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Monte Carlo Computations of Neoclassical Transport in TJ-II Stellarator

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Introduction

The calculation of neoclassical transport in three-dimensional systems, like in stellarators, is a complicated problem because of the lack of conserved components of the canonical momentum. However, it has been shown more important than in tokamaks. Analytical methods when applied to real stellarators seem to be impractical because of the large number of magnetic field components that has to be retained in the calculations. From the numerical point of view, there are two main approaches for computing neoclassical transport in stellarators: the drift kinetic equation solvers, and Monte Carlo methods, each with its benefits and drawbacks. Drift kinetic equation solvers allow computing all transport coefficients (the complete transport matrix) at the price of an unfavourable memory scaling with the number of magnetic field modes. On the other, hand Monte Carlo methods (MC) have a linear scaling with the number o f modes, and can be efficiently executed in massively parallel processing machines, but at the price of only giving the diffusive part of the transport matrix.

TJ-II stellarator [1] is a four period mid-size helical axis stellarator with the following parameters: R_0=1.5 m, 0.1 < a < 0.25, B_0 = 1 T. The main difference between TJ-II and other classical stellarators or torsatrons are a large helical axis excursion of the plasma, of approximately 25 cm, and a magnetic field mode structure, richer than in most other devices. It is precisely this broad $|B|$ spectrum, see Fig. 1, what makes TJ-II so especial with respect to neoclassical transport calculations and forced us to deal with Monte Carlo methods.

In this work we will present an evaluation of transport coefficients for the standard configuration of TJ-II stellarator. The ambipolar electric field is also computed for several plasma profiles, and the results for the particle and energy confinement times compared with some experimental discharges [2].

Local Diffusive Calculations

Using a newly developed Monte Carlo parallel code (working in Boozer co-ordinates), based on the MCT code [3], the monoenergetic diffusion coefficient, normalised to the tokamak plateau, has been computed for the standard configuration of TJ-II stellarator for several magnetic surfaces over a wide range of collisionalities and radial electric fields. Once these monoenergetic particle distributions are convoluted with the appropriate Maxwellian energy distributions it is possible to perform a one-dimensional study of the particle and energy fluxes as a function of the temperature, density and electric potential profiles. This one-dimensional study also allows us to estimate the particle and energy confinement times for the radial electric field, E_r, solution of the ambipolarity condition ($\Gamma_e = Z_i \Gamma_i$).

In this calculations it was found that, for the nominal magnetic field of TJ-II (1 Tesla), in the long mean-free path (LMFP) collisionality regime the local diffusion is not a dominant feature. Moreover the effect tends to increase at outer ψ, because of the radial ripple dependence of the configuration. Formally it is possible to reduce this effect in the calculations by increasing the magnetic field, since all the quantities involved are normalised. In this way it is possible to override the problem of direct losses and makes it possible to compute only the local diffusive part of the transport. However the contribution o f these non-local fluxes to the real transport remains to be addressed. In doing these studies for TJ-II stellarator several points have been taken into account; namely: 1) the number of modes used in the description of $|B|$ (> 100); 2) the number of particles needed to obtain convergence of the result as a function of collisionality; 3) the scaling of the magnetic field modulus for obtaining local diffusive results. We have constructed a database containing the normalised nonoenergetic diffusion coefficients, D^*, for ten flux surfaces, six different electric potentials and twenty-four different collisionalities ($10 \times 6 \times 24 = 1320$). This data base has been fitted with a neural network [4], called multilayer perceptron (MLP), with only one hidden layer, MLP1, using as inputs the magnetic surface, the normalised collision frequency and the ratio of the electrostatic potential to the particle energy, $D^*(\psi, \upsilon^*, e\Phi/T)$. A rather good fit is obtained using only three nodes in the hidden layer (i.e.; 16 coefficients), see Fig. 2.

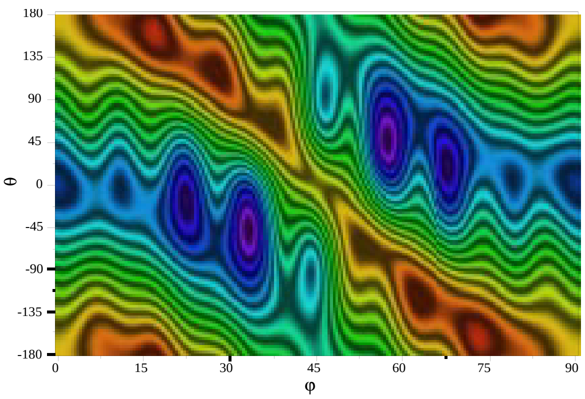

***Figure 1**: Contour plot of |B| on the magnetic surface Ψ = 0.25 within one field period for the standard configuration of TJ-II stellarator.*

