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Impact of the Dynamic Ergodic Divertor DED on the Plasma Edge at TEXTOR - Detection and structure of the laminar zone

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Introduction

The Dynamic Ergodic Divertor *(DED)* [1] installed at TEXTOR couples a resonant perturbation to the plasma edge in order to modify heat and particle exhaust. The magnetical topology induced was prescribed by field line tracing and mapping methods collected in the *ATLAS-Code* [2, 3]. In radial outward direction three regions showed up in the perturbed volume: A region with *island chains*, a region where these islands overlap, called *ergodic region* and a *laminar region*, where the field lines - before they get decorrelated - are deflected towards the DED target tiles with short connection lengths L_c. These laminar field lines form isolated helical flux tubes which are surrounded by ergodic regions and end on the DED target. The intersection of the flux tubes with the DED target at the high field side (HFS) forms four helical strike point patterns with two divertor legs each and a private flux region in between. Ergodic fingers connecting to the inner part of the perturbed edge region are embedded into the flux tubes in front of the target. As a consequence, the heat and particle flux pattern at the DED target can be expected as a superposition of the plasma flow along the laminar flux tubes in the so-called ergodic divertor scrape-off layer (ED-SOL) and within the ergodic fingers as connection to the inner plasma region with higher density and temperature [4, 6]. This contribution discusses the experimental findings on the response of plasma edge parameters n_e and T_e and the particle flux to the DED target on this complex magnetic topology in the DED $m/n = 12/4$ base mode configuration.

Detection of laminar flux tubes

For these experimental investigations we used *Beam Emission Spectroscopy (BES)* on a thermal Helium beam positioned at the low field side (LFS) of the TEXTOR vessel at $\Theta = 5°, \Phi = 90°$ [5]. We determine electron density $n_e(r)$ and electron temperature $T_e(r)$ in the plasma edge at $r/a \in [0.9, 1.2]$ with a high spatial resolution of 1.2 mm. Supplementary CCD cameras equipped with H_α interference filters were used to observe the particle fluxes of recycling hydrogen normal to the DED target tiles. Due to the strong dependence of the coupling of the DED perturbation to the plasma on the resonance conditions we choose a reference scenario for this investigations which places the resonant q=3 surface near to the DED target tiles ($I_P = 360kA$, $B_t = 1.9T$, $P_H = 300kW$, $R_0 = 1.73m$, $a = 0.435cm$). Figure 1 show the development of a time trace $p_e(t)$ at r=0.425 m in comparison with the DED current. The pressure decreases continuously with increasing DED current. Accompanied the particle flux on the DED target is redistributed and finally splits into two separate stripes at highest DED current.

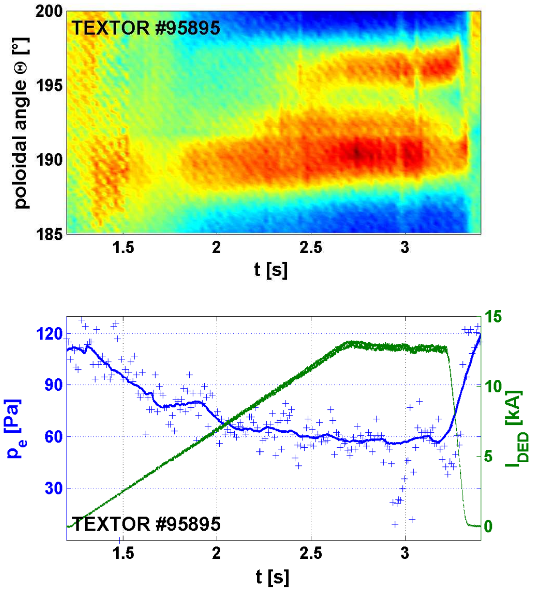
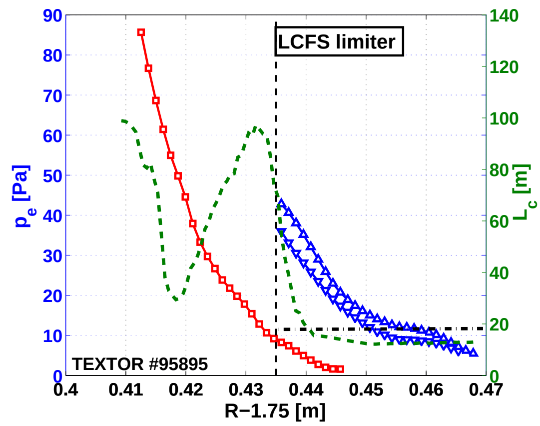


