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Charge Exchange Neutral Particle Fluxes and Poloidal Asymmetries in the TJ-II Stellarator

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Charge exchange neutral particle fluxes and its energy spectra have been measured in the TJ-II stellarator (R = 1.50 m, a < 0.22 m, B < 1.2 T, iota = 0.9 – 2.2) [1]. Hydrogen plasmas were obtained using ECR heating with injected power P_{ECRH} = 300 kW.

Measurements were carried out by two neutral particle analyzers. One of them is a five-energy channel analyzer [2] and another one is an Acord12 [3]. Analyzers can scan a poloidal cross section along a vertical line. This poloidal cross section is very close to the toroidal angle $\phi = 0^{\circ}$. To increase the neutral flux in front of the spectrometer collimator, gas was puffed in the same port of the vacuum chamber during the plasma discharge.

Present experiments have been mainly performed at two magnetic configurations, 100_28_59 with average radius 18.3 cm and 100_16_55 with average radius 14.7 cm, with standard and reversed magnetic fields and comparing separatrix and limiter behaviour. The three numbers in the name refer to the different currents in the TJ-II coils that determine the configuration [1]. First configuration has a central iota of 1.21 and second one has 1.38. None of them present rational surfaces that could induce the presence of islands within the plasma. GradB and curvature drifts are very important in TJ-II and radial electric field tends to diminish the effect of those drifts induced by magnetic field inhomogeneity [4]. Circulating particles will be sensitive to the drifts and so do trapped particles. The magnetic ripple reaches values of about 35 % in the edge, which makes that the fraction of trapped particles in the corners of the device (toroidal angles $\phi = 0^{\circ}, 90^{\circ}, 270^{\circ}, 360^{\circ}$) reaches pretty high values (about 10 % near plasma axis and about between 30 and 40 % near plasma edge).

Average electron densities were ranged $\bar{n}_e \approx 0.5 - 1.2 \times 10^{19}$ m^{-3} and electron temperatures were varied $T_e \approx 500 - 800$ eV. Density $\bar{n}_e > 1.0 \times 10^{19}$ m^{-3} is refered as high density. Preliminary calculations performed with the DOUBLE code [5] for similar plasma conditions provide an upper limit for central neutral density of 5×10^{15} m^{-3}. The ion collisionality is about $\nu_{ii} \approx 3 \times 10^{3}$ s^{-1} which gives $\nu^* = \nu_{ii} / \nu_{bounce} \approx 10^{-1} - 10^{0}$, being ν_{bounce} the bounce frequency, for these configurations and for the typical plasma parameters that are reached in these discharges.

For the general conditions of TJ-II plasma the ion temperature, T_i, measured by both neutral particle analysers is about 100 eV. Plasma size was small enough to allow a complete radial scan in the experiments presented in this work. Since confinement time scales as squared minor radius, plasma density and temperature were lower than under normal TJ-II conditions. An example of a spectrum measured by each analyzer at equivalent positions is shown in Fig.1. The scan along the vertical line to measure the energy distribution of the charge exchange neutral fluxes has provided us with ion temperature profiles. Vertical drifts of trapped particles have been detected under certain conditions. They seem to be in qualitative agreement with the predicted values, shown in Fig.2 [4].

Ion temperature profiles for configuration 100_28_59 are shown in Fig. 3a for both standard and reversed magnetic fields with limiter at effective radius 0.7. The same profiles are shown for 100_16_55 in Fig. 3b for reversed magnetic field with and without limiter. Plasma potential measured by the Heavy Ion Beam Probe HIBP [6] for 100_28_59 is also shown in Fig. 4. It was observed that plasma potential depends highly on density [7] as can be seen in Fig. 5

For the 100_28_59 standard case, with limiter inside the plasma at effective radius 0.7, densities were low, around $\bar{n}_e \approx 0.5 - 0.6 \times 10^{19}$ m^{-3}, the $T_e \approx 600$ - 800 eV and the $T_i \approx 70$ eV+/- 5 eV. There is a voltage drop from limiter to plasma bulk of 600 V approximately for this low density case, as is shown in Fig. 4. For the case of reversed magnetic field, densities are around $\bar{n}_e \approx 0.8 \times 10^{19}$ m^{-3} , $T_e \approx 700$ eV and T_i is slightly higher. The T_i profile is flat for these conditions.

For the 100_16_55 case only reversed field is shown with last close flux surface determined by the separatrix and by the limiter at an effective radius of 0.9. Without limiter, density was around $\bar{n}_e \approx 1.0\text{-}1.2 \times 10^{19}$ m^{-3} and electron temperature was $T_e \approx 700$ eV, and with limiter $\bar{n}_e \approx 0.8 \times 10^{19}$ m^{-3} and $T_e \approx 700$ eV. In the first case T_i profile shows a clear up-down asymmetry while in the second one is flat again. For this magnetic field orientation there are no electric field measurements by HIBP and the only available information is the rotation measurements which give average values at the plasma core around $\omega_r \approx 4 \times 10^5$ rad s^{-1} for the separatrix case and $\omega_r \approx 18 \times 10^5$ rad s^{-1} for the limiter one, both in the sense indicating a positive electric filed. Electron density is not exactly the same but one possible explanation for this increase of plasma rotation could come through an increase in the electric field.

