*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-4.016 (2008)*

Spectroscopic Measurements of the radial electric field under conditions of improved particle confinement (IPC) with the Dynamic Ergodic Divertor (DED) in the Tokamak TEXTOR

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Introduction

Resonant Magnetic Perturbations are a method to control the plasma edge. It was shown [Evans '06] that external resonant magnetic perturbations can be used to suppress potentially harmful ELM. In ITER, ELMs can be very dangerous for plasma facing components. Understanding the transport changes caused by RMPs is thus a potential key to its safe operation. Measurements on the radial electric field can contribute to create a coherent picture of the influence of RMPs on the plasma edge transport and plasma confinement.

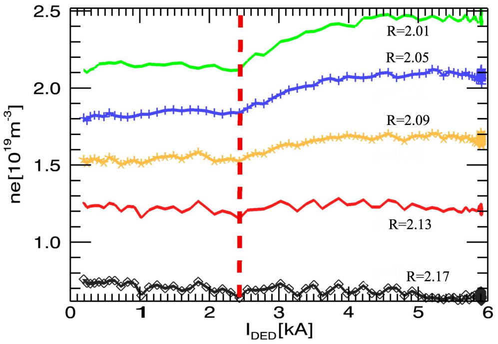
At TEXTOR the influence of RMPs is being investigated with means of the DED, which can be operated with different toroidal(m) and poloidal(n) mode configurations, m/n= 3/1, 6/2, 12/4.The 12/4 mode gives a very shallow stochastic zone, while for 3/1 operation a deeper penetration is anticipated. During DED operation a significant influence on the poloidal and toroidal rotation is visible ($\mathcal{O}(1\ \text{km}, 10\ \text{km})$), leading to a change of the radial electric field (~ 7 kV/m) and the $E \times B$ - shear rate ($1.5 \cdot 10^5 s^{-1}$). In this paper the influence of the DED on the plasma confinement is shown, presenting data on magnetic topology and E_r.

Measurement

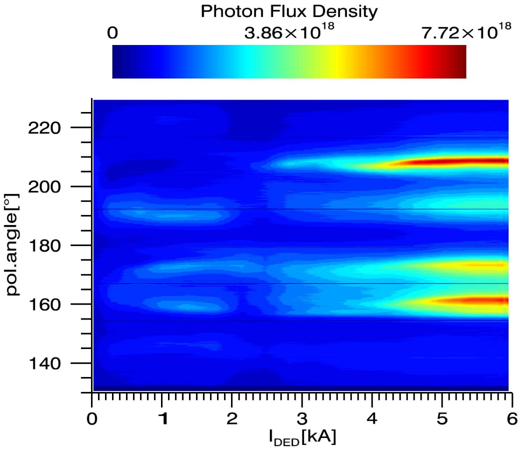
The presented data was taken with the poloidal and toroidal spectroscopic observation systems on the RuDI[Deichuli'05] diagnostic hydrogen beam. Both systems cover about 50% of the minor plasma radius ($a \cong 47$ cm) and utilize the active CXRS on CVI ($\lambda = 5290.5\ \AA$). The poloidal system uses direct imaging from the top of the vessel as well as an opposing line of sight (fiber), putting the CVI emissions onto a high resolution spectrometer. This method allows an in-situ wavelength calibration for the ion rotation measurements[Coenen'08, Busch'05]. The toroidal system is located in the equatorial plane of the machine, utilizing optics and optical fibers connecting to a second spectrometer. In this case the wavelangth calibration is peformed via a Neon lamp imaged onto one of the bundled fibers.

Results

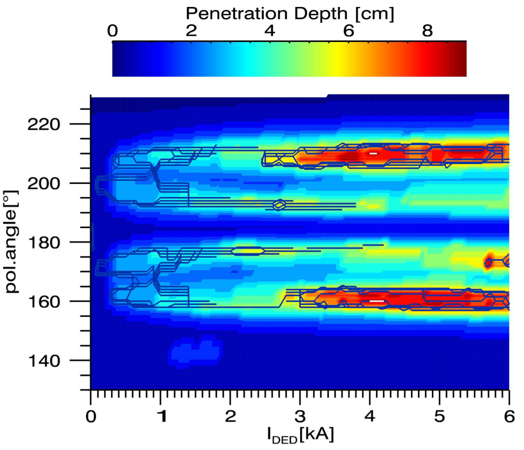
The following plasma scenario is being used: $I_p = 395$ kA, $B_\phi = 2.1$ T, $n_e = 2 \cdot 10^{19}$ m^{-3},$P_{NBI} =$ 1 MW, $R_0 = 1.74$ m, $a = 0.47$ m , $q_a = 3.8$.



