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DEVELOPMENT OF THE HEAVY ION BEAM PROBING DIAGNOSTIC AND NEW RESULTS IN THE PLASMA ELECTRIC POTENTIAL INVESTIGATIONS

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Introduction

A heavy ion beam probe (HIBP) diagnostic is a unique tool for plasma research in fusion facilities. It has been successfully realized up to now on a number of devices with magnetic confinement ranging from tokamaks and stellarators to variety mirrors. In principle, the HIBP method gives an opportunity to measure simultaneously a few plasma parameters as well as their fluctuations with high temporal and spatial resolution They are an electric potential Φ_{pl}, electron density n_e, electron temperature T_e, and a poloidal magnetic field component B_p[1]. The measurements of Φ_{pl} and radial particle flux Γ_r have been successfully made in previous HIBP experiments [2]. Other parameters measured by this diagnostic (n_e profiles, poloidal magnetic field, magnetic fluctuations and electron temperature $T_e(r)$) have been investigated in rather uncommon cases and developed not so good. The specific feature of the HIBP diagnostic is that each HIBP equipment is faced with its own unique set of hardware related to the type of the fusion facility, its size, configuration and strength and topography of the magnetic field. Installation of a probing beam at a new facility requires a new development of a diagnostic hardware and preliminary computer simulations.

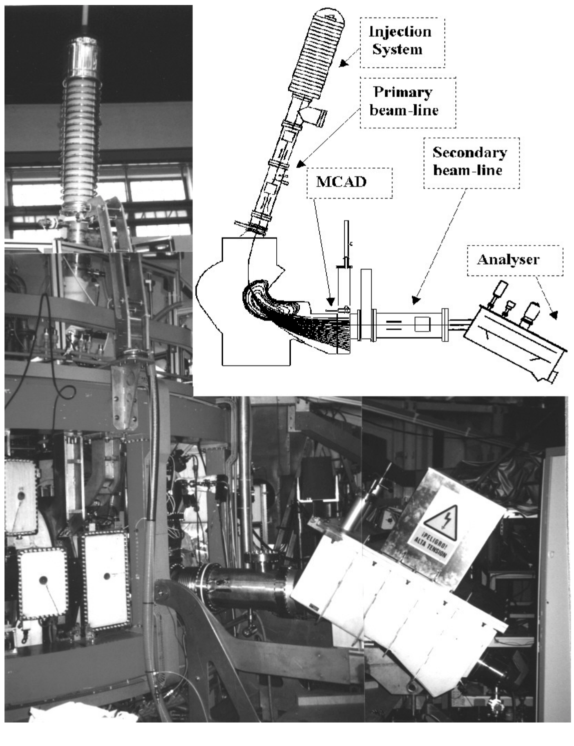

Fig 1. TJ-II HIBP photograph and setup

A new HIBP equipments

An advanced HIBP diagnostic equipments were developed and manufactured for TJ-II stellarator (Spain, Madrid) [3] and tokamak TUMAN-3M.(St. Petersburg, Russia) [4] .

A 200 keV heavy ion beam probing equipment has been developed for the TJ-II flexible heliac to measure of plasma electric potential and density profiles as well as the fluctuation characteristics of these parameters. Traditional engineering composition of this equipment consists of two parts: injector of primary probing beam and energy analyzer of secondary particles. The advantage of TJ-II HIBP system is in simultaneous utilization of two different detection systems for the secondary ions - 30^0 Proca-Green electrostatic energy analyzer and multiple cell array detector (MCAD). The schematic diagram and the photograph of the HIBP installation on TJ-II are shown in Fig.1.

In the system developed for TUMAN-3M is used new detection system with secondary electrons suppression.

These innovative designs aim to spread and improve the HIBP capabilities in simultaneous measurements of plasma parameters. Now these two new diagnostic equipments started in operation.

Initial operation of HIBP on TJ-II

HIBP experiment has been started with probing beam passing through all magnetic fields and investigated plasma. However, a strong HX-rays were detected when 120 keV Cs^+ beam was injected into TJ-II. The creation

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of HX-rays is attributed to the runaway electrons appeared during ramp-up phase of the toroidal magnetic field. This effect always accompanied plasma discharge in TJ-II when vacuum conditions were worse then 1×10^{-7} torr. Diagnostic beam could complementary stimulate HX-ray due to ionization of the residual gas and knocked of the wall of the TJ-II vacuum vessel. The problem was vanished with an special oven-door, which pushed into discharge chamber in time and additional remote controlled Faraday-like target introduced across the beam at the exit of acceleration tube during toroidal field ramp-up.

