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The Relation between Global Confinement and the Shear of the Radial Electric Field with RMP at the Tokamak TEXTOR

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Introduction

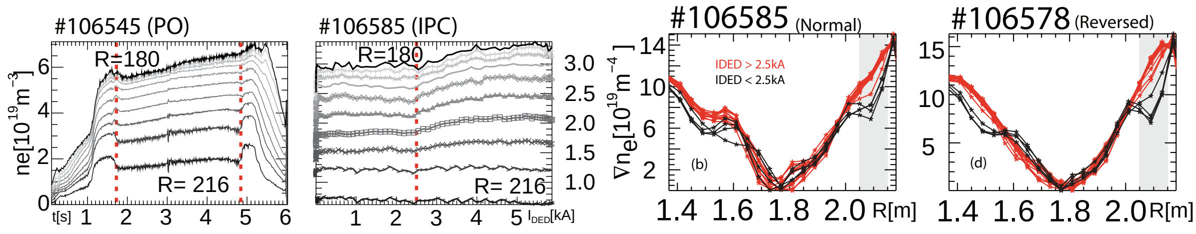
Resonant Magnetic Perturbations (RMP) are a method to control the plasma edge. Understanding the transport changes due to RMPs is a potential key to safe tokamak operation [4]. At TEXTOR the influence of RMPs is investigated with means of the Dynamic Ergodic Divertor (DED), which can be operated with different toroidal (m) and poloidal (n) modes(m/n)[5]. The $12/4$ mode gives a very shallow stochastic zone, while for $3/1$ operation a deeper penetration is given. During DED operation a significant influence on the poloidal (v_θ) and toroidal v_ϕ rotation is visible ($\mathcal{O}(1\text{ km}, 10\text{ km})$). The E_r increases with RMP and the $E\times B$-shear rate can changes locally at q=5/2 ($\Delta\Omega_{E\times B} = 1.5\cdot 10^5 s^{-1}$) [2].

We present an analysis of the radial electric field (E_r) under confinement transitions at TEXTOR. The improved particle confinement (IPC) with sudden increase in density and particle confinement and the so called particle Pump Out (PO) with decreased particle confinement are induced by applying external perturbation via the DED [10]. The analysis studies the changes in the radial electric field contributions coinciding with those transitions (IPC,PO). With radial profiles of the electric field a relation between the confinement stages, the magnetic field topology and the changes in Ω can be established. With increasing particle confinement the shearing rate Ω increases locally at $q = 5/2$, while the magnetic topology shows a small dose of open field ergodic lines connecting the $q = 5/2$ surface and divertor target. For the Pump Out this local increase in Ω is absent. The measurements show clear evidence for a correlation of confinement transitions and the increase of Ω at $q = 5/2$. Measurements are performed via Charge Exchange Recombination Spectroscopy (CXRS)[3, 2].

Results

The plasma parameters for the IPC setups (Normal $(-B_\phi, +I_P)$ & Reversed $(+B_\phi, -I_P)$) are: R_0 =1.74 m , a =0.47 m, q_a =3.77, R_{sep} =2.21 m with $B_\phi = 2.1$ T and $P_{NBI(counter)} = 0.6/1$ MW and $I_P = 395$ kA. For the PO : R_0 =1.755 m, a =0.458 m, q_a =3.4, R_{sep} =2.213 m with B_ϕ =2.1 T and I_P =410 kA and $P_{NBI(counter)}$ =1.6 / 2 MW.

To visualize the transition figure 1(a) shows the electron density during typical transitions. For the PO a clear drop and for the IPC an increase in density is visible at 1.8 s (I_{DED} =2.5 kA) This correlates with a change in particle confinement time of -30% and +40% respectively [10]. During the IPC (cf. Figure 1(b)) the density gradient is increased locally at 2.15 m(q=5/2). To stress the systematic the IPC has been performed with two different tokamak configurations ($(-B_\phi, +I_P)$ & $(+B_\phi, -I_P)$), still the behavior remains the same (cf. figure 1(b)). In [10] the clear correlation of particle confinement, density gradients and magnetic topology was shown. Here the evolution of E_r will be correlated in the same way.



(a) Density traces for the PO and IPC Scenario (b) $n_e(R)$ for the IPC: $(-B_\phi, +I_P)$ & $(+B_\phi, -I_P)$

