Pedestal MHD stability of 3D tokamak configurations

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In H-mode tokamak plasmas, the achievable edge pressure-gradient is limited by edge localized modes (ELMs). Since ELMs can cause significant damage to future fusion devices, it is crucial to explore methods to mitigate or suppress them, such as the application of magnetic perturbation (MP) fields. The ELM onset in axisymmetric plasmas is well-described by linear magnetohydrodynamic (MHD) stability. However, until now, there was no analysis of the impact of MPs on the achievable pressure-gradient, making linear MHD stability analysis of 3D tokamak plasmas an essential ingredient for extrapolating such scenarios to future devices.

We use the CASTOR3D code [1], which is the only linear non-ideal MHD stability code including full 3D equilibrium geometry, for the numerical stability analysis of non-axisymmetric (3D) tokamak plasmas corresponding to realistic MP field strengths. The code has been extended by an energy functional, unveiling the energetic decomposition of ideal and resistive instabilities, which provides valuable insight on the driving and stabilizing mechanisms for these instabilities [2]. Recent numerical and computational improvements allow instabilities with both low and high toroidal mode number n to be studied, enabling the first investigations of ELM stability in full 3D geometry.

We demonstrate that the instabilities are helically localized such that they mainly occupy energetically favourable regions of the 3D equilibrium [3]. The localization predicted by linear MHD matches the experimental ECE measurements.

We show for the first time that linear MHD predicts a significant reduction of the stability boundary by MP fields. A full scan of the edge pressure-density space reveals the destabilizing effects of MPs for low-n and high-n instabilities, resulting in a decrease of the critical pressure gradient by up to 30% in agreement with experimental observations [4]. The stability analysis is extended to two AUG discharges, featuring ELM mitigation and ELM suppression, as well as a range of equilibria between these discharges. Including ion diamagnetic drift effects in realistic 3D tokamak geometry for the first time, we show that the ELM mitigated discharge is destabilized by the externally applied MP field and the empirical stability limit from Ref. [4] is well reproduced.

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