(a) n_e vs. I_{DED} , onset of the IPC at 2.5kA



(b) photon flux density in m^{-2} s^{-1}



(c) Field line penetration depth in cm

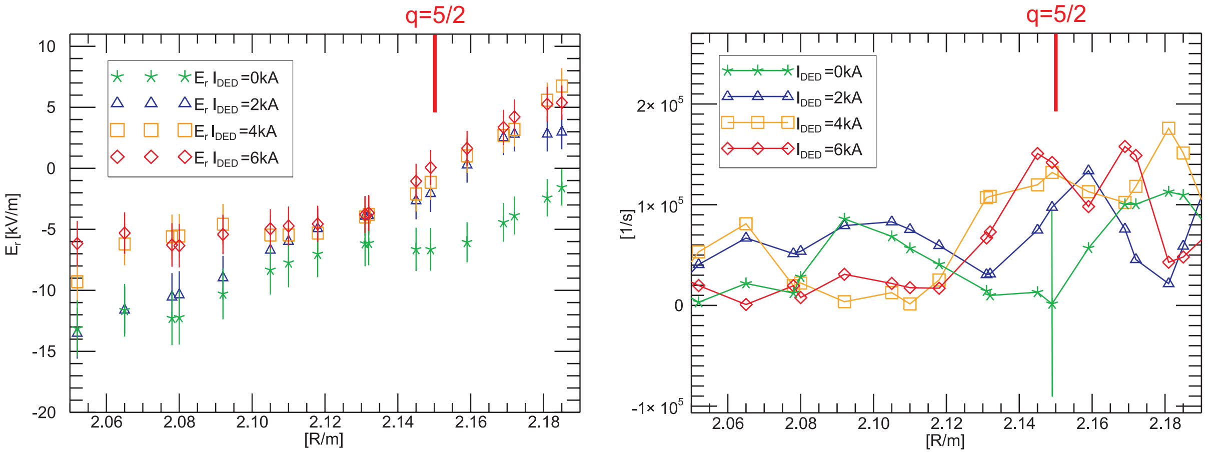
Figure 1: IPC, discharge #106585

As soon as the plasma reaches a stable phase the DED is ramped up quickly (0.5s) and kept constant. The CXRS data was acquired during this plateau phase, since a time integration of 3s is necessary. The IPC, as its obvious feature, shows a stepwise increase of the electron density [Finken'07], as can be seen in fig. 1(a). As soon as the DED reaches 2.5 kA the density increases inside of $q = 2.5$ ($R = 2.15$) about 15%. This increase is connected to a sudden appearance of structures on the DED target plates (fig. 1(b)) (observed via CII emissions [Clever'08]). At 2.5 kA the pattern in the photon flux changes, the stripes become clearly visible and change their poloidal position indicating changes in the magnetic topology induced by the DED. This can be confirmed when considering the penetration depth of the field lines connecting to the target as seen in fig. 1(c) and comparing it to the particle flux depicted by the CII emissions in front of the target. The topology was calculated in vacuum approximation, superimposing the RMP (DED field) components on the plasma equilibrium. At I_{DED}=2.5 kA a sudden step in the penetration depth (6 cm) is visible, showing a connection to the island chain located at the $q = 2.5$ surface. In particular an ergodization of the x-point and a connection to the wall (homoclinic tangles) [Jakubowski'07] is observed.

For further analysis the radial electric field (fig. 2(a)) is calculated via the radial force balance according to Eq. (1).

$$E_{\text{r}} = \frac{1}{Zen}\frac{\partial p}{\partial r} - v_\theta B_\phi + v_\phi B_\theta \tag{1}$$

The pressure (p) and plasma rotation ($v_{\theta,\phi}$) profiles are input parameters taken from the CXRS diagnostic. The diamagnetic contribution to E_r is negligible. The toroidal and poloidal rotation change into ion diamagnetic drift direction and co-current direction respectively. This general rotation spin-up is due to a $j \times B$ torque [Unterberg'07] 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, while the poloidal rotation is influenced more locally by the stochastization of the field lines and hence gives rise to local effects in E_r.



(a) Radial Electric Field in kV m^{-1} (b) $\Omega_{E\times B}$ shear rate in s^{-1}

Figure 2: IPC discharges at $0, 2, 4, 6$ kA DED . A typical errorbar is displayed at $q = 2.5$.

