

THE DYNAMIC ERGODIC DIVERTOR OF TEXTOR-94: TOPOLOGY AND PROPERTIES OF THE LAMINAR ZONE

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1. Introduction

The Tokamak TEXTOR-94 will be equipped with a Dynamic Ergodic Divertor(DED)[1]. In fusion research different ways are in discussion how to distribute the power load from the core plasma to the wall elements in a moderate way. One attempt to this problem is the concept of an ergodic divertor. Perturbation coils break the flux surfaces in the edge of the equilibrium tokamak field resulting in an ergodic region. Although the plasma in the ergodic region has a nearly homogenous distribution the energy and particle fluxes to the target plates in front of the coils show areas with high impact and areas without. These areas are defined by the near field of the perturbation coil system. In this so called laminar zone[3] field lines intersect the wall elements and connect the edge plasma with the target plates. In the case of TEXTOR-DED it has been shown that in a large operational space both the energy and particle transport to the target plates is dominated by laminar transport and the laminar zone has a well defined structure as compared to the ergodic region. These structures of field lines with well defined properties allow a modeling concept for the laminar zone which is adopted from 'classic' poloidal divertors.

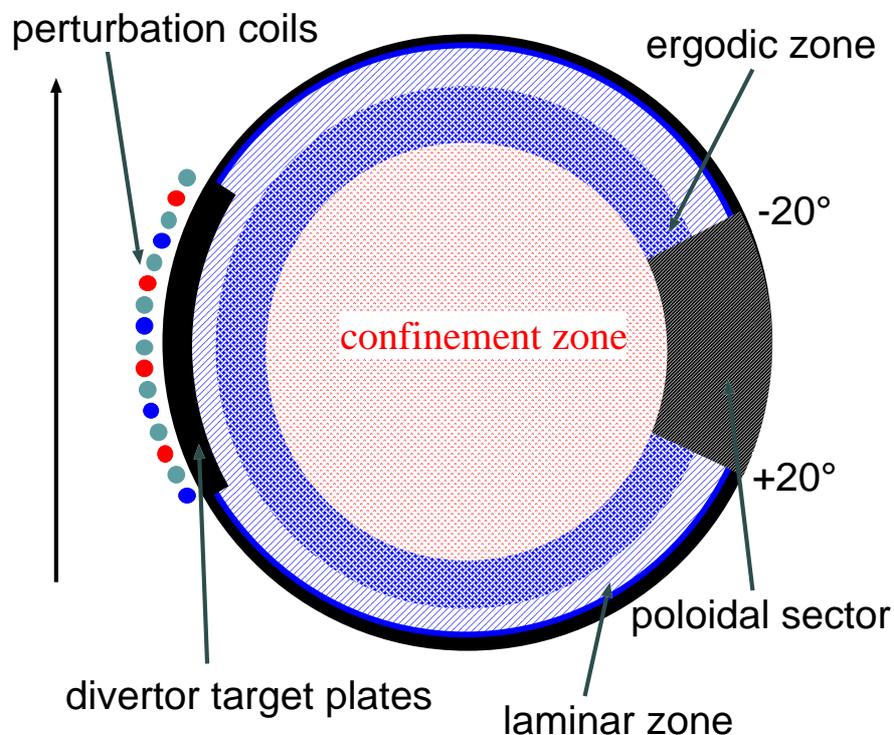


Fig. 1: A poloidal cross section shows the structure of the different regions generated by the DED perturbation coil arrangement. A poloidal sector can be chosen to present the whole magnetic field line topology.

2. The magnetic field structure

It was shown that the combination of the perturbation field and the tokamak equilibrium field generates three regions of different properties. Fig. 1 gives a survey of these structures in a poloidal cross section. The laminar zone envelopes the ergodic zone which envelopes the zone of confinement. A imaging technique was introduced as the tool to get information about the laminar zone [2]. Due to the four fold symmetry of the coil geometry and current distribution a poloidal sector in Fig. 1 can be chosen to present the whole topology. The poloidal sector is shown in Fig. 2. Field lines are traced with a numerical method until intersection with the target plates or their neighbourhood giving the connection length as the basic information about the laminar zone. There is a large region of field lines of connection lengths of one poloidal turn ($L_c \approx 1 \cdot 2\pi qR$) which is marked with '1' and two minor regions with connection length of two poloidal turns ($L_c \approx 2 \cdot 2\pi qR$) which are marked with '2'. The sizes of these regions are in the order of the typical plasma decay lengths. Regions with more poloidal turns are much smaller than the latter ones and are not taken into account. The well defined areas containing field lines

