*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-2.058 (2007)*

Absolute plasma potential, radial electric field and turbulence rotation velocity measurements in low-density discharges on the T-10 tokamak

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The highest fusion plasma parameters have been obtained in the conditions where ExB shear stabilization mechanisms are likely to play a key role; both edge and core transport barriers are related to a large increase in the ExB sheared flow. The direct experimental study of plasma radial electric fields is the key issue to clarify ExB shear stabilization mechanisms. The plasma turbulence rotation velocity measurements, compared with $E_r x B_{tor}$ drift rotation velocity may explain whether turbulence moves together with the plasma or independently.

The absolute value of the core plasma potential was measured for the first time in the T-10 tokamak (R = 1.5 m, a = 0.3 m) by Heavy Ion Beam Probing (HIBP) diagnostics [1] using Tl^+ ions with the energy 220 - 260 kV. The core plasma turbulence was studied by correlation reflectometry.

In the Ohmically heated phase of the regime with on-axis ECR heating of low density plasma (B_0 = 2.4 T, I_p = 190 kA, n_e = 1.3 x10^{19} m^{-3}) the potential measured at r = 0.21 - 0.27 m was negative. The profiles presented in Fig 1 were obtained with a single spatial scan of HIBP with beam energy Eb = 240 keV. Corresponding temporal evolution in the deepest point of the scan are shown in Fig. 2.

The potential profile presents linear-like function with the lowest absolute value at the deepest point $\varphi(0.21) = -600$ V. The slope of the potential profile gives the estimation of the mean radial electric field $E_r \sim -6.7$ kV/m.

In the ECRH phase of the discharge (on-axis heated plasmas with P_{EC} ~0.4 MW) the absolute potential well becomes significantly smaller, $\varphi(0.21) = -210$ V, and the electric field decreases to E_{r} ~ -2.3 kV/m. cm

In the Ohmic heated plasma ($B_0 = 2.31$ T, $I_{\mathrm{p}} = 180$ kA, $n_{\mathrm{e}} = 1.3 - 1.5\mathrm{x}10^{19}$ m^{-3}) the deepest point lies at $r = 0.195$ m for $E_b = 245$ keV. To extend the profile towards the center we got a series of reproducible shots and increased the beam energy at 5 keV from shot to shot up to 260 keV (the instrumental limitations). The profiles, obtained in each shot overlap with each other. The resulting 10 cm long radial profile is shown in Fig 3. Here various profiles are marked with different colours, The deepest was obtained with highest $\mathrm{E_b} = 260$ keV. Similar to the previous case, the potential was negative in the area of measurement $r = 0.17 - 0.27$ m.

The potential profile again presents linear-like function with the lowest absolute value at the deepest point $\varphi(0.17) = -900$ V. The slope of the potential profile gives the estimation of the mean radial electric field E_{r} ~ -7.5 kV/m.

In the ECR phase of this regime (off-axis heated plasma, $P_{\mathrm{EC}} = 0.4$ MW) the depth of the potential well becomes significantly smaller, $\varphi(0.17) = -720$ V, (upper set of lines)and the electric field decreases to E_{r} ~ -5.5 kV/m.

Due to the instrumental restrictions (Eb<260 keV), the observed area is limited. The observed radial interval moves towards the plasma center with B_T decrease. For $B_T = 2.12$ T, the observed radial range was approximately 13 - 20 cm.

Finally, in the Ohmic phase of the discharges ($B_0 = 2.12$-2.4 T, $I_{\mathrm{p}} = 180$-190 kA, $n_{\mathrm{e}} = 1.3 - 1.5\ \mathrm{x}10^{19}$ m^{-3}) the electric potential in the observed region of the outer one third (one half) of the plasma, was negative. In the ECR heated plasmas with on- and off-axis power deposition ($\mathrm{P_{EC}} = 0.4 - 1.2$ MW) the depth of the potential well becomes significantly smaller. During ECR heating pulse the potential follows by the electron temperature, getting the additional value up to + 400 V, still remaining negative. The potential follows the local Te with lower increment. (Fig 4.) The characteristic time of the potential evolution is ~ 50 ms, higher than energy confinement time τ_E .

