Influence of Drifts on Plasma Parameters in the Boundary Layer of TEXTOR-94

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Introduction

Drift motions have strong influence on the plasma edge parameters. Above all this is the case when the poloidal symmetry is broken by a toroidal limiter structure or a divertor. For the latter case asymmetries in density and temperature between inner and outer divertor plates have been observed [1]. In this paper we want to focus on the effects arising from drifts in a tokamak with a toroidal belt limiter. We measured poloidal asymmetries in the boundary layer of TEXTOR-94 and interpreted them by model calculations.

Drifts are induced by radial pressure gradients and electric fields in the boundary layer. The drift velocities for the ions can easily be found from the equation of motion for the electrons (Ohm's law) to be

$$v_\perp = \frac{1}{en}\left(-\frac{1}{B}\frac{\partial p_e}{\partial r} + j_\perp\right) - \frac{E_r}{B} + \frac{\eta_r j_r}{B} \quad \text{and} \quad v_r = \frac{1}{en}\left(\frac{1}{B}\frac{\partial p_e}{\partial \theta} + j_r\right) + \frac{E_\perp}{B} - \frac{\eta_\perp j_\perp}{B}.$$

The currents arising from the nonambipolar motion of ions and electrons can be written as

$$j_\perp = \frac{1}{B}\frac{\partial}{\partial r}(p_i + p_e) \quad \text{and} \quad j_r = -\frac{1}{B}\frac{\partial}{\partial \theta}(p_i + p_e) - \frac{m_i n}{B}(\mathbf{v}\cdot\nabla\mathbf{v})_\perp,$$

neglecting source terms and viscosity. In particular the perpendicular (allmost poloidal) drift leads to distinct asymmetries on both sides of the toroidal limiter. Calculations with the 2D fluid code TECXY [2] for a high density discharge with $\bar{n}_e = 4.5 \times 10^{19} \text{m}^{-3}$ (about 85% of the Greenwald limit) show typical drift velocities $v_\perp$ in the vicinity of the LCFS up to 10^4m/s, which is about 10% of the sound speed. The radial drifts are strongest near the toroidal limiter with velocities v_r up to 500m/s. Due to the nonambipolar motion of electrons and ions diamagnetic current densities $j_\perp$ of about maximal 25kA/m^2 arise inside the LCFS and smaller radial current densities j_r with maximum around 100A/m^2 are found near the limiter. In low density discharges probe measurements of the poloidal Mach number give values around $M_\theta \approx 0.07$ [3] in the transition layer near the separatrix. This is in agreement with the calculations.

Analysis of measurements and calculations

The investigations were performed at TEXTOR-94, a medium size tokamak with major radius $R_0 = 1.75$m, minor radius $a = 0.46$m and a typical toroidal field $B_t = 2.25$T. The toroidal belt limiter ALT-II is located 45° below the equatorial plane at the low field side. All measurements were done in NBI heated discharges.

The thermal helium beam diagnostic is a suitable, non disturbing method to measure electron density and temperature profiles with high temporal and spatial resolution in the plasma edge [4]. At TEXTOR-94 effusive helium beams can be injected at three different poloidal positions (Figure 1), namely at the low field side (LFS), the high field side (HFS) and at the bottom (BOT). The observation is done with various methods: at the LFS a system with filters and linear diode array cameras is used, whereas at the HFS a spectrometer selects the three Helium lines at $\lambda_1 = 667.8$nm, $\lambda_2 = 706.5$nm and $\lambda_3 = 728.1$nm. At the bottom position both, a 2D diode array camera with filters and a spectrometer are applied. The evaluation methods including background subtraction and radial calibration are discussed elsewhere [4,5].
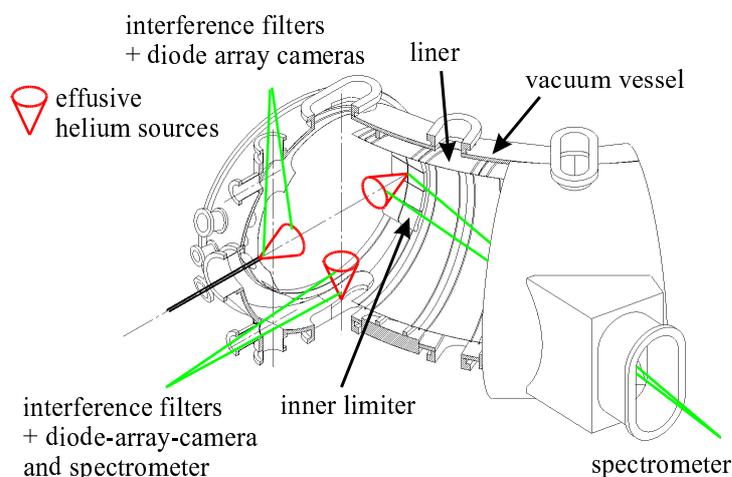

