35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.32D, P-4.047 (2008)

A Full F Analysis of Turbulent Transport in the FT-2 Tokamak Configuration

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In the FT-2 tokamak, lower hybrid heating for ions and electrons has been used to trigger an internal transport barrier causing a transition to improved confinement regimes [1] [2]. It is stated that changes in the radial electric field could be responsible for this ITB creation by suppressing the turbulence with strong $E_r \times B$ rotation shear [3]. Neo-classical and micro turbulence effects are expected to play a crucial role in the behavior of radial flows, and as such modeling the interplay of these two effects is of major interest for understanding the radial electric field behavior and ITB creation. Furthermore at the FT-2 tokamak poloidal rotation is measured with Doppler reflectometry [4]. Both phase velocity of the modes and $E_r \times B$ velocity can contribute to the measured poloidal velocity and further analysis is needed to distinguish between the two contributors. In reference [5] studies of the radial electric field dynamics and the poloidal flows in the FT-2 tokamak with the full f gyrokinetic code ELMFIRE [6] were presented. The density and temperature profiles presented in this reference had experianced strong relaxation caused by transport, as shown in Figure 1. In this manuscript de studies presented in refenerce [5] are repeated but this time cooling at the edge and heating at the center is introduced to prevent the density and temperature profiles to change drastically from the initial values, as shown in Figure 2. The results of the new simulation including cooling at the edge and heating at the center (CH case) is compared to the results of the simulation in which relaxation of the input profiles occured (Relax Case).

Simulation profile parameters are again adopted from the FT-2 tokamak and are give by: major radius R0 = 0.55 m, minor radius a = 0.08 m, toroidal magnetic field BT = 2.2 T, total plasma current I = 32 kA with current density profile of $j(r) = j0(1-(r/a)^2)$ and a simulation region of r/a = 0.2 - 0.8 . The distribution function f was initialized with quiescent initialization [6] for specified density and temperature profiles as shown in figure 1for the Relax case and Figure 2 for the CH case. Hydrogen is the only ion specie. For the outer boundary condition the potential was set to zero. On the inner boundary the radial component of the electric field was allowed to vanish. A grid of $41 \times 300 \times 4$ in radial, poloidal and toroidal directions and a time

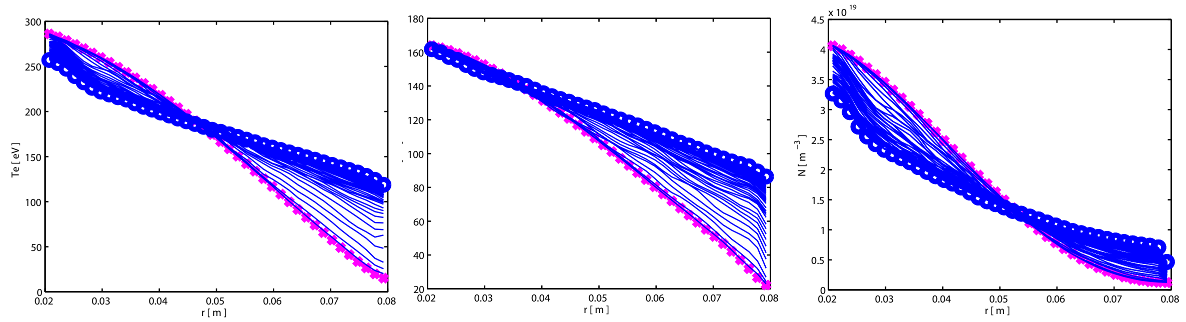

Figure 1: The time evolution of the radial temperature profiles for electrons (Te) and ions (Ti) and density profile for electrons and ions (N) for the Relax case

