding to realistic MP field strengths. Recent numerical and computational improvements allow MHD instabilities with both low and high toroidal mode number n to be studied, enabling the first investigations of linear pedestal stability in full 3D geometry.

We show that the application of MP fields results in a significant reduction of the critical pedestal top pressure, above which ELMs are predicted to occur. The MHD stability analysis of a range of equilibria, covering the edge pressure-density space, reveals the destabilizing effects of MPs for low-n as well as high-n instabilities, resulting in a decrease of the critical pressure top pressure by up to 30% in agreement with experimental observations [2]. Furthermore, the stability of two ASDEX Upgrade (AUG) discharges, featuring ELM mitigation and ELM suppression, as well as a range of equilibria between these discharges was studied. In order to accurately predict the experimentally observed MHD stability threshold, ion diamagnetic drift effects, which have been recently implemented in the CASTOR3D code [3], must be taken into account. Including ion diamagnetic drift effects in realistic 3D tokamak geometry, we show that the ELM mitigated discharge is destabilized by the externally applied MP field and the empirical stability limit from Ref. [2] is well reproduced.

[1] E. Strumberger & S. Günter 2019 NF **59** 106008
[2] W. Suttrop et al 2018 NF **58** 096031
[3] E. Strumberger et al 2023 JPP **89** 905890309