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EDGE TURBULENCE STUDIES AT TEXTOR DURING DYNAMIC ERGODIC DIVERTOR OPERATION BY MEANS OF REFLECTOMETRY

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1 Introduction

The dynamic ergodic divertor (DED) [1] at TEXTOR generates a perturbation field which matches the $q = 3$ surface in the plasma. The perturbation field is produced by a set of 16 coils wrapped helically around the high field side (HFS) side of the vessel. The perturbation field can be generated in several different configuration, the long radial range (3/1) configuration and the short radial range (12/4) configuration. In this paper the effects of the dc DED on the turbulence at the plasma edge is studied. The turbulence properties are measured by poloidal cross correlation O–mode reflectometry [2] in the equatorial plane in a range $0.8 \leq r/a \leq 1.0$. The system, including antenae and TEXTOR geometry, is sensitive to $k_\Theta < 4$ cm^{-1}.
The plasma parameters for both configurations are different. In the 12/4 configuration the plasma is shifted to the HFS by 5 cm and auxiliary heated by tangential neutral beam injection with $P = 800$ kW. At $I_p = 370$ kA and $B_T = 1.9$ T the electron temperature (T_e) at the plasma edge [3] drops significantly on a radial range of $\Delta r \approx 3$ cm when the DED is switched on. Furthermore the toroidal plasma rotation increases slightly during DED operation. The experiments in the 3/1 configuration are performed with $I_p = 300$ kA and $B_T = 2.25$ T. The plasma is auxiliary heated by tangential neutral beam injection with $P = 300$ kW. At $I_{DED} = 700$ A a large locked $m/n = 2/1$ mode is produced [4], which is accompanied with a drop of E_{dia} by 10% and a drop in the central toroidal plasma rotation causing a completely flat rotation profile for $q \leq 2$.

2 Turbulence and Plasma Propagation

The amplitude and coherence spectra in both configuration show some similarities. The spectrum is composed of (i) broad band turbulence (BB), (ii) coherent high m–number turbulence (QC) and (iii) the low frequency turbulence. With the onset of the DED the quasi coherent (QC) turbulence disappears and low frequency (LF) turbulence is dominant. During the radial transition into the DED effected region the QC–turbulence decreases in center frequency and amplitude until it has completely vanished. Furthermore a change in the turbulence rotation from the electron diamagnetic drift direction to the ion diamagnetic drift direction is observed. Also the amplitude spectra changes from one with broad QC structures to one with an exponential decay only. In Figs. 1,2 the turbulence rotation (Ω) for both configurations is shown for the case with and without DED. In the phase without DED the turbulence rotation is in the direction of the electron diamagnetic drift. In the 12/4 configuration the rotation due to

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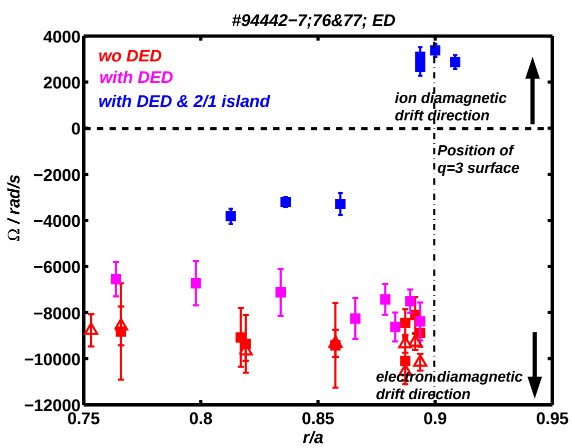

Figure 1: Turbulence rotation estimated in 3/1 configuration.

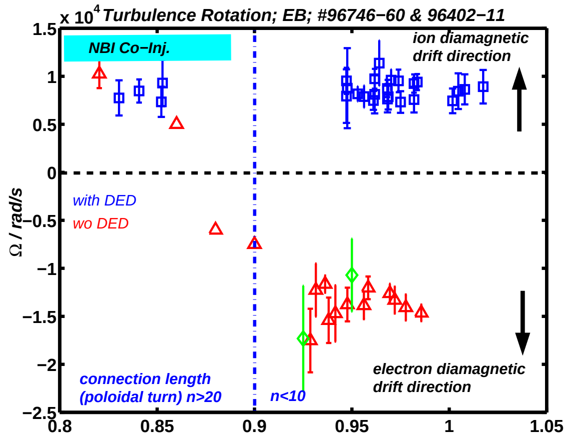

Figure 2: Turbulence rotation in 12/4 configuration. In addition Ω_Θ estimated from Doppler shifted carbon ions is shown in green

NBI co–injection is dominating and at $r/a \leq 0.9$, the direction of the rotation changes. With the onset of the dc DED in the 3/1 configuration the turbulence propagation estimated from the QC turbulence increases. With the onset of the $m/n = 2/1$ mode a further increase is observed and at $q = 3$ the angular rotation changes the direction. In the 12/4 configuration the angular rotation in the divertor region changes to the ion diamagnetic drift direction. The divertor is established for $r/a \geq 0.9$, where the connection length to the wall decreases significantly. Since the rotation for $r/a \leq 0.9$ is dominated by co–injection no change in the rotation direction is observed at that radius.

