§4. Benchmark of Monte Carlo Scheme of EMC3 Dealing with Non-Uniform Cross-Field Transport Coefficients and Implementation in LHD

Kobayashi, M., Feng, Y. (Max-Planck-Institut für Plasmaphysik), Yamada, I., Hayashi, H., Kawamura, G.

The understanding of plasma transport properties in stochastic magnetic field is one important issue for magnetically confined fusion devices. The 3D edge fluid transport code, EMC3-EIRENE [1,2], has been implemented in order to analyze the transport properties [3]. In these studies, comparison with the electron temperature (T_e) profiles obtained experiments have shown that there appears almost always systematic and substantial deviation between the modelling results and the experimental data, if we use spatially constant cross-field transport coefficients [3]. The results indicate a significant change of the cross-field transport in the stochastic layers. The extension of EMC3 to deal with non-uniform cross-field transport coefficients has been motivated to cope with the problem [4].

For the benchmark of the new code version of EMC3, a cylindrical geometry has been taken, where a finite difference method can apply. Magnetic field lines are aligned straight along the axial direction of the cylinder. The transport coefficient D is changed in arbitrary form, where it changes from 0.3 to 3.0 m2/s at around the middle of the radius of the cylinder. Figure 1 summarizes the benchmark results with a finite difference method against the time steps $\Delta t_\perp$, where the corresponding jump step size ($\Delta x_\perp$) with respect to the grid size (dr), $\Delta x_\perp/dr$, and to the scale length of spatial change of $D_\perp$ (λ_D), $\Delta x_\perp/\lambda_D$, are also indicated. If one assumes that the criterion of tolerable error for comparison with experiments is ~ several %, the results suggest that the selection of time step should be such as $\Delta x_\perp/\lambda_D$ and $\Delta x_\perp/dr$ < several 0.1 %.

The new code version has been implemented in the stochastic layer of LHD. The magnetic field structure in the edge region is precisely incorporated in the code by means of field line aligned 3D grid. The transport equations treated in the code is standard Braginskii equations for particle, momentum and energy conservation [1], in which the parallel transport along field lines is prescribed by classical formulae. On the other hand, the cross-field transport coefficients are free input parameters and selected such as the code results best fit the profiles of electron temperature (T_e) and density (n_e) obtained in experiments. The jump step of Monte Carlo particles is executed at the local coordinate in the 3D space which consists of three orthogonal vectors. Therefore, the cross field transport coefficients, $D_\perp$ for particles and $\chi_\perp$ for energy, represent the transport magnitude exactly perpendicular to magnetic field at each local position. The selected plasma condition is as follows: The magnetic configuration is the one so-called magnetic axis (R_{ax}) = 3.75 m, which has substantial radial width of stochastic layers, ~ 0.1 m on average in poloidal direction. The input power is 7 MW of NBI and the density at the last closed flux surface (LCFS), n_{LCFS}, is ~ 1.9×10^{19} m^{-3} (shot number: 109715, t = 4.40 ± 0.05 sec).

T_e and n_e obtained by Thomson scattering system along the midplane have been fitted by iterations of runs and the best fitted results are shown in Fig. 2. It is found that in order to reproduce T_e, $\chi_\perp$ has to be significantly reduced at the inner region of the stochastic layers (2.78 m< R <4.78 m) down to 0.2 m^2/s. Outside of this region ($R \leq$ 2.78 m, $R \geq$ 4.78 m), $\chi_\perp$ takes the value of 4.0 m^2/s. At the outer most region (R < 2.66 m, R > 4.88 m), it is set to 30.0 m^2/s. For comparison, the results with spatial constant. $\chi_\perp$ with 0.2 and 4.0 m^2/s are plotted. For the both cases, one finds significant deviation from the experimental observation. It is found that for the particle transport, the spatially fixed coefficient, $D_\perp$ = 1.0 m^2/s, provides reasonable agreement of the n_e profile with the experiments, as shown in Fig. 2.

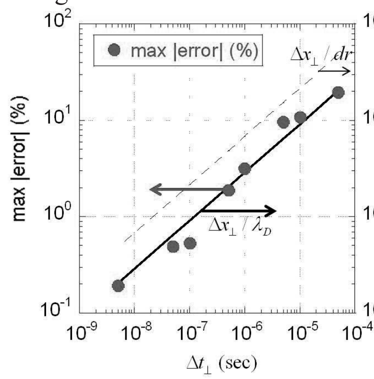

Fig. 1. The error as a function of time step $\Delta t_\perp$, closed circles. The size of jump step, $\Delta x_\perp$, relative to grid resolution dr and scale length of $D_\perp$, λ_D, are also indicated on the right axis.

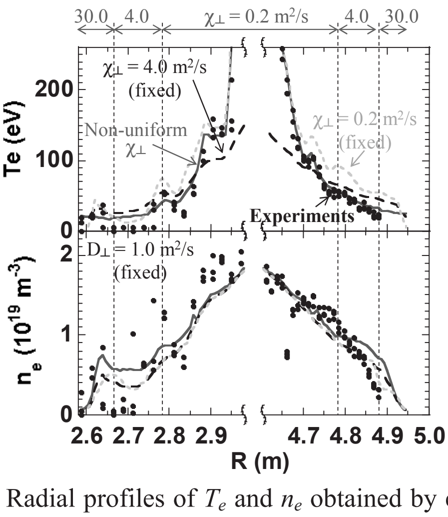

Fig. 2. Radial profiles of T_e and n_e obtained by experiments (closed circles) and with EMC3-EIRENE (lines) for non-uniform $\chi_\perp$ (solid), fixed $\chi_\perp$ of 0.2 (broken) and 4.0 (dashed) m^2/s.

1) Feng, Y. et al.: Contrib. Plasma Phys. **44** (2004) 57.
2) Reiter, D. et al.: Fusion Sci. Technol. **47** (2005) 172.
3) Kobayashi, M. et al.: Nucl. Fusion **53** (2013) 033011.
4) Feng, Y. et al.: Computer Physics Communications **184** (2013) 1555.