STUDIES OF IMPURITY ION ROTATION IN EXTRAP-T2 REVERSED-FIELD PINCH PLASMA

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1. Introduction

The increased interest in the ion flow and temperature measurements in magnetically confined plasmas is a consequence of better understanding of their importance for the global plasma characteristics. In tokamaks strong gradients in radial electric field at the plasma edge leading to strongly sheared **E**×**B** plasma flow are related to H-mode transition [1]. In reversed-field pinches (RFP) sawtooth and mode-locking events are associated with fast changes in the plasma flow profile [2]. Flow and temperature fluctuations are important features of transport and the magnetohydrodynamic dynamo [3]. Recently, regimes of improved confinement accompanied by a modification of the radial electric field shear at the edge has been reported from RFP [4]. The underlying edge plasma physics for tokamak, RFP and also stellarator shows many similarities [5].

In order to study the plasma flow properties at the Extrap-T2 RFP experiment an investigation of impurity rotation characteristics has been undertaken. The plasma edge data from Langmuir probe and emissivity profile measurements together with one-dimensional transport code results are used to obtain a consistent picture of the plasma flow. The measured flow profile shows a strong radial shear with the highest value in the vicinity of the reversal surface where electric radial field (E_r) changes sign. A simulation of the edge plasma flow due to **E**×**B** and diamagnetic drifts has been made.

2. Experimental results and discussion

The toroidal rotation of the plasma is obtained spectroscopically by Doppler shift measurement of line radiation from impurities. Two high-resolution spectrometers equipped with OMA detectors are used to measure Doppler shift of four different impurity lines simultaneously [6]. Two opposite tangential lines-of-sight are used. A perpendicular line-of-sight is used for frequent checking of the positions of the spectral lines from non-rotating ion species. The integration time of a single time point is 0.5 ms and measurements are repeated every 2 ms during the plasma discharge. The relative accuracy of the measured rotation velocities is of the order of 1-2 km/s depending on the intensity of the measured signal. From the Doppler broadening of the fitted lines the ion temperature is also obtained.

The ion rotation velocities are related to the radial electric field and ion pressure gradients through the momentum equation. The toroidal flow of impurity ions should to a good approximation reflect those of the majority ions in the plasma [7]. The parallel (to the magnetic field) velocities should be almost equal due to the friction force on the small population of the impurity ions from the majority ions (the calculated collision equilibration time for carbon and

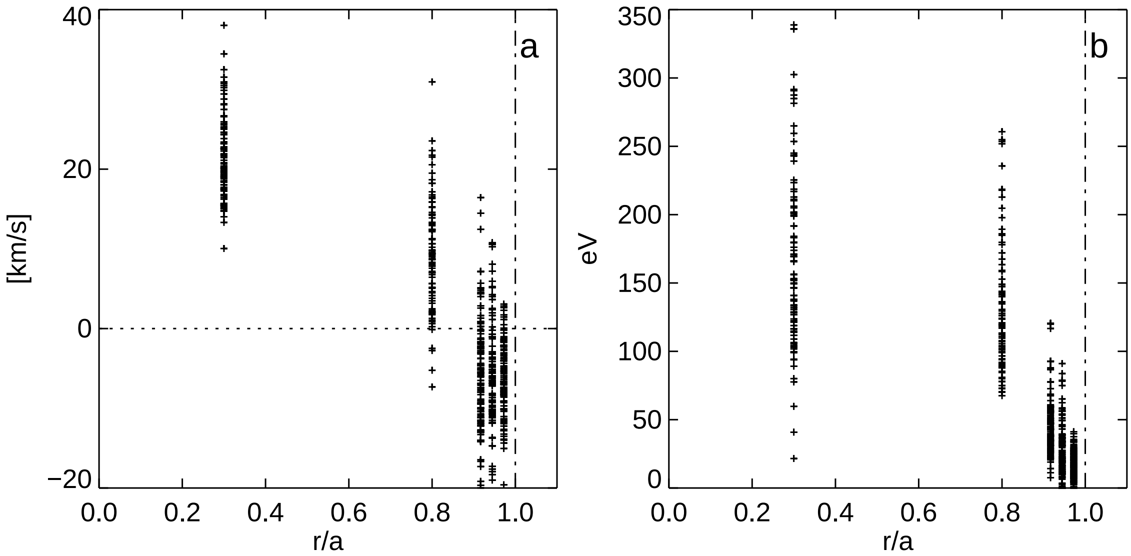

Figure 1. Ion rotation velocity (a) and temperature (b) for an ensemble of 150 kA discharges. Each ensemble is plotted at the normalized radius at which the ion is estimated to occur. From center to edge: C^{4+}, O^{4+}, O^{2+}, C^{2+} and C^{1+}.

oxygen impurity ions with the majority protons is less than 100 μs). Since the $\mathbf{E}\times\mathbf{B}$ drifts are identical the difference in toroidal flows between majority ions and impurities is due to diamagnetic drifts. In the core the difference in diamagnetic drifts between impurity species and majority ions is small compared to the $\mathbf{E}\times\mathbf{B}$ drift. The edge impurity species have locally peaked pressure profiles with both positive and negative pressure derivatives which cause locally opposing Doppler shifts. The local diamagnetic drifts should average to approximately zero giving only contribution to a slight increase of the measured ion temperature. This can also be seen in the results of the simulation of the edge plasma flow. Consequently the measured toroidal rotation of edge impurity ions should probably also represent the flow of the majority ions.

