INVESTIGATION OF PLASMA TURBULENCE AND LOCAL ELECTRIC FIELD IN THE T-10 TOKAMAK AND TJ-II STELLARATOR BY HIBP DIAGNOSTIC (REVIEW)

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Direct study of the electric potential and its fluctuations for comparable plasma conditions in the T-10 tokamak and TJ-II stellarator by HIBP diagnostics has been performed. The following similar features of potential were found: the scale of several hundred Volts; the negative sign for densities $n_e > 1\times10^{19}$ m^{-3} and comparable values in spite of the different heating methods. When n_e or τ_E rises, the potential evolves to negative values. During ECR heating and associated T_e rise, τ_E degrades and the potential evolves to positive direction. Oscillations of potential and density in the range of Geodesic Acoustic Modes in T-10 and Alfvén Eigenmodes in TJ-II were observed.

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1. INTRODUCTION

Study of the electric potential and its fluctuations in the core plasma allow us to understand the role of the electric field for the plasma confinement in magnetic fusion devices. Here we present a small review of direct measurements of potential in the T-10 tokamak and TJ-II stellarator by Heavy Ion Beam Probe (HIBP) diagnostic.

T-10 is a circular cross-section tokamak with major and minor radii. R=1.5 m, a=0.3 m, the toroidal field B_0 = 1.55…2.5 T, current I_p = 180…260 kA, density $\bar{n}_e$ ~ (1.5…4.5)×10^{19} m^{-3}. The Ohmic and ECR heated plasmas with on- and off-axis power deposition (P_{EC}<1.6 MW) were studied. TJ-II is a four-period low-magnetic shear flexible heliac with the mean $\langle R \rangle$ = 1.5 m, $\langle a \rangle$ = 0.22 m and B_0 = 1.0 T. The plasma is created and heated by ECRH (P_{EC}= 300…600 kW) with boron or lithium coating of the chamber wall; two 30 kV, H^0 neutral beam injectors (P_{NBI}< 450 kW each), directed along/opposite to B_0, heats the ECRH target plasmas with typical parameters: $T_e(0)$ ~ 1 keV, T_i ~ 80 eV, $\bar{n}_e$ ~ (0.5…1) ×10^{19} m^{-3}.

HIBP was implemented in both devices and allows us to study directly with a good spatial (1 cm) and temporal (10 μs) resolution the plasma electric potential φ and density, radial and poloidal components of electric and magnetic fields (E_r and B_{pol}) and their fluctuations [1]. In T-10, the study of plasma potential and electron density as well as their fluctuations at radii ρ=0.2…1 and densities up to 4×10^{19} m^{-3} were done. In TJ-II, HIBP was upgraded for two-point measurements of radial turbulent flux and poloidal field E_{pol} at radii ρ= -0.8…1. Main parameters of both devices and HIBP are shown in the Table, also see [2,3].

Comparison of devices and HIBP parameters

Parameter	TJ-II	T-10
$\langle R \rangle$, m	1.5	1.5
$\langle a \rangle_{lim}$, m	0.22	0.3
B_0, T	1.0	1.5…2.5
$\bar{n}_e$, 10^{19} m^{-3}	0.3…6	1…4
P_{EC}, kW	≤ 600	≤ 1600
P_{NBI}, kW	≤900	-
E_{beam}, keV	125	300
probing ion	Cs$^+$	Tl$^+$
observation area	-1 < ρ < 1	0.2 < ρ < 1

2. MEASUREMENTS OF POTENTIAL

Plasma potential in T-10 has negative sign and scale up to -1600 V. The absolute value of potential is decreasing with the rise of P_{EC} and increasing with rise of density. Stronger negative electric field E_r is associated with higher energy confinement time τ_E (Fig.1, a). In TJ-II, low-density ECR heated H or He target plasmas ($\bar{n}_e$=(0.3…1.1)×10^{19} m^{-3}) are characterized by a positive potential up to φ(0)= +1200 V. The density rise due to gas puffing or NBI fueling is accompanied by the decrease of potential, which evolves to smaller absolute values, becoming fully negative at $\bar{n}_e$ > 1×10^{19} m^{-3} (Fig. 1, b).

In both devices, in discharges with modulated ECR heating, growth of T_e due to increasing of ECRH power leads to increase in plasma potential (Figs. 2, 3).

