Spontaneous plasma rotation in limited and diverted TCV ohmic discharges

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Introduction. This paper compares measurements of intrinsic toroidal plasma rotation in the TCV tokamak for limited and diverted magnetic configurations. Toroidal rotation profile were measured in ohmically heated L-mode configurations (no external torque applied) by a Charge eXchange Recombination Spectroscopy diagnostic in a previously described experimental arrangement [4]. For ohmic TCV discharges with $\overline{n}_e$ up to 8×10^{19} m^{-3} an experimental uncertainty of 2 krad/s is regularly achieved around the plasma centre and 5 krad/s at the plasma edge. High spatial resolution measurements in the edge region were obtained by vertically displacing the plasma axis such that the diagnostic chords observe the plasma edge (Fig. 1).

Limited Ohmic L-mode. Stationary toroidal rotation profiles have been studied as a function plasma current I_p and electron density n_e, for steady state discharges. For plasma currents $I_p <$ 380 kA and central densities up to 8×10^{19} m^{-3} the plasma is found to rotate in the counter current direction (electron diamagnetic drift direction, negative values), with absolute values ω_ϕ up to 40 krad/s, in the centre of the plasma, decreasing to ≈ 0 krad/s in the edge region [1]. The rotation profile is flat or hollow inside the sawtooth inversion radius and peaks at low plasma currents when the q=1 surface is absent.

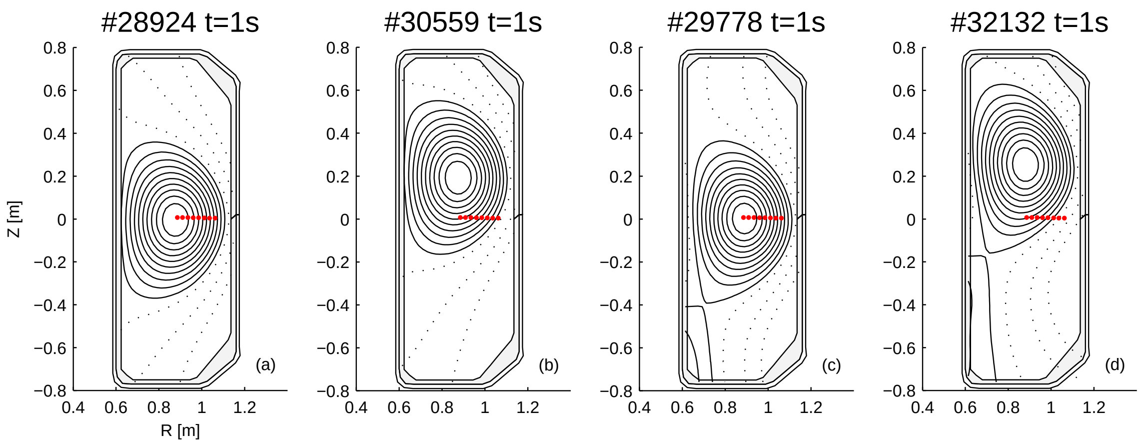

Figure 1: Magnetic configurations in TCV limited (a,b) and diverted (c, d). Red dots indicate the CXRS measurement locations.

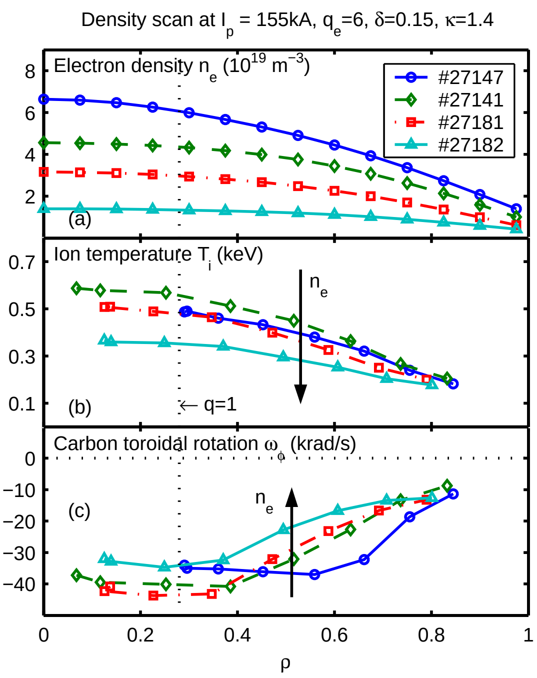

Figure 2: n_e, T_i, ω_ϕ profiles, for a density scan in limited configuration. In shot 27147 an MHD mode flattens the ω_ϕ profile outside the inversion radius.