Though the loading of the analyzer split detector by plasma radiation seems not to be a serious problem (especially with a new modified bias split detector, mentioned above), it still exist for the operation of MCAD, because of much more close arrangement to the plasma.

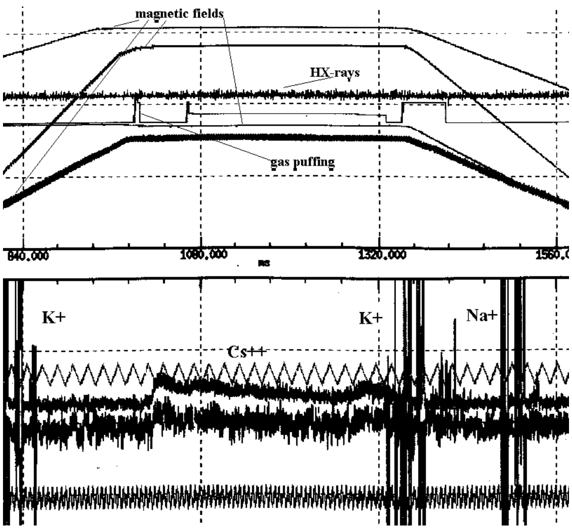

Fig.2. Time traces of some discharge parameters

Fig.2 presents a trace of beam signal in the secondary beam line tube. Experiment has been made with full set of TJ-II magnetic fields and without plasma in chamber. The behavior of signal demonstrates passing of a primary Na^+ and K^+ ions into analyzer-connected tube in time of increasing and decreasing of the magnetic fields (in initial Cs^+ probing beam there are up to 15% impurity alkali ions). Small signal at the moment of gas puffing could be attributed to secondary Cs^{++} ions formed in collisions with gas target. Future experiments and detail comparison with calculation must improve these results.

Behavior of the plasma electric potential during the internal and external transport barriers formation

The plasma potential profile was measured on the T-10 tokamak (R = 150 cm, a = 30 cm) by HIBP diagnostics in the regimes with the external (H-mode) and internal transport barriers (ITB). The diagnostic Tl^+ beam with the energy up to 250 keV and intensity of about a few dozens μA was used to probe the outer half of the plasma column in the low field side.

This paper reports the HIBP study of the regimes with electron ITB obtained by off-axis ECRH/ECCD (140 GHz, 0.5-0.8 MW) with B = 2.1 - 2.14 T, I_p = 200 - 330 kA, q_{lim} = 2.4 [5]. We investigate the extra potential values with respect to initial steady state phase (L-mode). The time evolution of the extra potential profile was obtained by the periodical scan of the beam injection angle. The power supply system provides the 7 ms scan every 20 ms.

In the previous experiments we have investigate the regime with the external transport barrier (H-mode) B = 2.28 T, I_p = 160 kA, $\grave{a}_{lim}$ = 25 cm, q_{lim} = 3. It was shown that during the L-H transition the peripheral plasma potential forms narrow layer with strong electric field (~300 V/cm) in the vicinity of the limiter [6].

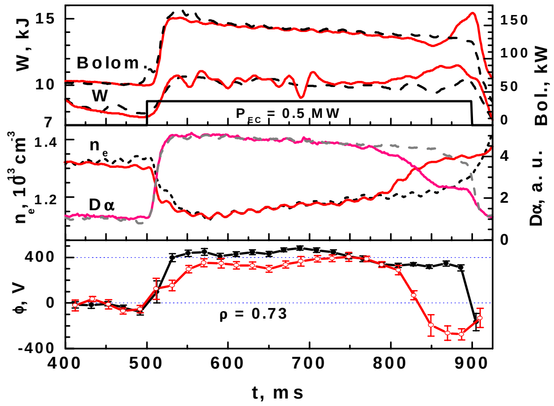

Fig.3. Time traces of some plasma parameters

Figure 3 shows the time evolution of the plasma parameters in the in with H-mode in comparison with the reference one. One can see that the fall of the plasma potential occurs simultaneously with the typical H-mode features: increase of the line-averaged density and fall of D_α emission. The local potential in the observed point with r = 18 cm falls down simultaneously with increase of n_e and fall of D_α. The observed sample volume was located in between the edge barrier (r = 23-24 cm) and the region of EC resonance (r = 14 cm). The local plasma potential in the inner point correlates with D_α intensity: D_α and potential rises up and falls down similarly.

