

## Plasma Potential Formation under the Edge Polarization

A. Melnikov, L. Eliseev, L. Krupnik<sup>1</sup>, S. Lysenko, V. Mavrin, S. Perfilov, Yu. Dnestrovskij, K. Razumova, M. Ufimtsev<sup>2</sup>, O. Yudina, L. Zimeleva

*Nuclear Fusion Institute, Russian Research Center 'Kurchatov Institute', Moscow, Russia*

<sup>1</sup>*NSC 'Kharkov Institute of Physics & Technology', Kharkov, Ukraine*

<sup>2</sup>*Moscow State University, Moscow, Russia*

### 1. Introduction

Plasma edge polarization studies have shown that formation of the radial electric field plays an important role in improvement of plasma confinement [1, 2]. The region of the electrode shadow, located between the electrode and limiter, has been typically studied in biasing experiment. The layer with the strong electric field and the transport barrier for particles leading to improvement of global confinement has been observed in the electrode shadow [1, 2]. The Heavy Ion Beam Probe (HIBP) is the only diagnostics allowing us to investigate directly the plasma potential in the core and edge plasma. The local plasma potential can be obtained from the change of the beam energy in the sample volume. The secondary beam current indicates the local density. The exact density measurement has to take into account the beam attenuation along the trajectories. Using the HIBP in the T-10 tokamak ( $B_0 = 2.42$  T,  $R = 1.5$  m,  $a_{\text{lim}} = 0.3$  m), we study the evolution of the plasma potential and density profiles under the electrode biasing. The radial profiles were measured at the plasma edge,  $0.8 < \rho < 1$  ( $\rho = r/a$ ), both outside and inside the electrode radius  $\rho_{\text{el}} \sim 0.9$  [3].

### 2. Experimental set-up

HIBP and electrode were separated toroidally in  $180^\circ$  with a limiter between them; 200 – 220 keV Tl<sup>+</sup> beam was used. Scanning of the beam entrance angle into the plasma in the single shot produces a profile each 20 ms. The scanning time is about 5 ms. The spatial resolution of measurements is 5-15 mm, the analysed bandwidth is 3-50 kHz.

### 3. Experimental Results

The study were done in OH and on-axis ECRH shots with  $I_p = 230$  kA,  $n_e \sim 1.5 \times 10^{19} \text{ m}^{-3}$ ,  $P_{\text{EC}} \sim 0.4$  MW. The time history of the typical ECRH shot is presented in Fig. 1 with  $t_{\text{bias}} = 600$  ms,  $U_{\text{bias}} = +400$  V. The rise of the line-averaged density and decrease of  $D_\alpha$  after biasing typically indicate the H-mode features [3]. However, confinement improvement was not pronounced in regimes with HIBP measurements.

HIBP observes the following:

1. The changes in potential profile after biasing with respect to the level before biasing  $\Delta\varphi(r,t) = \varphi(r,t) - \varphi(r,t_{\text{base}})$ , looks like a hill, located near  $\rho_{\text{el}}$ . In the plasma interior,  $0.8 < \rho < 0.85$ , the extra potential is small. At both sides of the potential peak the regions with strong changes of the electric field are placed. Peak of the hill rises up rapidly (faster than 20 ms interval between scans) and decays with a time scale of the density variation and  $U_{\text{bias}}$  decay. The location and the shape of the hill remain unvarying till the end of the shot.
2. Time evolution of the secondary beam current profile  $I_{\text{tot}}$  (Fig. 2) shows the typical flattening (in the vicinity of the potential peak) surrounded with two areas with steeper gradients. This shoulder-like shape of  $I_{\text{tot}}$  remains self-similar till the end of the line-averaged density pulse ( $\sim 780$  ms). Afterwards the slope becomes more homogeneous.
3. The spatial-temporal evolution of the power spectra of  $\varphi(r, t)$  and  $I_{\text{tot}}$  oscillations was investigated. The whole scan was divided to four spatial zones, as shown in Fig. 2. In each

zone the power spectra for  $\varphi(r, t)$  and  $I_{\text{tot}}$  were found by periodogram with sliding window before (base) and after biasing. The level of the  $\varphi(r, t)$  and  $I_{\text{tot}}$  oscillations strongly decreases after biasing outside as well as inside the electrode position (Fig. 4).

4. Observations described above are similar in OH biasing regime.

5. During the negative biasing  $U_{\text{bias}} = -400\text{V}$  no changes in the global plasma parameters and HIBP data were seen.