Figure 1: Density behavior during IPC and PO

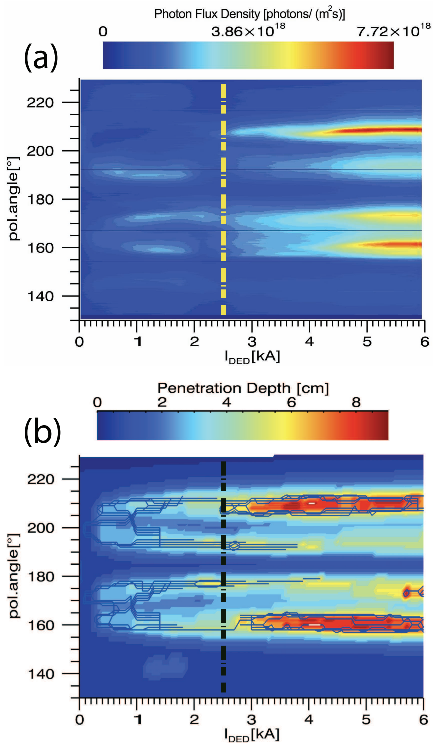
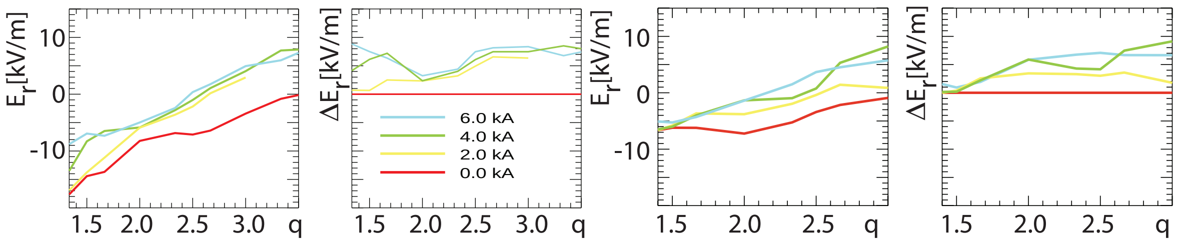


Figure 2: (a) Photonflux on target, (b) Field line penetration depth (IPC)

The change in particle confinement [10] is connected to the magnetic topology suddenly changing at 2.5kA. For the IPC a clear indication for changes in the magnetic topology is seen. Figure 2(a) shows the sudden appearance of visible emission patterns on the DED target correlated with the I_{DED} amplitude. At 2.5kA the pattern changes, stripes become clearly visible, change their poloidal position.This indicates a significant change in the magnetic topology is changed [8]. Figure 2(b) shows the field line penetration depth. The topology was calculated using the vacuum approximation, superimposing the RMP and the plasma equilibrium B-field. At I_{DED}=2.5 kA the penetration depth jumps up to 6-7 cm, indicating a connection between the DED target and the q=5/2 surface at R=2.15m (homoclinic tangles [9]). The island chains x-points becomes ergodized and in case of the IPC the field lines cause changes in the potential at q=5/2. For further analysis and understanding of the differences between IPC and PO with respect to the localized changes at q=5/2 the radial electric field will be considered. In Fig. 3 the E_r is calculated based on the radial force balance according to

$$E_\mathrm{r} = \frac{1}{Zen}\frac{\partial p}{\partial r} - v_\theta B_\phi + v_\phi B_\theta. \quad (1)$$

Pressure (p) and rotation ($v_{\theta,\phi}$) profiles are taken from the CXRS diagnostic. The toroidal and poloidal rotation change into ion diamagnetic drift co-current direction respectively with RMP. This general rotation spin-up is thought to be caused by a $j \times B$ torque [11] caused by an ion return current compensating for the enhanced electron losses in the stochastic plasma edge.The toroidal rotation increases rather homogeneously over the whole profile due to strong radial viscosity, while the poloidal rotation is influenced more locally by the stochastization of the field lines (neoclassical dampening) and hence gives rise to local effects in E_r (cf .[2]). For the IPC and PO the total radial electric field is evaluated. Figure 3 shows the radial profiles of the absolute values and the changes with respect to the non DED discharges. For both scenarios the mentioned increase in E_r with the perturbation is observed, a general increse is typically due to the fast loss of electrons in the stochastic zone [11, 13] (here $2.5 < q < 3$). The profiles show the



(a) IPC SCenario (b) PO Scenario

Figure 3: Radial profiles of the radial electric field and its changes due to the RMP .

radial electric field being more negative close to be plasma core due to beam induced toroidal rotation. From the phenomenology of the IPC and PO [2, 10] one sees that at $2-2.5$ kA at $q = 5/2$ ($R = 2.15$m) strong changes occur, hence we plot the E_r versus the safety factor q, to distinguish the different resonant surfaces and observe changes induced locally by the RMP.

For the IPC (fig. 3(a)) apart of the general increase with I_{DED} , a localization at q=5/2 is visible, the E_r steepens. The strongest change occurs at 2 kA just before the transition. For the PO Scenario the E_r behaves rather different, the general increase can be observed, while no strong local steepening is visible. This means that for the IPC the E_r changes seem to be localize just at the same position as the changes in density gradient, and topology (cf. fig. 1(b),2). To correlate plasma confinement, changes in topology and especially the changes in E_r we utilize the $E \times B$-shearing rate. Typically the shearing in rotation and E_r is connected to suppression of turbulent transport and thus assumed to be one reason for changes in confinement (cf. H-Mode [12, 1]) The shearing rate is expressed as follows:

$$\Omega_{E\times B} = \left| \frac{RB_\theta}{B_\phi} \frac{\partial}{\partial r} \left(\frac{E_r}{RB_\theta} \right) \right| \qquad (2)$$