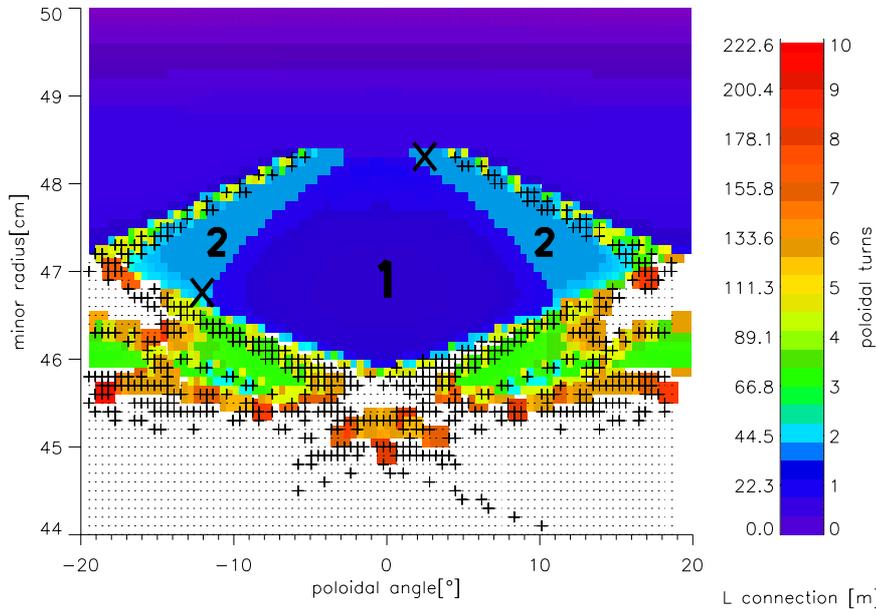


Fig. 2: The spatial distribution of L_c in the poloidal sector is the basic information about the laminar zone. Regions of $L_c = 1$ poloidal turn and $L_c = 2$ poloidal turns are indicated.

of $L_c = 1$ or 2 poloidal turns are similar to that one establishing the scrape-off-layer (SOL) of a 'classic' poloidal divertor although the topology is more complex. The field lines of $L_c = 2$ poloidal turns have an additional property: These field lines traverse the poloidal sector two times and are radially and poloidally mixed. An example for this mixing is the field line which traverses the poloidal sector at the positions $\theta = -12^\circ, r = 46.8\text{cm}$ and $\theta = 2^\circ, r = 48.3\text{cm}$ with θ as the poloidal angle. In Fig. 2 these positions are indicated by the 'x'. The radial deflection is about 1.5cm . Other examples would show less radial deflection. All values including no radial (although poloidal) deflection are possible. The dots mark the regions of field lines which do not intersect the divertor target plates. Those field lines belong to the ergodic zone. The '+' marks those field lines which intersect the target plates in only one tracing direction due the limit in computation time and accuracy ($L_{max} \approx 24 \cdot 2\pi R$).

3. Modeling of the edge plasma

The laminar zone of the DED has a well defined but three dimensional structure. Different approaches have been done to model a three dimensional magnetic field structure. The goal of this simple approach compared to the more refined model E3D[4] is to understand the basic transport phenomena in relation to the topological characteristics.

A basic quality of the model is the transformation in a 2-dimensional coordinate plane for the cross field transport. The coordinates are the perpendicular distances between the field lines which are computed numerically. The parallel transport is estimated via loss times defined by the local connection lengths. For the regions of $L_c = 2$ poloidal turns radial conductive and convective fluxes along the field lines arise from the radial field line mixing. They are computed by solving the momentum equations along the field line at characteristic points. It is assumed that the ergodic zone has a constant temperature and density at the border to the laminar zone. A finite element code (PDE2D) is used as the numerical tool. For the calculation T_i and T_e are set equal, $D_{\perp} = 0.5m^2/s$, $\chi_{\perp} = 0.5m^2/s$ and $\kappa = \kappa_{elec}^* T^{5/2}$.

$$\nabla_{\perp}(D_{\perp}\nabla_{\perp}n) + \nabla_{\parallel}(nv_{\parallel}) = 0 \quad (1)$$

$$\nabla_{\perp}(\chi_{\perp}n\nabla_{\perp}T + 5TD_{\perp}\nabla_{\perp}n) + \nabla_{\parallel}(5nv_{\parallel}T - \kappa\nabla_{\parallel}T) = 0 \quad (2)$$