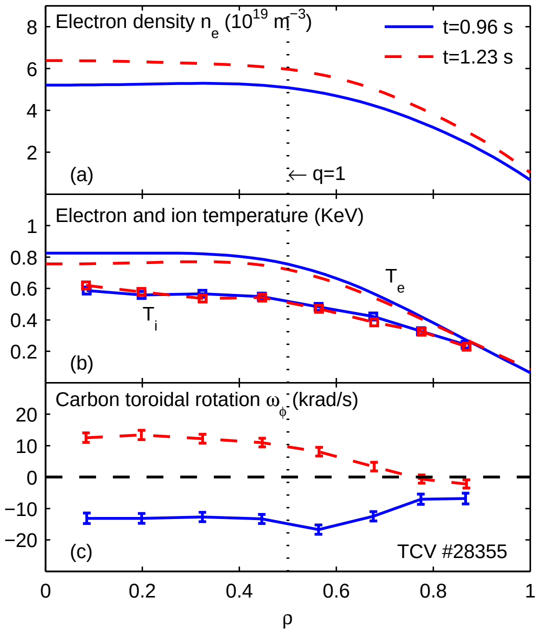

Figure 3: n_e, T_i, ω_ϕ profiles for co and counter current regime in limited configuration.

As observed in other tokamaks, the toroidal rotation profile is strongly linked to the ion transport. Outside the inversion radius, the stationary rotation profile follows the T_i profile, and the maximum absolute rotation is found to linearly depend on the ion temperature, summarised by a scaling law proposed in [1], $v_{\phi,Max}$ [km/s] $= -12.5T_{i,max}/I_p$ [eV/kA] where $v_{\phi,max} = \omega_{\phi,max}R$ is the maximum toroidal velocity, $T_{i,max}$ the maximum ion temperature and I_p the plasma current. The dependence on n_e has been investigated using a steady state density scan at fixed $I_p = 155$ kA. The ω_ϕ profile is always negative and depends weakly on the electron density (Fig. 2); in particular, the rotation at $\rho \approx 0.9$ appears independent of n_e, with values ≈ 10 krad/s. The increase of ω_ϕ may be attributed to the increased T_i from the increased thermal coupling to the electrons.

This behaviour changes when high density ($n_{e0} > 6\times10^{19}$ m^{-3}) and high current ($I_p >$ 290 kA) are simultaneously attained. A different regime occurs, with the central toroidal rotation now directed with the plasma current (ion diamagnetic drift direction)[2]. The dashed solid curve in Fig. 3c shows the rotation profile measured, after increasing n_{e0} from 5.2 to 6.4×10^{19} m^{-3}. The plasma core now rotates in the ion diamagnetic direction up to $\rho \sim 0.8$ with a flat or slightly centrally peaked profile, and a central velocity of ~ 12 krad/s. The outermost CXRS measurements suggest a rotation in the outermost plasma region still counter current,

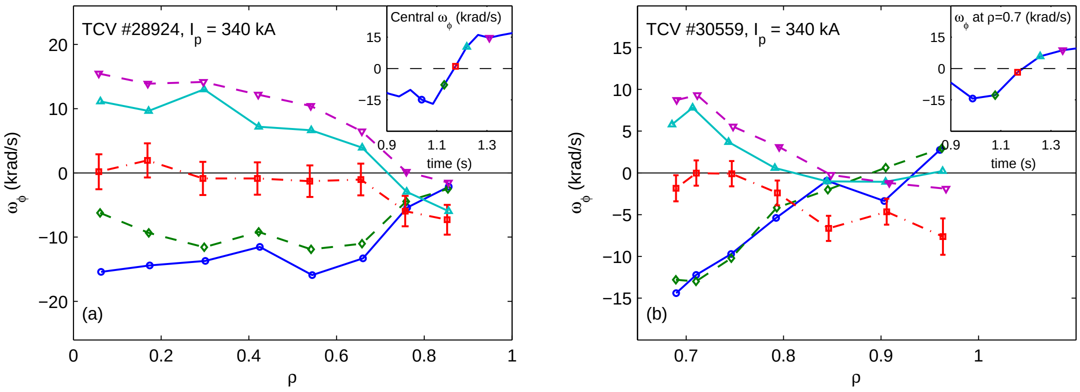

Figure 4: Temporal evolution of ω_ϕ profile during a rotation inversion in limited configuration, measured in the core (a) and in the edge region (b).

to within the error bars. The two rotational states occur for similar temperature and density profiles (Fig. 3a, b), both flat inside the sawtooth inversion radius. In the central region, T_e is only slightly decreased. In particular the T_i profile is constant across the transition, within the measurement uncertainty.

