Using Double code to improve the ion temperature calculation in TJ-II stellarator

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Introduction

The TJ-II is a 4-period heliac-type stellarator with major radius of 1.5 m, a bean shaped cross-section with an average minor radius of 0.22 m, and a magnetic field B0=1T [1]. The temperature of the main ion species in the plasma is measured using three neutral particle analyzers (NPA) [2], of which two view the poloidal position (named top and bottom analyzers) and one the tangential position. Then, by assuming that the ion distribution function is Maxwellian the ion temperature can be calculated from the fluxes of neutrals that escape from the plasma at different energies [3].

The Double code is an analytical code developed at the Ioffe Institute [4] which is used to calculate the expected neutral flux in the NPAs. For this it solves the Boltzman kinetic equation, describing the neutral particle distribution in stationary conditions and then integrates the results along an NPA line-of-sight. Using as its input the main plasma parameters and the positions of the analyzers, the code returns the expected neutral flux reaching the
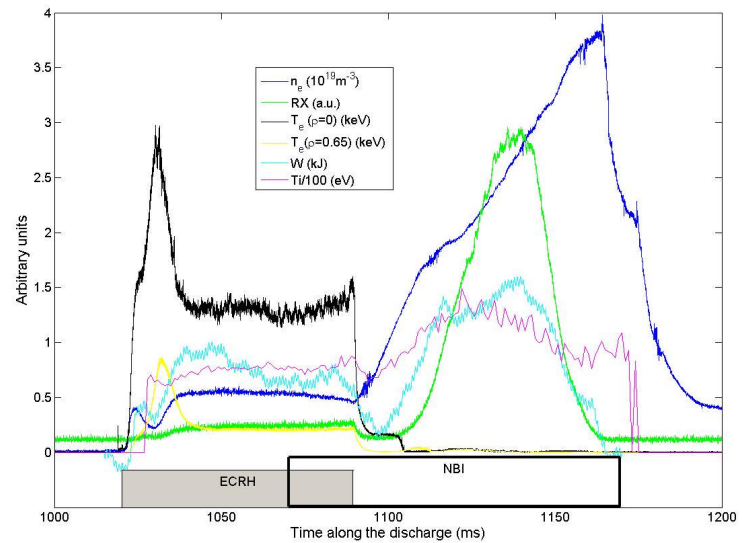

Figure 1: Parameters of the discharges used. In the lower part, there is the heating scheme. In the upper part are depicted the main parameters: line density, soft X-rays, core electron temperature, edge electron temperature, plasma energy and ion temperature.

analyzers, the neutral density in the plasma, the birth place of the neutrals that escape from the plasma and the emissivity. In this work adapt the Double code to simulate TJ-II plasmas and we analyze a series of discharges to verify the calculation of the ion temperature.

Experimental data

At present, the poloidal analyzers measure the flux of escaping neutrals along a discharge at six discrete energies. These fluxes are then used to determine the plasma ion temperature evolution at one plasma radius. Thus, to obtain a radial temperature profile a series of reproducible discharges must be performed and the lines-of-sigth are changed between discharges. In the test case presented here we use a series of 23 discharges varying the vertical position of the two poloidal analyzers shot to shot, thereby obtaining an ion temperature profile with 46 points. The density and electron temperature values are taken from the Thomson scattering diagnostic [5].

The discharges are created by electron cyclotron resonance heating (ECRH) with both gyrotrons heating off-axis and providing 250 kW each. Once the plasma is created the neutral beam injection (NBI) is switched on and after about 20 ms the ECRH is turned off, so thereafter is pure NBI plasma. Note: only the co-injector was used to heat these discharges. The NPAs have a time resolution of 1 ms but the Thomson scattering diagnostic provides only one radial profile per shot. However taking advantage of the reproducibility of the discharges the Thomson scattering diagnostic was fired during the ECRH phase in some discharges and in the NBI phase in others, thus we have profiles in both phases of the discharge.

