FIRST POLOIDAL ROTATION MEASUREMENTS IN THE TJ-II FLEXIBLE HELIAC

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Introduction. The main motivation in obtaining poloidal rotation measurements in present fusion devices is to obtain information about the radial electric field. Neoclassical theory suggests that in stellarators the electric field reduces helical ripple loss and consequently improving plasma confinement. Poloidal rotation measurements have been reported in ECR heated plasmas in stellarator devices but as they were made using passive emission spectroscopy of ions that emit in the visible most of the results obtained are from the plasma periphery. For example, in the Heliotron-E device, the radial electric field at r $\approx$ 0.7-0.9<a> was found to be positive (the electron root) in low density plasmas (n_e < 1x10^{13} cm^{-3}) and negative (the ion root) in high density plasmas (n_e > 2x10^{13} cm^{-3}) [1]. In electron cyclotron heated (ECH) plasmas ($n_e \approx$ 5x10^{13} cm^{-3}) in the Weldelstein VII-A stellarator, the negative electric field observed was consistent with theoretical predictions [2]. In the Advanced Toroidal Facility, a positive electric field was observed in ECH low density plasmas ($n_e \approx$ 5x10^{12} cm^{-3}) in measurements made using a heavy-ion beam probe technique [3]. Here, we report on the first measurements of poloidal rotation of impurity ions in the TJ-II flexible Heliac from which we estimate the sign and magnitude of the radial electric field. In addition, we describe the experimental set up used and finally we discuss the results obtained in TJ-II in the context of results from other stellarator devices.

Experimental. TJ-II is a low magnetic shear stellarator of the Heliac type with an average major radius of 1.5 m and average minor radius of $\leq$ 0.22 m. The plasma is created and heated by 250 kW of ECR power at 53.2 GHz perpendicularly injected and tuned at the second harmonic. This experiment was carried out using standard TJ-II configurations (1): 100_50_65 with an iota of 1.61 at the centre and 1.73 at the edge; and 100_40_63 with slightly lower iota values.

The poloidal rotation of TJ-II plasmas were studied by measuring the line shift of the 227.1 nm C V line. Two different experimental system have been used for this purpose. Measurements, made during the first campaign and employing the ECRH line QTL-1, were obtained using a 1 m spectrometer equipped with a 2400 g/mm grating working in 2nd order and by using a shot by shot technique to scan the plasma cross section. This system has an intensified photodiode array at its focal plane that integrated spectral emissions for several

successive temporal windows (20-50 ms) along the duration of a typical discharge (≤ 250 ms). This system, described in more detail in Ref. (5), has the advantage of using the entire height of the input slit for light collection for each experimental chord, and therefore its throughput is higher than that achieved using a multichannel system. However, it relies on a shot to shot technique to scan the plasma cross section which consequently needs thermal correction of the data during the whole sequence to obtain a profile. A sketch of the scanning geometry of this system with respect to the plasma configuration is shown in Fig. 1.

During the second TJ-II experimental campaign, the QTL-2 ECRH line was used to heat plasmas and measurements were performed with an eight channel system that allows profiles to be obtained in a single shot but without time resolution. Note: this heating system uses a gyrotron that is similar to QTL-1 and an optic system that is capable of higher power densities. In this case, we used a 1 m image corrected spectrometer with a CCD mounted at its focal plane. The detector was mounted in a manually adjusted optomechanical system that allows for fine focusing and rotation. A set of 8 fibre channels were attached on one end to the spectrometer input slit while on the other end they viewed a set of 8 parallel chords through the plasma. The tip of each fibre was focused on a few millimetre diameter circular spot in the plasma by means of a single quartz lens for each channel. The relative sensitivity and residual shift of each channel were calibrated using a long Hg lamp and the He emission of the cleaning glow discharge and good agreement was achieved with both methods.
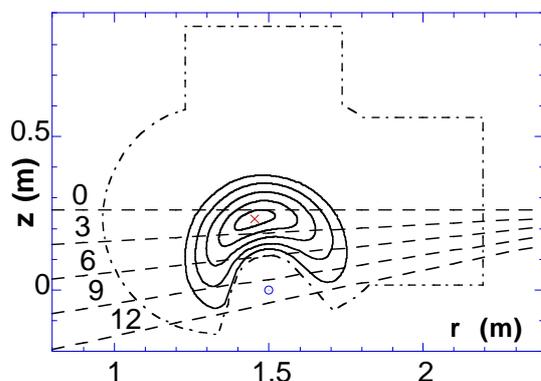