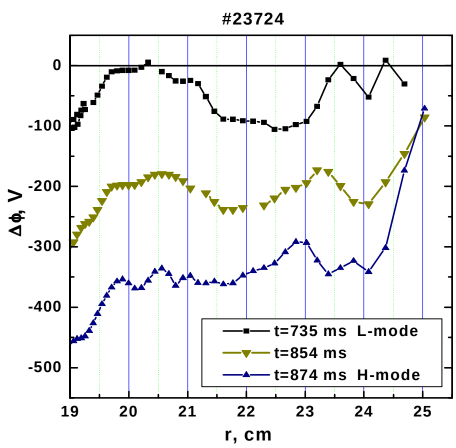

Fig.4. The temporal evolution of the potential profiles

Figure 4 presents the typical time evolution of the extra potential profile in the L-H transition with respect to the L-mode level. The narrow layer (width about 1.5 cm) with a strong electric field is formed just near the limiter. The potential fall is about -400 V.

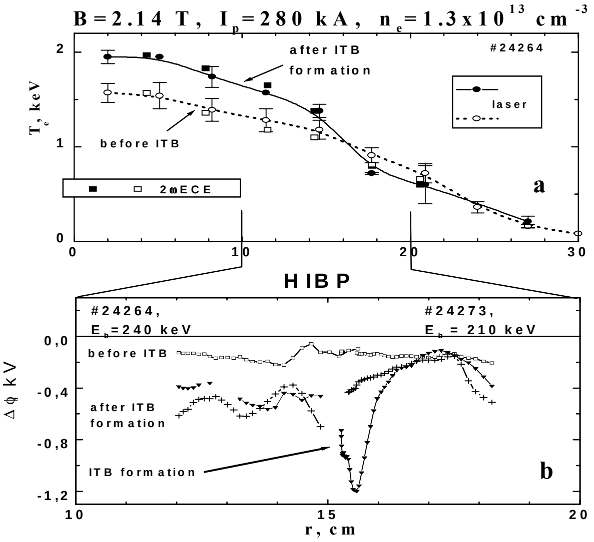

Fig. 5. The electron temperature profiles (a) and the plasma potential (b)

Figure 5a shows the T_e profiles measured both by Thomson scattering and ECE methods after and before the transition. It shows the formation of the steep gradient on the T_e profile at the region of EC resonance (r~16 cm). Figure 5b shows the time evolution of the potential profile. During the electron ITB formation the plasma extra potential forms the transient local deep negative well with maximum value up to -1000 V in the vicinity of the internal barrier. This local well disappears in the post-barrier steady state.

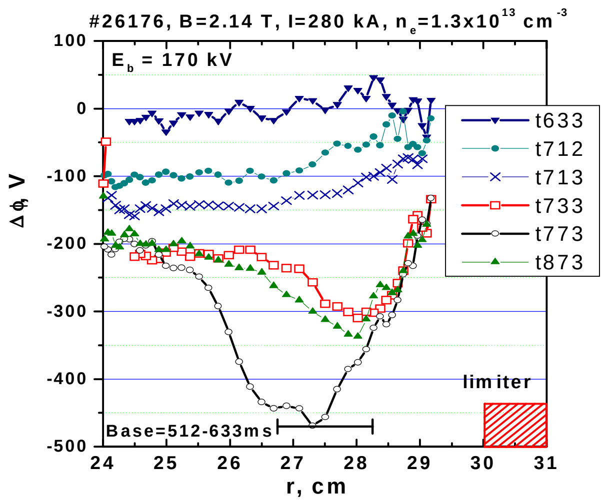

Fig. 6. The temporal evolution of the plasma potential

The reference values were found at the initial steady-state phase. The presented profile was obtained as the combinations of the two parts measured in two similar discharges with the beam energies E_b=240 keV and E_b=210 keV. The observed radial intervals overlap in about 1 cm.

It was shown in [5] that in the discussed regimes the electron ITB formation correlates with potential fall, drop of D_α and increase of line-averaged density n_e.

The area of observation was limited by the diagnostic restrictions. To observe the outer part of the plasma the beam energy was changed to E_b=170 keV.

The temporal evolution of the outer part of the plasma potential profile in the shot #26176 with ITB is presented in Fig. 6. The area of the sharp decrease of the plasma potential just near the limiter appears to be similar to the one shown in Fig. 4.

During the edge and internal transport barriers formation the local potential near both barriers behave similar: when the density rises up the potential falls down, when the density keeps constant the potential rises up, the post-barrier steady-state extra potential profile with respect to the pre-barrier steady state has the stair shape with a sharp jumps Δϕ ~ - 400 V near the barriers [7].

Conclusions

1. The inter transport barrier is formed with such a current distribution, where dq/dr=0 and q value is placed near the resonance.
2. A deep narrow potential well occurs during the barrier formation, which manifests the improvement of the electron confinement in the barrier zone.
3. At $q_{L\leq}$ 4 values two barriers appear simultaneously. The external barrier has the features of the L-H transition.

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