

PLASMA ELECTRIC POTENTIAL EVOLUTION AT THE CORE AND EDGE OF THE TJ-II STELLARATOR AND T-10 TOKAMAK

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In this article are presented main results on electric potential investigations in stellarator/torsatron TJ-II and tokamak T-10 in a comparable regimes of device operation.

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1. INTRODUCTION

The discovery of the high confinement modes (H-mode) in ASDEX [1] initiated the interest to understanding the important role of the electric fields in confinement of toroidal plasmas both of tokamaks and stellarators. The L/H transition was explained by a spontaneous bifurcation of the radial electric field, E_r , in the edge of the toroidal plasmas, which indicates the important role of E_r in the transition phenomena. It was also found that the external plasma polarization (biasing) could induce the L-H transition.

Taking into account that role of the electric fields in the neoclassical conception of plasma confinement for tokamaks and stellarator is not identical, and drawing attention to recent experimental investigations on similar behavior of electric fields in different effects (regimes) of tokamaks and stellarators we can assert that comparative examinations of the electric fields in these devices are rather actual task.

In this article same results are presented on behavior of plasma electric potential in stellarator TJ-II and tokamak T-10 in comparable regimes of device operation. Both machines were equipped with systems of ECR heating and a Heavy Ion Beam Probing diagnostic (HIBP). The main aim of HIBP installation was to investigate the radial electric field and its fluctuation in the plasma core as well as at the periphery [2].

2. MAIN PRINCIPLES OF THE HIBP

Heavy Ion Beam Probe (HIBP) is effective method to measure the poloidal profile of the electric potential and density of plasma [1]. When the beam of high-energy single charged ions passes through the plasma, some of the beam ions ionize, predominantly by the electrons. The ionization takes place along the full path of the beam in the plasma (Fig. 1). Because of their higher charge state, a the secondary ions deviate from the primary beam and form a broad fan of ions leaving the plasma. The secondary ions that enter the detector small part of the primary beam in the plasma, called the sample volume, which has typical dimensions of $(0.5...1) \text{ cm}^3$. The difference between the secondary ions leaving the plasma and the primary ions is equal to the electric potential ϕ , at the sample volume. The intensity of the secondary beam reflects the electron density, n_e , in the sample volume.

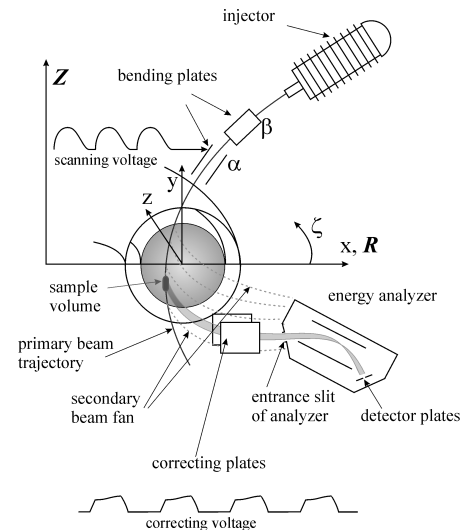


Fig. 1. Basic principles

The toroidal velocity of the secondary beam in the detector reflects the poloidal component of magnetic vector potential (poloidal magnetic field or plasma current density). The position of the sample volume can be rapidly changed by redirecting the probing beam with electrostatic sweep plates or by changing the energy of the primary particles. HIBP has a continuous character of the signal, which provides a high temporal resolution, limited by the acquisition electronic.

3. J-II AND T-10 DEVICES

TJ-II is a four periods heliac with parameters: $B(0) < 1.2 \text{ T}$, $R = 1.5 \text{ m}$, $a = 0.22 \text{ m}$, transform range $(0.9 < i(0)/2n < 2.2)$. TJ-II plasmas have been produced and heated with ECRH (2 gyrotrons, 300kW each, 53.2 GHz, 2nd harmonic.). The last mirror of the quasi-optical microwave transmission line is located inside the vacuum vessel and allows for current drive up to 1 kA. The HIBP diagnostic used Cs^+ ions with beam energy up to 140keV. Observed interval was $-1 \leq \rho \leq +1$, where ρ is the normalized minor radius. [3].

