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PLASMA POTENTIAL MEASUREMENTS BY HEAVY ION BEAM PROBE IN THE TJ-II STELLARATOR

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Abstract

First plasma potential measurements by the HIBP diagnostic have been obtained in the TJ-II stellarator. Plasma potential depends on plasma density and working gas (H versus He). In the low density regime (4×10^{12} cm^{-3}) plasma potential increases up to 300 V. With increasing of plasma density (1×10^{13} cm^{-3}) the plasma potential reaches negative values of about -500V. The absolute value of plasma potential is smaller in He plasmas than in H plasmas. Measurements of plasma potential radial profiles (ρ = 0.3 –1) have shown core plasma potential values up to 1 keV. An important improving in the signal to noise ratio allows the measurements of plasma potential fluctuations with a resolution better than 20 V. The radial profile of plasma potential fluctuations shows a decrease in the root mean squared value (rms) of plasma fluctuations as the HIBP sample volume moves from the edge (rho ≈ 1) to the core (rho ≈ 0.3). Radially localized bursts in plasma potential fluctuations have been observed ($\rho \approx 0.4$) in the frequency range 30 – 40 kHz. These results might be related to the presence of rational surfaces (e.g. 3/2).

1. Introduction.

The advantage of HIBP system in operation in the TJ-II stellarator is based on the simultaneous utilization of two detectors for the secondary ions: a 30^o Proca-Green electrostatic energy analyzer and a multiple cell array detector (MCAD) [1]. During operation with the electrostatic energy analyzer the sample (ionization) volume position is controlled by changing the entrance angle of the primary beam to the plasma, using electrostatic sweep plates. The trajectory of the primary beam inside the plasma arranges a sequence of the sample volumes for the MCAD. The operation with these detectors allows enlarging the number of the sample volumes inside the plasma to obtain profiles of the electron density and its fluctuations.

The HIBP installation in the TJ-II device is composed of three main parts: injection system, detectors, and control and data acquisition system. In the experiments described in this paper, the HIBP operates with a 125 keV Cs^+ beam and the electrostatic energy analyzer to measure the plasma potential. The paper is organized as follows: a description of the TJ-II electrostatic energy analyzer is presented in Section 2; first investigation of the influence of plasma density in the plasma potential is discussed in section 3, radial profiles of plasma potential and fluctuations are discussed in section 4.

2. The TJ-II electrostatic energy analyzer.

The electric potential measurement is based on the conservation of energy as the primary Cs^+ ion passes through the plasma. When it is additionally ionized, an electron is stripped off, removing a potential energy of $-e\Phi_{pl}$, where Φ_{pl} is plasma potential in the given ionization point. The secondary Cs^{2+} ion energy is therefore higher than the primary one on the same amount $e\Phi_{pl}$. The plasma potential is obtained by measurements of energy of the secondary ions.

The relation for plasma potential, using a 30º Poca-Green electrostatic energy analyzer, with a split plate detector is given by the expression:

$$\Phi_{pl} = 2U_a(\delta iF + G_a) - U_b \qquad (1)$$

where U_b and U_a are the accelerator and analyzer voltages, $\delta i = (i_t - i_b)/(i_t + i_b)$ is the normalized difference of the currents on the top (i_t) and bottom (i_b) detector plates, G_a and F are the analyzer gain and dynamic coefficients, respectively, which depend on the analyzer geometry and the beam entrance angle. The analyzer built for the TJ-II HIBP has no guard rings. A high uniformity of the electric field inside analyser (better than 10^{-4} at the midplane) is achieved with special configurations of the top HV electrode and grounded shield. Both the HV electrode and shield can be shifted in toroidal direction up to ±10 cm inside the analyzer vacuum tank, allowing an additional tune of the analyzer position in different regimes of TJ-II. A manual control of the split detector position allows us to adjust the geometric parameters of the analyzer, thus to modify and optimize the gain G_a. Figure 1 shows the gain curve obtained in the analyser calibration experiment.

3. Plasma potential measurements and influence of plasma density.

TJ-II is a medium size stellarator with 4 periods, major radius of 1.5 m, and magnetic field of 1 T. [2]. Experiments reported in this paper were carried out in ECRH plasmas (P_{ECRH}= 300kW) and plasma densities in the range (0.4 – 1) x 10^{13} m^{-3}.