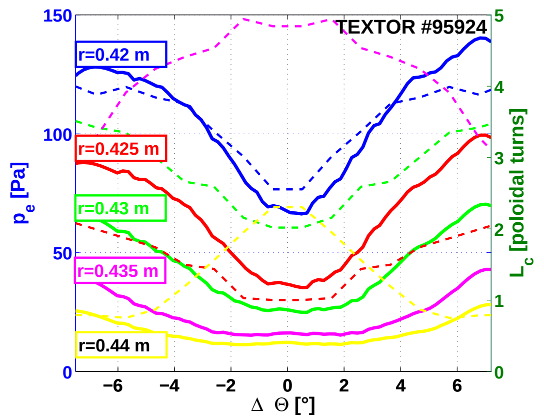
Figure 1: *Upper subplot: time evolution of H_α in the region of one paired footprint on DED target*
Lower subplot: Decrease of $p_e(t)$ in correlation with I_{DED}

ATLAS calculations performed for this shot scenario show the development of a flux tube with short L_c to the DED target in the observation volume with the poloidally widest extension at $R - 1.75 = 0.425m$. The experimental findings confirm the expectation that this flux tube introduces a strong sink into this region of previously enclosed magnetic flux surfaces. Due to a high convective transport [4] along this laminar field lines particles and energy are channeled to the DED target. This laminar flux tube connects the upstream region at the LFS with the split strike point region on the DED target and acts as the scrape-off layer of this ergodic divertor (ED-SOL). This new SOL is positioned radially further inside and it redefines the plasma wall interaction. However, the heat and particle flux to the DED target is not only characterized by the intersection of laminar field lines but as well by ergodic flux channels reaching from regions radially further inside to the target tiles [3]. Both kind of field lines contribute to the flow of energy and particles to the DED target.

Figure 2(a) shows the inward movement of the $p_e(r)$ profiles into this ED-SOL region. The radial width of the flux tube can be estimated to about 2.5 cm for this shot scenario comparing the profile position with and with out DED. In order to characterize the decay behavior of $n_e(r)$ and $T_e(r)$ in this ED-SOL we deduced the e-folding lengths λ_{n_e} and λ_{T_e}. In the transition from the ordinary limiter SOL to the ED-SOL this quantities are reduced significantly: λ_{n_e} decreases from $\lambda_{n_e} = 25 \pm 4mm$ and $\lambda_{T_e} = 50 \pm 6mm$ to $\lambda_{n_e} = 15 \pm 3mm$ and $\lambda_{T_e} = 25 \pm 5mm$.



(a) Profiles $p_e(r)$ with (red line with squares) and without (blue lines with triangles) DED



(b) $p_e(\Theta)$ (solid lines/left abscissa) and $L_c(\Theta)$ (dashed lines/right abscissa) during sweep

Figure 2: *Radial profile* $p_e(r)$ *and poloidal profile* $p_e(\Theta)$ *show the existence of poloidally isolated laminar flux tubes positioned radially further inside as the ordinary limiter SOL.*

