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Investigation of the plasma potential behaviour at the periphery of the T-10 tokamak

A.V. Melnikov, L.G. Eliseev, S.V. Perfilov, V.A. Mavrin, V.A. Vershkov, S.A. Grashin,
S E. Lysenko, L.I. Krupnik[1], R.V. Shurygin, G.N. Tilinin
Nuclear Fusion Institute, RRC "Kurchatov Institute", 123182, Moscow, Russia,
[1] Institute of Plasma Physics, NSC “KhIPT”, Kharkov, Ukraine

Although more than a quarter of the century passed since the discovery of the state of High plasma confinement (H-mode) [1], the physical mechanism underlying the phenomenon is still unclear. It was stated in the many theoretical works and found experimentally [2] that the electric field has a leading role in the process of the confinement improvement. The detailed knowledge of the electric field structure at the plasma edge is important for both H- and L-modes. Heavy Ion Beam Probing (HIBP) is the only diagnostics, which is able to measure the plasma electric potential in the bulk plasma. An overlapping of the HIBP bulk potential profile and Langmuir probe edge potential profile is an important issue in the studies of the periphery plasma. The changes of the edge plasma potential during the L-H transition have been measured by HIBP in tokamaks [3, 4]. The subject of the report is the structure and the evolution of the quasi steady state periphery potential profile in a circular tokamak, which has not been reported so far.

The edge plasma potential profile was investigated by HIBP at the low field side of the T-10 tokamak (R = 1.5 m, B_0 = 2.4-2.5 T) within the radial interval of 26-30 cm ($0.86 < r/a < 1$). The plasma was limited by the movable rail limiter at a_{lim} = 27 – 30 cm, and the circular limiter at $a_{\mathrm{c\ lim}}$ = 33 cm. The plasma potential profile was measured along with the probing beam current, representing the density profile.

In the Ohmic phase of the deuterium discharge (I_p = 180 kA, $\overline{n}_e = 1.5\times10^{19}$ m^{-3}) the negative plasma potential was observed (Fig. 1). The gradient part of the profile takes place in the bulk plasma inside the last closed magnetic surface (LCMS), (26 cm < r < 30 cm). The absolute reference of the HIBP potential profile was done by Langmuir probe data at the rail limiter position $a_{\mathrm{r\ lim}}$ = 30 cm. The slope of the potential profile allows us to estimate the mean radial electric field, which is in a range of E_r = –110 V/cm with error ΔE_r = 10 V/cm. In the ECRH phase with on- and off- axis power deposition (P_{EC} = 1- 1.2 MW, r_{ECRH} = 0, -13 cm) the potential well becomes significantly shallower. The mean radial electric field was in a range of E_r = –60 V/cm, ΔE_r = 10 V/cm. The potential time-trace is shown in Fig. 2.

Along with the D plasma, the He discharges (I_p = 240 kA, $\overline{n}_e = 2.5\times10^{19}$ m^{-3}) were studied. The insertion of the rail limiter into $a_{\mathrm{r\ lim}}$ = 27 cm leads to the modification of the plasma profiles (Fig. 3). The potential profile was shifted together with the rail limiter position, while its shape remains the same. In the rail limiter shadow, 27 cm < r < 30 cm, the potential variation is small within the experimental accuracy. The angle point in the potential profile was found to be an empirical marker of the limiter. The existence of such empirical marker helps us to verify the radial reference and decrease the E_r uncertainties.

To verify the link between the position of LCMS and the edge potential profile, the experiment with shift of the plasma column during one shot was performed [5]. It was shown that the gradient part of the potential moves with LCMS position. Secondary beam current profile is shifted accordingly. The rms errors in potential have reasonable peak-to peak values of 50 V (±25V) inside the LCMS (Fig. 5). The changes in the profiles are above the experimental accuracy inside the LCMS. Outside the LCMS, in the SOL, the density and temperature are quite low, and efficiency of the plasma target for the secondary ionisation of probing beam became smaller. Due to the low secondary beam current outside the LCMS, HIBP data have significant rms errors in the potential, > ±100V. However, the tendency of the decrease of the maximal potential value is clear in both HIBP and Langmuir probe data.

In the Ohmic and ECRH phases of the He discharge the negative plasma potential has the shape and dynamics similar to the ones in the D plasma, with the similar E_r (Fig. 4).

