Self-induced transport barrier in the helium plasma on the tokamak GOLEM

P. Macha[1,2], J. Adamek[2], J. Stockel[2], V. Svoboda[1], J. Seidl[2]

[1] *Faculty of Nuclear Sciences and Physical Engineering CTU in Prague, Prague, Czech Rep.*

[2] *Institute of Plasma Physics of the CAS, Prague, Czech Rep.*

Transport barriers and transmissions into different regimes of plasma confinement are currently very discussed topics. The lattes research showed a connection between transport barriers and $\mathbf{E} \times \mathbf{B}$ shear flows, which are able to suppress turbulent structures by tearing them apart. This process leads to better particle and also temperature confinement. Therefore, there is a significant effort for transport barrier studies. Usually, transport barriers are induced by an external electric field, which is used for plasma biasing. This method is useful, however, spontaneously formed transport barriers can provide more information about the processes taking place in a tokamak plasma. In this paper, the self-induced transport barrier in the helium plasma on the tokamak GOLEM is observed and analyzed.

Tokamak GOLEM is the smallest still operating machine used mostly for the education of future fusion specialists. It has a circular cross-section with limiter, ohmic heating, a minor radius 8.5 cm, a major radius 0.4 m, and a possibility to use hydrogen, helium, deuterium, or even argon as a working gas. Tokamak GOLEM is equipped with several diagnostics. The combined probe head equipped with ball-pen and Langmuir probe, a set of Mirnov coils, and a fast camera are used in this work. The diagram of these diagnostics is shown in Fig 1. The combined ball-pen and Langmuir probe allow fast plasma potential Φ and electron temperature T_e measurements. Ball-pen probe is a modified probe, which uses dielectric shielding to balance ion and electron currents in order to measure the plasma potential directly. To be able to measure electron temperature with a high temporal resolution, the combined probe must be calibrated first. The calibration is based on the equation describing the relationship between both floating

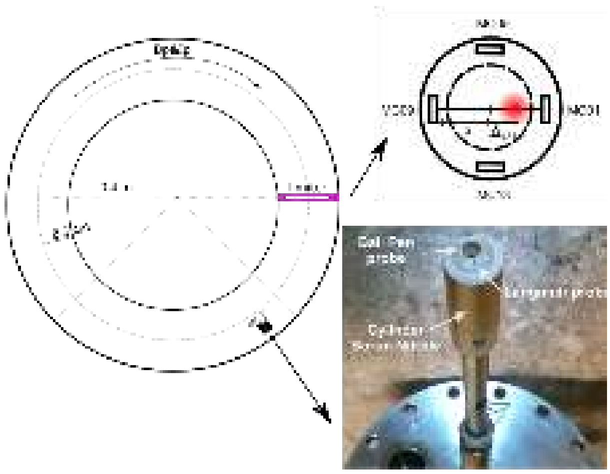

Figure 1: Experiential setup used for the measurement.

U_{fl} and plasma Φ potentials and electron temperature T_{e}:

$$\Phi - U_{\mathrm{fl}} = \alpha T_{\mathrm{e}}, \alpha = \ln\left(\frac{A_{\mathrm{e}} j_{\mathrm{e}}^{\mathrm{sat}}}{A_{\mathrm{i}} j_{\mathrm{i}}^{\mathrm{sat}}}\right) \tag{1}$$

where α is the calibration constant. In the process of calibration, floating potential is measured by Langmuir probe, plasma potential by ball-pen probe and electron temperature is obtained from IV characteristics of Langmuir probe fitted by 4-parameter fit $I_{\mathrm{probe}} = I_{\mathrm{sat}}\left(1 - \beta\left(\frac{U_{\mathrm{probe}} - U_{\mathrm{fl}}}{T_{\mathrm{e}}}\right) - I_{\mathrm{sat}}\left(\exp\left(\frac{U_{\mathrm{probe}} - U_{\mathrm{fl}}}{T_{\mathrm{e}}}\right)\right)\right)$, where I_{probe} is the probe current and U_{probe} is the probe biased voltage. IV characteristics are based on shot-to-shot method. The result of the calibration are shown in Fig 2.

