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Empirical transport modeling for the edge region of H-mode plasmas for integrated simulations

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In magnetically confined fusion devices, the confinement performance of H-mode plasmas highly depends on the pedestal in the edge region. EPED1 model [1], which is widely used to predict the pedestal, determines the pedestal height and width based on MHD instabilities and turbulence without considering energy fluxes. However, consistent energy fluxes at the boundaries with the core region and the scrape-off layer should be handled by the models for each region in integrated simulations. To this end, a transport model, which can predict energy fluxes in the edge region, is required, but the development of such a model is complicated since transport in the region is believed to be dominated by instabilities over a wide range of size scales. In this study, empirical modeling is performed using experimental observations.

The pressure in the pedestal region gradually increases in the transport timescale, and then it suddenly decreases when it reaches the upper limit constrained by MHD instabilities and turbulence. To express the repeated increase and decrease, we solve a transport equation, checking whether the pressure is lower than the upper limit at each time step. Here, if the pressure exceeds the upper limit, it is forced to reduce at the next time step. In the previous study [2], the diffusivity in the inter-ELM phase and the ELM crash phase is calculated by giving an unknown quantity as a constant. We empirically evaluate the diffusivity in the inter-ELM phase and the reduction in the pressure in the ELM crash phase.

In this study, we solve a heat transport equation with a given density profile and a fixed magnetic equilibrium. The location of the pedestal shoulder is kept as $\rho_{\mathrm{ped}} = 0.8$, and a constant upper limit of the pressure is used. In such a simplified case, the temperature profile can be predicted by determining the heat diffusivity in the inter-ELM phase and the magnitude of the decrease in the temperature due to ELMs. The heat diffusivity is calculated by multiplying the diffusivity given by the model for the core region by fac_χ given as $\mathrm{fac}_\chi = f(\rho_{\mathrm{ped}})/f(\rho)$, where f is defined with the Gaussian distribution and it is adjusted with a coefficient c_χ. The magnitude of the decrease in the temperature due to ELMs is given by multiplying the temperature by fac_T, which is given with the cosine function and is adjusted with another coefficient c_T. We have solved the transport equation with different combination of c_χ and c_T, and estimated $f_{\mathrm{ELM}}\Delta W_{\mathrm{ELM}}/P$ (figure 1(a)), where f_{ELM}, ΔW_{ELM}, and P are the ELM frequency, the drop in the stored energy, and the heating power, respectively, and $f_{\mathrm{ELM}}\Delta W_{\mathrm{ELM}}/P$ is indicated to be almost constant by JT-60U experiments [3]. When $f_{\mathrm{ELM}}\Delta W_{\mathrm{ELM}}/P = 0.2$ and $f_{\mathrm{ELM}} = 80\,\mathrm{Hz}$, c_χ and c_T are given as marked with the cross in figure 1(a). The resultant c_χ and c_T are used to predict the temperature (figures 1(b) and (c)).

We have also developed a neural network model that quickly checks whether the peeling ballooning mode is stable or not (figure 2). The model is trained on the ideal MHD stability code MARG2D [4], and it estimates the stability for $n = 1, 2, 3, 4, 5, 6, 8, 10, 15, 20$, and 30 using radial profiles of parameters including the density and temperature, where n is the toroidal mode number. The model will be implemented with the transport solver to perform integrated simulations that consider the MHD stability and transport simultaneously.

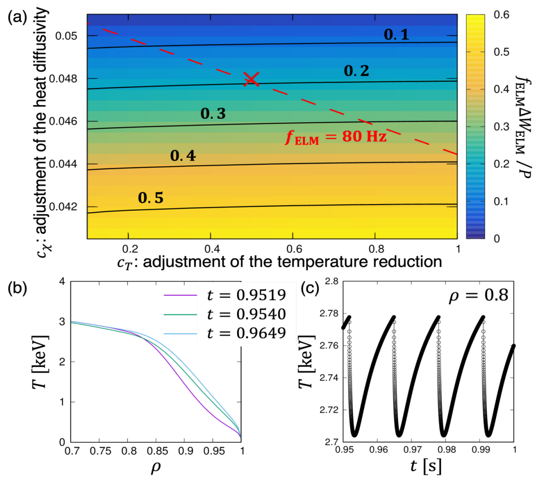

Figure 1. (a) The dependence of $f_{\mathrm{ELM}}\Delta W_{\mathrm{ELM}}/P$ on c_χ and c_T (heat map) and the combination of c_χ and c_T with $f_{\mathrm{ELM}} = 80\,\mathrm{Hz}$ (red line). (b) The radial profile and (c) the time evolution of the temperature at the cross in (a).

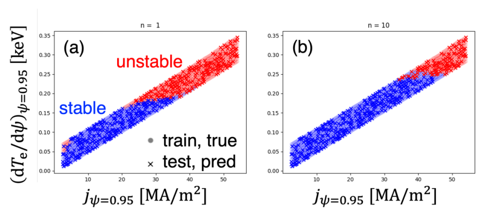

Figure 2. The temperature gradient and the current at the poloidal flux $\psi = 0.95$ in the training and test datasets. The neural network model predicts stable or unstable for (a) $n = 1$ and (b) $n = 10$.

References

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