§20. Edge Plasma Simulation for Stellarator System with 2D Transport Code UEDGE

Takayama, A., Tomita, Y., Ishiguro, S.,
Pigarov, A.Yu., Krasheninnikov, S. (UCSD),
Rognlien, T.D. (LLNL)

A new and simple approach for stellarator edge modeling is presented. This is based on averaging of edge plasma parameters and introducing effective 2-dimensional flux surfaces which allow to use UEDGE transport code, widely used for a tokamak edge plasma modeling. This approach is applied to edge modeling of Large Helical Device (LHD). It should be noted that our model is based on 2-dimensional configuration which is called as stellarator-equivalent tokamak (SET), while stellarator system is inherently 3-dimensional.

It is recognized that magnetic configuration at the edge of a stellarator system is very complicated and contains a mixture of closed flux surfaces and stochastic field lines. Because of its complexity, at present, there is no complete plasma transport code that fully accounts for all of the features of this highly complicated case. Moreover, it is even not very clear what kind of set of transport equations can be used for these purposes. At the same time, it is feasible that due to a strong anomalous cross-field plasma transport and convective plasma flows, rather detailed features of stellarator magnetic topology do not matter much for averaged plasma parameters. Therefore, it is worth to try a simple approach to the modeling of stellarator edge plasma based on "averaging" of edge plasma parameters along the magnetic axis and introducing effective two-dimensional flux surfaces. In this sense, we substitute the stellarator edge with what can be called a stellarator-equivalent tokamak (SET) edge. As a consequence 3-dimensional property of stellarator system cannot be investigated, but it is still possible to clarify the "averaged" 2-dimensional property of stellarator edge region and difference between stellarators and tokamaks in point of connections length of magnetic field lines and compression factor of a magnetic flux tube. We simulate the LHD-stellarator-equivalent tokamak with 2D multi-fluid edge plasma transport code UEDGE$^{1)}$.

This method has following properties: Double null (bottom and top X-points) configuration; same large aspect ratio with LHD; same plasma cross-section elongation with the vertically elongated cross section of LHD; similar positions of X-points, strike points at divertor plates, and the magnetic axis; same radial gradient of magnetic flux in the core region adjacent to separatrix with LHD; and similar compression factor of a magnetic flux tubeat the scrape-off layer (SOL) mid-plane and its width in the divertor near strike points.

In the LHD-SET configuration the characteristic connection length $L_{\rm SOL}$ of magnetic field lines from the SOL mid-plane to the divertor plates is typically set equal to the characteristic connection length in the real stellarator configuration calculated with 3D magnetic field line tracing code and smoothened over a certain part of the SOL.

The UEDGE code solves the 2D multi-fluid plasma transport equations and reduced set of Navier-Stokes equations for neutral transport. The plasma sources are the ionization of recycling atoms from divertor plates and walls and flux from NBI-fuelled core plasma. Plasma is neutralized at divertor plates and walls and corresponding boundary conditions are similar to those in tokamaks$^{1)}$. We assume the up-down symmetry with mid-plane and simulate only the bottom half domain. The constructed numerical mesh is non-orthogonal and non-uniform. The combined effect of small-scale magnetic islands, stochastic magnetic field layers as well as intermittency (infrequent but large-scale transport events) on cross-field plasma transport is modeled in UEDGE by prescribing the 2D profiles anomalous convective velocity $V_{\rm conv}$ and anomalous diffusivities ($D_\perp$, $\chi_\perp$) and by adjusting these profiles in order to match the experimental plasma profiles and recycling data$^{2)}$.

Figure shows a simulation result (ion velocity profile) of the case with the following conditions: $B_{\rm t}$ = 3 [T], R_0 = 3.75 [m], $n_{\rm ec}$ = 4.0x10^{19} [m^3], $P_{\rm e}$ = $\gamma_{\rm ei}W_0$, $P_{\rm i}$ = (1- $\gamma_{\rm ei}$)W_0, $\gamma_{\rm ei}$ = 0.4, W_0 = $W_{\rm NBI}$-$W_{\rm rad}$, $W_{\rm NBI}$ = 3.5 [MW], $W_{\rm rad}$ = 0.5 [MW]. In the obtained steady-state solutions, the plasma flux through core interface is equal to the neutral flux plus the NBI fuelling rate $F_{\rm NBI}$. Anomalous diffusivity for this case is $D_\perp$ = 0.20 [m^2/s], $\chi_\perp$ = 0.40 [m^2/s].

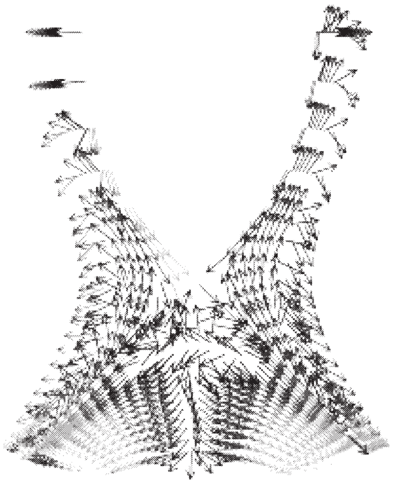

Figure Ion velocity profile

References

1) Rognlien, T.D. *et al.*, J.Nucl.Mater. **196** (1992) 345.
2) Pigarov, A..Yu. *et al.*, J.Nucl.Mater. **313** (2003) 1076.