3. STUDY OF FLUCTUATIONS

Various types of the quasi-coherent potential oscillations were studied in both devices in view of the link with turbulence. Geodesic acoustic modes (GAMs) HF branch of zonal flows may be possible mechanism of the turbulence self-regulation [4].

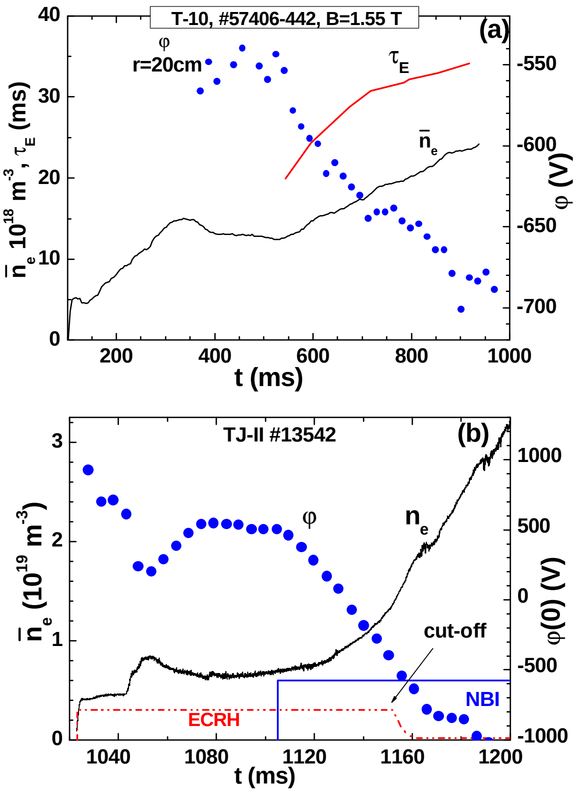

Fig. 1. The potential falls down in regimes with density rise on T-10 (a) and TJ-II (b)

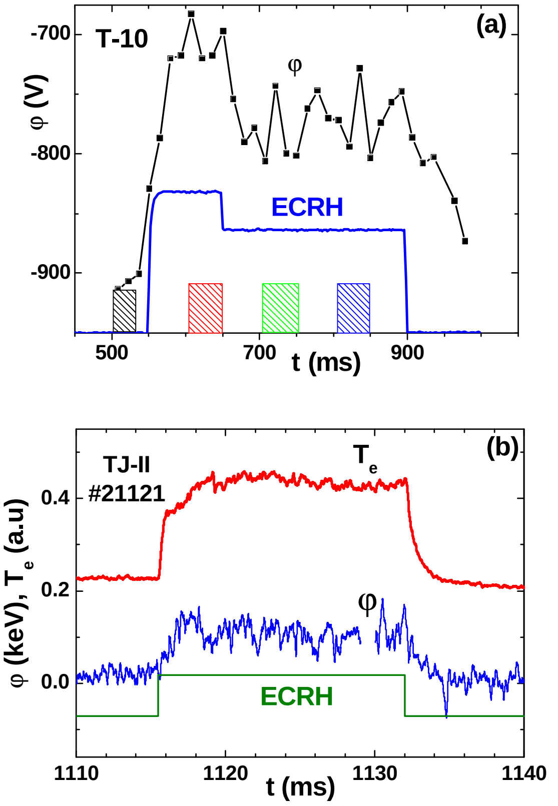

Fig. 2. Time evolution of potential in regimes with modulated ECRH in T-10 (a) and TJ-II (b). Hatched rectangles in (a) mark instants of potential profiles, shown in Fig. 3(a)

