Effect of resistivity on pedestal predictions from Europed

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*See the author list of CF. Maggi et al., Nucl. Fusion 2024, https://doi.org/10.1088/1741-4326/ad3e16

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Pedestals in type I ELMy H-modes are typically well-described by the ideal peeling-ballooning (PB) stability. MHD stability, combined with a criterion for the pedestal width, allows to predict height, width and gradient of type I ELMy H-modes pedestals. The most common predictive model (EPED [1]) employes the so called KBM constraint which assumes $w = k\sqrt{\beta_p^{\text{ped}}}$, where w is the pedestal width, β_p^{ped} is the poloidal normalized pressure at the pedestal top and k is a constant that is typically set to 0.076 based on DIII-D experimental data. This work uses the predictive code Europed [2] which is an implementation of the EPED model. Europed until now used ideal stability analysis tools. However, in JET-ILW, discrepancies were seen between the ideal PB model and the experiments [3, 4, 5]. Instabilities are triggered in some cases before reaching the ideal PB stability boundary. A recent work [6] highlighted that resistivity significantly affected the pedestal MHD stability and that including resistivity in stability calculations could explain experimental correlations. The present work aims to implement resistive stability tools in the predictive code Europed and investigate the effect of resistivity on pedestal predictions.

In the first place, the linear resistive MHD code CASTOR [7] has been implemented in Europed. A reference pulse has been chosen to study the effect of resistivity. For simplicity, the reference pulse (#84794) has been chosen to be well described by ideal MHD stability The pulse is part of power and gas scans described in [4]. The reference pulse is at 1.4MA/1.7T, $P_{\text{NBI}} \simeq 16\text{MW}$, $\Gamma_{\text{D}} = 2.7 \times 10^{21}\text{e/s}$, low-$\delta$. In the stability calculation, the following toroidal mode numbers have been chosen: $n = 1, 2, 3, 4, 5, 7, 10, 20$, and the KBM constant k used in Europed has been fine-tuned to have good quantitative agreement between ideal predictions and the experimental observations for the reference pulse: $k = 0.1$ is used for all runs presented in this work. The Alfvén stability criterion is used ($\gamma / \omega_A < C_{\text{crit}}$, where C_{crit} is an arbitrary threshold typically set to 0.03). From the refereance pulse, several parameters are scanned: the pedestal density n_e^{ped}, the normalized separatrix density $n_e^{\text{sep}}/n_e^{\text{ped}}$, and the total normalized pressure β_N. These parameters influence pedestal stability, and the goal is to assess how ideal and resistive predictions differ when changing both resistivity and one of these parameters. In the present work, when resistive predictions are made, the resistivity profile is based on the Spitzer resistivity

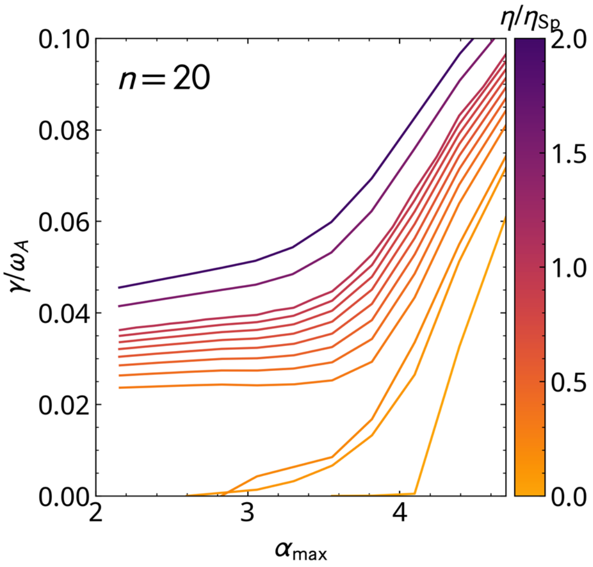

***Figure 1**. Growth rate of the n=20 mode for different resistivities.*

($\eta_{\mathrm{Sp}} = f(Z)T_e^{-3/2}$ [8]) and rescaled between ideal MHD ($\eta = 0$) and the neoclassical resistivity ($\eta = 2\eta_{\mathrm{Sp}}$, as $\langle \eta_{\mathrm{neo}}/\eta_{\mathrm{Sp}} \rangle_{\psi_N \geq 0.9} = 1.93$ determined with the Redl formula [9]).