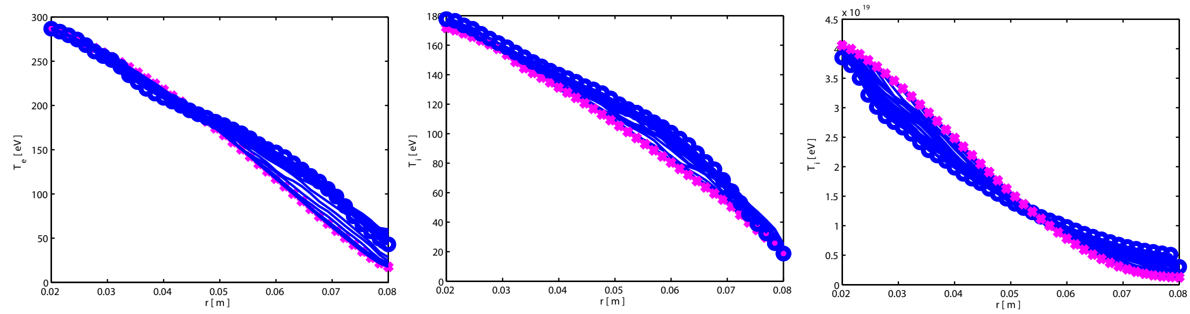

Figure 2: The time evolution of the radial temperature profiles for electrons (Te) and ions (Ti) and density profile for electrons and ions (N) for the CH case

step of $\Delta t = 50ns$ was used. The run was allowed to develop self-consistently with turbulence, trapped particle effects, and electron-ion, ion-ion and electron-electron collisions are taken into account. 110 million test particles are used in this simulation and convergence is reached after $20\mu s$. In the following analysis the CH case and the Relax case are compaired at time $40-50\mu s$.

In figure 3a for the Relax case and figure 4a for the CH case, the flux-surface averaged value from the 3D electric field of the gyro-kinetic (GK) simulation is compared to the neo-classical radial electric field analytically estimated from the analytical theory of Hazeltine-Hinton [7] (HH). In the relax case the radial electric field reaches the value predicted by the neo-classical theory on the left central region of the simulation where in the CH case the overlap region no longer exists. Fluctuations as well as perpendicular turbulent transport may inhibit the neo-classical radial electric field through non-ambipolar fluxes from finite Larmor radius effects, Geodesic Acoustic Mode (GAM) oscillations and Reynolds stresses. For both cases there is a clear GAM oscillation with a frequency around 90 kHz seen in the inner edge which is in good agreement with the analytical estimate of GAM oscillations [8]. These GAM oscillations will contribute to the difference between the analytical and simulated values of the radial electric field seen between r= 0.02-0.03 m in figure 3a and 4a. Another possible contributor is turbulence driven Reynolds stresses [9] and in figure 3/4b the flux surface averaged and time-integrated component of Reynolds stress is shown. This figure shows however, a severe contribution of Reynold stresses in the inner, central and outer part of the simulation and damping phenomena of poloidal flows and Reynold stresses have to be investigated in more detail. From both figure 1 and 2 it is seen that the HC model is influencing the turbulence behavior.If one studies the creation of the radial electric field in time one can see that the Relax case is slitly behind in time. From this result one could concluded that convergence is probably reached later in the CH case.