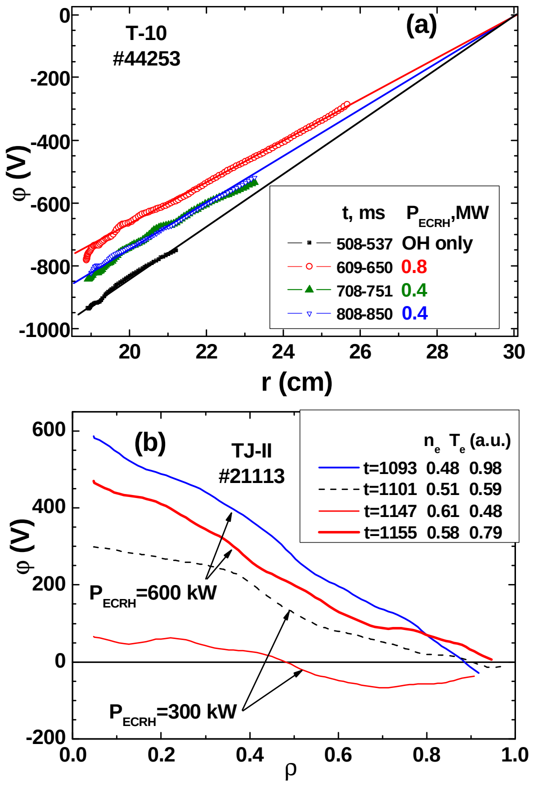

Fig. 3. Profiles of potential: (a) T-10; (b) TJ-II

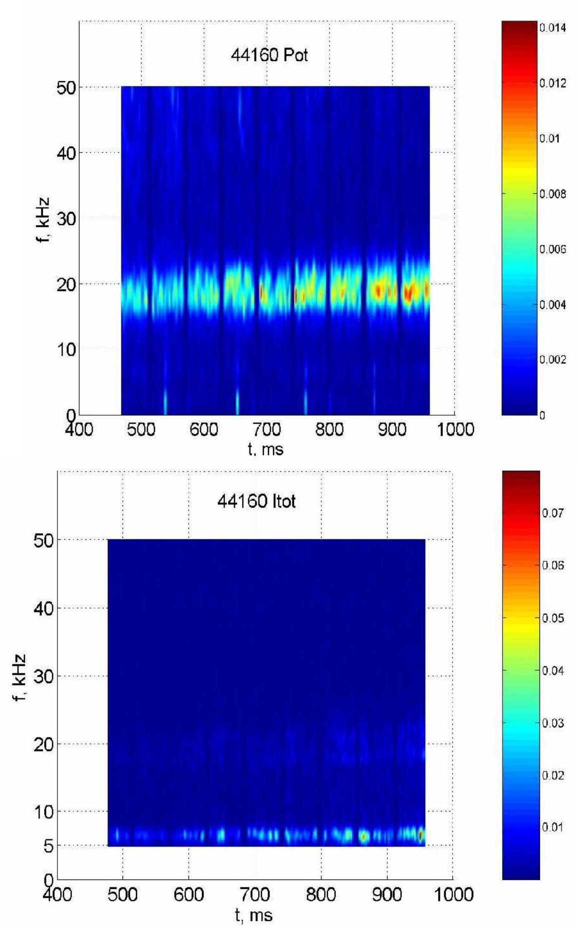

Fig. 4. GAMs (20 kHz) are seen on the potential (a), but hardly seen on spectra of density fluctuations (b), where MHD mode m=2 (f_{MHD}=7 kHz) is seen

The theory proposes the unified dispersion relation for GAMs and Beta induced Alfvén Eigenmodes (BAE) [5]. In T-10, the mode, identified as GAM, presents a dominant peak in the power spectral density of potential. It was shown by HIBP and Langmuir probes that GAMs are more pronounced in the plasma potential rather than density (total secondary beam current I_t). Figs. 4 and 5 shows the potential and density power spectra, obtained by HIBP at the same time. It is clearly seen that GAM peak (sometimes with satellites) dominates in the potential spectra, while MHD m=2 peak with f_{MHD} = 7 kHz dominates the density spectra. The GAM frequency scales with the local electron temperature in the sample volume as $f_{\mathrm{GAM}} \sim T_e^{1/2}$.

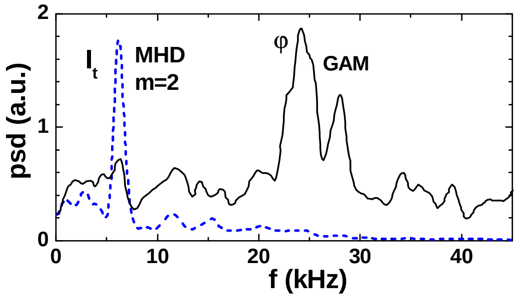

Fig. 5. Main peaks of GAM and satellite are seen on the potential φ *. MHD modes are seen on density fluctuations*

The modulation of the GAMs by sawteeth was found in the OH and ECRH phase. The GAMs were observed of the outer part of the phase reversal radius, r = 12 cm. Peak frequency follows the oscillating temperature with the same period of several milliseconds. The mode amplitude is also modulated by the reversed phase of T_e sawteeth oscillations, Fig. 6. The long-range density-potential correlations were found, and the global character of GAMs was observed.

