STUDY OF PLASMA POTENTIAL, ITS FLUCTUATIONS AND TURBULENCE ROTATION IN THE T-10 TOKAMAK

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Plasma potential, its oscillations and turbulence rotation were studied on T-10 in a wide range of ohmic and ECRH regimes. The potential has negative sign over the whole plasma cross section. Broadband turbulence tends to rotate with $E\times B$ drift velocity. Rotation and potential evolve together with plasma confinement. Frequency of potential oscillations in the range of geodesic acoustic modes does not change with radius that disagrees with theoretical predictions.
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1. INTRODUCTION

The direct experimental study of plasma radial electric field E_r is the key issue to clarify $E\times B$ shear stabilization mechanisms. Comparison of plasma turbulence and $E_r\times B_t$ drift rotation may explain, whether the turbulence moves together with the plasma or independently. The absolute value of the core plasma potential φ was measured in the T-10 tokamak (R = 1.5 m, a = 0.3 m), by Heavy Ion Beam Probing (HIBP) with Tl^+ ions. New high-voltage power supply and new system of remote control of focal distance allow us to increase the beam energy E_b up to 300 keV and focus the beam in any desirable point of the detector grid in plasma. The primary beam current achieved 200 μA and the beam diameter ~ 4 mm. Therefore we can observe the core potential at high densities ($\bar{n}_e \le 4.1\times10^{19}\,m^{-3}$). The φ profile in a wide area ($0.2 < r/a < 0.9$) was assembled from radial fragments measured with various E_b and injection angles in a series of reproducible shots. At the limiter, the plasma potential and density were measured by Langmuir probes. The core plasma turbulence was studied by correlation reflectometry (CR). Also we used the standard set of diagnostics: soft X-rays (SXR), electron cyclotron emission (ECE), diamagnetic loops and other. Missing radial distributions of plasma parameters invoked from transport model with T-11 scaling for diffusivity [1].

2. POTENTIAL MEASUREMENTS

Various regimes with ohmic (OH), on- and off-axis ECR heating (B_t = 1.55…2.4 T, I_p = 140…250 kA, $\bar{n}_e$ = (1.3…4.1)×10^{19} m^{-3}, P_{EC} < 1.5 MW) were first studied [2]. In first low-B_t, ohmic regime (1-*l* and 1-*h* in the Table) HIBP observed practically the whole plasma cross-section. Evolution of plasma parameters is shown in Fig. 1. The density $\bar{n}_e$ rises due to gas puffing, while the electron temperature T_e slightly decreases. The potential profile evolution is shown in Fig. 2: the potential and E_r tends to decrease with gas puff. The second regime had additional ECR heating and the current ramps up from 165 to 212 kA (Fig. 3).

Parameters of studied regimes

Reg.	$\bar{n}$, 10^{19} m^{-3}	E_r, V/cm	Δr, cm	B_t, T	I_p, kA	τ_E, ms
1-*l*	1.3	55	6-30	1.55	140	20
1-*h*	2.4	65	6-30	1.55	140	36
2 OH	2.5	70	7-22	2.08	165	38
2 EC	2.1	55 /47	7-22	2.08	165 /212	13/12
3	4.1	90	16-27	2.4	210	50

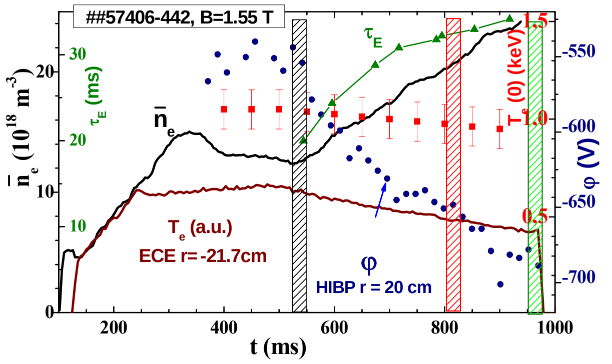

Fig. 1. Evolution of density n_e, potential φ, energy confinement time τ_E and electron temperatures T_e at the centre and at 21.7 cm in low-field regime

During ECRH phase, the potential well becomes significantly shallower, E_r decreases and confinement degrades. The potential has a weak dependence on I_p. No any strong irregularities in the potential near the EC power deposition radius r_{EC} =15 cm during the slow (10 ms) timescale are seen: E_r inside and outside r_{ECRH} was the same. The high-density ohmic regime 3 has maximal E_r (Fig. 4). In all studied regimes, the potential was negative and $E_r(r)$ ~ const < 0 in the whole radial range of HIBP measurements, the potential well becomes deeper, and the mean E_r increases with rise of density and the energy confinement time τ_E.