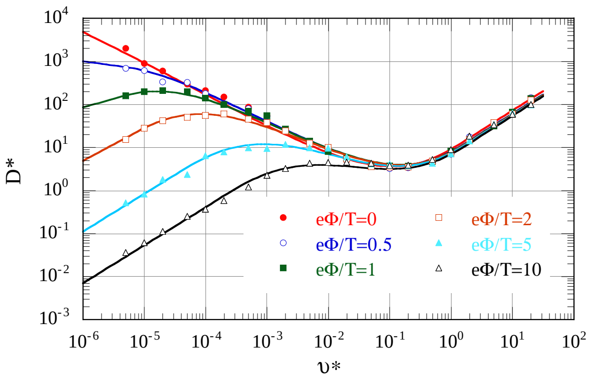

***Figure 2:** Normalised monoenergetic diffusion coefficient, at Ψ = 0.25, computed (dots) and fitted (lines) vs. normalised collisionality*

Making the appropriate convolutions of the monoenergetic diffusion coefficient, D^*, it is possible to derive the different perpendicular transport coefficients and the particle and energy fluxes. For the experimental plasma profiles of Fig. 3, for broad ion temperature profiles with central values $T_i(0)$ = 90 and 125 *eV* respectively, the ambipolar radial electric field and the particle flux are plotted in Fig. 4.

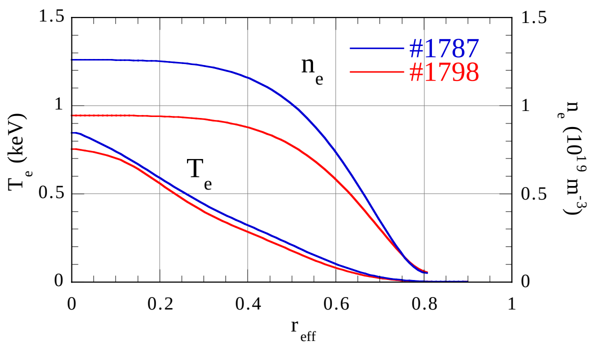

***Figure 3:** Density and temperature profiles for two TJ-II shots.*

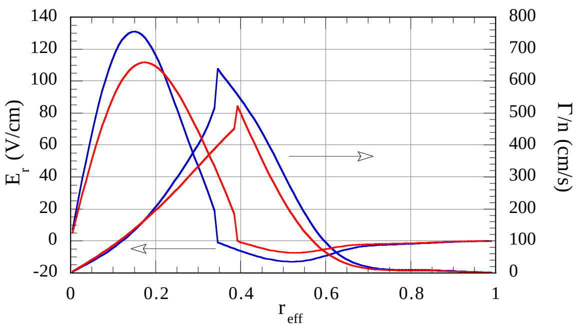

***Figure 4:** Ambipolar radial electric field and particle flux vs. the effective radius*

With the assumption we have made in the MC calculation,i.e.; neglecting non-local fluxes and direct losses, and only considering local diffusive particles, the figures, obtained for the profiles of Fig. 3, for the particle and energy confinement times and the heat conductivity are in reasonable agreement, see the following Table, with the experimental findings and the transport analysis [5].

Shot	τ_p (ms)		τ_E (ms)	
	Neo.	Exp.	Neo.	Exp.
#1787	13	---	8	5
#1798	9	---	5	3

Non-Local Calculations

The problem of direct losses has been addressed by computing the total particle and energy fluxes for fixed density and temperature profiles [6]. For these simulations particles have been started randomly in ψ following a parabolic density profile, and for each position their energy has been chosen from a Maxwellian with a parabolic temperature profile; their pitch, toroidal and poloidal positions haven been also chosen randomly. These particles, ions and electrons were followed during 50 *ms* taking into account both pitch angle and energy scattering with a fixed background and a parabolic electrostatic potential. Two different cases with $T_e(0)$ = 500 eV and $T_e(0)$ = 750 *eV* were considered, with the same central density $n_e(0) = 1.5 \times 10^{19}$ m^{-3} and central ion temperature $T_i(0)$ = 125 *eV*. For each case fifteen different central electrostatic potentials were considered, ranging from $-3 \le e\Phi(0)/\ T_e(0) \le 3$. The fluxes for each magnetic surface are computed directly from the trajectories of the particles.

The particle fluxes computed by direct flux simulations are larger, especially at outer radii, than those of the local diffusive approach described earlier, see Fig. 5 ($T_e(0)$ = 750 *eV*), and their dependence on the radial electric field, Fig. 6, is quite different, and reflects the importance of the non-local ion transport on TJ-II. The radial electric field, solution of the ambipolarity condition, and the particle flux obtained with both methods are presented in Figs. 7 and 8, cases $T_e(0)$ = 500 *eV* and 750 *eV* respectively.