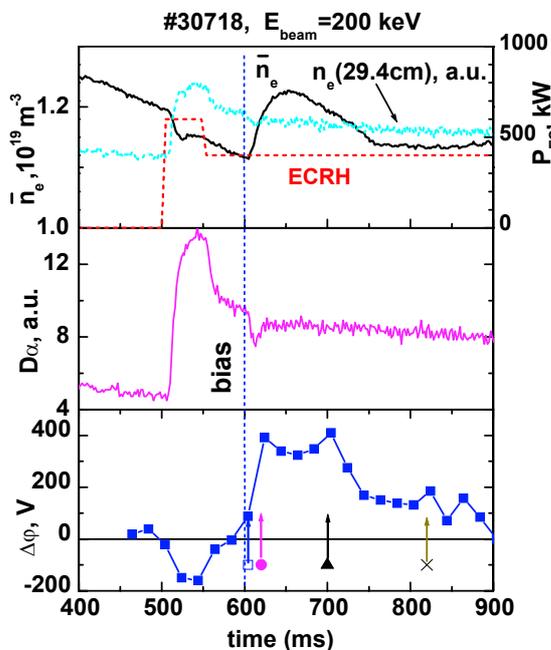


Fig. 1. Time history of typical biasing shot. Simultaneous rise of the line-averaged density, fall-down of  $D\alpha$  and rise of the extra potential measured at 28 cm are seen after biasing. The edge density (29.4 cm) slightly decreases.

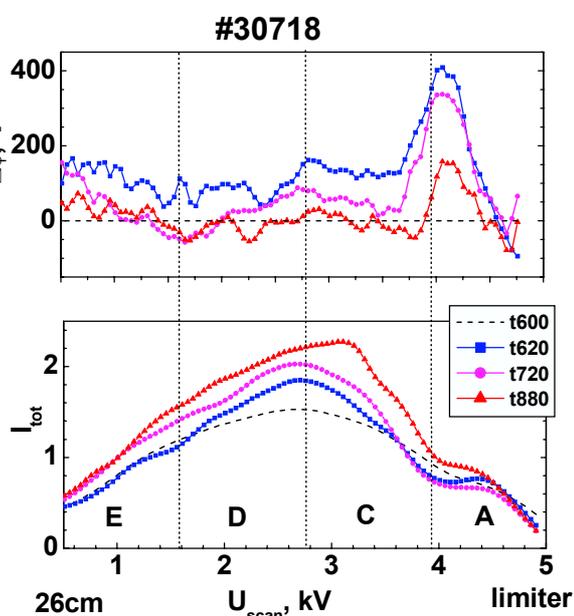


Fig. 2. The profiles of the extra potential and the total secondary beam current  $I_{\text{tot}}$  as functions of scanning voltage. The shelf on  $I_{\text{tot}}$  coincides with the peak of the potential.

#### 4. Discussion

The reconstruction of the radial profiles of  $\varphi(r, t)$  and  $I_{\text{tot}}$  is presented in Fig. 3. The radial uncertainty of the profile as a whole is indicated as a bar in a limiter position. The absolute potential profile was derived from the *in situ* calibration with He gas. The absolute reference was chosen as  $\varphi(a_{\text{lim}}, t_{\text{base}}) = 0$ . The potential errors vary along the radius due to Signal/Noise caused by  $I_{\text{tot}}$  variation. At the edge the errors are higher. Before biasing the plasma potential in the area of 27 – 29 cm has slightly negative well of about  $-100\text{ V}$ . After biasing the local hill is forming at this area with the top value of  $+300\text{ V}$ . Hill keeps the shape, while the peak value decreases with time. Two regions, where the electric fields are approximately equal, but have opposite signs,  $E_r \approx \pm 300\text{ V/cm}$ , are placed at both sides of potential peak. The error in  $E_r$  is systematic due to the radial reference uncertainty and lies between  $\pm 100\text{ V/cm}$ .

The total secondary beam current is proportional to the local plasma density  $I_{\text{tot}} \sim n f(T_e)$ . The attenuation factors can be neglected here due to the low edge density and the short longitude of the trajectories. The time evolution of  $I_{\text{tot}}$  profile shows the local flattening at the area of  $E_r = 0$  (top of the potential hill in Fig. 3). This flattening indicates the local sink in the density profile. The negative E-field layer (27-28 cm) coincides with the area of the

increased  $I_{tot}$  slope, which indicates the  $n_e$  slope rise and can be interpreted as possible transport barrier. The changes in the slope are shown clearly by  $\Delta I/I_{tot} \sim \Delta n_e/n_e$  deviation from zero (Fig. 3). The positive E-field layer (28-30 cm) lies in the vicinity but a bit inside of the outer  $n_e$  slope area (29-31 cm). The signal of 29.4-cm chord density (Fig. 1) also indicates the slight decrease of the edge density.

The observations are not in contradiction with the widely accepted assumption of the fluctuation suppression by the plasma rotation induced by the radial electric field as a driving mechanism of confinement improvement.