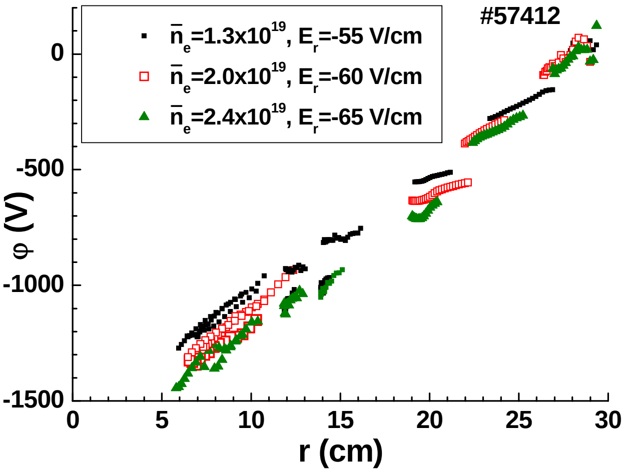

Fig. 2. The potential profile assembled from set of the scans for three densities in time instants marked by hatched rectangles in Fig. 1

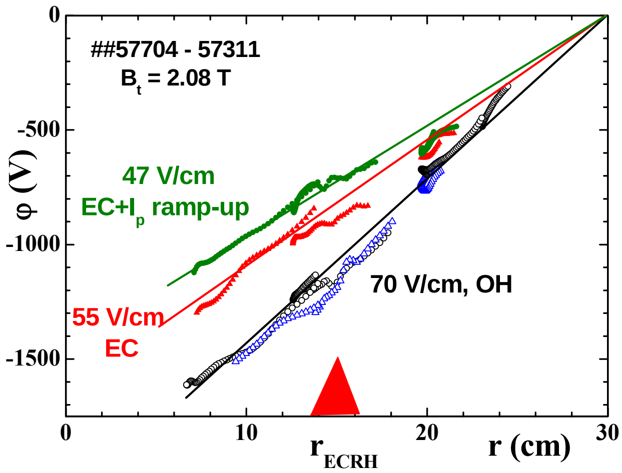

Fig. 3. The potential profile in regime with additional heating and current ramp-up; ▲ *marks position of EC resonance*

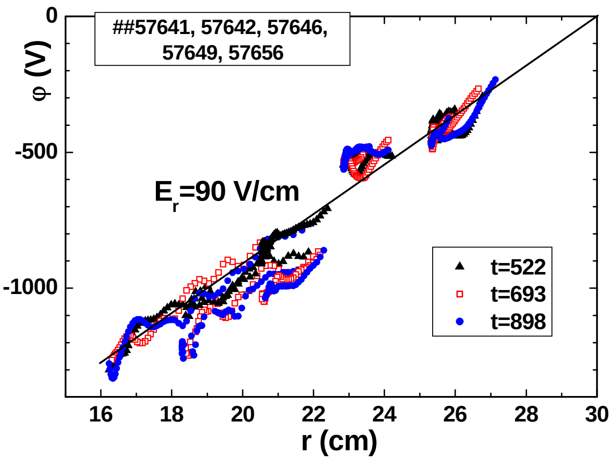

Fig. 4. The potential profile in high-density ohmic regime

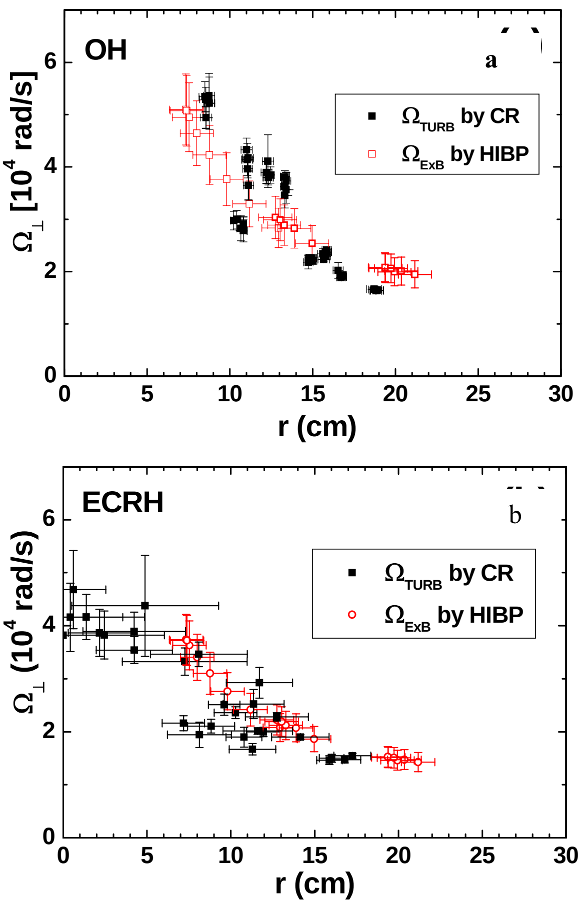

Fig. 5. Plasma ExB and turbulence rotation in regime 2, measured by correlation reflectometer (CR) and ion beam (HIBP) in ohmic (a) and ECR phases (b)