The balance of momentum fluxes and sources was investigated by inducing transitions between the two regimes by means of density ramps. Fig. 4a. shows the evolution of the ω_ϕ profile during the inversion: a change in the rotation profile first occurs in the centre with the plasma core accelerating rigidly in the co-current direction. Intermediate profiles indicate a transitory counter current acceleration for $\rho > 0.8$, that was confirmed by high spatial resolution edge measurements (Fig. 4b): the edge rotation value recovers after rotation inversion, when the rotation profile is positive for $\rho < 0.85$. This is not consistent with a diffusive flux of positive momentum from the plasma edge and suggests that when traversing the n_e threshold, a different balance of non diffusive momentum fluxes is established in the plasma central region. The transient edge acceleration can be explained as a conservation of the total momentum, which is then dissipated on longer timescales.

Diverted ohmic L-mode. The dependence of the plasma density on the stationary rotation profile was extended to diverted magnetic configurations. Fig. 2 shows the results of a shot by shot n_e scan on a $I_p = 255$ kA target discharge ($\delta = 0.3$, $\kappa = 1.4$). For the presented discharges $\mathbf{B} \times \nabla B$ was directed away from the X point. For central density up to $n_{e0} = 6 \times 10^{19}$ m^{-3}, plasma column rotates in the current direction, with central velocity of $\omega_\phi \approx 20$ krad/s. The rotation profile is positive and peaked, even for I_p and n_e lower than that required for rotation inversion in the limited case. The outer CXRS measurement at $\rho = 0.85$ indicates rotation is positive with values of $\omega_\phi = 7 - 12$ krad/s. Edge measurements for vertically displaced plasmas confirmed a positive rotation > 10 krad/s up to $\rho = 1$, for $n_{e0} = 4 \times 10^{19}$ m^{-3}.

With increasing density, the whole rotation profile rigidly decreased, with, in particular, a decrease in the edge rotation (12 to 5 krad/s, passing from 4 to 8×10^{19} m^{-3} on axis), not observed in the limited case (Fig. 2). This suggests that the edge rotation may act as a boundary condition for ω_ϕ profile. Whereas, with a limiter, the plasma wall interaction constrains the edge rotation to values close to zero, in diverted configurations edge rotation is freer to adapt to the plasma processes. The shape of rotation profile may be then determined by the internal transport of toroidal momentum, which depends on plasma parameter profiles (n_e, T_e, T_i). Increasing the density further to $n_{e0} = 8\times10^{19}$ m^{-3} resulted in a new inversion of the rotation profile (magenta curves in Fig. 5), which now become similar to those measured with a limiter. This, relatively recent, observation is under investigation but does not disagree with [3], where similar ω_ϕ in the core was measured for high density plasmas in limited and diverted Ohmic L-mode discharges.

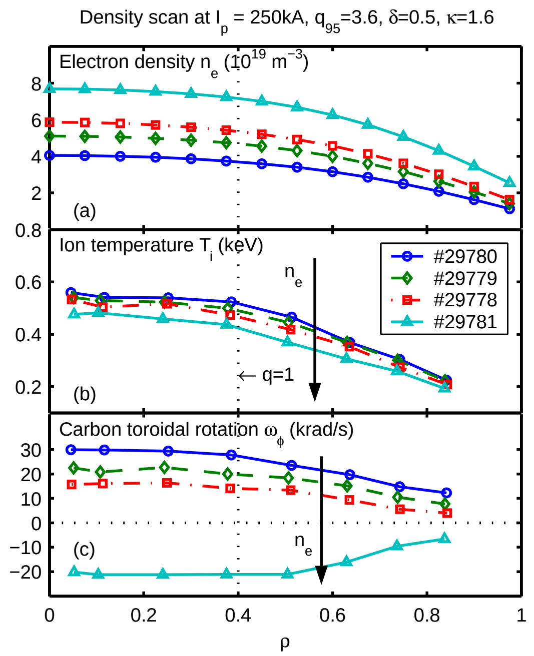

Figure 5: n_e, T_i, ω_ϕ profiles, for a density scan in diverted configuration.

Conclusions. Extended measurements of the intrinsic toroidal rotation in the TCV tokamak reveal a varied phenomenology. Co and counter current toroidal rotation regimes are found in both limited and diverted configurations by varying the plasma parameters. The physical mechanisms that generate the intrinsic toroidal momentum within the plasma are still not identified. The comparison of limited and diverted stationary ω_ϕ profiles, indicates that the plasma edge is constrained to values close to zero in the limited case, while in the diverted configuration it may vary with the plasma parameters, acting as a boundary condition to the ω_ϕ profile. Experiments are planned to investigate the role of the $\mathbf{B}\times\nabla B$ direction and possible coupling of plasma edge to the parallel fluxes in the scrape-off layer.

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References

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