Since the effect is connected to the $5/2$ surface as seen from the above results figure 4 shows $\Omega_{E\times B}$ at the $q = 5/2$ surface. In addition the extent of stochastic and laminar zone is shown. Stochastic means long connection length field lines and laminar meaning short connections [6]. During the IPC the stochastic zone evolves early but does not extend towards the $q = 5/2$ surface. With increasing extend the dose of field lines connecting target and $q = 5/2$ surface increases the confinement and Ω increases. The confinement only drops again when the $q = 5/2$ surface is completely ergodized and a large laminar zone is developed. For the PO with a

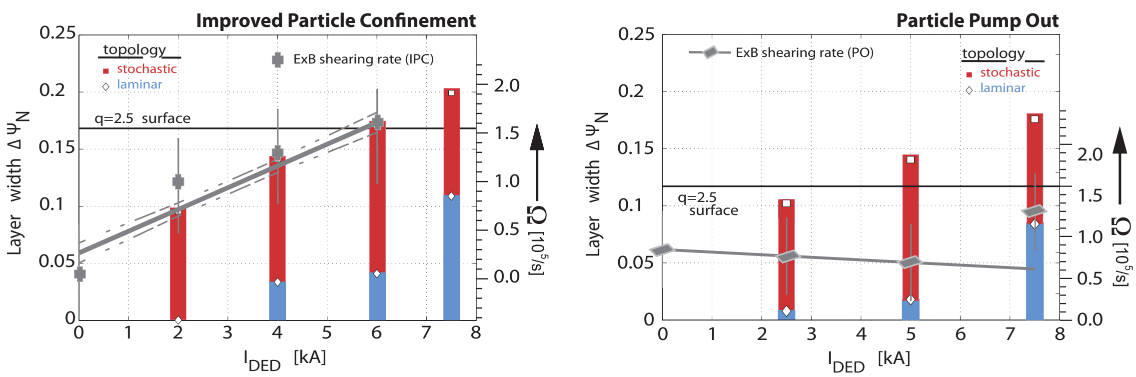


Figure 4: Comparison of Ω with the evolution of the magnetic topology (during IPC & PO).

smaller edge safety factor the $q = 5/2$ surface is more easily reached, the shearing is almost unaffected , and a large part of the $q = 5/2$ surface is readily ergodized. With the last step I_{DED} =7.5 kA the laminar zone again increases drastically thus changing in this case the plasma radius moving the Scrape Off Layer like behavior deeper inside (shear increases).

As a final remark the radial versus the poloidal localization of those changes can be discussed. Local island structures can be large enough to change transport and may thus be visible in the radial electric field. First indications are shown here. Figure 5 shows the radial electric field and its contributions for the normal and reversed setup of the IPC. Even though the general behavior of the shear does not change (radial direction) and thus the IPC is achieved in both cases [2], some local structures seem to move. Due to the changes in plasma current and field the phase between poloidal and RMP field is shifted, the island structures (x-point vs. o-point) are located at different poloidal angle at the toroidal position of observation. The observation volume covers different island structures. The blue (normal) and red (reversed) curves differ at positions q=3/2, q=5/2 where typical island chains are located. Visible changes in the E_r originate from this poloidal shift of the island chain. The confinement is as expected not changed. .

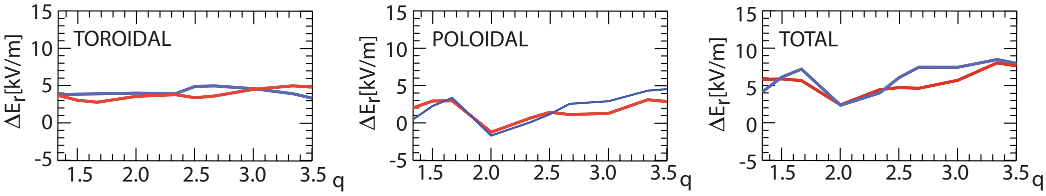


Figure 5: E_r changes with DED between NORMAL and REVERSED IPC Scenario

Summary & Outlook

For the IPC and PO different evolution of the radial electric field and its shear has been found. While during the IPC the RMP induced changes cause a spin-up of the shear locally at the q=5/2 surface and thus a decrease in transport the PO due to the large extend of stochastization already at low amplitudes suffers from enhanced transport along the field lines to the target. The clear changes in shearing rate and its correlation with topology and confinement underline the importance of the $E \times B$ shear for the understanding of radial transport suppression and show the validity of RMP as a tool for inducing changes in the edge transport. The changes in Ω are radially localized. Switching between forward and reversed (B_ϕ/I_p) causes only locally a shift of the island. For the confinement, which is an integral quantity, this has no effect at all. Analysis with respect to turbulent suppression during IPC indicate the connection with $E \times B$ shear and radial transport reduction. The question of causality remains unanswered.

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