Results

Experimental ion temperature, electron temperature and density profiles for ECH and NBI plasmas have been used as input parameters for the code. To calculate the ion temperature the the flux values have been averaged in a stationary part of the discharge, in the ECRH phase this average is longer than in the NBI phase because of the fast increase of the density in the NBI part of the discharge. To obtain electron density and temperature profiles the different Thomson scattering profiles have been averaged to obtain an ECRH and a NBI profile for each heating scheme.

The Double code permits changing different parameters to reproduce the neutral fluxes. The most sensitive is the neutral density at the edge. This parameter has been adjusted to reproduce the experimental data. Once the NPA data for one discharge is accurately reproduced all the variable parameters are fixed and the only change considered is the position of the spectrometers. The result of the simulations shows good agreement in both analyzers for all the positions, except for the geometrically upper and lower lines-of-sight where the portion of plasma viewed by the spectrometers is not clear and they may receive neutrals that result from collisions with the vacuum chamber.

The main conclusion from this first set of simulations was the necessity to change the energy used to calculate the ion temperature. Up till now only the four lower energy channels (i.e. from
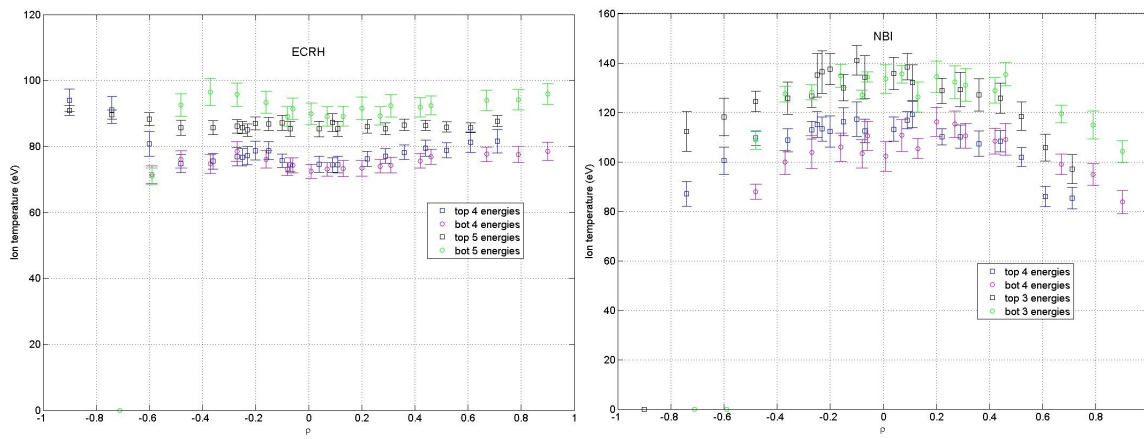
Figure 2: Ion temperature profiles. Left panel ECRH phase and right panel NBI phase. Blue (top) and magenta (bottom) signs values calculated using the four lower energy channels, black (top) and green (bottom) ones using the corrections in the simulations with the Double code. Squares are for the top analyzer and circles for bottom analyzer.

200 eV to 600 eV) have been used, but looking at the results of the simulations it is clear that, in the ECRH phase, the fifth channel also receives thermal ions, so we must include this one on the calculations. On the other hand, in the NBI phase, it appears that the flux collected in the lowest energy channel originates from the edge and not from the plasma centre, as occurs in the intermediate energy channels, so this channel should be removed from the calculations. With these corrections the ion temperature increases by 15 % in both cases. A similar correction has been found in the Globus-M Tokamak when the discharge is analyzed with the Double code [6].
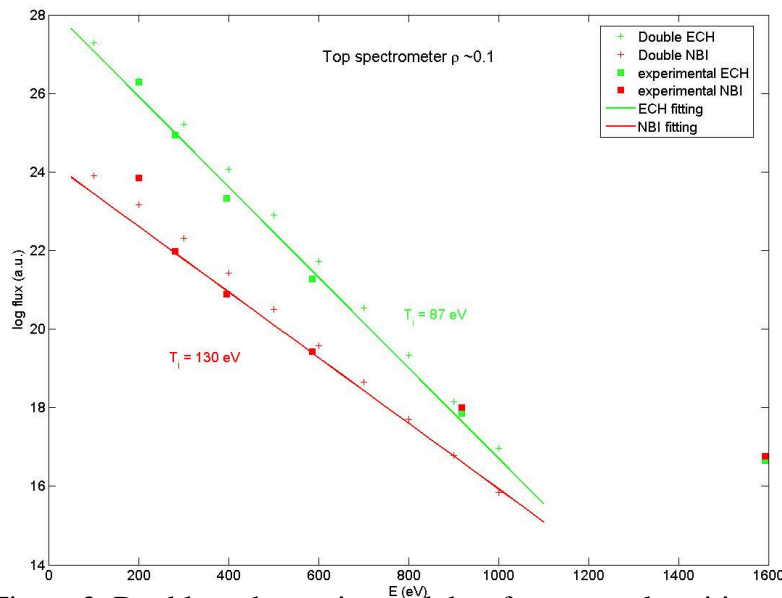