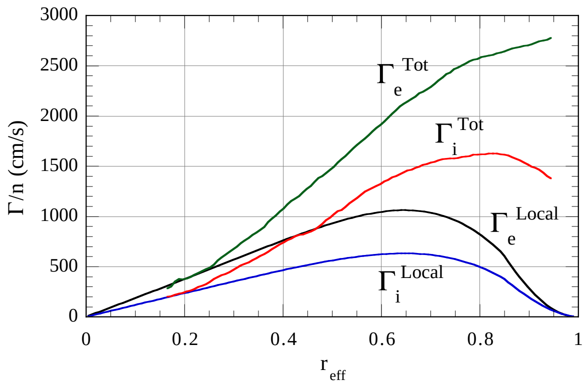

Figure 6: *Electron and ion particle fluxes vs. effective radius for* $e\Phi/T_e = 0$.

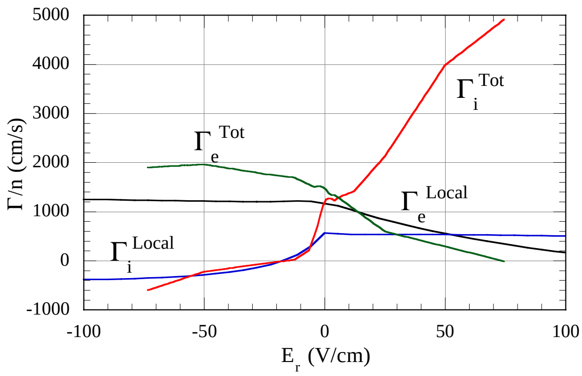

Figure 5*: Electron and ion particle fluxes vs. radial electric field for* $r_{eff} = 0.5$ *(or* $\psi = 0.25$*).*

Notice the clear transition from an *ion* to an *electron* root depending on the central electron temperature. Although these simulations were made with fixed parabolic profiles, its results indicate that non-local fluxes might influence the transport, but at this point is very difficult to say that they invalidate the *electron-root* feature.

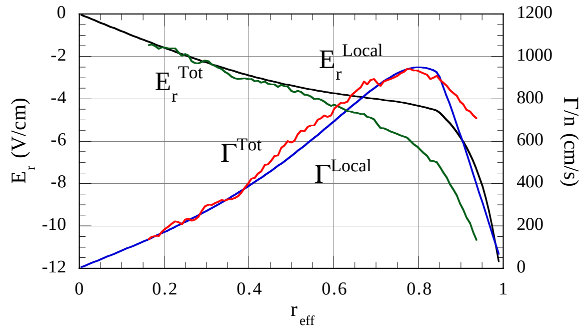

Figure 7*: Particle flux and radial electric field vs. effective radius for $T_e(0)$ = 500eV*

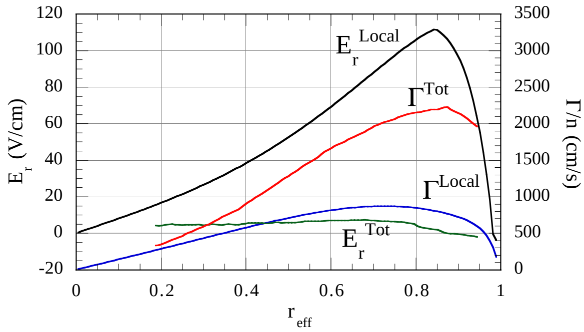

Figure 8*: Particle flux and radial electric field vs. effective radius for $T_e(0)$ = 750eV*

Conclusions and Prospects

The local diffusive part of the neoclassical transport of TJ-II stellarator, computed using a Monte Carlo method, is presented. For the typical conditions of TJ-II plasmas, corresponding to the long mean-freepath (LMFP) collisionality regime, it was found that direct losses might play an important role in determining the ambipolar electric field and the particle and energy confinement times. However, if direct losses are neglected;i.e.; only considering local diffusive particles in the MC calculation, the figures, obtained for real TJ-II shots, for the particle and energy confinement times and the heat conductivity are in reasonable agreement with the experimental findings and the transport analysis. The problem of direct losses was also addressed in this work by computing the total particle flux for fixed density and temperature profiles. The results of the total flux simulation show an increase in the particle fluxes, being more important for ions, and a reduction of the radial electric field for conditions with high electron temperature.

More studies are in progress in order to simulate the total fluxes using real plasma profiles, relaxing the condition of frozen temperature profiles, and increasing the number of particles to improve the energy statistics. This later point is especially severe for electrons, since their simulation is very expensive in computertime.

In the near future we will check these results with new experimental data, which will be available from the heavy ion beam probe.

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