interference filters
+ diode array cameras

liner

vacuum vessel

effusive
helium sources

interference filters
+ diode-array-camera
and spectrometer

inner limiter

spectrometer

Figure 1: *Helium beam diagnostics at TEXTOR-94*

The densities measured at the LFS and HFS (Figure 2) show smooth radial profiles for low density discharges whereas for high densities a shoulder appears at the LFS. The HFS density profiles as well as the temperature profiles at both positions do not exhibit a deformation with increasing density.

The formation of the density shoulder can be explained by drift effects. In the model calculations with the code TECXY, drift effects can be identified by including respec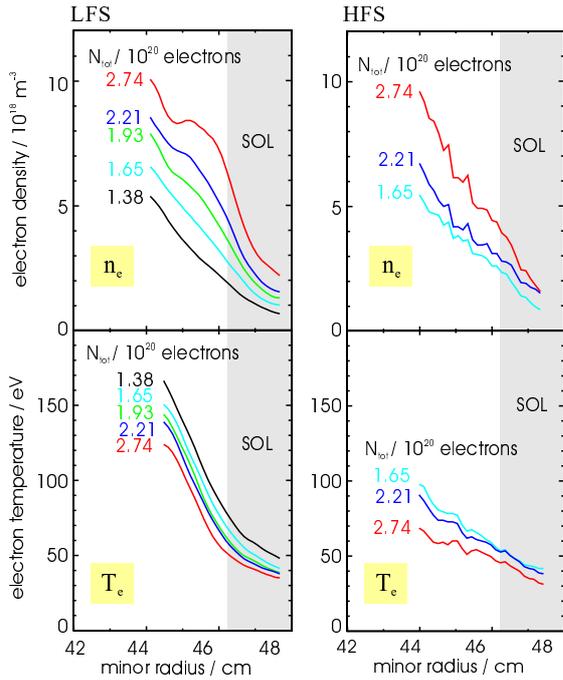tively excluding the drift terms. A comparison of edge profiles for the high density discharge modelled by TECXY is shown in Figure 3. The most significant effect of the drifts is a marked asymmetry arising in the density profiles. A plateau is building up in the vicinity of the limiter on the LFS as well as at the BOT position. The change in temperature is negligible. The plateau at the LFS can be simply understood as a density accumulation since the perpendicular drift $v_\perp$ leads to a plasma flow towards the limiter. To understand the plateau in the density profile at the bottom, one must have a closer look into the boundary conditions at the limiter (Figure 4). The poloidal velocity is restricted to $\pm c_s$ at the sheath entrance. This leads to a parallel flow $v_\parallel$ which is enhanced on the bottom (near ion side) and reduced at the LFS (near electron side). A poloidal pressure gradient has to provide the large parallel velocity at the i-side, hence a higher density is build up at the bottom position. The reduced parallel velocity at the e-side additionally amplifies the density increase at the LFS.

