Temperature Pedestal Limits and ELMs: A Model Based on Full Spectrum Stability Analysis and Nonlinear Simulation

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Maximizing the pedestal temperature ($T_{\rm ped}$) while maintaining acceptable ELMs is a key issue for optimizing tokamak performance. Theoretical analysis of edge instabilities which may limit the pedestal height and drive ELMs is complex, in part because the sharp pressure gradients, and consequent large bootstrap currents, near the H–mode edge can destabilize kink, peeling, and ballooning modes over a wide range of toroidal mode numbers (n). The dominant modes are often coupled "peeling-ballooning" modes, driven by both parallel current and the pressure gradient. An important modification of classical ballooning theory [1] allows treatment of the coupled system of edge ballooning and peeling modes at higher $n \gtrsim 10$. A new 2-D edge MHD stability code, `ELITE`, has been developed to solve Connor *et al.*'s edge ballooning equations through $\mathcal{O}(1/n)$, in order to study these intermediate to high-n coupled peeling-ballooning modes. The `ELITE` code, together with an enhanced version of the low-n MHD stability code `GATO`, allows the study of the ideal MHD edge stability of real tokamak equilibria over essentially the full spectrum of toroidal modes, leading to insights on ELMs and the importance of parallel current and second stability access. Using model equilibria, we investigate the variation of the maximum temperature pedestal with shape and collisionality, and analyze the type and structure of instability limiting $T_{\rm ped}$ in various regimes. These results are used to further elaborate and quantify the working model of ELMs presented in Ferron *et al.* [2], making predictions about the relationships between ELM size and frequency, and geometrical and bootstrap current effects. We also present edge stability analyses of reconstructed experimental equilibria from multiple tokamaks, to test the validity of our model.

Ultimately, nonlinear simulation is needed to study the coupled interaction of p', $J_{\rm boot}$, $v_{E\times B}$, and fluxes in ELMy H–mode edge plasmas. To gauge the impact of X-point geometry, non-ideal effects, and nonlinear dynamics, simulations are carried out with the electromagnetic Braginskii code `BOUT`, enhanced to include parallel current terms. The dynamics of coupled peeling-ballooning modes are studied, and compared to linear codes and ELM formation in experiments.

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References

[1] Conner *et al.*, Phys. Plasmas **5**, 2687 (1998).
[2] Ferron *et al.*, Phys. Plasmas **7**, 1976 (2000).