The clear link between the core plasma potential and ECRH power was observed: the stronger power leads to the higher (more positive) absolute potential. (Fig. 2). This tendency found first earlier [1] was also obtained in TJ-II stellarator during experiments with the ECRH power modulation [2].

At the observed plasma conditions in radial range of the HIBP measurements Er ~ const, the plasma column rotates not as a rigid body due to the B(r) dependence. The typical values $\mathbf{V_{E\times B}}$ ~ 3.0 km/s, $\mathbf{\Omega_{E\times B}}$ ~ $1.5*10^4$ radian/s for the Ohmic stage and $\mathbf{V_{E\times B}}$ ~ 2.4 km/s $\mathbf{\Omega_{E\times B}}$ ~ $1.25*10^4$ radian/s for the ECRH stage.

The turbulence rotation velocities were measured by correlation reflectometry (CR) duringthe same discharges. The experimental layout is shown in Fig 5. CR antennae are located 90 degree anticlockwise from HIBP along the torus. E×B drift velocity $\mathbf{V}_{\mathbf{E\times B}} = E_r/B_{tor}$ was taken by E_r, obtained by HIBP, and B_{tor} for the x coordinate, corresponding to the CR measurements. The absolute values of the angular rotation velocity $\mathbf{\Omega_{TURB}}$ are close to the plasma drift rotation velocity $\mathbf{\Omega_{E\times B}}$, see Fig 6. $\mathbf{\Omega_{TURB}}$ shows the radial dependence in consistency with $\mathbf{\Omega_{E\times B}}$ rotation. Both velocities decrease accordingly when ECRH applied. Within the achieved experimental accuracy turbulence tends to rotate with plasma ExB rotation velocity.

The difference in HIBP and CR measurements at plasma periphery could be produced by difference in plasma density. HIBP needs low density to avoid beam attenuation and get signal from plasma periphery, while CR requires high density for the same task. Higher density leads to higher E_r and higher $\mathbf{V}_{\mathbf{E\times B}}$.

To clarify the link between the plasma drift rotation and turbulence rotation more work should be done, specifically at the plasma periphery, where CR and HIBP measurements differs to each other.

This work was partly funded by the IAEA technical contract under the CRP on Joint Research Using Small Tokamaks.
Kurchatov team was supported by Goscontract RF 02.516.11.6068 and Grants RFBR 05-02-17016, 07-02-01001, INTAS 100008-8046, NWO-RFBR 047.016.015.

References

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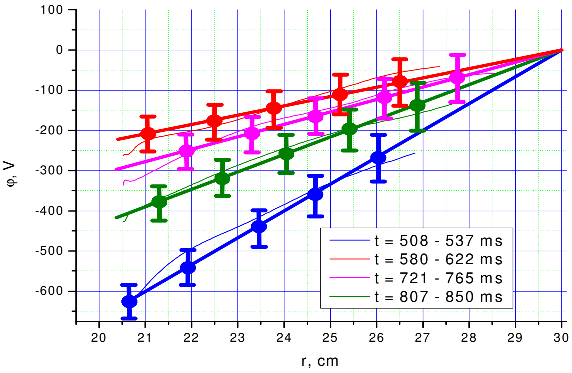

Fig 1. Single scan potential profiles on OH phase (blue) and ECRH with two (red and purple) and one (green) gyrotrons operating.

