36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-4.184 (2009)

Radial Electric Field Computations in TJ-II and Comparison with HIBP Measurements

J. J. Martinell[1], D. López-Bruna[2], F. Castejón [2], V.I. Vargas[3], C. Gutiérrez-Tapia[4] and A. Ortiz-Tapia[5]

[1]*Instituto de Ciencias Nucleares, UNAM, A. Postal 70-543, México D.F., Mexico*

[2]*Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain*

[3]*Instituto Tecnológico de Costa Rica, Cartago, Costa Rica*

[4]*Instituo Nacional de Investigaciones Nucleares, A. Postal 18-1027, México D.F., Mexico*

[5]*Instituto Mexicano del Petroleo, México D.F., Mexico*

Introduction. Neoclassical transport in stellarators is not intrinsically ambipolar, which gives rise to the build up of a radial electric field in order to balance ion and electron fluxes. On the other hand, particle and energy flows are usually anomalous at some radial intervals, as opposed to neoclassical, due to the presence of turbulent fluctuations producing noncollisional transport that usually dominates collisional transport. Thus, the transport coefficients deduced from experimental data give no information about the electric fields present within the plasma, since the latter are governed by neoclassical transport if one assumes that turbulent transport is electrostatic and, hence, ambipolar. In order to theoretically obtain the structure of the radial electric field it is necessary to compute it from the transport rate difference between ions and electrons. For this, one needs a way to calculate neoclassical transport coefficients based on some model. Several approaches can be taken towards this end, ranging from the use of analytical expressions for the transport matrix obtained from fluid or kinetic equations, to the utilization of Monte Carlo simulations of transport, to the more complex one based on drif kinetic simulations to compute the transport. The results of all these approaches have to be tested against experimental data giving information about the radial electric field. In this respect, the most appropraite diagnostics are the Heavy Ion Beam Probes (HIBP) which determine the value of the electrostatic potential by the deflection of ion beams [1]. In this way, radial profiles of the potential (or the electric field) are obtained, which have to be compared with those resulting from theoretical computations, which in turn allows an evaluation of the goodness of the model being employed.

Here we report on simulations of the stellarator TJ-II made using the Astra code [2], that include the analysis of several discharges with electron cyclotron resonance heating (ECRH), covering a range of both density and ECRH heating power. Thus, the dependence of the radial electric field on these two quantities can be assessed. The transport coefficients fed to Astra include neoclassical and anomalous contributions, but only the neoclassical part is relevant for setting up of the electric field, which is obtained by imposing the ambipolarity condition. Similar computations of the radial electric field have been made in preliminary form for a particular TJ-II discharge [3].

The Simulations. The computation of the electric field is made by solving the equation for the time evolution of the E_r-field,

$$\frac{dE_r}{dt} = A(\Gamma_e(E_r) - \Gamma_i(E_r))$$

with $A = ev_A^2/\varepsilon_0 c^2$, until ion and electron neoclassical fluxes are balanced, thus obtaining the equilibrium E_r value. It is assumed that the E-field evolves in a faster time scale than the transport scale, and thus the equation is solved in a single Astra timestep. Different neoclassical transport models have been used in order study the electric field and its dependency on the plasma conditions. The Astra code is first used to fit the experimental plasma profiles, adjusting the anomalous transport coefficients. For this we use a semi-empirical model based on [4] for a low collisionality regime with trapped electrons, but there are four free constants for adjusting the transport. There is also a convective term whose magnitude is varied to adjust the peak density position. For the fit, we focus mainly on the density and temperature profiles. Once the transport parameters are adjusted, the electric fiel is computed by the procedure described. Resulting neoclassical coefficients including E-field contributions are then added to the total transport. Usually the equilibrium is not altered significatively since the anomalous part still dominates, but in few cases the final equilibrium is modified quite a bit.

The first transport model we tested (called model 1) was based in a compilation of neoclassical coefficients in stellarators made by Beidler [5]. This includes toroidal and helical ripples of the magnetic field. The second model (model 2) uses the coefficients obtained by Kovrizhnykh [6] which have an axisymmetric component and a nonsymmetric one that uses a single harmonic (l=1, m=4) for the B-field which incorporates a helical ripple. For the two models the radial electric field profile was obtained for a set of discharges that allowed to make a density scan in the range $\langle n_e \rangle = 5 - 8 \times 10^{18} m^{-3}$, and an EC power scan $\langle P_{EC} \rangle = 0.2 - 0.6 MW$.

Results. The E_r profiles obtained have always a positive large value near the plasma edge which is usually the maximum value and the value at the center depends on the model used: small positive for model 1 and negative for model 2. So, both models give substantially different profiles. For some discharges where HIBP data are available the profiles are compared with the experimental ones, but the agreement is not so good especially in th edge, which is not

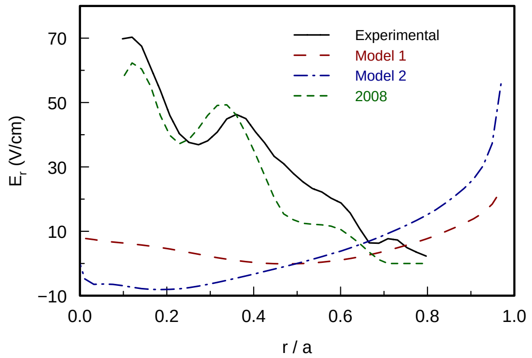

Figure 1: Electric field profiles for: experimental values (HIBP), Astra simulation from previous work, and Astra transport simulations for model 1: Beidler and model 2: Kovrizhnykh.