Figure 3: Double and experimental data for a central position of the top poloidal analyzer.

After recalculating the ion temperatures with the new channel configuration the simulations were performed again. For this, the value of the neutral density has been changed to simulate correctly the flux in the NPAs energy channels. As can be seen in figure 3 the new simulations show good agreement with the experimental data. This result is very similar in all positions, in the ECH case the five first channels show good agreement with the simulation whereas in the NBI case the lowest energy channel seems to collect cold neutrals from the edge of the

plasma.

In figure 4 we plot the emissivity of the plasma for the case of figure 3, i.e. top spectrometer looking at a central plasma position ($\rho \sim 0.1$). As the emissivity depends plasma-NPA spectrometer separation in this case the whole plasma diameter has been plotted. The low energy ions, during the NBI heating phase, present the highest difference between the edge and the centre of the plasma, thus indicating that the neutrals collected in the diagnostic come mainly from the edge of the plasma. The medium and low energy ions during the NBI heating are clearly lower than in the ECRH phase, this could be because of the difference in the density, the optical path is thicker so few neutrals can reach the spectrometer.

Conclusions

In this work we have adapted the Double code to simulate the experimental results of neutral particle analyzers in TJ-II stellarator. Even though we simulate a cylindrical plasma, the real TJ-II plasma is a complicated bean-shaped plasma, the results show good agreement between simulations and experiment.The results of the code have been used to improve the calculation of the main
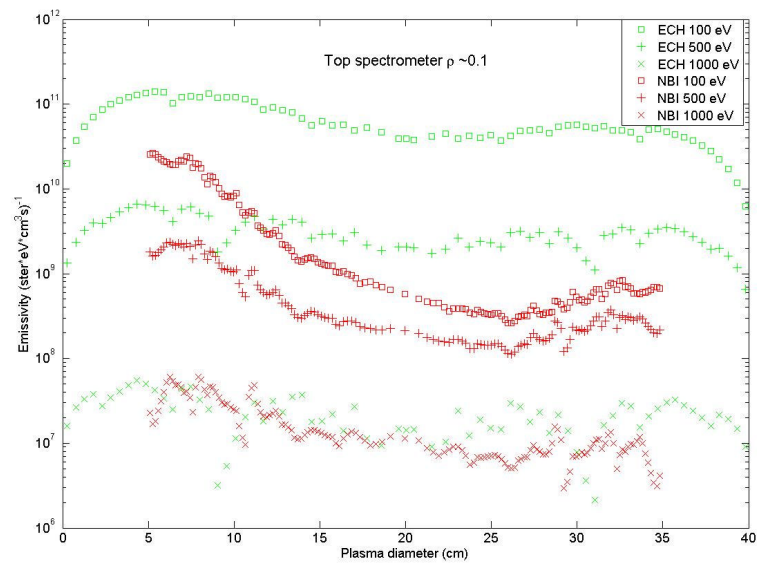

Figure 4: Emissivity for low (100 eV), medium (500 eV) and high (1000 eV) energy ions. The spectrometers are closest to 0 cm. The plasma centre is in 20 cm.

ion temperature of the plasma, giving a correction of about 15% higher in both heating schemes, ECRH and NBI plasmas.

Future work will include simulations for the tangential analyzer and introduce real geometry.

Acknowledgements

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