T-10 Tokamak ($R = 1.5 \text{ m}$, $a = 0.3 \text{ m}$) with $B_T = 2.12... 2.5 \text{ T}$, $I_{pl} = 180...260 \text{ kA}$, $\langle n_e \rangle \sim (1.5... 2.5) \times 10^{19} \text{ m}^{-3}$. The Ohmic and ECR heated plasmas, using two frequencies were 22 m that can explore a wide rotational studied, $P < 1...2 \text{ MW}$, $f_{\text{ECRH}} = 129...144 \text{ GHz}$. To probe the plasma core, Tl^+ ions were accelerated up to 250 keV. For $B_T =$

2.12 T, the observed radial range was approximately 13...20 cm [4].

The edge plasma potential profile was investigated at the low field side within the radial interval of 25...30 cm. The plasma was limited by the movable rail limiter at $a_{lim} = 27...30$ cm, and the circular limiter at $a_{c lim} = 33$ cm.

4. THE LINK BETWEEN THE PLASMA POTENTIAL AND ECRH POWER

ECRH modulation experiments in TJ-II

In the experiments presented below the impact of ECRH heating power on plasma potential profiles has been investigated. In the present experimental set-up, one gyrotron line (L1) provides a continuous heating (200 kW) whereas the second line (L2) is modulated with 100 ms period. Fig. 2 (a) shows the time evolution of heating power (L2), and plasma average density. Plasma potential and secondary total current profiles are presented in Fig.2 (b,c).

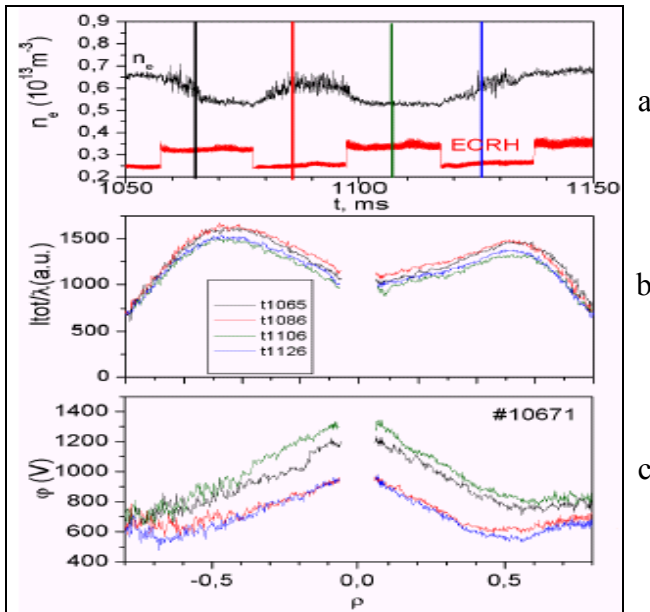


Fig. 2. Time evolution of ECR modulation and radial profiles ϕ and I_{tot} in max and min of time modulation

The total plasma density decreases as ECRH power increases, whereas plasma potential become more positive[5]. Interestingly, that density profiles become more hollow. This behavior can be a manifestation (or at least is consistent) of the outward particle flux induced by ECRH (the pump-of effect). In addition, ECRH power modulation experiments have proven to be a powerful method to investigate the transport properties in fusion plasmas. As expected, the induced perturbation is much higher in the plasma potential than in the plasma density.

Ohmic and ECR heated plasmas in T-10

In the Ohmic phase of the discharge the plasma potential in the observed region was negative. The slope of the potential profile allows us to estimate the mean radial electric field in a range of $E_r = -80...-150$ V/cm. In the ECR heated plasmas with on- and off-axis power deposition, the depth of the potential well becomes significantly smaller. The estimation of the mean radial electric field gives a range of $E_r = -20...-50$ V/cm. The potential follows by the electron temperature, getting the additional value up to +400 V, still remaining negative

(Fig. 3.) The characteristic time of the potential evolution is ~ 50 ms, higher than energy confinement time.