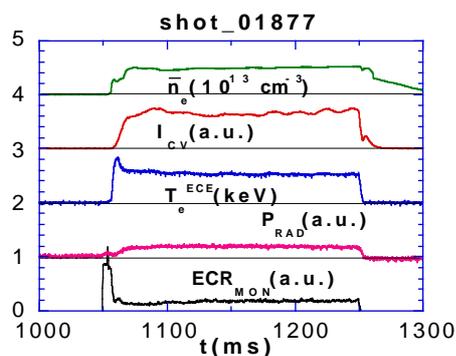**Fig. 1.** Sketch of the observation geometry with the fan observation of the shot to shot method.

Fig. 2. Typical traces of an ECRH TJ-II discharge in which rotation measurements have been performed.

Results. We first present some typical results obtained during the first campaign with the time resolution system where we measured C V (2271 Å) shift profiles as a function of time along a fixed chord through the TJ-II standard configuration. Typical results obtained when measuring along an intermediate and a peripheral chord are shown in Figs. 3 and 4; open symbols correspond to chord-integrated emission (circles) and ion temperature (triangles), rotation is depicted by full points. Higher velocities are found at the beginning of the

discharge while lower but somewhat oscillating rotation velocities are observed along the rest of the discharge. For these, the photon emission was integrated in 50 ms windows and the chord angle was varied using a mirror, (see the alpha angles of Fig. 1).
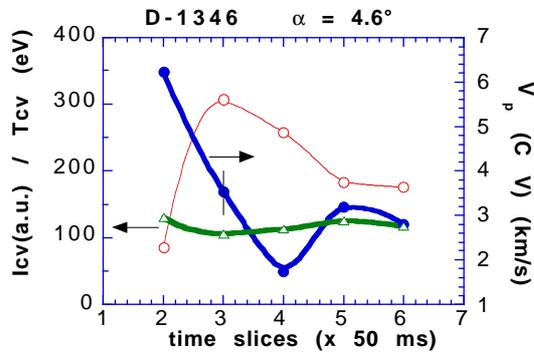

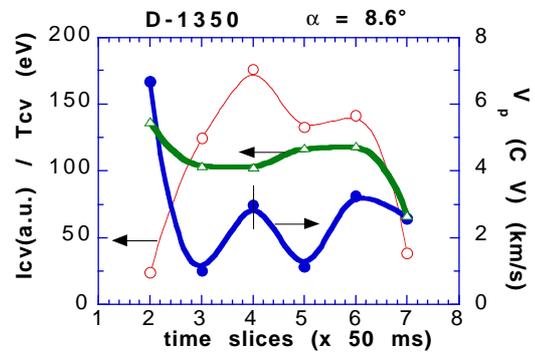**Fig. 3.** Plot of time evolution of chord-averaged C V intensity (o) rotation velocity (•) and T_i.

Fig. 4. Similar plot for a peripheral chord, nominal plasma edge is at $\alpha \approx 10°$

We have obtained, using a set of reproducible discharges, several discrete profiles for a plasma in the 100_50_65 configuration and with electron densities $\approx 0.5 \times 10^{13}$ cm^{-3} and a central T_e of 450 eV. A typical averaged profile, for the plasma plateau, that covers the plasma from its centre to the lower tip of the bean-shape plasma is shown in Fig. 5. The jump observed close to the 5° chord corresponds to the zone close to the TJ-II hardcore groove. Finally, in Fig. 6, we show the C V poloidal rotation time evolution along different plasma chords measured with this system.
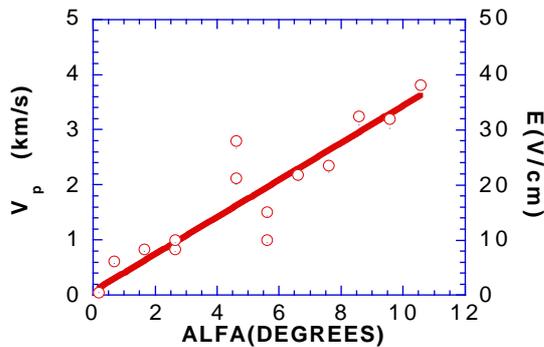