To compare the measurements with theory, the 4-field {φ, n, P_e, P_i} electrostatic turbulence modelling was performed. The set of non-linear equations was solved in the framework of the reduced two-fluid Braginskij hydrodynamics having single-helicity approximation to reduce the 3D to 2D problem [6]. The radial electric field E_r was calculated by reduced radial force balance:

$$V_{ExB} = -V_\theta^{plasma} + V_{dia} \qquad V_{ExB} = \frac{cE_r(r)}{B_0}, \quad V_{dia} = \frac{c}{Z_{eff}\, e n_e(r) B_0}\frac{dP_i(r)}{dr}. \tag{1}$$

where V_θ^{plasma} is the plasma poloidal rotation velocity as whole and $V_{E\times B}$ is the $E\times B$ drift velocity.

The calculation area coincides with area of HIBP measurements $r_0<r<a$, r_0=27cm, a=30 cm.

Plasma parameters are: B_0=2.5 T, I_p=220 kA;

[OH]: $T_{e,i}(r_0)$=90 eV, $T_{e,i}(a)$=30 eV, $n_e(r_0)=1.8\times10^{19}$ m^{-3}, $n_e(a)= 0.9\times10^{19}$ m^{-3} ,Z_{eff}=1.4.

[EC]: $T_e(r_0)$=130 eV, $T_e(a)$=30 eV, $T_i(r_0)$=60 eV, $T_i(a)$=30 eV, $n_e(r_0)=2.0\times10^{19}$ m^{-3},

$n_e(a)= 1.2\times10^{19}$m^{-3}, Z_{eff}=1.6.

The OH to ECRH transition was simulated by increase of the $T_e(r_0)$, $n_e(r_0)$, $n_e(a)$, Z_{eff} and some decrease of $T_i(r_0)$. The model describes the experimental potential profiles, Fig 5. Modelled E_r shows the same sign and an average value as experimental ones for both OH and ECRH phases, Fig. 6. Calculation shows that decrease of absolute values of $\varphi(r)$ and $E_r(r)$ during ECRH happens mainly due to the decrease of the gradient of ion pressure $P_i=nT_i$ in (1). The modelling shows the rise of the turbulent flux at the ECRH phase in a factor of two. The increase of T_e and n_e, and also decrease of the $E\times B$ drift velocity at the plasma periphery cause the turbulent flux enhancement. This enhancement is in agreement with known degradation of the energy confinement during the ECRH.

Conclusions

The edge plasma potential was studied by Heavy Ion Beam Probing and Langmuir probes at the low field side of the T-10 tokamak within the radial interval of 26-30 cm ($0.86<r/a<1$).

In the Ohmic phase of the D discharge (I_p = 180 kA, $\overline{n_e} = 1.5\times\cdot10^{19}$ m^{-3}) and He discharge (I_p = 240 kA, $\overline{n_e} = 2.5\times10^{19}$ m^{-3}) as well, the negative plasma potential was observed. The slope of the potential profile gives the estimation of the mean radial electric field in a range of E_r = –100 V/cm. In the shadow of the limiter the potential variation is small. The gradient region of the potential moves with the position of LCMS.

The ECRH heating leads to decrease of the edge electric field.

The model of the electrostatic turbulence describes the potential profile in OH phase, and shows the decrease of E_r and the rise of the turbulent flux in the ECRH phase in accordance with experiment. Behaviour of E_r at the periphery is determined by the turbulent mechanism.

Acknowledgements

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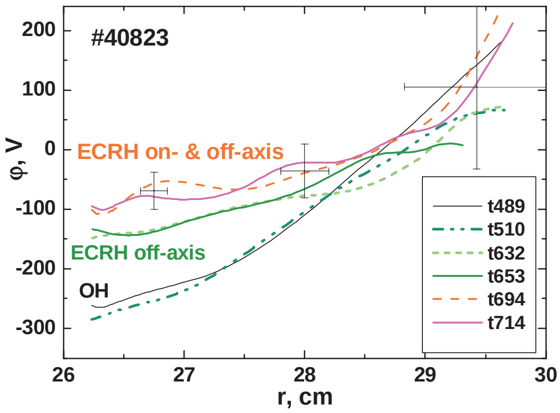

Fig. 1. The potential profile in the Ohmic phase (OH) of the D discharge. During the ECRH phase the potential well becomes significantly shallower.

