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THE EPED PEDESTAL MODEL: EXTENSIONS, APPLICATION TO ELM-SUPPRESSED REGIMES, AND ITER PREDICTIONS

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The EPED Pedestal Model: Extensions, Application to ELM-Suppressed Regimes, and ITER Predictions

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The EPED model predicts the H-mode pedestal height and width based upon two fundamental and calculable constraints: 1) onset of non-local peeling-ballooning modes at low to intermediate mode number, 2) onset of nearly local kinetic ballooning modes at high mode number. Calculation of these two constraints allows a unique, predictive determination of both pedestal height and width. The model [1] calculates both constraints directly, has no fit parameters, and includes important kinetic effects. The model has been successfully compared to numerous experiments on several devices. Here we apply the EPED model to edge localized mode (ELM) suppressed regimes, and to ITER prediction and optimization. A major result is the development of a new working model to understand ELM suppression by resonant magnetic perturbations (RMPs).

The pressure at the top of the edge transport barrier (or "pedestal height") strongly impacts global confinement and fusion performance. In addition, large ELMs can significantly limit component lifetimes. Hence, accurately predicting the pedestal height in ITER, as well as developing a predictive understanding of ELM suppression, are essential elements of prediction and optimization of fusion performance. Investigation of intermediate wavelength MHD modes (or "peeling-ballooning" modes) has led to improved understanding of important constraints on the pedestal height and the mechanism for ELMs. Calculation of the peeling-ballooning (P-B) stability constraint over a broad range of toroidal mode numbers (typically *n*~3-30), with an efficient MHD code, such as ELITE [2], provides a "global" constraint on the pedestal height, as a function of the edge barrier width (or "pedestal width"), as shown by the solid line in Fig 1(a). The EPED model employs local onset of the kinetic ballooning mode (KBM), as a second constraint. The local KBM constraint can be

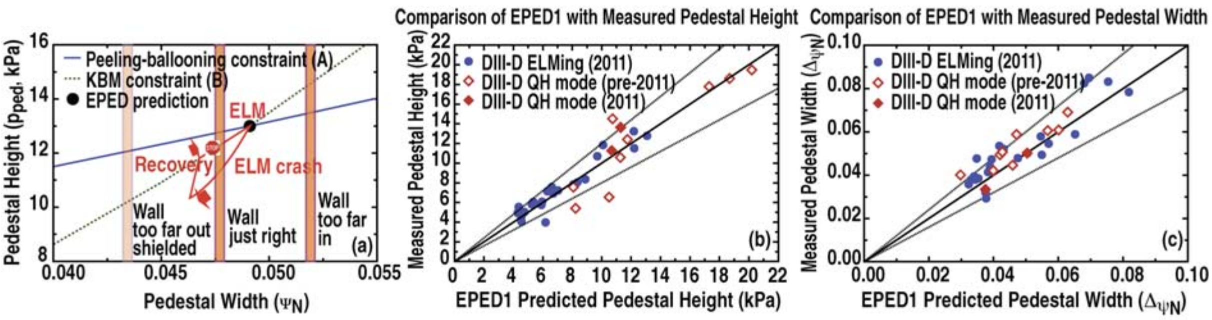

Fig. 1. (a) The EPED model predicts the pedestal height and width (solid circle) from the intersection of P-B (solid blue line) and KBM (dotted green line) constraints. A typical dynamic ELM cycle in this parameter space is illustrated in red. Placing a "wall" in the proper location (center) can interrupt the recovery part of the cycle and suppress the ELM. (b,c) The EPED predicted pedestal height (b) and width (c) is compared to a set of DIII-D QH-mode (diamond) discharges, finding good agreement.

integrated across the pedestal using the "ballooning critical pedestal" (BCP) technique [1]. Here we test and supplement the BCP technique with gyrokinetic calculations of KBM onset using GYRO. The integrated KBM constraint is then combined with the calculated P-B constraint to yield a unique prediction of the pedestal height and width, as shown by the filled circle in Fig. 1(a), which can then be compared to a past or future experiment.