Fig. 5. Profile of chord-averaged C V poloidal rotation as a function of the line-of-sight angle.
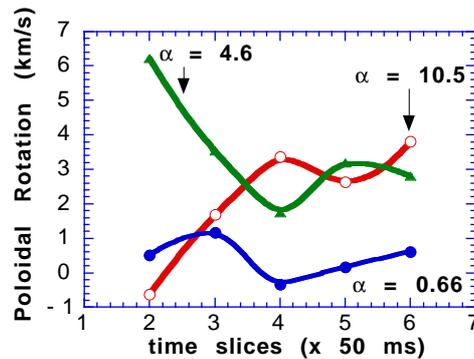
Fig. 6. Time evolution of C V poloidal rotation for three different plasma chords.

In Figs. 7 and 8, we present the first results obtained with the multichannel system described previously. In Fig. 7, we show the chord integrated profiles of the C V 227.1 nm line emission with the poloidal rotation velocity deduced from the spectral shift of this line for the 100_40_63 plasma configuration. Here, positive velocities are associated with ion-diamagnetic drift direction or positive radial electric fields (the lower part of the plasma is moving towards the observer for a counter-clockwise toroidal field). The emission was

integrated for 150 ms along the plateau. The maximum emission for this discharge corresponds to a chord passing at a distance approximately 7.5 cm below the magnetic axis; the central temperature of this discharge is $\approx$ 690 eV. In Fig. 8, we plot, for different discharges, the poloidal rotation obtained along chords where the C V emission is maximum versus the central temperature of the plasma as measured by electron cyclotron emission. In this figure, we can see that the rotation velocity changes between 2 and 8 km/s and is higher for hotter plasmas. If we assume that the rotation is dominated by ExB then the resulting positive radial electric field displayed in the right vertical axis of this figure, varies between 20 and 80 V/cm. The line drawn in this figure is only a guide for the reader. The maximum line-averaged densities of those discharges are between 0.5 - 0.9x 10^{13} cm^{-3}.
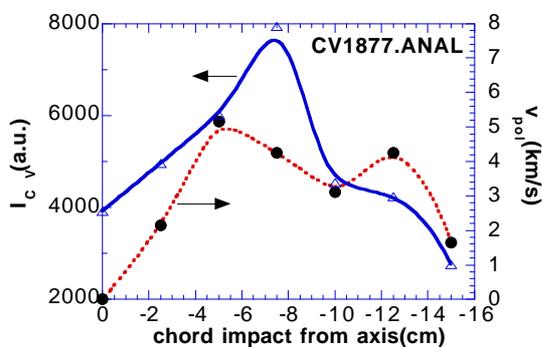

Fig. 7. Plot of the CV poloidal velocity and intensity (chord-averaged) obtained with a multichannel system.
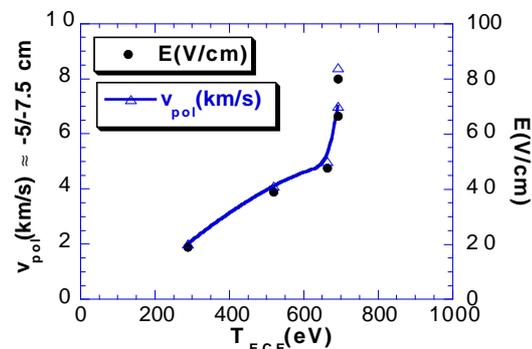
Fig. 8. Plot of the CV poloidal rotation vs. $T_e(0)$ for a few discharges.

In conclusion, we have measured, for the first time, the poloidal rotation of an ion that is representative of TJ-II. This ion rotates in the ion-diamagnetic drift direction consistent with positive radial electric fields of tens of V/cm similar to other stellarators. These data were taking while the TJ-II was being tuned to understand TJ-II plasma operation and therefore they do not necessarily represent the best discharges which can be achieved in this device.

References

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