

Effects of edge ergodization induced by DED on turbulence and particle transport in TEXTOR

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1. Introduction

In TEXTOR the dynamic ergodic divertor (DED), which consists of a set of 16 coils wrapped around the vessel at the high field side creates a perturbation field resonant to the $q=3$ surface [1]. The concept of an ergodic divertor follows mainly two goals: first to enhance the particle outflow at the edge and concomitantly to reduce the power load onto the target region by sweeping of the strike points; the second to affect the edge electric field and its shear, which has an influence on the turbulence. With the unique feature of the dynamic operation of the ergodic divertor it is thought to exert a torque onto the plasma causing rotational shear. In this paper we will focus on two aspects: the electric field in the edge and the turbulent transport.

2. Experimental setup

All presented data refer to a campaign, where the DED has been operated with poloidal/toroidal mode number equals 3/1. In the 3/1-configuration the penetration of the perturbation field is fairly strong, penetrating approximately up to $r=30$ cm, and a field line diffusion coefficient D_{fl} in the order of 10^{-5} m²/m is expected. During the flat-top phase of an ohmic discharge, with a central line averaged density of 1.5×10^{19} m⁻³, $I_p=250$ kA and a $B_t=1.9$ T, the coil-currents have been ramped-up. Four different settings of the DED-currents have been studied: (1) the static case (perturbation current $I_{pb}=2.5$ kA), (2) slow sweep of the edge structure over the diagnostics ($I_{pb}=1.8$ kA), (3) AC co-DED operation with a phase in the two coil currents such that a co-rotation is imposed and (4) AC counter-DED (each $I_{pb}=2.5$ kA with $f_{AC}=1$ kHz). The "co-rotation" means with respect to the poloidal direction the ion diamagnetic direction and with respect to the toroidal one the direction of the plasma current. At a perturbation current of about 1.25 kA an onset of a $m/n=2/1$ tearing mode, which is accompanied by a drop in the core plasma density and a loss of confinement. This tearing mode occurs in all four cases except during AC-co DED operation. In the studied discharges with the 2/1-mode a drop in the confinement has been observed (Fig. 1).

3. Edge floating potential profile

A probe with 16 electrical pins has been used to monitor changes in the edge profiles of floating potential, electron density, electron temperature and their fluctuations during all phases of the discharges. In figure 2 the temporal and radial evolution of the floating potential during a scan of the DC-DED current is shown. The last closed flux surface before the DED switch-on is at approximately 47.2 cm. In the ohmic phase, the potential and the electric field are negative, i.e. pointing inward. With increasing current the potential becomes less negative and even reverses sign after the mode onset. The changes in the edge profile are rather modest as has been measured by atomic beam diagnostics in a comparable discharge. Hence the contribution of the temperature gradient to the plasma potential profile has been neglected. As a consequence also the electric field and the resulting ExB shear are reduced, which counteracts on turbulence suppression as will be seen later. In AC-operation one expects the exertion of a torque perpendicular to the magnetic field lines onto the plasma due to the alignment of the DED-currents in the coils [2]. By changing the phase of the currents in two coil-sets, the toroidal and poloidal rotation should be altered correspondingly. However, as seen in figure 3, for both cases, AC-co and AC-counter DED-operation, the electric field is reduced, which can be explained by the enhanced ion transverse conductivity. In [3] a model, taking into account the additional electron losses due to field line diffusion, for the conductivity has been presented: $\sigma_{st} = e^2 D_{\parallel} n_e \sqrt{2/\pi m_e T_e}$, which is for $D_{\parallel} \sim 10^{-5} \text{ m}^2/\text{m}$ about 0.25 A/Vm. One should note that in these plasmas, the neo-classical radial conductivity is in the range of $2 \times 10^{-3} \text{ A/Vm}$. The drop in the electric field is accompanied with a decrease of the toroidal rotation in the plasma core and can be allocated with the mode onset, except for the co DED-AC case, where no mode-onset is observed [4]. A quantitative calculation of the electric field and the ExB shearing rate has been relinquished due to the missing measurement of the electron temperature gradient.

By changing the current distribution in the two coil sets, while the total current stays constant at 3.6 kA ($I_{pb}=1.8 \text{ kA}$), the edge structure induced by the DED can be swept over the probe diagnostic. The probe pins pass intersecting field lines with different connection length. Figure 4 shows a discharge, where the poloidal angle has been scanned over 30° . The solid line is the field line connection length as determined by the ATLAS-code [5]. The radial position corresponds to the innermost pin position ($r=45.8 \text{ cm}$) like in figure 3. As seen in the other discharges, the potential increases during the DED-phase to a value of -40 V, when the probe connects at $\theta=0^\circ$ to field lines with long connection length (see Fig. 4), i.e. originating from a deeper region of the plasma. When the probe reaches areas with short connection length, the temperature drops and the floating potential rises like expected. The resulting plasma potential ($V_{pp}=V_{\parallel}+3.9 T_e$) shows only little variation with the poloidal angle.