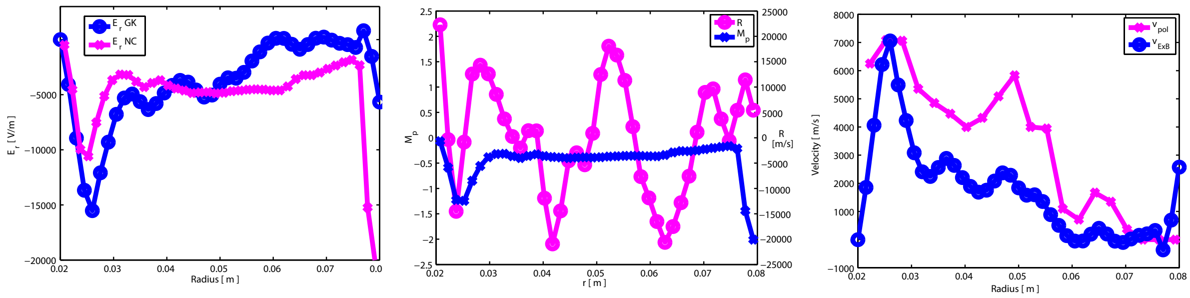

Figure 3: a) Comparison of flux surface averaged Er and the corresponding Hazeltine-Hinton model predictions. b) The poloidal Mach number (M=Er/Bpvt) and the time-integrated Reynolds stress (R). c) The $E_r \times B$ velocity and the poloidal velocity found by correlation techniques for the Relax case.

With the ELMFIRE code one can obtain information on poloidal velocity with the help of correlation techniques and underlying phenomena causing the poloidal velocity can be studied [10]. $E_r \times B$ velocity and the phase velocity of the modes can contribute to the measured poloidal velocity. In figure 3/4a the $E_r \times B$ velocity and the poloidal velocity found by correlation techniques are shown. In the Relax case the outer and inner parts show good agreement but in the central part a difference is found. The poloidal velocity of the modes contain $E_r \times B$ velocity and the phase velocity of the modes and can be studied by the special Fourier coefficients of the density fluctuation in the linear phase of the simulations. As shown in ref. [5] the angular frequency of the modes is found from the slope of the linear fit of the imaginary part of the logarithm of the spatial Fourier coefficients in the linear phase and velocities between 3500-5500 m/s were found, comparable to vpol in figure 3a. From these results we can conclude that, for these simulation parameters, $E_r \times B$ is the main contributor to the poloidal velocity with a medium sized contribution of the modes phase velocity of the modes at the central region of the simulation. In the CH case the observed difference between the $E_r \times B$ velocity and the poloidal velocity is much less. The linear mode analysis however finds similar unstable modes with simular growth rates and angular frequencies as find in the Relax case. This result also supports the theory that convergence is probably not yet reached in the CH case.

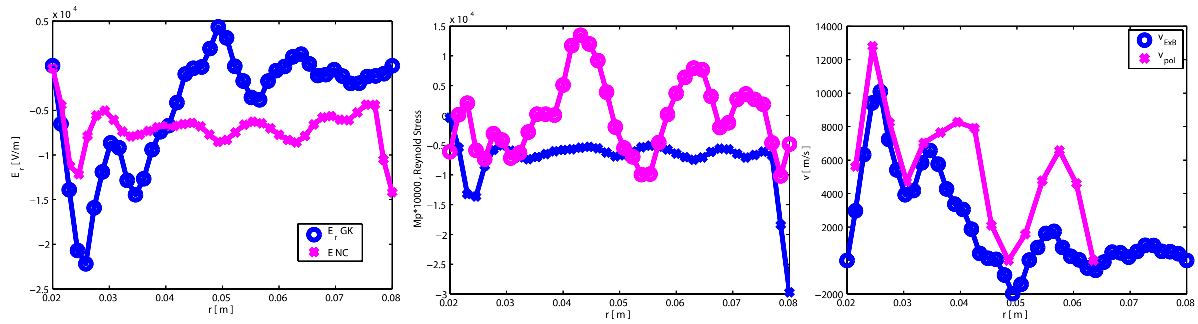

Figure 4: a) Comparison of flux surface averaged Er and the corresponding Hazeltine-Hinton model predictions. b) The poloidal Mach number (M=Er/Bpvt) and the time-integrated Reynolds stress (R). c) The $E_r \times B$ velocity and the poloidal velocity found by correlation techniques for the CH case.

The facilities of the Finnish IT Center for Science have been used for this work. This work was supported by the INTAS grant Nr 05-1000008-8046. We thank Dr. S.I. Lashkul and Dr. V.V. Bulanin for their cooperation.

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