Poloidal structure of the perturbed plasma edge

The poloidal structure of the perturbed edge can be investigated with low frequency sweeps of the DED currents. This kind of sweeps move the induced structure with a deviation of $\Delta\Theta = 4.5°$ at HFS and $\Delta\Theta = 7.8°$ at LFS. Figure 3 shows the the resulting strike zone pattern $H_\alpha(\Theta, t)$ on the target and $p_e(\Theta, t)$ at LFS. The strike pattern follows clearly the DED current which changes its maximum from one of the sketched coils to the other. Correspondent a clear modulation of the electron pressure $p_e(t)$ in the stagnation point region at LFS shows up. Mapping of the $L_c(\Theta, \Phi)$ distribution in front of the He beam diagnostic during this sweep explain this result: The perturbation caused by this shot scenario evokes a laminar flux tube which is positioned right next to the observation volume. Figure 2(b) shows the effect of the movement of the laminar flux tube into the observation volume ($\Delta\Theta = 0°$ is the return point of the sweep). Short L_c lead to a decrease of $n_e(\Theta)$, $T_e(\Theta)$ and with this of $p_e(\Theta)$.

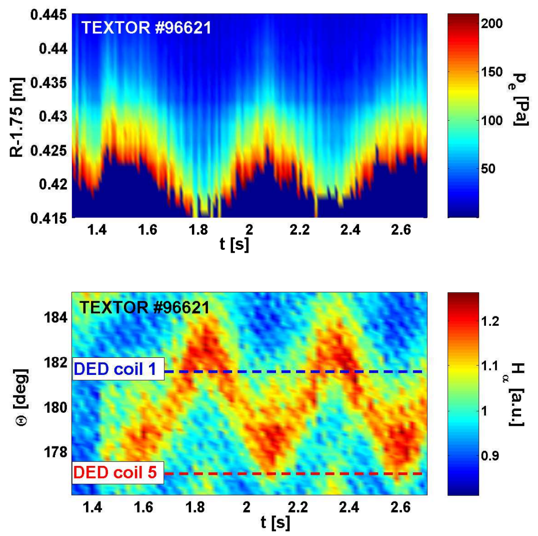


Figure 3: $H_\alpha(\Theta, t)$ *pattern on DED target and* $p_e(\Theta, t)$ *at LFS follow sweep of DED currents*

The deduction of e-folding lengths λ_{n_e} and λ_{T_e} in radial and poloidal direction in this flux tube gives a twofold result: In radial direction a reduction of this quantities showed up in accordance to the findings of the previous section. However, in poloidal direction the electron temperature is only weakly affected by the laminar flux tube. The profiles stay flat leading to very high values of $\lambda_{T_{e}pol} \approx 150mm$.

Discussion and Conclusion

The response of the plasma to the structure induced by the DED caused a decrease of n_e, T_e and with this of p_e in poloidal and radial direction accompanied with a splitting of the particle flux pattern on the DED target. This measurements confirmed the existence of laminar flux tubes which are poloidally isolated by surrounding ergodic field lines. They create extended local sinks guiding the plasma to the DED target acting as an scrape-off layer of the divertor structure imposed by the DED. This ED-SOL is more complex than the similar shaped poloidal divertor SOL caused by the ergodic flux channels surrounding the laminar flux tubes. They lead to an particle influx into the ED-SOL and the expected influence on the transport properties is indicated by the different change of the e-folding lengths in radial and poloidal direction. The decay of λ_{n_e} and λ_{T_e} in radial direction show a more efficient sink activity than without DED. The convective transport along the laminar field lines is dominating. In poloidal direction the ergodic regions neighbouring the flux tubes change by a high diffusive transport the heat and particle influx into the flux tube. The poloidal electron temperature profile remain unchanged in the ergodic regions and even in the boundary to the flux tubes. Only further outside where T_e in general decreases the transport of heat along the laminar field lines is recognized. This is probably caused by a dominating conductive transport of heat in the poloidal direction and the flux tube is not wide enough to have an impact on the heat transport. Further interpretation of this findings needs modelling: The EMC3-Eirene code package - a three dimensional modelling approach - will be used in future to order this findings into the context of transport phenomena and analyze the transport properties in the ED-SOL in more detail.

The results presented are part of an ongoing PhD thesis at the Heinrich Heine Universität Düsseldorf.

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