

An investigation of the relationship between toroidal rotation and bootstrap current in the TJ-II stellarator

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Introduction. The important role of currents in plasmas has been highlighted in several works [1-3]. Whereas in tokamaks they are absolutely necessary, in stellarators can be a drawback since they can perturb the desired magnetic topology. Therefore, their study is essential to understand some aspects of plasma dynamics and, in particular for helical devices with almost flat iota profiles such as TJ-II. In this work, measurements have been made of toroidal rotation velocities for several ions in order to make an experimental estimation for the ion part of this current as well as to attempt to figure out if it can be theoretically explained. Such velocities are directly related to the current by means of shifts in its distribution function by $j = nq \int v_{\parallel} f(v) dv$. The bootstrap current, being a neoclassical effect, it decreases strongly with increasing collisionality. However, since the ion temperature in TJ-II plasmas is much lower than the electron temperature $T_e \gg T_i$ in ECRH operation, it is not expected that the ion part of the bootstrap current has a significant contribution to total current. We extend the toroidal rotation work, previously performed [4], to the problem of estimating the ion current density profile in the TJ-II stellarator.

Results and discussion. Toroidal rotation measurements of protons and impurities have been performed in TJ-II heliac by means of passive emission spectroscopy. An absolutely calibrated single channel spectral system allows to measured averaged toroidal rotation along the line-of-sight [4]; this system has been upgraded to measure rotation profiles on a shot to shot basis by remotely changing the view angle of the line-of-sight. We present, in Fig. 1 a), the time evolution of toroidal rotation velocities in ECRH plasmas. As we can see, typical values are between 10 and -5 km/s, depending on the ion under study. Also, the zero velocity has been calculated for each spectral zone using the calibration lines of a hollow cathode lamp. The positive sign corresponds to the counter-direction of the equivalent plasma current (clock-wise direction). With a positive radial electric field (that is in agreement with preliminary results obtained with the heavy ion beam probe for ECRH conditions) we would expect a toroidal drift in the

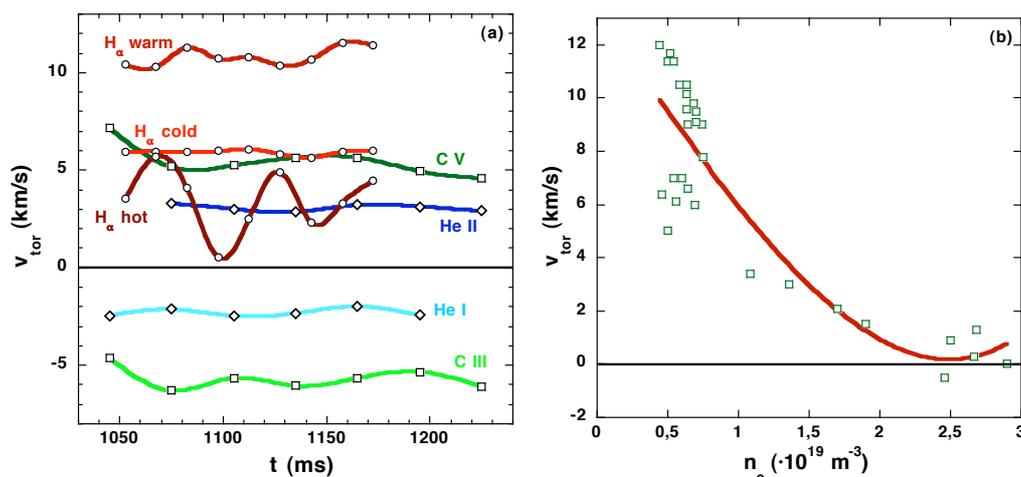


Figure 1. a) Toroidal rotation velocities in ECRH regime from different ions lying at different plasma radii. The exposure time was 15-30 ms. b) Toroidal rotation integrated velocities versus the averaged electronic density for C V.

equivalent plasma current co-direction, which is opposite to our measured toroidal flows. Therefore, other mechanisms must be invoked as the main cause for the observed rotations. Fig. 1 b) shows the behaviour with density of the toroidal velocity for a group of similar discharges of an inner impurity, i.e. C V. In the low density range, $0.4\text{--}0.7 \cdot 10^{19} \text{ m}^{-3}$, velocity changes smoothly with this parameter; however, when the density increases as consequence of the neutral beam injection a more dramatic reduction is observed, since in this regime the density change is more significant due to the density profile peaking. This dependence with electron density, that had been already observed in other devices [5], is directly related to the collisionality, suggesting that the mechanism responsible for the observed flows might be related to bootstrap currents. If

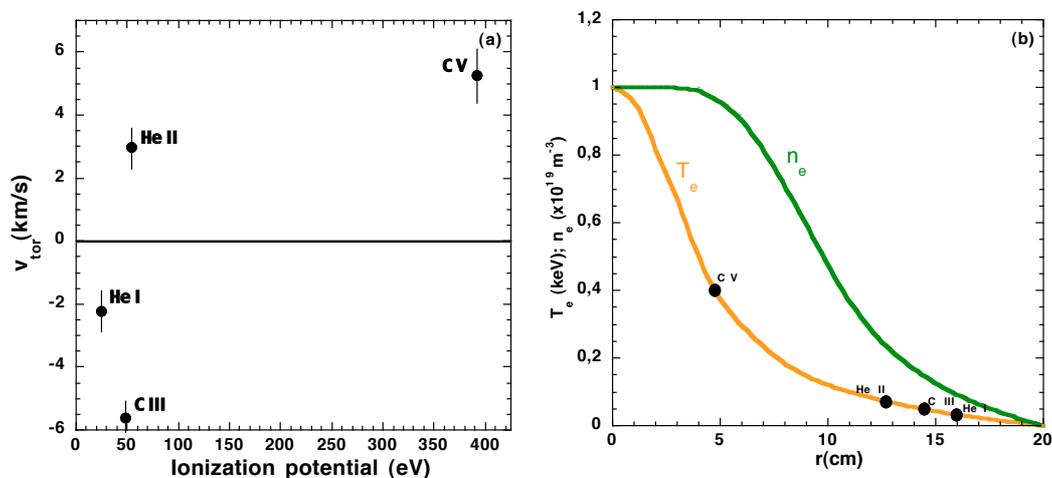


Figure 2. a) Toroidal rotation velocities versus the ionization potential for four types of impurity ions. b) Typical electron temperature (orange line) and electron density (green line) profiles in TJ-II.

