# Progress in the modelling of 3-D effects on MHD stability with the PB3D numerical code and implications for ITER

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The magnetohydrodynamic (MHD) stability of tokamaks is often investigated with the assumption of axisymmetric equilibria, which is in many cases justifiable. There are important cases, however, when 3-D aspects of the equilibria have significant consequences for the stability of these configurations. Examples thereof include the noticeable lowering of attainable pedestal heights in H-mode plasmas, as seen for example in the JET TF ripple experiments [Saibene 2007] and in the mitigation of ELMs due to the 3-D effects on the plasma configuration by ELM control coils [Evans 2008].

The PB3D (Peeling Ballooning in 3-D) code has been developed to allow the study of such 3-D ideal MH stability effects for peeling ballooning modes [Weyens 2017] and is under constant improvement. In this paper we present recent advances in its simulation capabilities, such as the development of a new interface with general 3-D VMEC equilibria that do not need to have any kind of symmetry, both from free and fixed-boundary simulations, and the implementations for the calculation of vacuum potential energy due to plasma boundary perturbations which are essential to model peeling mode stability.

The paper will also describe simulations performed to assess the 3-D edge MHD stability of H-mode plasmas in the reference ITER scenarios from pre-fusion plasma operation to high Q DT operation. These simulations focus foremost on the ballooning stability of these configurations taking into account the effects of toroidal field (TF) ripple as well as the influence of other types of 3-D effects such as those applied for ELM control. Both effects can be rather complex in ITER because, for instance, the ripple map varies in both magnitude and shape when the toroidal field is varied, as the ferromagnetic inserts are optimized for 5.3T operation and over-compensate the TF ripple corrections for lower TF values. In these ballooning stability studies, MHD equilibria are created with VMEC starting from ITER reference 2-D plasma equilibria by varying pedestal pressure magnitude and considering various TF ripple levels and maps (e.g. with/without ferromagnetic inserts) and with a range of toroidal current waveforms (current magnitudes, toroidal harmonic and phases) in the ELM control coils. The ballooning stability of these 3-D equilibria is being assessed with PB3D and the results will be presented in this paper.

[Saibene 2017] Saibene, G., et al., EFDA-JET CP(07)03/62 report (2007).

[Weyens 2017] Weyens, T., et al., In: J. Comput. Phys. **330** (2017) 997.

[Evans 2008] Evans, T., et al., Nuclear Fusion **48** (2008) 024002.