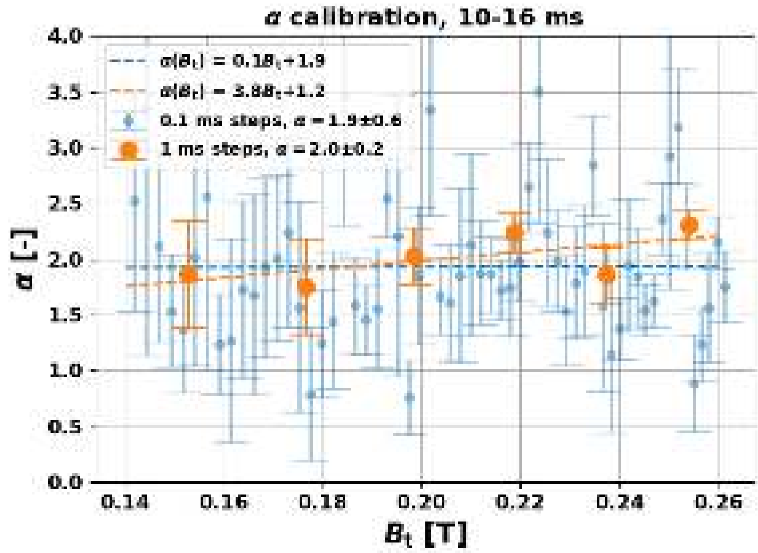

Figure 2: Resulting dependency of calibration coefficient α on the toroidal magnetic field.

Despite the possible linear trend, the value will be considered as a constant being equal to $\alpha = (2.0 \pm 0.2)$, because the linear trend has a negligible impact on the following analysis. Also note, that both fits for the different temporal resolution of IV characteristic construction gives similar results.

Reproducible discharge series was performed in order to measure radial profiles. Plasma macroscopic parameters are shown in Fig 3. Based on the calibration, radial profiles of the plasma potential are measured using the shot-to-shot method. Based on the plasma potential profiles, the radial electric field is calculated as its derivative. The position where the radial electric field is zero is used to determine the velocity shear layer (VSL) position. All the following radial profiles are then plotted with respect to the VSL position, therefore, the plasma movement is eliminated from the profiles. Finally, radial profiles of electron temperature are constructed based on the calibration. The resulting profiles are shown in the following Fig 4.

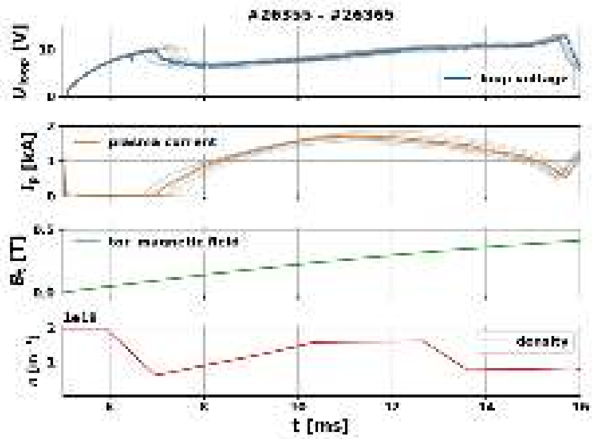

Figure 3: Time evolution of macroscopic parameters of reproducible discharge serie.