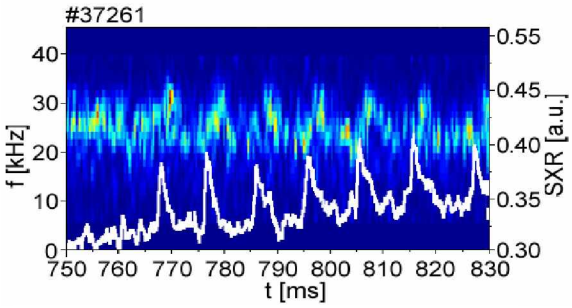

Fig. 6. Modulation of GAM by sawtooth oscillations

In experiments with Li-coating and NBI heating, the spontaneous L-H transitions occur. During the L-H transition, the edge and core fluctuations of n_e (seen on I_t) and φ shows some reduction, H_α emission falls down and the energy store W increases. The strong suppression of plasma density fluctuations and their coherence with E_{pol} in the H-mode was observed, Fig. 7.

Recent experiments with NBI heating have shown evidence of AEs driven by energetic injected ions. AEs are seen by HIBP on fluctuations of local potential, density and poloidal magnetic field B_{pol}. The strong suppression in plasma density fluctuations and the density $\bar{n}_e$ rise was observed after ECRH cut-off and NBI start. Simultaneously the AE frequency falls down as $f_{\mathrm{AE}} \sim \bar{n}_e^{\ 1/2}$, Fig. 8. AE contribution to the bulk plasma turbulent particle flux depends on the phase relations between E_{pol} and n_e oscillations. More details see in [6].

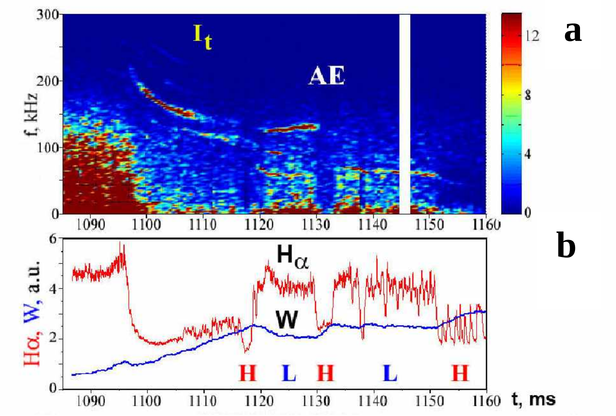

Fig. 7. Regime with L-H transitions. When the H-mode occurs, density fluctuations are suppressed (a); H_α emission falls down and the energy store W increases (b). In the L-mode, H_α recovers, W decreases. Alfvén eigenmodes are seen also

