UNDERSTANDING REACTOR RELEVANT TOKAMAK PEDESTALS

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Abstract
It is important to understand reactor relevant pedestals so that we can design tokamak fusion power plants and confidently predict their performance. This collaboration investigated the following areas:

- Pedestal prediction
- Poloidal density variation
- Small ELM regimes – type II/Grassy ELMs and type III ELMs
- QH mode (Quiescent H-mode)

Improved Pedestal Prediction
Seek to test ideas for improving the Europed model [Saarelma]. JET pedestals can have different density and temperature widths so Europed has now been upgraded to allow different density and temperature widths. We test an idea to remove the pedestal density as a model input by using a gyrokinetic calculation. We assume the heat source at the top of the pedestal is equal to the heat crossing the separatrix.

The work flow is as follows:
1) Use Europed to calculate a set of pairs of density and temperature profiles around the predicted pressure profile (Figure 1).
2) Use a gyrokinetics based calculation to calculate the heat flux associated with each pair of profiles.
3) The pedestal prediction is then the density and temperature pair that reproduce the experimental heat flux.

Unfortunately, when we tested this method the gyrokinetic runs did not significantly differ from each other. Indeed, \( n_p \) is similar for the three sets of profiles.

We need to re-examine how we could use physics-based calculations to reduce the inputs to Europed.

Figure 1: Density (left) and electron temperature (right) as a function of normalised flux in the pedestal region for JET-ILW pulse \#84793. An nth fit to raw HRTS data is shown in black. Blue, orange, and green traces show Europed pedestal predictions using 3.0x10^19 m^-3, 3.5x10^19 m^-3, and 4.0x10^19 m^-3 respectively. Vertical black line denotes the location of the temperature pedestal top for the widest pedestal prediction.

Poloidal Density Variation
We have calculated the effect on the bootstrap current of a poloidal variation in the density using both analytical and numerical (using the code ELMFIRE [Heikkinen]) approaches.

It was found that the bootstrap could be altered by poloidal density variation. Figure 2 shows results from ELMFIRE with a particle source at four different locations

Figure 2: Scan of a) banana current and b) total bootstrap current as a function of radius for thermal particle source located at four different poloidal angles.

Type III ELMs
Extended the theory of resistive ballooning modes, by including plasma shaping effects and equilibrium poloidal ExB flows within the drift-MHD model. Simple dispersion relation derived by employing the ballooning framework. Elongation alters the magnetic well and both layer resistivity and plasma inertia contributions.

Additional branches of the dispersion relation appear due to the ExB frequency shift, acting similarly to the ion FLR corrections.

QH-mode
Nonlinear equilibrium modelling has produced saturated MHD states that may explain the QH-mode. There are two different mechanisms that produce these states: a current driven mode and a pressure driven mode [Kleiner].

We compare the linear ballooning stability of these two states. The current driven mode in its saturated state changes the 2D Grad-Shafranov equilibrium to a 3D equilibrium that is more unstable to ballooning modes than the original equilibrium. This may indicate that KMBs are more unstable in this 3D equilibrium. These KMBs may produce the density transport required to avoid ELMs. The pressure driven mode doesn't change the ballooning stability significantly. This analysis would suggest the QH-mode is related to the current driven mode but there is more to this picture than this one element.

Neural Networks for Pedestals
Empirical pedestal model based on neural networks trained on H-mode (Type-I ELM) plasmas from JET predicts both temperature and density (electrons) from global parameters:

- Global \( \beta_p \), \( I_p \), \( B_p \), Minor radius, \( \chi \), NBI power, Total power, \( \delta_{2D} \), \( \delta_{3D} \), plasma volume, \( \nu_0 \), \( Z_{eff} \)

Integrated in the European Transport Solver (ETS)

Figure 3: Contours of the ideal ballooning mode growth rate for (left) the current drive mode and (right) the ‘external’ or pressure driven mode.

Summary
There is still much to understand before we can predict the height and width of suitable reactor relevant pedestals i.e., which have no/small ELMs. We have taken first steps towards understanding some of the key issues i.e., improved physics understanding of the pedestal structure, the effect of poloidal variation, and improving physics understanding of small/no ELM regimes.

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References