The influence of plasma density on plasma potential has been investigated at a fixed radial location ($\rho \approx 0.5$) in the plasma configuration shown in figure 2. It shows the location of the ionization point and trajectories of primary and secondary ions. The ionization point is located at a distance 4 cm from the plasma axis.

The currents of Cs^{2+} ions measured on different collector plates of analyzer split detector during discharge are shown in Fig.3. Modulation of the primary beam allows subtracting the plasma loading offset in further data processing. Fig.4 presents the time evolution of the average electron density, electron temperature, and plasma potential for two plasma shots, #5474 and #5484 (He plasmas). The plasma potential is about +200 V with plasma densities about 4 x 10^{12} cm^{-3} (shot 5474). At higher densities the plasma potential increases from -400 V up to +250 V as density decreases from 0.8 x 10^{13} to 0.6 x 10^{13}. The evolution of plasma potential with density is quite similar for Hydrogen and Helium plasmas, although in He plasmas the absolute value of the potential is about a factor of two smaller than in H.plasmas (Fig. 5). The total secondary Cs^{++} ion current is given by $I_{tot} \propto \nu\ f(T_e)$, where n is the local plasma density at the ionisation point, and f is the effective croos section of ionisation, which is a weak function of T_e.for TJ-II plasma parameters. The TJ-II secondary beam current shows a correlation with the average plasma density.

In general the sources of the errors in plasma potential measurement may be classified in two groups: errors due to accuracy of the accelerator and analyzer voltages (U_a, U_b) and the errors due to geometrical uncertainties of the experiment (including the entrance angle into analyzer, the stray magnetic field effect on analyzer operation, etc), which formally influence the analyzer gain G_a and dynamic F coefficients. The values of the voltage on the accelerator and analyzer power supplies are known with accuracy better than 10^{-4}. The measurement of the loading to power supplies by plasma radiation show that this influence is about 10 V.

To minimize the errors due to geometrical uncertainties, we used G_a coefficient values obtained in the experiments with gas target directly on the TJ-II device, and the value of F from the analyzer calibration measurements on the HIBP test facility. In stellarators the trajectory of the secondary ions in the gas is almost identical to the trajectories in the plasma. Therefore in the TJ-II stellarator such a gas target (He) calibration can be performed in each shot during the time after plasma pulse, when the additional gas puffing is used to suppress the runaway generation and magnetic configuration still remains the same. For a rough estimation of the error in the measured plasma potential determined by geometrical uncertainties we use the difference between gain coefficients obtained in calibration experiment on gas target and test facility. It gives a value $\pm 10^{-3}$ U_a(i.e. about 100V).

4. Radial profiles and fluctuations

First measurements of the plasma profiles show an increasing of potential from the edge (ρ = 1) to the plasma core ($\rho \approx$ 0.3). Core plasma potential can reach values up to 1 keV. Measurements show a dependence of core plasma potential with plasma density. Radial scan of the total secondary beam current shows evidence of significant attenuation of the probing beam in the plasma.

Recently, an important improving in the signal to noise ratio allows the measurements of plasma potential fluctuations with a resolution better than 20 V. The radial profile of plasma potential fluctuations shows a decrease in the root mean squared value (rms) of plasma fluctuations as the HIBP sample volume moves from the edge ($\rho \approx 1$) to the core ($\rho \approx 0.3$). Interestingly, radially localized bursts in plasma potential fluctuations have been observed near $\rho \approx 0.4$ in the frequency range 30 – 40 kHz. In this plasma region there is a significant increase in the root mean squared (rms) value of plasma potential fluctuations. These results might be related to the presence of rational surfaces (e.g. 3/2) and suggest the existence of fluctuating radial electric fields linked to rational surfaces in the plasma core.

References.