4. Turbulence properties

In front of the probe, four pins are installed at one radial position with a poloidal separation of 7.5 mm, which allow by using the common triple probe and two-point correlation technique the determination of density fluctuation, of poloidal electric field fluctuation and of their correlation. The data have been sampled at a rate of 500 kHz and the quantities are determined from 24000 samples.

In figure 5 the density and poloidal electric field fluctuation, their cross-correlation and the resulting turbulence driven radial transport Γ_{AC} is shown versus the DED DC-current. In ohmic plasmas Γ_{AC} is at TEXTOR typically in the range of $10^{18} \text{m}^{-2} \text{s}^{-1}$ and positive, i.e. indicating losses of particles. With increasing DED-current all fluctuations are decreasing and converging to a certain level. However, large changes in the cross-correlation cause a sign reversal of Γ_{AC} at low perturbation currents. This has been observed in all studied DED-discharges. At the DED-current, where the 2/1-mode onset occurs, again a sign reversal is observed and Γ_{AC} saturates at a slightly higher level than in the ohmic phase of the discharge. Whether a flattening of the edge profile or another effect causes the drop in the fluctuations could not yet been revealed.

In case of AC-operation, the co- and counter operation have an opposite influence on the radial transport. Figure 6 shows the time traces of the DED-current amplitude and Γ_{AC} for the co- and counter-case. One should note that only in during co-rotating DED-fields the mode onset has been observed. This probably leads to a distinct behaviour of the turbulence. Similar to the DC-case first a reduction and sign reversal is observed, which remains in case of the co-DED. Like in the DC-case, large turbulence driven particle losses are observed after the mode onset during counter-DED. This is mainly due to strong enhancement of density and electric field fluctuations. From the above described observation, one can conclude that an ergodic field structure in the edge can affect turbulence in two ways: first by reducing the amplitude of fluctuations, second by changing the cross-correlation. At low currents a reduction is observed, however the onset of a 2/1-mode causes the transport to enhance again. To fully disentangle the underlying mechanisms, high spatially resolved measurements of the electric field, electron density and temperature profiles are needed.

[1] Special Issue: Dynamic Ergodic Divertor, Fusion Engineering and Design **37** (1997) 335.

[2] K.H. Finken, Nuclear Fusion **39** (2004) 707.

[3] I. Kaganovich, *et al.*, Phys. Plasm. **5** (1998) 3901.

[4] M. de Bock, *et al.*, this conference, P2.042.

[5] M. Jakubowski, *et al.*, this conference, P1.021.

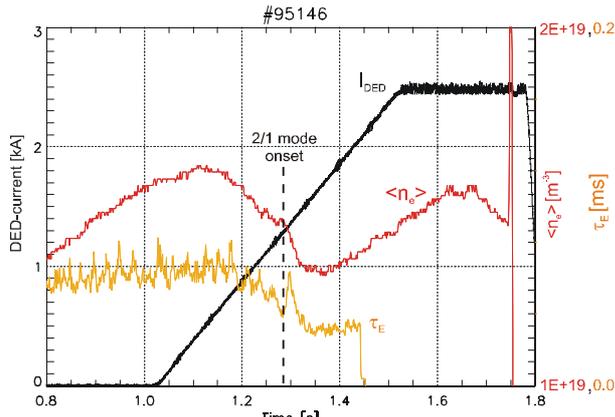


Fig. 1: Time traces of DED-current I_{DED} , central line averaged density $\langle n_e \rangle$ and energy confinement time τ_E .

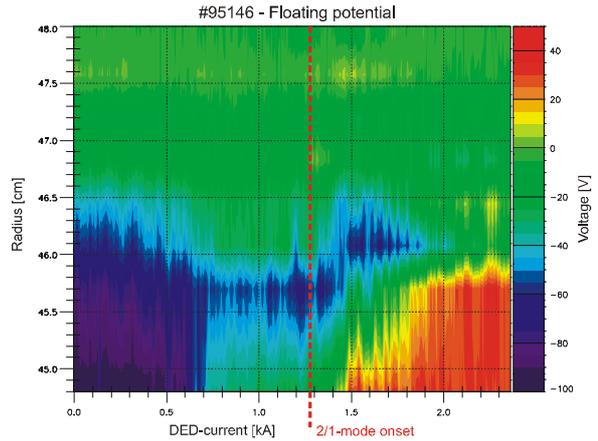


Fig. 2: Contour plot of floating potential profile during ramp-up of DC-DED current.