Considering the clear evidence of the IPC at $I_{\text{DED}} = 2.5$ kA and the localization via fig. 1(c) at $q = 2.5$ ($R = 2.15$) one can observe a drastic change in E_r at that position. Close to the IPC threshold (2.5 kA) at 2 kA a sudden jump in E_r by 7 kV/m can be observed, while the further increase of I_{DED} only leeds to a flatening of the profiles further inside $R \leq 2.11$. This clearly indicates that the IPC is connected to the ergodization of the $q = 2.5$ island chains which starts close to I_{DED} =2.5 kA. With increased I_{DED} the island chain gets ergodized completely, but no deeper penetration of the ergodization is observed. If one compares the effect on E_r with the $E \times B$ shear rate according to Eq. (2) one can clearly see a structure at q=5/2.

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

At 2 kA the shear increases (fig. 2(b)) ($\Delta\Omega_{E\times B} \simeq 1 \cdot 10^{15} s^{-1}$), while the following steps (4 kA and 6 kA) only add slightly to that level, the IPC is fully developed at 2.5 kA. For q< 3/2 a flattening of the profiles and a decrease in the shear rate is observed, which is not yet understood. To show the effect more clearly fig. 3 displays the shear rate at q=2.5 . The higher the DED current, the higher Ω. The innermost island chains are destroyed, and field lines from the x-points connect to the wall (homoclinic tangles). This is supported by measurements with changes in the phase of the perturbation (reversing toroidal magnetic field and plasma current). The IPC still occurs with a comparable signature. In general the energy confinement is not affected [Finken'07] beyond the density scaling, while a clear effect on τ_p is observed (15% increase [Schmitz'08]). We described in this paper that RMPs are a way to control the plasma edge and evoke changes in the global plasma confinement.

In contrast to the IPC another scenario exists, the stochastical particle pump out (PO), which is characterized by a loss in electron density and τ_p as described in [Schmitz'08]. The topology between these two cases differs [Schmitz'08]; while during the IPC the x-points are ergodized and the homoclinic tangles connect to the target, the PO shows a much deeper penetration of the stochastic zone, causing an enhanced laminar zone and a loss in particle confinement.

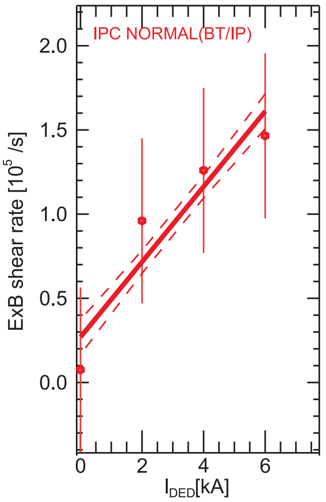


Figure 3: $\Omega_{E\times B}(I)$ at $q = \frac{2}{2}$

Conclusion & Summary

This paper describes the influence of the DED (RMP) on the plasma confinement especially IPC; the distinct density increase (fig. 1(a)), the changes in the target pattern (fig. 1(b)) and the corresponding penetration depth calculations (fig. 1(c)).

For the first time consistently measured profiles of the radial electric field under the influence of the DED at TEXTOR are given, relying on the combined CXRS diagnostics. These measurements show clear correlations with the IPC - The increase in the $E \times B$ shearing rate corresponds clearly to the increase in particle confinement around the q=2.5 surface. A steepening of the E_r may indicate a suppressed turbulent transport and hence be directly connected to the Improved Particle Confinement.

References

[Busch'05] C. Busch et al., Europhysics Conference Abstracts, 32nd EPS , (2005)
[Coenen'08] J.W. Coenen et al., DPG Verhandlungen (2008)
[Clever'08] M. Clever et al., DPG Verhandlungen (2008)
[Deichuli'05] P. Deichuli *et al.*, Fusion Science and Technology **47**, (2005) 330-332
[Evans '06] Todd E. Evans *et al.*, Nature Physics, **Vol 2**, June 2006
[Finken'07] K.H. Finken *et al.*, Physics Review Letters **98**, 065001 (2007)
[Jakubowski'07] M.W. Jakubowski, *et al.*,Journal Of Nuclear Materials, **363**, (2007), 371-376
[Schmitz'08] O. Schmitz et al., PSI Conference 2008, to be published in JNM 2008
[Unterberg'07] B.Unterberg *et al.*, Journal of Nuclear Materials 363-365 (2007) 698-702

Results are part of an ongoing PhD thesis at the "Heinrich-Heine-Universität, Düsseldorf". This work was partially supported by the German Research Foundation (DFG) under grant No. UN 265/1-1 and is included in the activities of the Research Training Group GRK 1203.