First, predictions are made on the reference pulse using both ideal and resistive MHD. In this part, experimental values of the reference pulse have been used ($n_e^{\mathrm{ped}} = 2.57 \cdot 10^{19}\ \mathrm{m}^{-3}$, $n_e^{\mathrm{sep}}/n_e^{\mathrm{ped}} = 0.4$, $\beta_N = 3$), and a resistivity scan is made. Results of this scan are presented in Figure 1, displaying the growth rate of the $n = 20$ mode as a function of the resistivity and the maximal normalized pressure gradient $\alpha_{\max}$. On this mode, resistivity has an important destabilizing effect: the growth rates are increasing with resistivity. For $\alpha_{\max} \leq 4$, there is no instability in the ideal case ($\gamma/\omega_A \simeq 0$), while the resistive predictions show instabilities with growth rates comparable to $C_{\mathrm{crit}} \simeq 0.3$. The instabilities at low α, seen only with $n = 20$ and resistivity, have growth rates with a weak dependency on $\alpha_{\max}$, leading to the plateau seen in Fig. 1. The other modes $n \leq 10$ are also destabilized by resistivity. A selection of modes is made, and their growth rates is plotted versus the resistivity in Figure 2. At high α (circles), all modes are destabilized by resistivity. The higher the toroidal mode number n, the bigger the destabilization. For lower α (squares), while all modes are stable in the ideal case, only the $n = 20$ has growth rates comparable to C_{crit}.

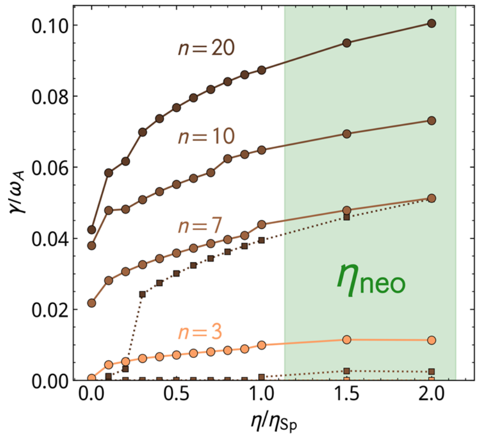

***Figure 2**. Growth rate versus resistivity, depending on the toroidal mode number, for fixed* $\alpha_{\max}$.
($\alpha_{\max} = 4.5$ *circles,* $\alpha_{\max} = 3$ *squares).*

***Figure 3**. Critical* $\alpha_{\max}$ *versus resistivity (orange squares). Critical pedestal pressure vs resistivity (red pentagons).*

Europed determines the critical values by identifying the maximum normalized pressure gradient at which the most unstable mode has growth rate below the critical threshold C_{crit}. In this work, $C_{\mathrm{crit}} = 0.05$ has been used. Critical values are then calculated from this marginally stable pedestal. Uncertainties on the critical values are determined assuming a $\pm 15\%$ variation in C_{crit} . In Figure 3, critical $\alpha_{\max}$ and critical pedestal heights are plotted against the resistivity, with their uncertainties. The critical values are decreasing with resistivity, and the uncertainties are growing. The decrease of critical values is explained by the increase of the growth rate, and the growth of the uncertainties by the weaker dependency of $\gamma\ /\ \omega_A$ on $\alpha_{\max}$ at high resistivity (see Fig. 1). In the scan of Figure 3, the most unstable mode is $n = 20$. The trend of α_{crit} is qualitatively similar to that of p_{crit}. This is expected, as the Europed predictions assumes $w = k\sqrt{\beta_p^{\mathrm{ped}}}$. Therefore, for simplicity in the rest of the work we will discuss only p_e^{ped}.

In the power and gas scans from which the reference pulse is taken, three key parameters are correlated with pedestal stability: β_N, $n_e^{\mathrm{sep}}/n_e^{\mathrm{ped}}$, and n_e^{ped}. Therefore, in this work a scan of these variables is done. The scans are repeated with three different resistivity profiles: $\eta =$