The observed behaviour of the T_i profile can be explained in terms of ExB drifts. As it is seen in Fig.2, where ion drifts are calculated for the case of reverse magnetic field in a standard equivalent configuration, the more energetic ions are expected to be down shifted for the case when electric field is absent. This shift is increased when the electric field is positive and decreased when the electric field is negative. The effect with electric field depends mainly on the ratio V_0/E_i where V_0 is the central potential assuming a parabolic profile decreasing to zero at the plasma border and E_i is the ion energy. The shift is observed when that ratio takes values around 0.4. If the ratio increases the distribution of ions spreads along the whole plasma radius. In the cases presented here we observe high bulk plasma potential, $V_0 \approx 900$ V, and low ion energy, $E_i \approx 100$ eV, for low density and thus $V_0/E_i > 1$. Preliminary results show that the plasma potential profile for the standard 100_16_55 with high density is flat. This fact would justify a rather low electric field in that situation and the more asymmetric T_i profile. In any case, the density dependence of the bulk plasma potential observed in all the cases shows that for high density we observe a rather low plasma potential in some bigger configurations. In all the other low density cases plasma potential decreases with radius giving a bigger electric field, ≈ 50 V/cm, that modifies the ion drifts so that they distribute over the whole plasma radius.

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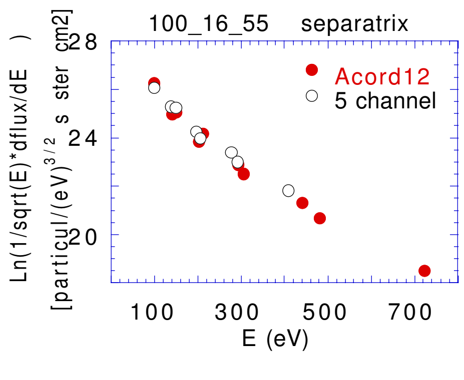

Fig.1 Ion energy spectra measured by both spectrometers looking at the plasma centre at the 100_16_55 configuration without limiter and high density. Deduced ion temperature is in this case (80+/- 5) eV.

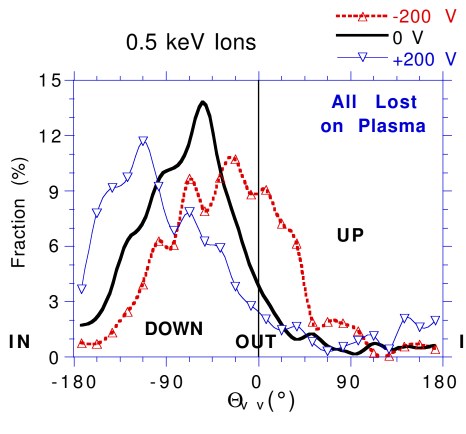

Fig.2 Poloidal profile of the loss distribution at the plasma border (normalized to 100%) for 500 eV ions at several electric potential. The NPAs scan from –90º to 90º.

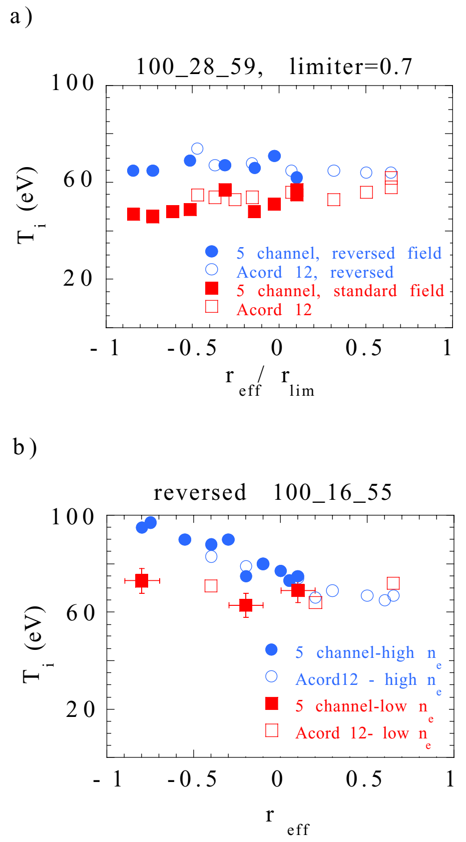

Fig. 3 Radial profiles of ion temperature for two configurations: a)100_28_59 with the limiter at 0.7 and low density in standard and reversed magnetic field and b) 100_16_55 with reversed magnetic field and comparing high and low densities.

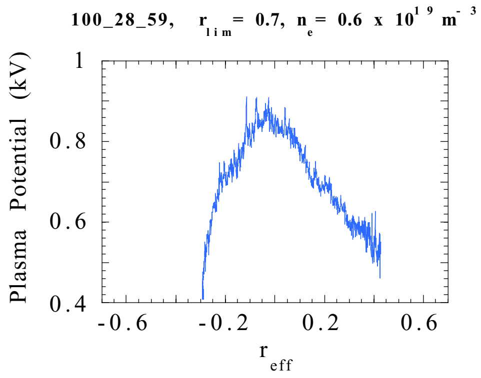

Fig. 4 Radial profile of plasma potential at the 100_28_59 configuration with the limiter at $r_{eff} = 0.7$ and low density.

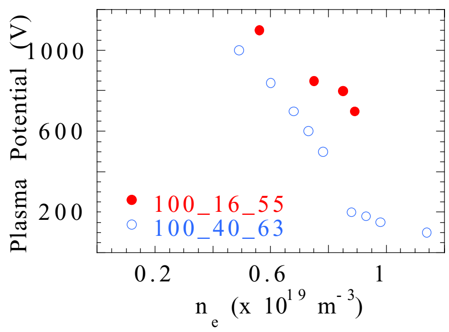

Fig.5 Density dependence of measured plasma potential. 100_40 _63 is one of the biggest configurations that have been characterized by the HIBP and is shown for reference.

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