SIMULATION STUDIES ON H-MODE PEDESTAL BEHAVIOUR DURING TYPE-I ELMS UNDER VARIOUS PLASMA CONDITIONS

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I. Introduction and Models

The edge transport barrier is modelled in the ASTRA transport code [1] by introducing a suppression of the turbulence growth rate \( \gamma_s \) due to \( E \times B \) shearing rate \( \omega_{E \times B} \), which is generated mainly by the ion pressure gradient during the Type-I ELMy phase. The magnetic shear plays an essential role in turbulence suppression both by increasing the critical pressure gradient and by decreasing the growth rate [1]. In this study, the following suppression model is employed after some examination of various functional forms; \( 1/(1 + (\omega_{E \times B}/\gamma_s)^4) \) (1).

Transport coefficients are multiplied by this suppression factor. We assume ITG mode turbulence and its growth rate \( \gamma_s \) [3] as the dominant turbulence, consistent with an ion transport coefficient in the core \( \chi_i^{ITG} \) [3]. For the electrons, we assume a critical \( V_{Te} \) model of RLW type yielding \( \chi_e^{RLW} \) [4]. The same suppression factor as the ions is assumed for the electrons. For the particle transport, the assumed diffusion coefficient is \( D \propto (\chi_i^{ITG} + \chi_e^{RLW}) \) assuming the same suppression factor for \( \chi \). In this study, however, the effect of density profiles on the pedestal characteristics is examined based on the measured or inferred density profiles, so the diffusion coefficient is adjusted to reproduce these density profiles. Detailed studies on the diffusion coefficient and its physical basis are presented elsewhere [5, 6]. Since, an accurate measurement of the density profile is not always available, especially in the low density pedestal region, model density profiles are also examined. An additional \( \chi \) is introduced when the pressure gradient approaches the critical one for ideal ballooning mode stability. The code calculates the bootstrap current \( j_{bs} \) and the modification of the magnetic shear is properly evaluated. ELMs expel a significant fraction of \( j_{bs} \) and thus it will be much lower than the steady state value. Modelling of the time-dependent behaviour of Type-I ELMs is now under development [7, 8]. In this study, the effects of ELMs on \( j_{bs} \) are
included only by the range of a reduction factor $f_{bs}$ (0.0; $j_{bs}$ is 0 due to ELMs and 1.0; $j_{bs}$ is not reduced at all).

II. Simulation results

The first simulation is done for the JT-60U data, in which the temperature pedestal width and height evolve during the Type-I ELM phase after the ELM-free phase [9]. Here, two probable causes are investigated for this evolution, (i) modification of the density profile, (ii) modification of the bootstrap current. We choose two typical time points (6.3s and 8.8s) to examine these probable causes. In the experiment, the density at the ion temperature pedestal shoulder is almost constant, although the location of the shoulder is changing due to increasing pedestal width. The simplest case (model-1) for this density profile is where the density increases in the close vicinity of the separatrix and stays almost constant up to some location inside the core. This is shown by the dotted line in Fig. 1 (a). A second case (model-2) is parabolic-like profiles shown by solid lines with squares (6.3s) and triangles (8.8s) in Fig. 1 (a), which are chosen to match the $n(0)$, $\bar{n}$ and $n_{ped}$ at each time point. $j_{bs}$ at 6.3s is still very large, since this is just after the termination of ELM-free phase, while at 8.8s $j_{bs}$ is significantly reduced. In model-1, the density gradient is too large for the ion pedestal at 6.3s (even with the largest $f_{bs}$) while it is too small at 8.8s (even with the smallest $f_{bs}$). The $E \times B$ shearing rate generated from the density gradient is very important for the pedestal characteristics. In model-2, pedestal profiles both at 6.3s and 8.8s can be reproduced with reasonable $f_{bs}$, which shows the importance of the modification of the magnetic shear by $j_{bs}$.

The simulated electron temperature $T_e$ profiles are somewhat lower and show a less clear pedestal. $T_e$ profiles are not well measured but if they are similar to the ions', we can examine a necessary further reduction of $\chi_e^{RLW}$ by magnetic shear. Fig. 2 shows the $T_e$ profiles in the pedestal region with no additional reduction for $\chi_e^{RLW}$ (solid line; only $E \times B$ shear.

![Fig. 1 (a) Examined density profiles (model-1 and model-2). (b) Simulation results for model density profiles (a).]
suppression as employed in Fig. 1), further reduction of $1/S^2$ (dashed line) and $1/S^4$ (dotted line). The additional reduction in the form of $1/S^2$ seems appropriate to reproduce the assumed $T_c$ profile. More detailed studies are necessary to identify definitively the form of the reduction.

The second simulation is done for a density scan experiment in JT-60U [10]. In this experiment, it is observed that the pedestal width decreases while the gradient increases with increasing density, and as a result the pedestal stored energy $W_{ped}$ remains almost constant. For the simulation, we use high and low density data, for which density profiles are provided [10]. However, we also examine a modified profile especially for the low density case assuming there was a large measurement uncertainty. The examined density profiles are shown in Fig. 3 (a). For the low density case, the dotted line is simply fitted from the data in the paper and the solid line is the modified one. $f_{bs}$ is fixed as 0.4 and no additional reduction for $\chi_{eR_{LW}}$ is used and all other simulation conditions are the same as in Fig. 1. Results are shown in Fig. 3 (b). In the high density case (red solid line), the $T_i$ profiles are reasonably well reproduced by the fitted density profile, while, in the low density case, the $T_i$ profiles are lower than in the experiments (dotted line in (b)) for the fitted density profile (dotted line). With the modified profile (solid line in (a)), the ion pedestal can be reproduced reasonably well (solid line). The pedestal energy $W_{ped}$ and width $\Delta_{ped}$ are shown in Fig. 4. For the low density case, the open square and circle are obtained with the fitted density profile, and the triangles are with the modified profile. The simulated $T_c$ is higher than the
measured one especially in the low density case even without an additional reduction factor for $\chi_{e}^{RIW}$, which results in somewhat higher $W_{ped}$. Reduction of $\Delta_{ped}$ with density roughly follows $\sqrt{T_{ped}}$, consistent with the model of Eq. (1). $j_{bs}$ and the pressure gradient ($\alpha$-parameter) for these corresponding cases are shown in Fig. 5. The higher $j_{bs}$ due to the lower collisionality in the low density case reduces the magnetic shear significantly, which reduces the achievable pressure gradient.

![Fig. 4 $W_{ped}$ and $\Delta_{ped}$ in experiments (closed) and simulations (open).](image)

![Fig. 5 Bootstrap current and $\alpha$-parameter for low and high density discharge.](image)

III. Conclusions

Models for the edge pedestal based on stabilisation of turbulence by the combined effects of electric field shear and magnetic shear are able to reproduce experimental results of the pedestal in JT-60U. The bootstrap current and density profiles play a crucial role and, by proper choice of these parameters, the general features of the pedestal can be reproduced well. However, the necessary change of particle transport and its physics basis are not clearly understood. They are essential in order to apply the model predictively [5, 6].

References