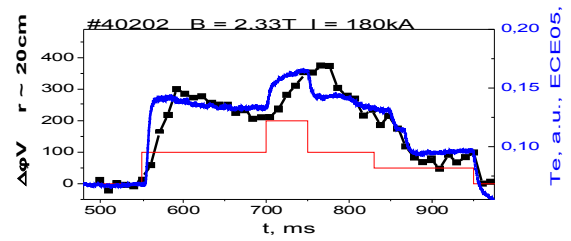


Fig. 3. Core potential evolution (squares) with T_e variations under ECRH

In the Ohmic phase, the negative plasma potential was observed also at the edge (Fig. 4). The gradient part of the profile takes place inside the LCMS ($25 < r < 30$ cm). The HIBP potential profile has zero reference value at the rail limiter position $a_{r lim} = 30$ cm. The slope of the potential profile gives the estimation of the mean radial electric field in a range of $E_r = -50...-100$ V/cm. Again, in the ECRH phase with on- and off- axis power deposition the potential well becomes significantly slower[6]. The estimated mean radial electric field was in a range of $E_r = -10...-30$ V/cm.

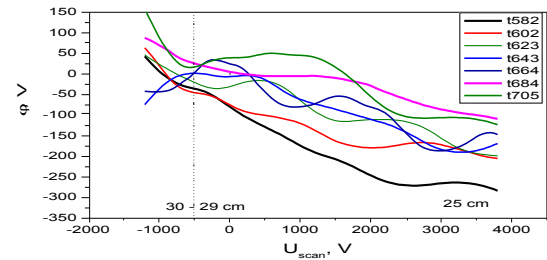


Fig. 4. Edge plasma potential profiles in OH (t582, down) and ECRH (t684, up) heating

The clear link between the core plasma potential and ECRH power was observed: the stronger power leads to the higher (more positive) absolute potential. This is right either for the core plasma or for the edge. Similar tendency was also found in TJ-II stellarator during experiments with ECRH power modulation.

5. DEPENDENCE OF POTENTIAL ON THE ELECTRON DENSITY

The Plasma potential evolution shows the link of the potential value with density on both devices[5]. The core plasma potential on TJ-II decreases as plasma density increases Fig. 5.

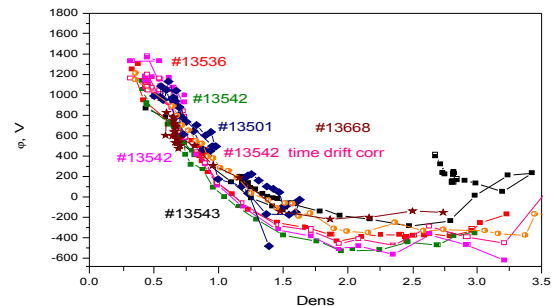


Fig. 5 The dependence of potential on density

During the C-pellet injection on T-10, the edge potential falls down to -100V with the density rise. The

mean value of the negative electric field become stronger up to $E_r = -120$ V/cm (Fig. 6). Generally, the higher the density the lower the plasma potential.

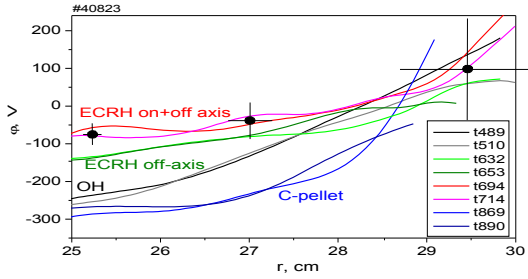


Fig. 6. Potential profile before and after C-pellet injection

6. PERIPHERY PLASMA PROFILE EVOLUTION WITH CHANGING LIMITER POSITION

An overlapping of the HIBP bulk potential profile and the Langmuir probe edge potential is an important issue in shifted together with the rail limiter position, studies of the periphery plasma. The edge plasma potential profile was investigated by HIBP of the T-10 tokamak within the radial interval of $(0.85 < r/a < 1)$ [6]. The insertion of the rail limiter into $a_{lim} = 27$ cm leads to the modification of the plasma profiles (Fig. 7).