In order to investigate wether the turbulence rotation measured by poloidal correlation reflectometry equals the poloidal plasma rotation v_Θ, a comparison with the poloidal velocity measured by Doppler shift of carbon ions at the plasma edge, is performed. Therefore the turbulence velocity $v_{Ref} = v_\perp + v_{phase}$ can be decomposed into:

$$v_{Ref} = v_\perp = v_\Phi \frac{B_\Theta}{B} - v_\Theta \frac{B_\Phi}{B} \tag{1}$$

assuming a negligible v_{phase}. Here v_Φ is the toroidal plasma rotation, measured by charge exchange recombination spectroscopy. B_Θ is obtained from a current profile of the form $j = j_0 \cdot (1-(r/a)^2)^3$. Regardless of a small radial overlap only, both diagnostic are in good agreement at $r/a = 0.95$ indicating that at this position the v_Φ and v_{phase} are negligible (green diamonds in Fig. 2).

Furthermore it is possible to compare v_{turb} and $v_\perp$ at half plasma radius, by assuming a neoclassical poloidal rotation and to prove wether the turbulence has a $v_{phase} \neq 0$ The different components of eq 1 are color coded presented in Fig. 3 for $0.45 \leq r/a \leq 0.50$. A difference between v_{Ref} and $v_\perp$ is observed indicating an additional that v_{phase}, however as indicated by the large error bars of the CXRS measurement no conclusive statement can be made up to now. With the assumption of $v_{phase} = 0$ the measurement of $v_\perp$ by poloidal cross correlation reflectometry allows the determination of the radial electric field E_r, according to:

$$v_{E\times B} = v_\perp - v_{dia} \qquad E_r = (v_{Ref} - v_{dia}) \cdot B \tag{2}$$

Where v_{dia} is the diamagnetic velocity, which can be deduced with the T_e obtained from the ECE diagnostic and Z_{eff} from carbon impurity measurements. Applying the above equations

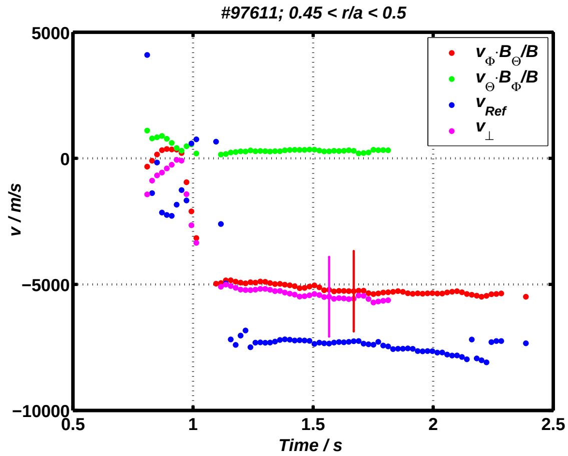

Figure 3: Calculated velocity components according eq. 1 and comparison to v_{Ref} for a plasma with $P = 1.2$ MW counter neutral beam injection and $P \approx 300$ kW co–injection.

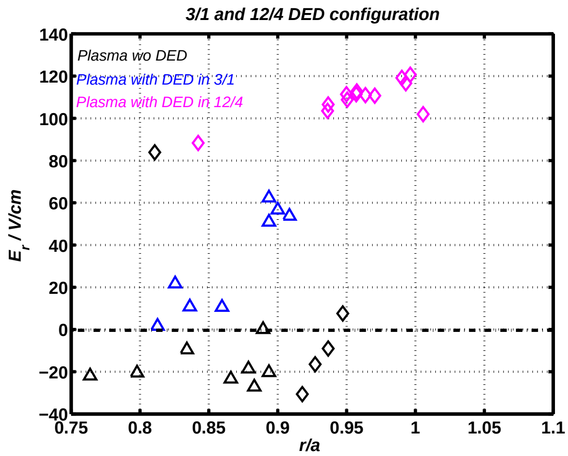

Figure 4: Estimation of E_r in plasmas with 12/4– (diamonds) and 3/1–configuration (triangles). For comparison E_r is also estimated for both sets of plasma parameters without DED.

for the estimation of E_r in the 3/1– and 12/4–configurations a change in the sign of E_r in the divertor region (12/4 configuration) and in the ergodic region at the q=3 surface (3/1 configuration) is found (Fig. 4). For the divertor configuration the expected inward shift of the inversion point of the radial electric could be found and is correlated with the radial position where the poloidal connection length increases significantly. Especially the observations in 12/4 configuration confirms and extends the observations obtained at Tore Supra where a change in the turbulence spectrum from the laser scattering was attributed to an inward movement of the inflection point of E_r [5]. Also in the 3/1 configuration a change towards positive E_r is observed in the vicinity of the $q = 3$ surface, where in addition a reduction of the inward propagation of Ar–impurities is found.