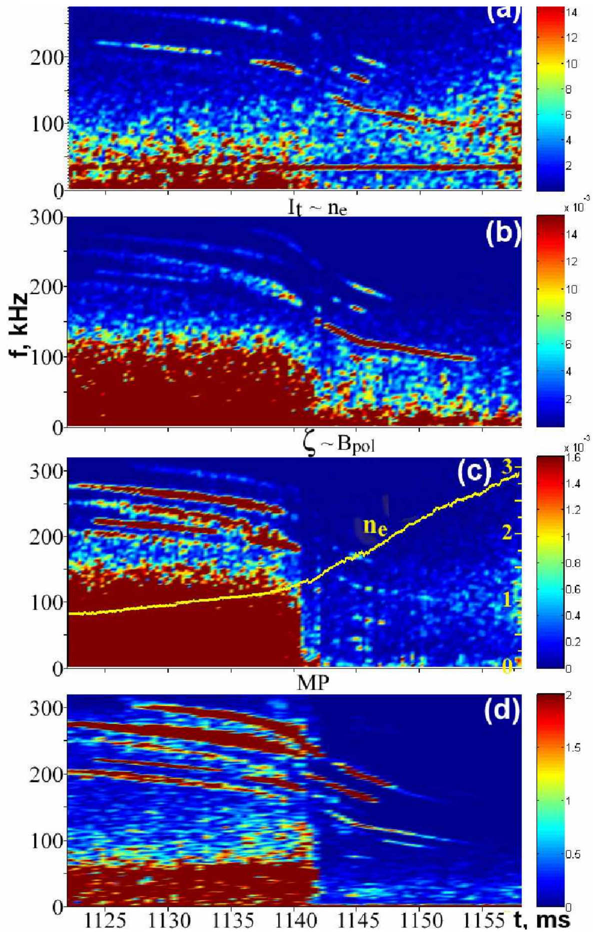

Fig. 8. Scenario with ECRH and balanced NBI. Alfvén eigenmodes are seen on the plasma potential (a), density (b) poloidal magnetic field (c) and Mirnov probe (d) spectra. After suppression of low-frequency broadband turbulence, the density $\bar{n}_e$ rises (c)

4. CONCLUSIONS

Summarizing the observations, we conclude: Despite the large differences in the topology of the confining magnetic field between two machines, the electric potential shows the following striking similarities: Similar values for the potential φ and electric field E_r. For $\overline{n}_e > 1\times10^{19}$ m^{-3}, the potential is negative with comparable absolute values despite of different heating methods: OH and ECRH in T-10, ECRH and/or NBI in TJ-II. Increase in n_e and τ_E is accompanied by similar diving of φ and E_r into the negative region. Application of ECRH, causing a rise of T_e and degradation of τ_E, results in shift of φ and E_r to positive values. Quasi-coherent modes, interacting with ambient turbulence, like GAMs in T-10 and AEs in TJ-II, have pronounced component in electric potential; φ and E_r plays important role in turbulence, thus in energy confinement: negative values are associated with better confinement both in TJ-II and T-10.

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ИССЛЕДОВАНИЕ ТУРБУЛЕНТНОСТИ ПЛАЗМЫ И ЛОКАЛЬНОГО ЭЛЕКТРИЧЕСКОГО ПОЛЯ НА ТОКАМАКЕ Т-10 И СТЕЛЛАРАТОРЕ TJ-II ДИАГНОСТИКОЙ ЗОНДИРОВАНИЯ ПУЧКОМ ТЯЖЕЛЫХ ИОНОВ (ОБЗОР)

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На токамаке Т-10 и стеллараторе TJ-II с помощью пучка тяжелых ионов в сравнимых режимах исследовалось поведение потенциала и его флуктуаций. Обнаружены общие свойства потенциала: масштаб порядка сотен вольт; отрицательный знак при плотностях $n_e>1\times10^{19}$ m^{-3} и сравнимые значения, несмотря на разные методы нагрева. Когда n_e или τ_E растут, потенциал растет в отрицательную область. При ЭЦР- нагреве и соответствующем росте T_e, τ_E ухудшается, и потенциал меняется в положительную сторону. Наблюдались колебания потенциала в диапазоне геодезических акустических мод в Т-10 и альфвеновских собственных мод в TJ-II.

ДОСЛІДЖЕННЯ ТУРБУЛЕНТНОСТІ ПЛАЗМИ ТА ЛОКАЛЬНОГО ЕЛЕКТРИЧНОГО ПОЛЯ У ТОКАМАЦІ Т-10 ТА СТЕЛЛАРАТОРІ TJ-II МЕТОДОМ ЗОНДУВАННЯ ПУЧКОМ ВАЖКИХ ІОНІВ (ОБЗОР)

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На токамаці Т-10 і стеллараторі TJ-II за допомогою пучка важких іонів в порівнянних режимах досліджувалася поведінка потенціалу та його флуктуацій. Виявлені спільні властивості потенціалу: масштаб близько сотен вольт; негативний знак при щільності $n_e>1\times10^{19}$ m^{-3} і порівнянні значення, незважаючи на різні методи нагріву. Коли n_e або τ_E зростають, потенціал зростає у негативну область. При ЕЦР-нагріві і відповідному рості T_e, τ_E погіршується, і потенціал змінюється у позитивний бік. Спостерігалися коливання потенціалу в діапазоні геодезичних акустичних мод у Т-10 та альфвеновських власних мод у TJ-II.