The sign of the drift velocities was changed by inverting both the toroidal magnetic field and the plasma current. The conditions at LFS and BOT are not simply exchanged, since due to the balloning effect the influx at the LFS is larger (see Figure 5). The simple picture shows, that the density profile at the LFS flattens whereas the profile at BOT steepens with reversed field. In addition the density at LFS drops in the reversed case, whereas at BOT the density increases.

Figure 2: *Measured density and temperature profiles at the LFS and HFS for different plasma densities. ($P_{tot} = 1.55 MW$)*
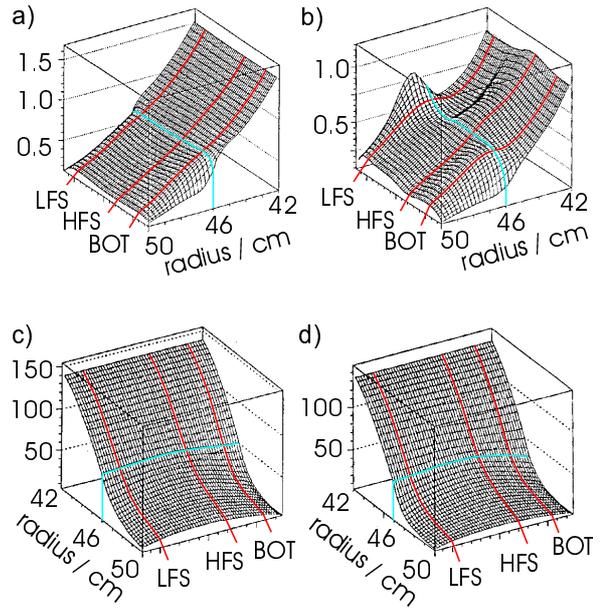

Figure 3: *TECXY calculations: Density $[10^{19}m^{-3}]$ profiles a) without drift and b) including drift effects. Temperature [eV] profiles c) without drift and d) including drift effects.*

Measured and modelled density profiles at different poloidal positions with both field configurations are shown in Figure 6. The absolute values and the radial position of the shoulder at LFS and BOT agree within the error bar. The changes in the calculated profiles due to the field reversal follow the simplified picture. However, the change of the absolute values of the measured densities deviates from this picture. This might be explained by a different impurity content in the plasma. E.g. a higher impurity concentration would increase radiation losses and reduce the effective energy input into the boundary layer. Together with the changed transport coefficients, this might influence the absolute values as well as the gradients of the densities and temperatures.

In the model calculation the decay length at the HFS are overestimated, because the inner limiter is not taken into account. Despite these deviations, the decay length show the expected behaviour in the model as well as in the measurements. The decay length for the measured profiles shown in Figure 6 are at the LFS $\lambda_n = 1.8/2.0$ cm (normal/reversed) and at BOT $\lambda_n = 1.6/1.2$ cm.

Conclusion

It could be shown, that the influence of drift motions is significant in tokamaks with toroidal limiter geometry. The drift flow leads to poloidal asymmetries and strong deformations of the density profiles. In particular in high density discharges a shoulder or even a minimum in the density arises in the vicinity of the limiter near the LCFS.
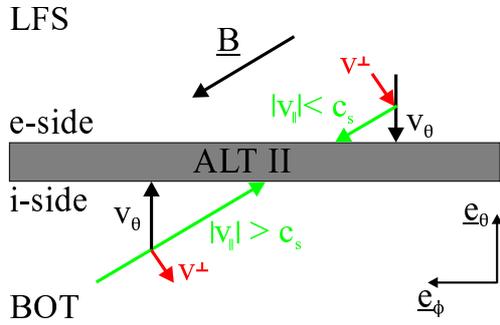
Figure 4: *Boundary conditions at the limiter. The poloidal velocity is fixed to the projection of the sound speed $v_\theta = \pm \frac{B_\theta}{B} c_s$ at the sheath. This leads to a parallel flow of $v_\parallel = \pm c_s - \frac{B}{B_\theta} v_\perp$ for the e-side/i-side.*
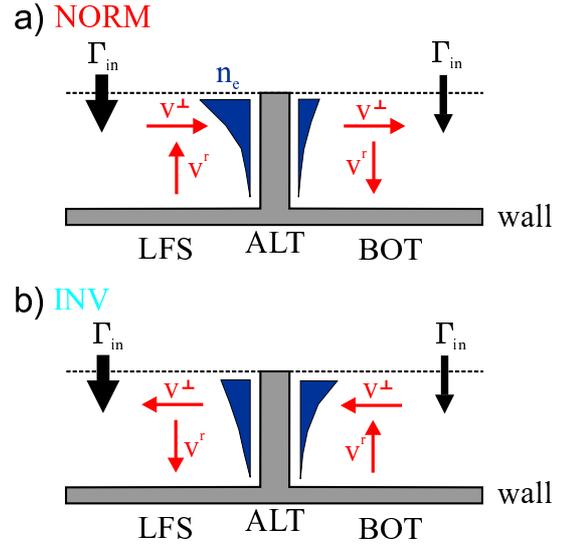