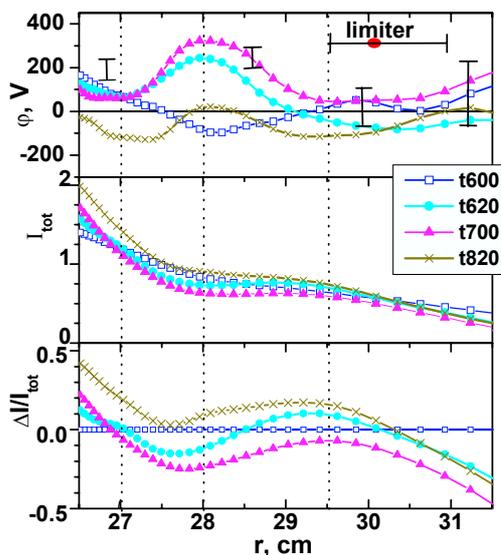


Fig. 3. The reconstructed profiles of the potential, total secondary beam current and the relative beam current in time instants shown in Fig. 1 with zeroing on the limiter. The horizontal bar in the limiter position shows the radial uncertainty of the profiles.

In other machines: stellarator ATF with limiter biasing, and tokamaks PBX-M and JFT-2M with divertor biasing, the local hill of the plasma potential was observed by HIBP [4] or reciprocated probes [5, 6]. In the tokamak CASTOR with electrode biasing the global shift of the plasma potential profile up to  $U_{bias}$  was observed by the probe array, but in case of separatrix biasing the local potential hill at the edge was formed [7].

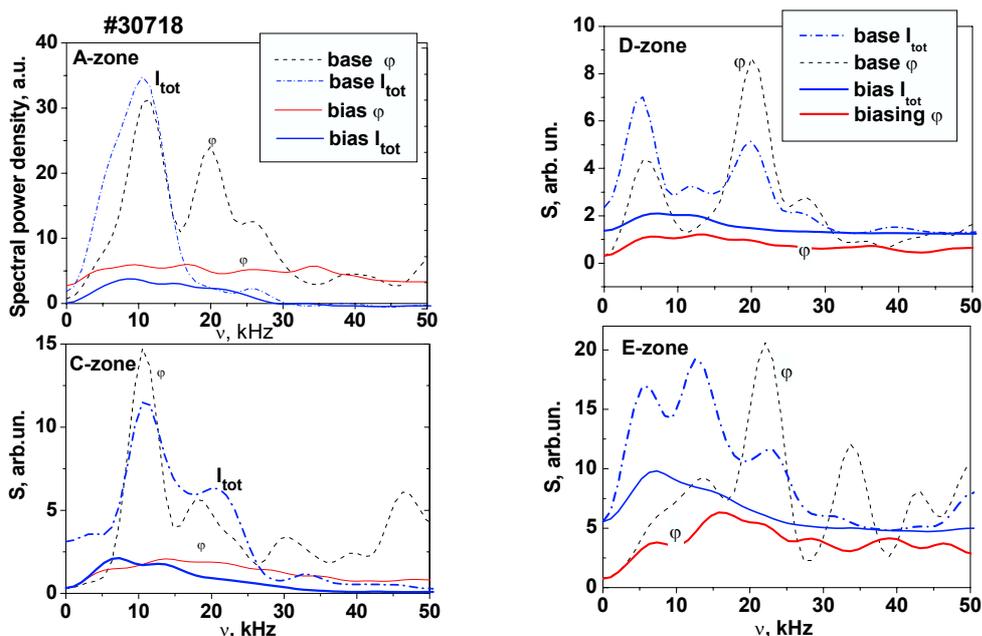


Fig.4. Suppression of oscillations of the potential and the total beam current under biasing.

## 5. Conclusions

HIBP observes that the plasma edge polarisation causes simultaneous effects in the vicinity of electrode: the formation of the plasma potential local hill, increase of the density slope close to the layers with strong  $E_r$ , and suppression of the potential and the secondary beam current oscillations. Thus we show that along with previously observed the strong E-field region in the electrode shadow,  $\rho_{el} < \rho < 1$ , another region with the strong E-field, located in the plasma interior,  $\rho < \rho_{el}$ , may be formed by electrode biasing in the limiter tokamak.

## Acknowledgements

Authors are grateful to our colleagues L.N. Khimchenko, G.S. Kirnev, G.N. Tilinin and the whole T-10 team for the collaboration in biasing experiments and helpful discussions.

This work was supported by RFBR Grants 02-02-17727, 02-02-06609, 02-02-06549 and 00-15-96536, INTAS 2001-2056 and NWO-RFBR Project 0047.009.009.

## References

- [1] R.L. Taylor et al., Phys. Rev. Lett., V. 63, No 21, P. 2365 (1989).
- [2] R.R. Weynants et al., Nucl. Fusion, V. 32, No 5, P. 837 (1992).
- [3] G. Kirnev, L. Khimchenko, S. Grashin, et al, Czech. J. Phys., V. 51, P. 1011 (2001).
- [4] T.R. Uckan et al., Nucl. Fusion, V. 32, No 5, P. 837 (1994).
- [5] L. Schmidt et al., In IAEA Technical Committee Meeting "Tokamak plasma biasing" (1992).
- [6] Y. Miura et al., IAEA-CN-64/O2-4, in Fusion Energy 1996, V.1, P. 167 (IAEA, Vienna, 1997).
- [7] G. Van Oost et al., Czech. J. Phys., V. 51, P. 957 (2001).