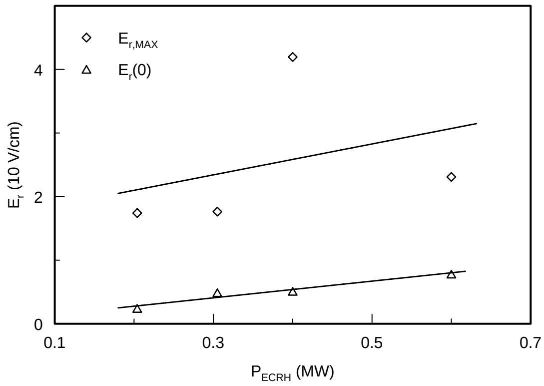

Figure 2: Power scan of electric field parameters $E_r(0)$ and $E_{r,MAX}$ for a constant $\langle n_e \rangle = 6.5 \times 10^{18} m^{-3}$ and the corresponding trends, for model 1.

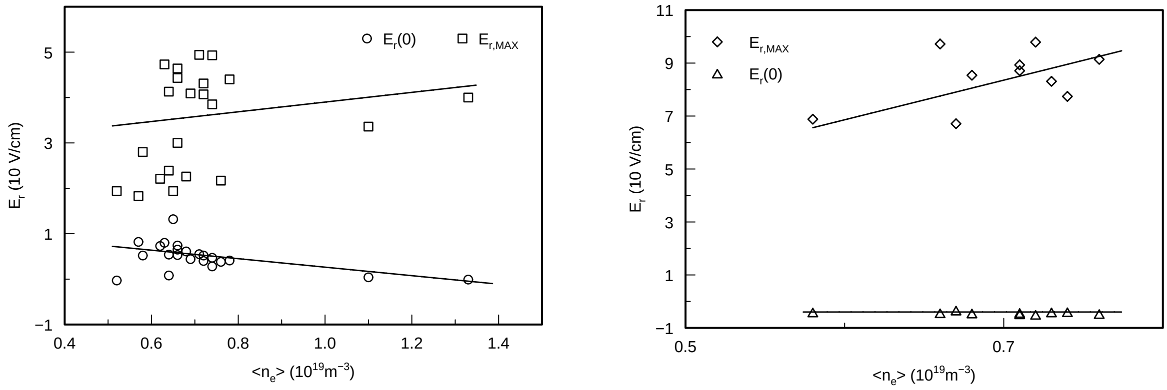

Figure 3: Radial electric field at the center and its maximum value (usually near the edge) in terms of the density for all the discharges simulated where a steady state is reached. Models 1 and 2 shown on the left and right, respectively. $P_{EC} = 400kW$ is kept constant.

surprising since that is just the region where both models are expected to fail. In Figure 1 we show the E_r-profiles for shot 17487 resulting from both models along with the experimental one. Also shown is the profile obtained from plasma simulations with Astra reported in Ref.[3] for the same shot, which compares more favorably to HIBP results. This may indicate that the analytical expressions for the transport coefficients used here are not very appropriate and more deatiled information is required to reproduce the experimental values. In particular, model 2 may be too crude since the use of a single harmonic is not approprate for TJ-II and model 1 reproduces the field in the centre, which means that the transport is properly simulated by this neoclassical approximatiion in the centre.

For the density scan we found that the behavior of the E_r-profile is quite similar for all cases that converged to a steady state, but the discharges having the largerst densities (and lowest neutral source) had difficulties to converge. This is due to the fact that the neoclassical coefficients had values approaching those for the anpmalous transport and thus the initial state found for $E_r = 0$ (and only anomalous transport) were altered quite a bit. For model 1 this is more noticeable than for model 2, since some shots that did not converge with the former, had convergence with the latter. In order to estimate the dependence of the E_r-profile with density we have chosen two parameters to characterize E_r: the radial electric field at the center, $E_r(r = 0)$ and its maximum value $E_{r,MAX}$. In Figure 3 these two parameters are plotted against the average electron density, for both models. It can be seen that the dependence, if any, is quite weak. The tendency is that the maximum electric field decreases slightly with $\langle n_e \rangle$, but the central value is almost independent of $\langle n_e \rangle$, especially for model 2. This indicates that E_r-profiles are not very sensitive to density. However, there is a wide variability among the discharges parameters and the lack of correlation is not a definite one.

A similar analysis was done for the EC power dependence, finding a more clear dependence of E_r on P_{ECR}. This is shown in Figure 2, where both $E_r(r = 0)$ and $E_{r,MAX}$ tend to increase with power, which is not surpising since, for similar densities, the field is governed by the electron temperature, which increases with power. Nevertheless, the number of discharges available for the power scan is small, and thus statistical validation is needed.

It is worth mentioning that the results will probably improve for NBI plasmas (as opposed to ECRH) since they are more collisional. Our work shows the need for a more precise way of calculating transport coefficients, when transport simulations are used. The next step is to obtain monoenergetic coefficients from kinetic numerical computations (using DKES or other NC code) and use them in the transport simulations.

Acknowledgements. Work partially supported by DGAPA-UNAM IN119408 and CONACyT 81232 Projects.

References

[1] I.S. Bondarenko et al., Czech. J. Phys. **50**, 1397 (2000)

[2] G.V. Perverzev and P.N. Yushmanov, ASTRA *Automated System for TRansport Analysis*, Max-Plank-Institute für Plasmaphysik Rep IPP 5/98 Garching (2002)

[3] V.I. Vargas et al., 35th EPS Conf. Plasma Phys., Hersonissos **P5.018** (2008)

[4] B.B. Kadomtsev and O.P. Pogutse, Nucl. Fusion **11**, 67 (1971)

[5] C.D. Beidler, *Neoclassical transport properties of HSR*, IPP-Report 2/331, p.194 (1996)

[6] L.M. Kovrizhnykh, Plasma Phys. Rep. **32**, 988 (2006)