we assume that the emission of an ion is located at the position where the electron temperature equals its ionization potential, a rotation velocity profile can be estimated. The impurity rotation velocities are depicted, in Fig. 2 a), as a function of its ionization potential, and the typical TJ-II electronic temperature and density profiles are also displayed in Fig. 2 b). It should be noticed that in a wide range we do not have enough points to cover most of the energies, due to the limited number of ions measured and available within our spectrometer spectral range. The localization of the main ion emission is more difficult, so we must attend to a different criteria based on the formation of the Balmer H_α line. Following the most common criteria [6], the ‘hot’ component emission arises mainly from atoms that have been thermalized via charge-exchange processes so its contribution is coming from the inner plasma whereas the ‘cold’ component is attributed to atoms residing in the plasma periphery.

Both the shape of the rotation profile and its direction suggest a comparison to the ion contribution to the neoclassical bootstrap current [7], and following this hint we have estimated the current density derived from our measured velocities through the simple formula, $j = n_i \cdot q \cdot v_{tor}$, where we have assumed that electron and ion densities are equal,

and that impurities and protons rotates with the same velocity.

We plot, in Fig. 3, the estimated experimental current density profile along with the theoretical neoclassical estimation [7], for the same electron density and temperature profiles. The experimental results are a factor of 2 larger than the theoretical estimation, suggesting that other mechanism should be added to the neoclassical term in order to

account for the observed effect. In fact, this is consistent with detailed and local measurements performed in other stellarators with rather low temperature plasmas [3].

Due to the limitations of the former method to construct a toroidal rotation profile, a first attempt has been made to determine a profile based on measurements performed

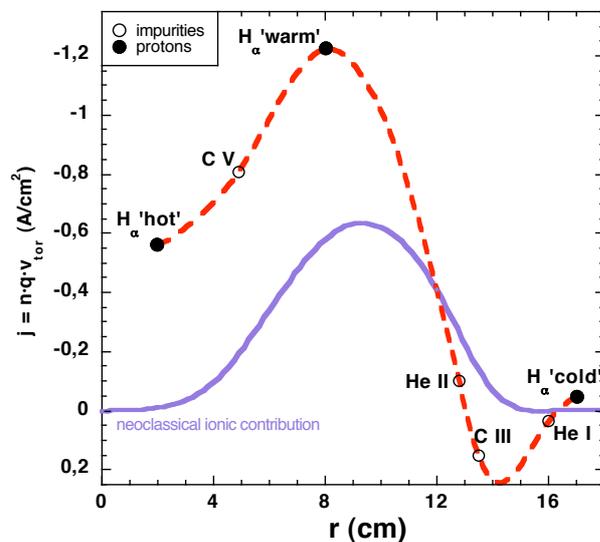


Figure 3. Comparison of the experimental current density, estimated from toroidal rotation of different ions (circles), with the ionic contribution to the neoclassical bootstrap current (solid line).

with a single ion that emits in most of the plasma radii, i.e. C V. We show, in Fig. 4, a raw data profile obtained with such a procedure, that has been converted to current density using the C V flow velocities averaged along the line-of-sight. Further analysis

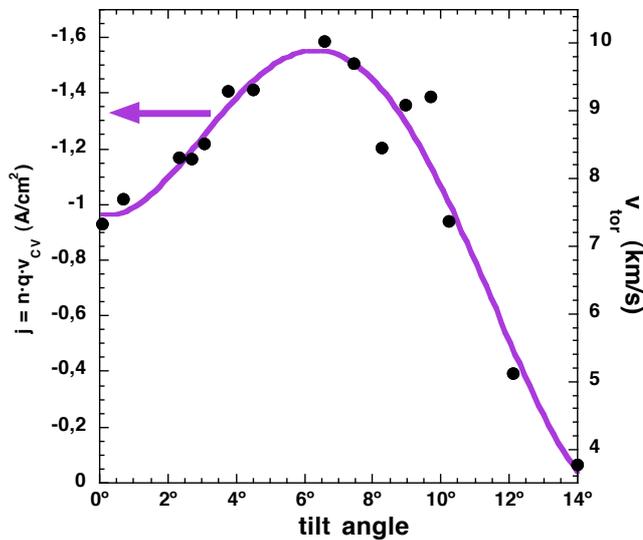


Figure 4. Current density estimates from toroidal rotation of C V averaged along the line-of-sight. A local model is under development to improve this analysis.

of these data in order to make a close comparison with the ion bootstrap current are in progress. It should be noted that both type of data, displayed in Figs. 3 and 4, do not fall to zero in the plasma core in contrast with the neoclassical estimation; this discrepancy has been also observed in some low temperature stellarator [8], where the local current density was measured by probes.

Conclusions. Experimental toroidal rotation velocities are inconsistent with the drift expected by a positive radial electric field. Nevertheless, in ECRH density regime of TJ-II, the current density estimated from rotation measurements is in agreement (within a factor of two) with the neoclassical ion bootstrap current density, except that it does not vanish at the plasma core.

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