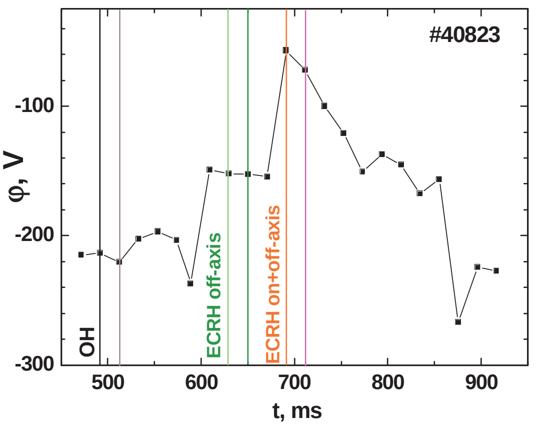

Fig.2. The time evolution of potential at *r*≈27 cm. Vertical lines show instants of profile measurements in Fig. 1.

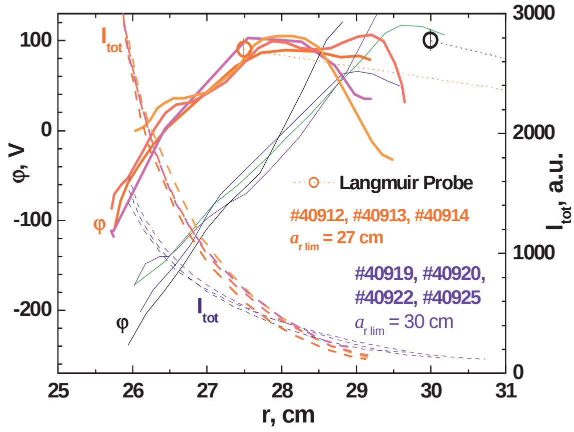

Fig. 3. The profiles of potential (solid) and beam current (dash), proportional to density, in He discharges with different positions of the rail limiter.

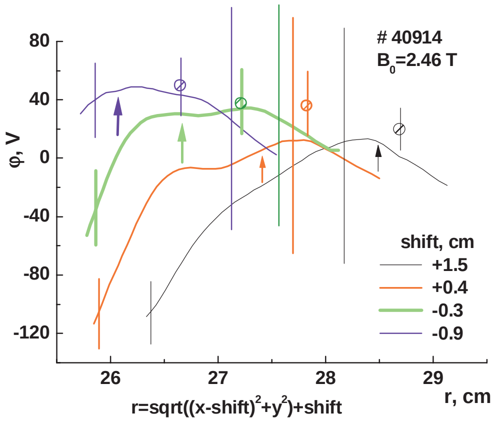

Fig. 4. The potential profile moves together with shifted LCMS. Circles are Langmuir probe data at the rail limiter. Vertical lines show error bars. Arrows show positions of LCMS.

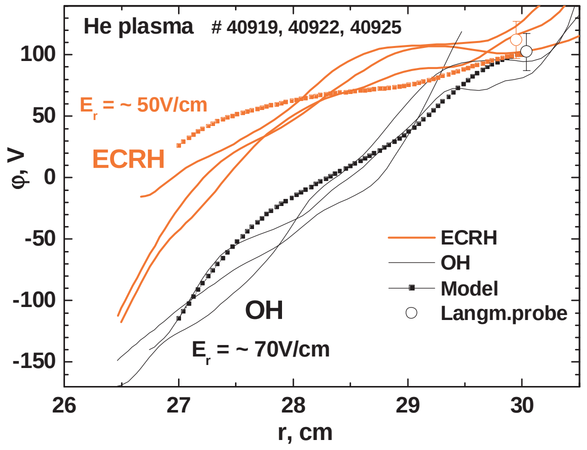

Fig. 5. Comparison of calculated potential profiles with measured by HIBP and Langmuir probe

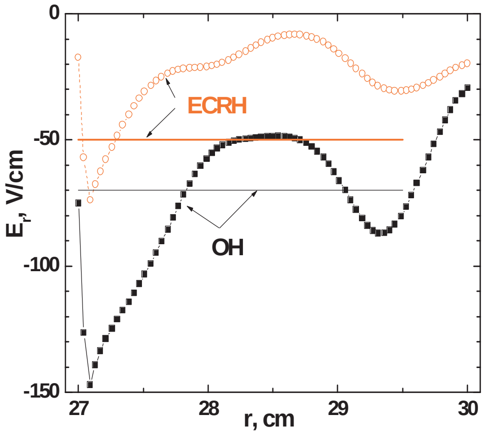

Fig.6. Calculated (points) and estimated (lines) electric fields in OH and ECRH phases of He discharge.