Figure 5: *Drift motions in the vicinity of the toroidal belt limiter ALT-II for a) normal and b) inverted field configuration*
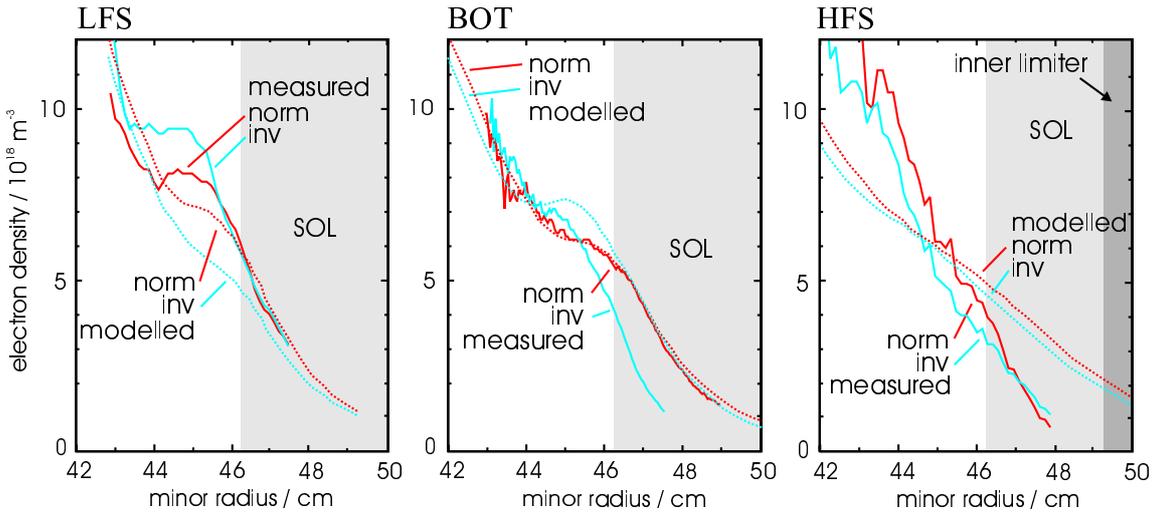

Figure 6: *TEXTOR-94 versus TECXY: Density profiles for both magnetic field configurations for discharges with $\bar{n}_e = 4.5 \times 10^{19} m^{-3} \approx 0.85 \, \bar{n}_e^{GW}$ and $P_{tot} = 1.55$ MW.*

References

[1] A.V. Chankin et al., Plasma Phys. Control. Fusion **36** (1994) 1853.

[2] R. Zagórski, H. Gerhauser, H.A. Claaßen, Contrib. Plasma Phys. **38** (1998) 61.

[3] H. van Goubergen, S. Jachmich, private communication.

[4] M. Brix, PhD thesis, Jül-report Jül-3638 (ISSN 0944-2952) Forschungszentrum Jülich Germany (1999).

[5] B. Schweer, M. Brix, M. Lehnen, J. Nucl. Mater. **266-269** (1999) 673.