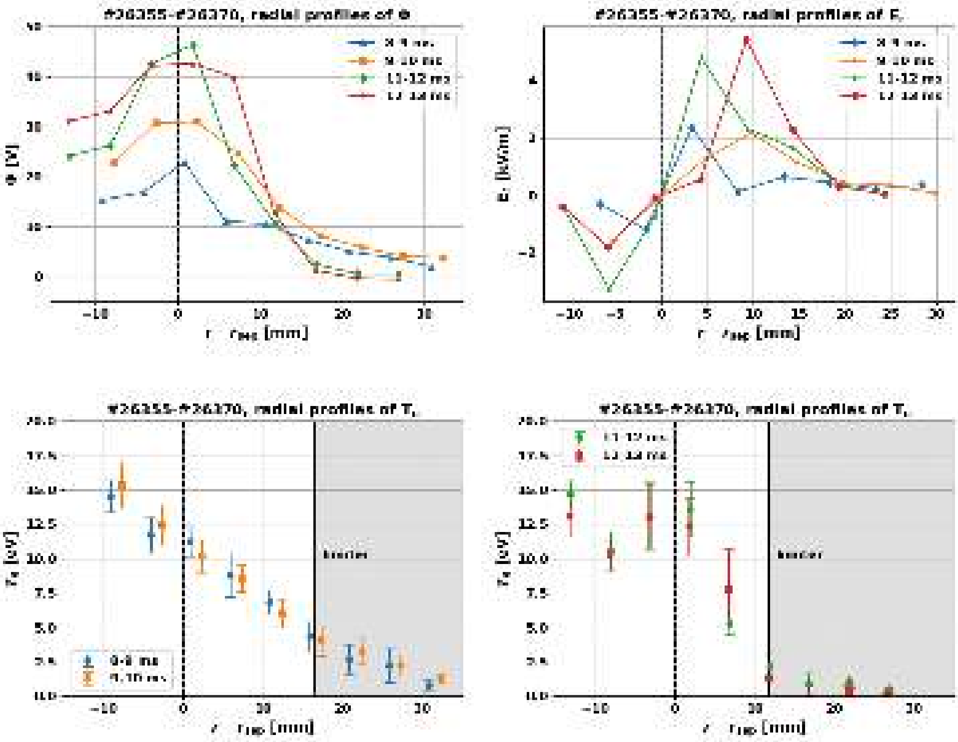

Figure 4: Radial profiles of plasma potential, radial electric field and electron temperature.

It is clearly visible a strong gradient of electron temperature is formed. It is evident that a transport barrier in electron temperature was formed between 10-11 ms. Moreover, the plasma potential has grown from 20 V to almost 50 V and the radial electric field started to gradually increase. In order to exclude an influence of plasma position during the discharge, the reconstruction by Mirnov coils and fast cameras was performed, showing the plasma column to be stable during analyzed time interval, see Fig 5.

Finally, the influence of transport barrier on transport was studied. The most significant ef-

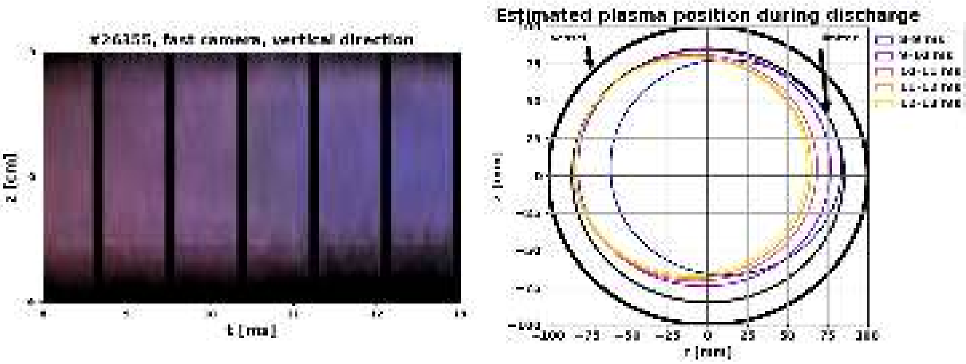

Figure 5: Plasma position determined by fast camera left), and by Mirnov coils right) .

fect is visible in floating potential, which corresponds to the electron temperature fluctuations. A significant decrease in low-frequency oscillations is observed after the barrier is formed. Moreover, significant decoherence between floating and plasma potential is observed. Both effect are shown in Fig 6. No visible suppression of plasma potential fluctuation is observed.

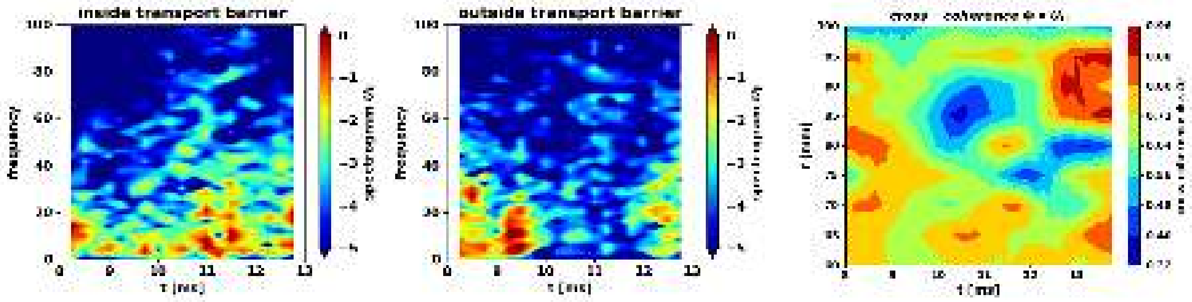

Figure 6: Spectrogram of the floating potential left), cross-coherence between plasma and floating potentials.

Unfortunately, the density measurements were not available during the experiment, therefore, there are no density analyses available. Even though, we can clearly say, the transport barrier in electron temperature was observed. Additional effort to determine the origin of the transport barrier formation is planned.

Acknowledgement: This work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS22/175/OHK4/3T/14.

References

[1] Tokamak GOLEM, Czech Technical University in Prague, http://golem.fjfi.cvut.cz/ [online]

[2] J. Adamek, et. al; Czechoslovak Journal of Physics volume 54, Article number: C95 (2004)