In Fig. 1 a) and b) we show a range of toroidal rotations and ion temperatures measured for a series of standard 150 kA discharges in hydrogen. C^{4+} and O^{4+} representing the plasma interior and O^{2+} and C^{2+} representing the plasma edge are measured simultaneously. Additionally C^{1+} and O^{4+} are measured simultaneously in a separate series of similar 150 kA discharges. The radial positions of emission peaks for all the impurity ions are obtained from transport code simulations and can also be measured with five chord spectroscopy [8].

The highest toroidal rotation is observed for C^{4+} which is present in the plasma core, the positive drift being by definition in the plasma current direction. The core toroidal rotation velocity is decreasing with increasing electron density, but no scaling of the core rotation with the plasma current is found, similar results have been obtained in the RFX plasma [9].

O^{4+} radiating from approximately r/a=0.8 shows, on the average, lower rotation velocities and can occasionally rotate even in the negative direction. For O^{4+} the highest rotation velocities are related to highest ion temperatures. For O^{2+} and C^{2+} no clear correlation of rotation with ion temperature is observed. However for C^{1+}, which is present closest to the wall, there is a tendency of higher negative rotation with increasing ion temperature, which could be due to the increasing distance to the wall of the C^{1+} emissivity profile.

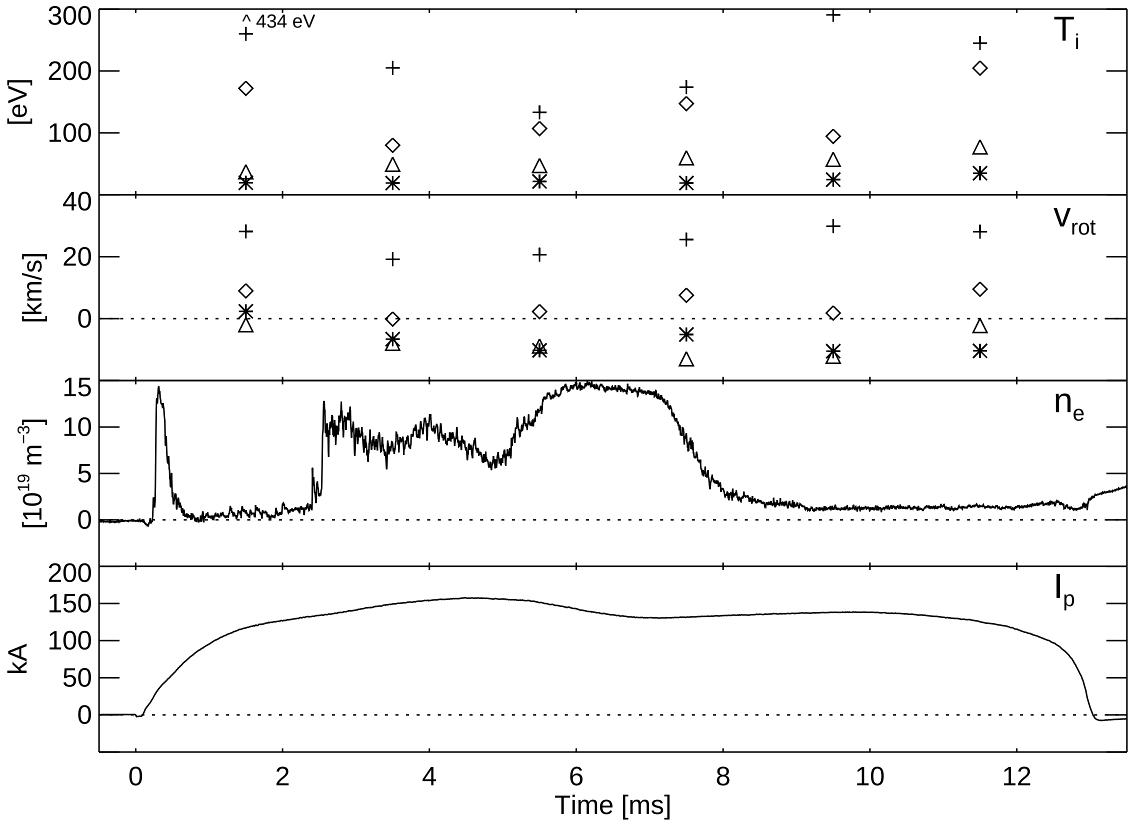

Figure 2. Ion temperature and toroidal rotation for C^{4+} ($+$), O^{4+} ($\diamond$), O^{2+} ($\triangle$) and C^{2+} ($*$) from discharge #6284. The electron density and plasma current are also shown.