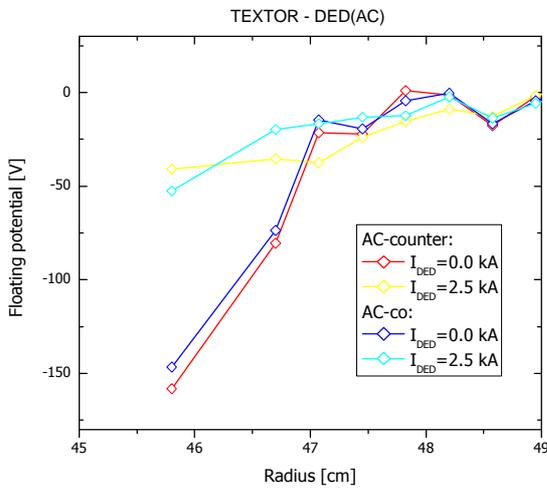


Fig. 3: Profiles of floating potential during two different DED-AC discharges ($f_{I,DED}=1$ kHz), one with co-phasing, another one with counter-phasing at same amplitude.

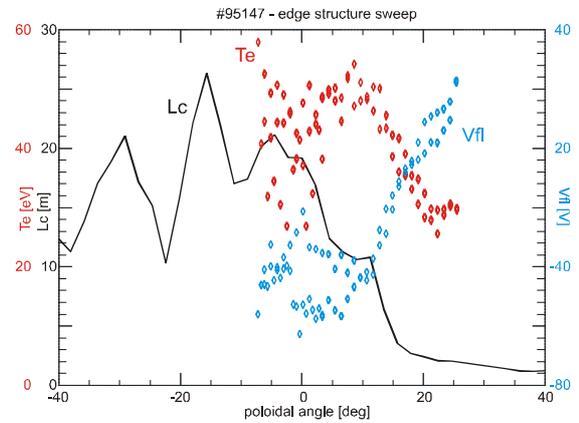


Fig. 4: Poloidal profile of electron temperature (red) and floating potential (blue), obtained by a slow sweep. The black curve shows the calculated field line connection length.

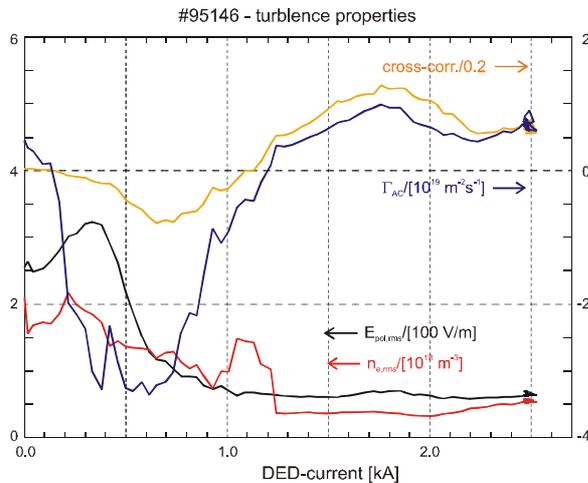


Fig. 5: Fluctuations of density (red) and poloidal electric field (black) vs. DED-current (DC). Also resulting cross.-corr. ($\gamma_{En} \cdot \cos\alpha$) and Γ_{AC} is shown.

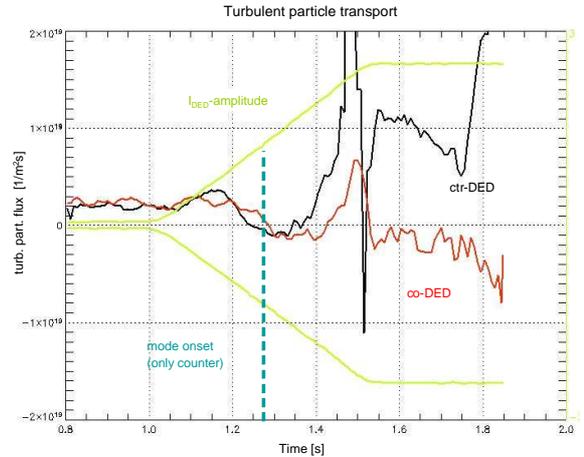


Fig. 6: Time traces of AC DED-current I_{DED} and Γ_{AC} in co- (red) and counter- (black) DED.