$$\nabla_{\parallel}(m_pnv_{\parallel}^2 + 2nT) = 0 \quad (3)$$

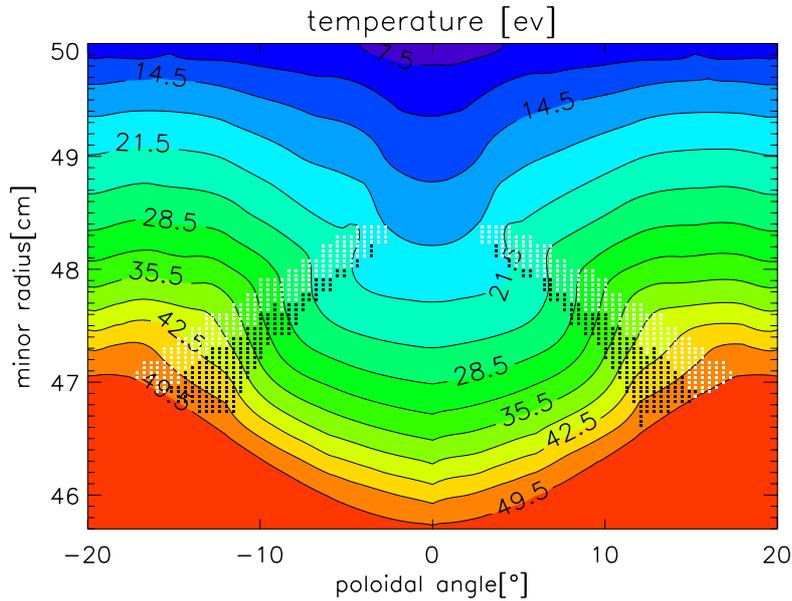


Fig. 3: The calculated temperature distribution for the laminar zone. The temperature decays on a curved arc. Influences of the radial transport along the field lines effect a strong deformation of isotherm lines indicated by the chequered regions.

Fig. 3 shows the calculated temperature distribution. The temperature is 50eV (density is $10^{19}m^{-3}$) at the border to the ergodic zone and decays on a curved arc. The additional radial fluxes along the field lines cause a strong deformation of the isotherm lines. From the dark chequered region the energy is transported to the white chequered region.

An important property of the divertor operation is the expected power load on the wall. From probe theory we adopt the expression for the power load:

$$p_{wall} = \gamma \Gamma_{\parallel} \cdot kT = \gamma n c_s kT = \frac{P_{wall}}{A} = \frac{P_{wall}}{A' \cdot \cos \alpha} \quad (4)$$

with k as the Boltzmann constant and α as the impinging angle of the field lines. The power deposition pattern for $820kW$ total power load is presented in Fig. 4 showing the TEXTOR-DED inner wall (target plates between the horizontal lines). An important result for later operation is the variation of the power deposition on the divertor target plates. In the 50Hz dynamic option of the DED this pattern can be smeared over the whole DTP in toroidal direction resulting in a more homogenous distribution.

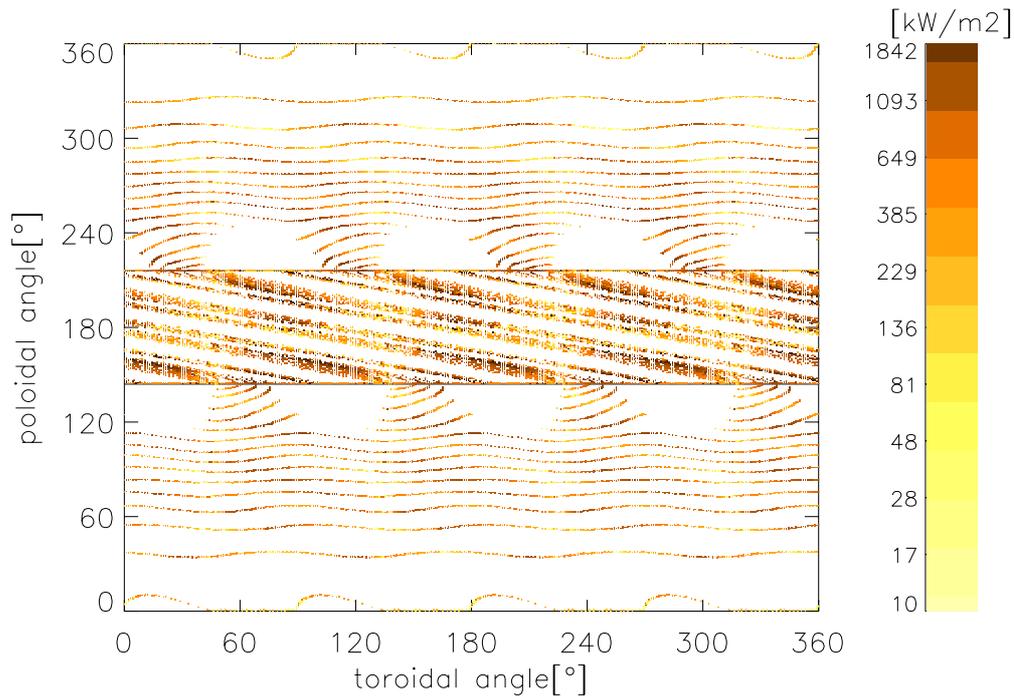


Fig. 4: The calculated power deposition structure on TEXTOR-DED inner wall. The power deposition pattern show a strong variation with regions of high and low impact.

Outlook: The next step will perform a more sophisticated treatment of the parallel transport including the momentum equation solved on several points at different poloidal cuts along the field lines leading to a simple but nevertheless 3-dimensional treatment of the laminar zone. The 3-dimensional treatment offers the choice to include recycling and re-ionizing effects in the laminar zone based on a neutral particle model.

References

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