For strong influxes of carbon, associated with plasma-wall interaction, the measured toroidal velocities of both C^{1+}, C^{2+} and even O^{2+} show tendency of decreasing down to zero. Associated ion temperatures for the edge ions are also decreasing rapidly. If the core ions are not strongly affected at the same time the plasma can still survive for several milliseconds. If the core ions are showing strong change in both rotation and temperature due to such an influx a fast termination of the discharge will follow.

A strong rotation shear is observed at the radial position between O^{2+} and O^{4+} ions. From the Langmuir probe measurements the profiles of edge electron temperature and edge electric field are obtained [10]. A minimum in the plasma potential is found at r/a=0.93 with E_r(r/a$<$0.93) about 6.0 kV/m and E_r(r/a$>$0.93) about -4.4 kV/m. The observed electron temperatures at the plasma edge are roughly equal to the average ion temperatures at the estimated radial position of the emission.

Fig. 2 shows a discharge with a sudden, massive increase in electron density at $\sim$2.8 ms. As a consequence of this the ion temperature of C^{4+} and O^{4+} decrease. Also the rotation velocity is influenced in the same way. Since spectroscopic diagnostics at other toroidal positions than the interferometer are not affected it is likely that the density increase is localized. The measurement of the radial distribution of the O^{4+} emission shows that the radial position of the light emission follows the change in rotation velocity for this discharge (Fig. 3), i.e. increased radial position of the emission is coupled to the lower rotation velocity. Similar relations are observed for other discharges as well.

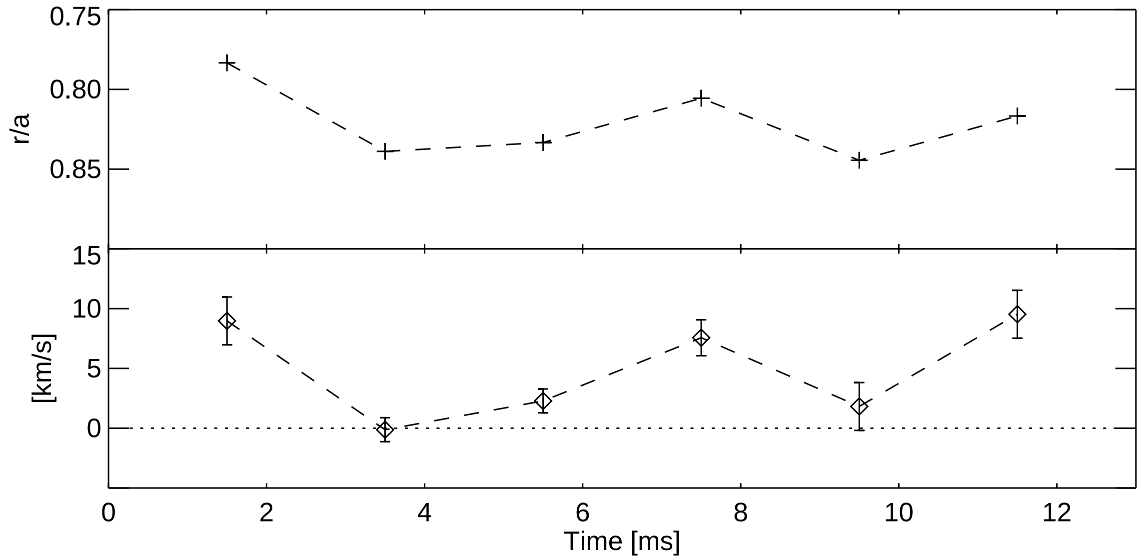

Figure 3. A comparison between the position of maximum emission (top) and the ion rotation velocity (bottom) for O^{4+} in discharge #6284. The position of the emission is measured with the radially resolved spectroscopy system [8]. Since the measurement is made during one plasma discharge the relative change in position should have good precision.

3. Conclusions

Toroidal rotation flow has been studied in the Extrap-T2 plasma. A presence of a velocity shear of the order of $\sim 10^6$ sec^{-1} at the plasma edge in the vicinity of the reversal surface has been found. A dependence on the electron density of the core rotation velocity has been observed. The simulations of the observed edge plasma flow are consistent with a radial electric field obtained from Langmuir probe measurements. Measured emissivity profiles for O^{4+} follow the observed toroidal rotation changes.

The future effort will be put in evaluation of rotation influence on the global confinement properties of the Extrap-T2 plasma. An attempt to quantify the effects of wall locking on the plasma rotation shear will also be made.

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