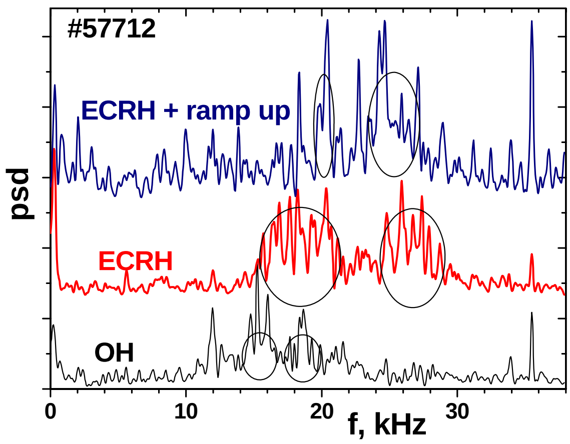

Fig. 6. Spectra of potential oscillations in regime 2. Peaks in ellipses are identified as GAMs

The plasma column rotates with *E*×*B* drift velocity not as a rigid body due to the $B_t(R)$ dependence. The typical values for angular velocity is $\Omega_{E\times B} \sim 1.5\times10^4$ rad/s for OH, and $\Omega_{E\times B} \sim 1.25\times10^4$ rad/s for ECRH stages (Fig. 5, a,b).

Broadband drift-wave turbulence tends to rotate together with the *E*×*B* driven bulk plasma. Faster rotation corresponds to better confinement.

3. FLUCTUATIONS

Geodesic Acoustic Modes (GAMs) may be possible mechanism of the turbulence self-regulation. The theory proposes the unified dispersion relation for GAMs and Beta induced Alfvén Eigenmodes (BAE) [3]. This mode presents a dominant peak in the power spectral density of potential. In some cases a higher frequency satellite appears (Fig. 6) [4]. Mode is more pronounced during ECRH, when the typical frequencies are seen in the band 22…27 kHz over the whole plasma cross-section. In all regimes the mode frequency is close to a constant over the investigated radial interval (Fig. 7) that inconsistent with theoretical predictions for the plasma core [5].

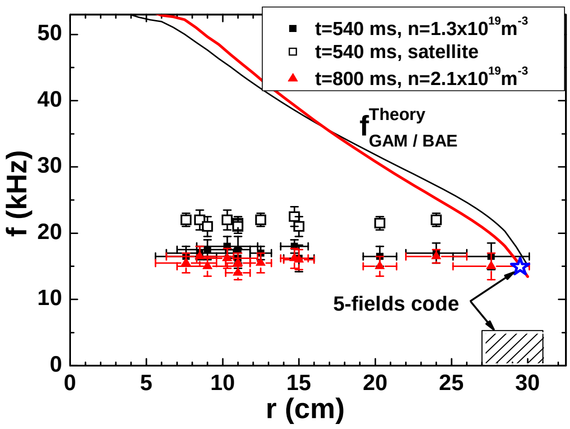

Fig. 7. Comparison of potential oscillations in regime 2 with analytical theory (lines) and 5-fields code calculations (star). Rectangle shows the region of the code validity

However, at the outer edge, ρ = 0.95, the frequency value is consistent with theoretical prediction [6], which may be indicative these mode are the edge driven spatially global eigenmodes. The frequency weakly depends on the magnetic field and plasma density. With the density rise, first the satellite and then the main peak consequently disappear. The amplitude of potential perturbations is quite pronounced, is about a few tens of Volts in the ECRH phase, and increases towards the plasma centre.

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ИССЛЕДОВАНИЕ ПОТЕНЦИАЛА ПЛАЗМЫ, ЕГО ФЛУКТУАЦИЙ И ВРАЩЕНИЯ ТУРБУЛЕНТНОСТИ В ТОКАМАКЕ Т-10

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Потенциал плазмы, его колебания и вращение исследовались на токамаке Т-10 в широком диапазоне омических и ЭЦР-режимов. Потенциал – отрицательный по всему сечению плазмы. Вращение турбулентности соответствует вращению за счет (*E*×*B*)-дрейфа. Вращение и потенциал чувствительны к изменениям удержания. Частота колебаний потенциала в диапазоне геодезических акустических мод не меняется по радиусу, что не соответствует локальной теории ГАМ.

ДОСЛІДЖЕННЯ ПОТЕНЦІАЛУ ПЛАЗМИ, ЙОГО ФЛУКТУАЦІЙ ТА ОБЕРТАННЯ ТУРБУЛЕНЦІЇ У ТОКАМАЦІ Т-10

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Потенціал плазми, його коливання та обертання було досліджено на токамаці Т-10 у широкому діапазоні омічних та ЕЦР-режимів. Потенціал має негативну величину по всьому перетину плазми. Обертання турбуленції відповідає обертанню за рахунок (*E*×*B*)-дрейфу. Обертання і потенціал чутливі до зміни утримання. Частота коливань потенціалу у діапазоні геодезичних акустичних мод ні змінюється в залежності від радіусу, що не відповідає локальній теорії ГАМ.