The HIBP potential profiles have the absolute reference at the plasma potential value of Langmuir probe, located at rail limiter. The potential profile was shifted together with the rail limiter position, while its shape remains similar to the initial one. In limiter shadow, $27 < r < 30$ cm, the potential variation is small within the experimental accuracy. The density profile shows the increase of the gradient when limiter is inserted at $a_{lim} = 27$ cm. 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 done (Fig. 8).

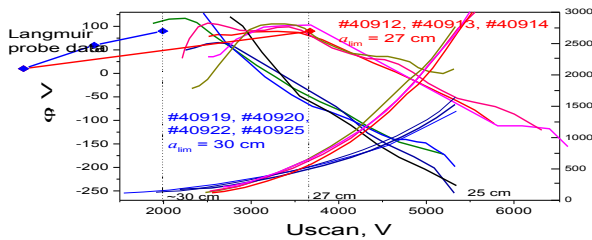


Fig. 7. Profiles of the ϕ and I_{tot} for $a_{lim} = 27$ and $a_{lim} = 30$ cm. The gradient region of the potential profile moves with limiter position

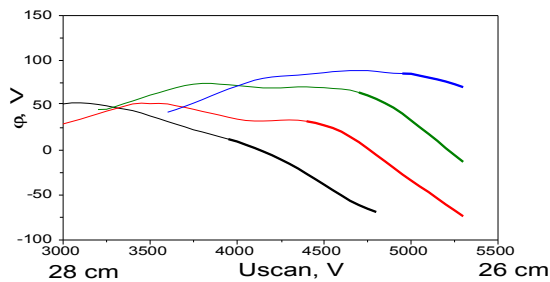


Fig. 8. Potential profiles with shifting of the plasma

The gradient part of the potential moves with LCMS position. Secondary beam current profile is also shifted accordingly.

The plasma edge profiles evolution with limiter position in TJ-II is shown in Fig. 9.

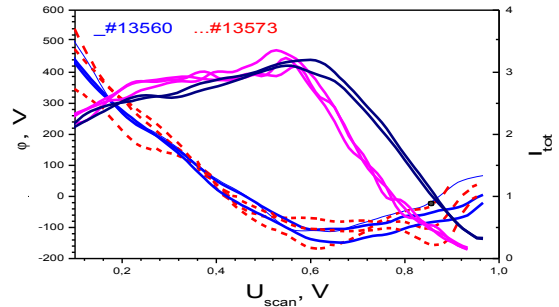


Fig.9. Plasma edge profiles evolution in TJ-II

Plasma density is more sensitive to the limiter insertion while plasma potential remains almost unchanged. In the TJ-II the sign of the edge potential has a clear dependence on density. The negative plasma potential was observed by Langmuir probes, and HIBP when n_e is above some threshold. The both diagnostics are demonstrated the same tendency: the higher density - the lower the plasma potential[7].

7. HIBP MEASUREMENTS IN BIASING EXPERIMENTS

In TJ-II (limiter biasing) have shown the first experimental example of the possibility of charging potential of the plasma column as a whole[8] with plasma response about $10 \dots 100 \mu s$, Fig. 10. Both edge and core plasma potential are affected by limiter biasing.