The EPED model has been extensively tested across a wide range of experiments. Combining new and published studies, the model has been compared to 259 cases on 5 tokamaks, covering a range of more than a factor of 20 in pedestal height [1,3-6]. The ratio of predicted to observed pedestal height in these 259 cases is 0.98±0.20, with a correlation coefficient of 0.92, consistent with ~10%-15% measurement uncertainty and 15%-20% model accuracy. A recent major upgrade to the Thomson scattering system on DIII-D allows very high-resolution measurement of the pedestal structure. A set of dedicated experiments to test the model across a wide range of plasma current and magnetic field has been undertaken, finding good agreement in both pedestal height and width, as shown in Fig. 1(b,c).

In addition to extensive tests on ELMing discharges, the model has recently been tested on a set of Quiescent H-mode (QH) discharges, in which there are no ELMs, and steady edge conditions are maintained with an Edge Harmonic Oscillation. The EPED model is able to predict the pedestal height and width in QH mode with ~20% accuracy [red diamonds in Fig. 1(b,c)], giving confidence to its ability to accurately predict the density limit for QH mode operation. ITER's operating density is expected to be well within the predicted range for QH operation, and rotation requirements for QH operation are under investigation.

While EPED is a static model, it can be used to interpret dynamics. Dynamically, the ELM crash is typically followed by a recovery, in which the pressure gradient encounters the KBM limit, but the pedestal can continue to broaden until the P-B boundary is reached, an ELM is triggered, and the cycle repeats [red cycle in Fig. 1(a)]. The ELM can be suppressed if this recovery phase is interrupted such that the width of the edge barrier is prevented from continuing to broaden. In Fig. 1(a), we illustrate this concept with a conceptual "wall" that blocks the inward expansion of the edge barrier.

We propose an EPED-based working model for suppression of ELMs by RMPs in which the conceptual "wall" is provided by a resonant island or stochastic region that drives strong transport and prevents inward pedestal propagation. To suppress the ELM, the location of this "wall" must be precise. If it is too far out, the RMP will be strongly shielded due to the very large electron perpendicular velocity ($v_{e,perp}$). If it is too far in it will not prevent the triggering of the ELM [Fig. 1(a)]. However, near the top of the pedestal $v_{e,perp}$ is generally small, and if the resonant surfaces are in the proper location, the ELM can be suppressed. This leads to a prediction of specific ranges of q in which ELM suppression is possible, along with a prediction that the pedestal will narrow, but the pressure gradient will change little, when ELMs are suppressed. In initial tests on DIII-D, these predictions are in agreement with observations, and further tests are planned.

EPED predictions for ITER have been made for more than 100 baseline and hybrid cases, finding a high pedestal that is further optimized at high density. Detailed predictions, including expected requirements for QH-mode and RMP ELM suppression, as well as coupling to core transport predictions, will be discussed.

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[1] P.B. Snyder, *et al.*, Nucl. Fusion **51**, 103016 (2011).
[2] H.R. Wilson *et al.*, Phys. Plasmas **9**, 1277 (2002); P.B. Snyder, *et al.*, Nucl. Fusion **47**, 961 (2007).
[3] P.B. Snyder, *et al.*, Nucl. Fusion **49**, 085035 (2009); P.B. Snyder, *et al.*, Phys. Plasmas **16** 056118 (2009).
[4] M. Beurskens, *et al.*, Phys. Plasmas **18** 056120 (2011); M. Beurskens *et al.,* H-mode workshop (2011).
[5] J.R. Walk *et al.*, PSFC/JA-11-32 submitted to Nucl. Fusion (2011).
[6] R.J. Groebner *et al.,* Nucl. Fusion **50** 064002 (2010); R.J. Groebner *et al.*, Nucl Fusion **49** 085037 (2009).