3 Turbulence Properties

With the knowledge of the Ω_{turb} k_Θ, λ_Θ and poloidal wave–number m can be estimated. Since the QC–turbulence is not well developed during DED operation λ_Θ is evaluated from the autocorrelation function as: $\langle\lambda_\Theta\rangle = v_{turb} \cdot \sigma_{AC}$, where σ_{AC} is the half width of the autocorrelation function. Comparing the $\langle\lambda_\Theta\rangle$ (Fig. 5) in both configuration we found a decrease by a factor two at the position of the $q = 3$ surface in the 3/1–configuration. In 12/4–configuration no change of $\langle\lambda_\Theta\rangle$ is found even in the divertor region. However a decrease in the poloidal mode number (Fig. 6) from $m \approx 30$ to $m \approx 10$ is found in the divertor region. The radius where m $drops$ is in good agreement with the decrease of the poloidal connection length (black curve in Fig. 6) extracted from Poincaré plots for the plasma parameters under investigation. Looking at the phase and density fluctuation level we found no change in the 12/4–configuration but in 3/1–configuration together with the locked $2/1$ mode at decrease by a factor two at the rational surface is observed.
The multi–horn setup of the antennae array allows the calculation of the de–correlation time (τ_c) and the correlation length (l_c) for the two DED configurations. This is of interest since it allows a rough estimation of the transport properties by assuming an underlying random walk like transport mechanism $D_{rw} \sim l_c^2/\tau_c$. The antennae array measures the poloidal cross

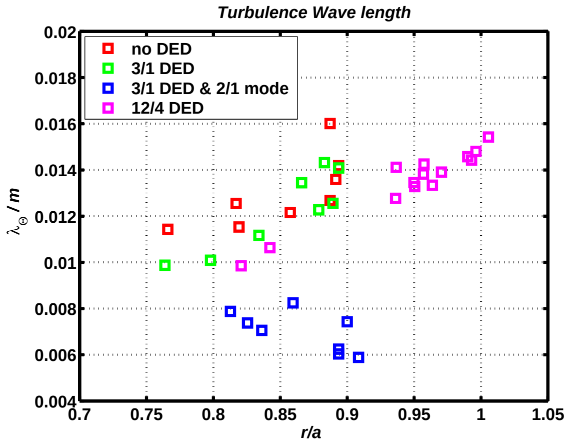

Figure 5: Estimated $\langle\lambda_\Theta\rangle$ from autocorrelation function. The locked 2/1 mode during 3/1–configuration yields to a reduction of $\langle\lambda_\Theta\rangle$ which is an indication of a reduced transport

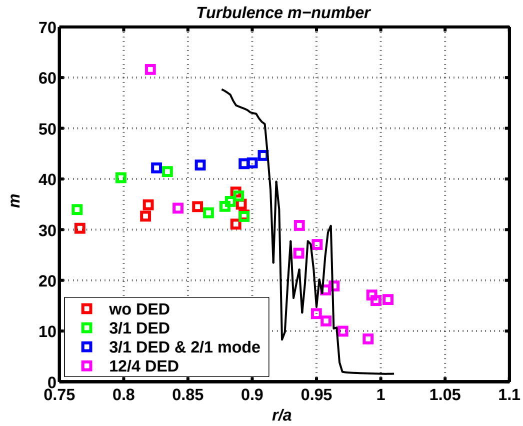

Figure 6: As expected the poloidal mode number during 12/4 operation drops significantly in the divertor region. In 3/1–configuration the mode number is not changed.

correlation for four different poloidal angles from $(1.4 - 5.6\ ^o)$. For the 3/1–configuration the analysis is restricted to the vicinity of the $q = 3$ surface, where the changes in the plasma turbulence are found to be large. Whereas l_c does not change significantly in the vicinity of $q = 3$, τ_c increases from $\tau_c = 7\ \mu$s to $\tau_c = 17\ \mu$s, indicating together with the decreased density fluctuation level a reduction in transport. With increasing distance of the reflection layer from the $q = 3$ surface the de–correlation time drops significantly.
During 12/4 configuration we observe an increase of the de–correlation time in the divertor region from $\tau_c = 3\ \mu$s to $\tau_c = 5\ \mu$s. For a reflection layer inside the separatrix τ_c is not changed at all. Also in this configuration no indication for a significant change in l_c is found.

4 Summary

The paper discusses the changes of the turbulence properties, the poloidal plasma rotation and the related radial electric field at the plasma edge due to the influence of the dynamic ergodic divertor in the 3/1– and 12/4–configuration at TEXTOR. A comparison of the turbulence velocity and $v_\perp$ is performed showing a good agreement at $r/a = 0.95$. A negligible v_{phase} is confirmed by the measurements. Independent of the configuration of the perturbation field the plasma propagation at the plasma edge changes its direction as well as E_r. The turbulence properties are quantitatively different but pointing in the same direction. However a decrease $\langle\lambda_\Theta\rangle$ in 3/1 configuration is found which is not observed in the 12/4 configuration. From the decrease of the poloidal wavenumber the radial extent of the divertor region was found to be in agreement with calculations.

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