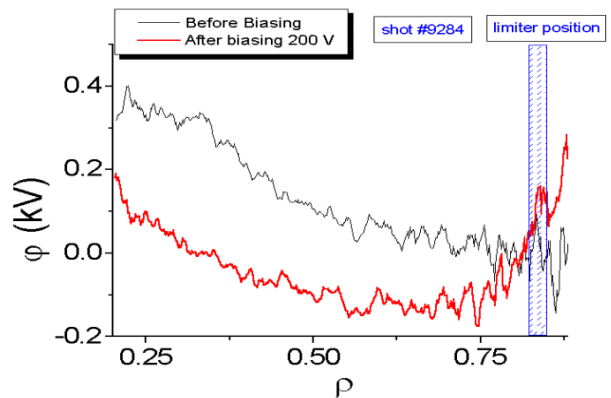


Fig.10. Plasma potential evolution with negative biasing (lower curve) and without biasing

For T-10, in contrast to TJ-II experiments, the electric field is modified mainly in the proximity of the biased electrode (with U_{bias}) Fig. 11.

But, in spite of the important differences in the magnetic configurations and experimental conditions between two machines, the basic features of the HIBP data show same similarities: the potential response $\Delta\phi_p$ has the same polarity and scale as U_{bias} and the fluctuations are suppressed near electrode (T-10) / limiter (TJ-II).

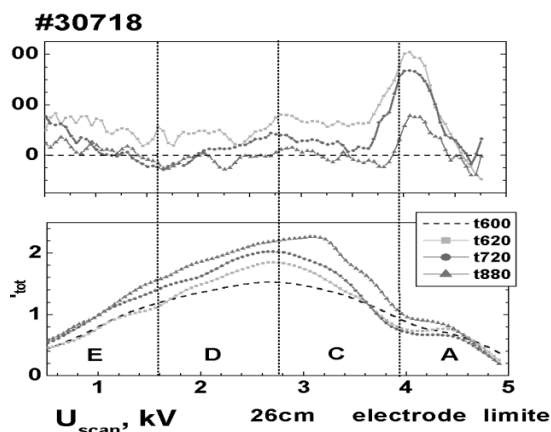


Fig. 11. The plasma extra potential $\nabla\phi$ and I_{tot} profiles evolution by negative electrode biasing on T-10

CONCLUSIONS

The evolution of the electric potential in a wide range of regimes with ECR heating using upgraded Heavy Ion Beam Probing diagnostic in T-10 and TJ-II is described.

Comparison of the plasma potential behavior in both devices was shown the clear link between the core plasma potential and ECRH power: the stronger power leads to the higher (more positive) absolute potential. On the T-10 tokamak the electric potential follows the electron temperature in similar way as was found on stellarator TJ-II.

РАЗВИТИЕ ЭЛЕКТРИЧЕСКОГО ПОТЕНЦИАЛА ПЛАЗМЫ В ЦЕНТРЕ И НА ПЕРИФЕРИИ ДЛЯ СТЕЛЛАРАТОРА ТЈ-II И ТОКАМАКА Т-10

Л. Крупник, А. Жежера, А. Мельников, К. Идальго, А. Алонсо, А. Чмыга, Л. Елисеев, А. Комаров, А. Козачек, С. Лысенко, И.Л. де Паблос, С. Перфилов

Представлены основные результаты исследований электрического потенциала плазмы, полученного на стеллараторе/торсатроне ТЈ-II и токамаке Т-10 при идентичных режимах работы установок.

ROZVITOK ELEKTRICHOHO POTENCIALU PLAZMI U CENTRI TA NA PERIFERII DLA STELARATORA TJ-II TA TOKAMAКА T-10

Л. Крупник, О. Жежера, О. Мельников, К. Идальго, А. Алонсо, О. Чмыга, Л. Єлісеєв, О. Комаров, О. Козачок, С. Лисенко, І.Л. де Паблос, С. Перфілов

Представлено основні результати досліджень електричного потенціалу плазми, одержаного на стеллараторі/торсатроні ТЈ-II та на токамаці Т-10 при ідентичних режимах роботи пристроїв.

The potential in the plasma core and edge is linked with plasma density in both machines.: the higher density – the lower plasma potential.. The negative plasma potential was observed when n_e is above some threshold value.

It is possible to modify global confinement and plasma parameters with biasing, illustrating the direct impact of the radial electric fields on stellarator and tokamak confinement properties.

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