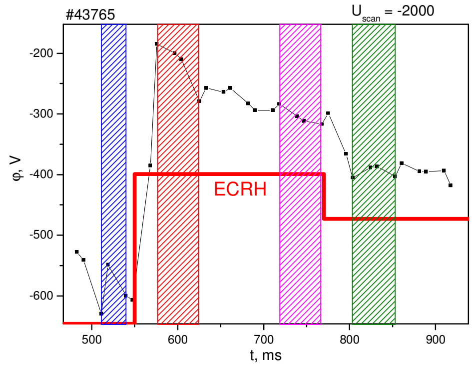

Fig 2. Potential evolution at the deepest penetration point r_{min} = 21 cm.

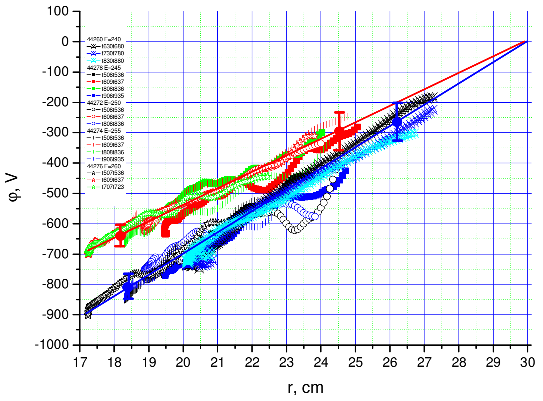

Fig 3. . Upper set of the profiles - ECRH phase. Lower set of the profiles - OH phase Straight lines - mean E_r estimation

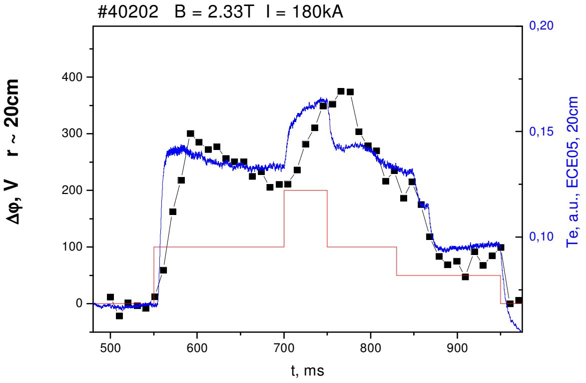

Fig 4. Core potential evolution (black squares) with Te (blue) variations under ECRH (red).

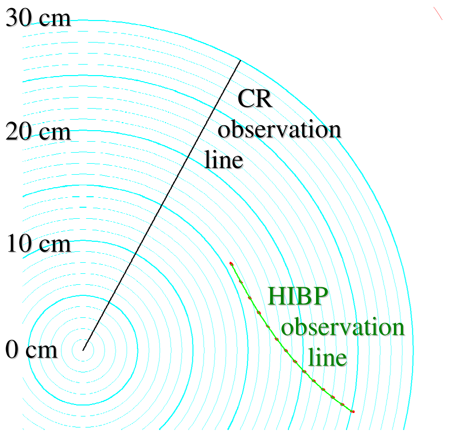

Fig. 5. Experimental layout for comparative rotation measurements.

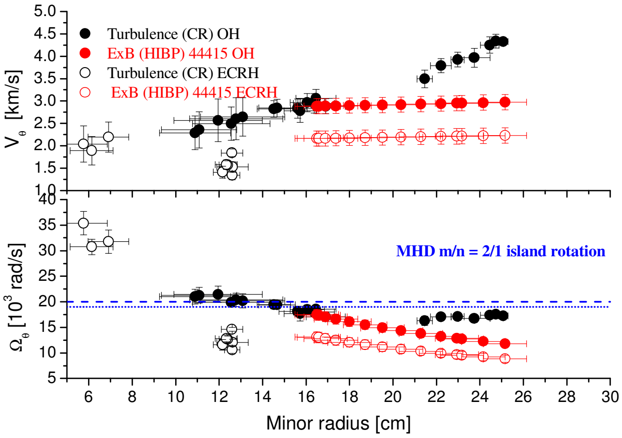

Fig. 6. Comparison of rotation velocities of density perturbations with core plasma rotation in OH and ECRH plasma.