[1] I.S.Bondaranko et al.,Chechoslovak Journal of Physics, Vol.50 (2000), No.12, p.1397;
[3] C.Alejaldre et.al., Fusion Technol. 17 (1990)p.131;[4]

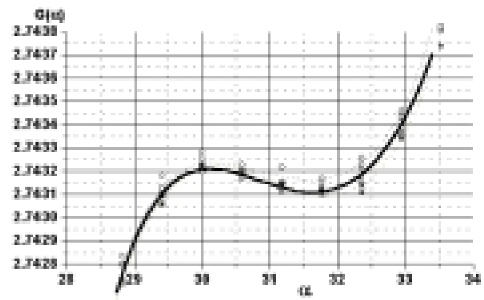

Fig. 1. Analyzer gain coefficient

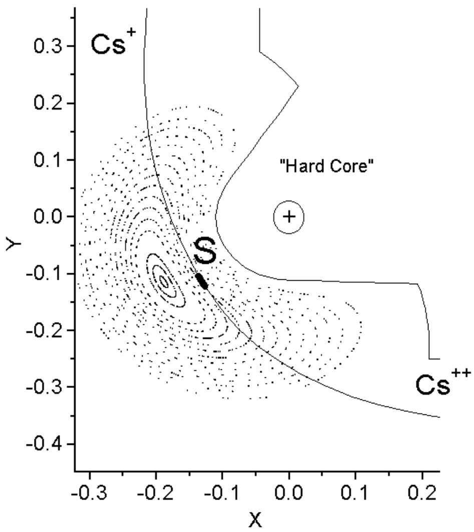

Fig. 2. TJ-II magnetic configaration

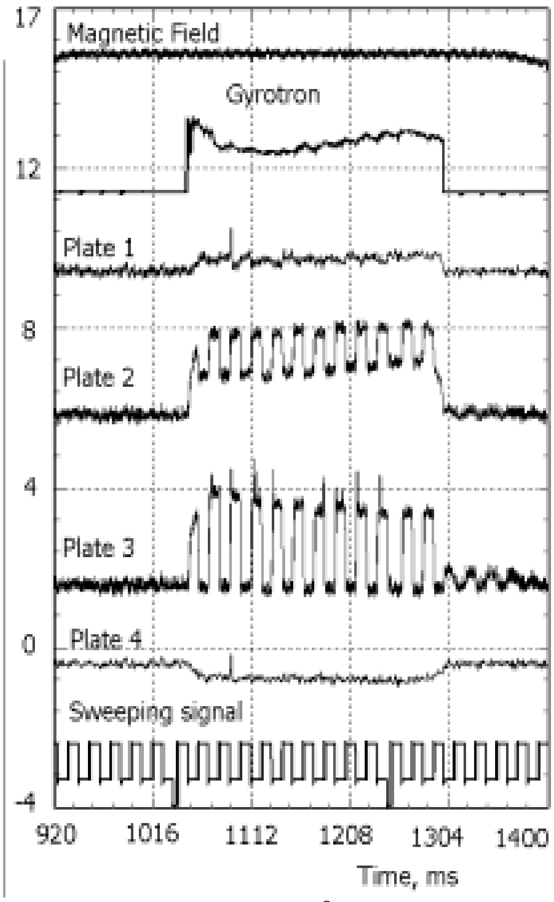

Fig.3. The currents of Cs^{2+} ions observed on different collector plates

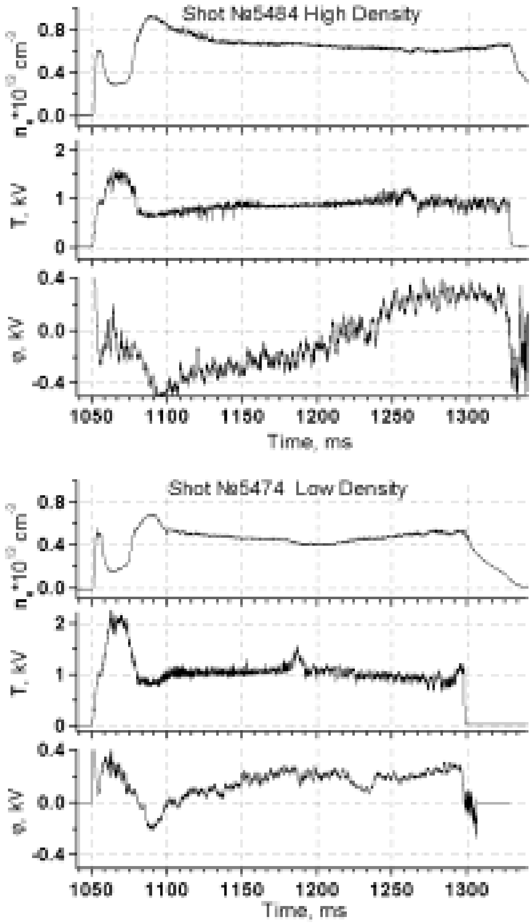

Fig. 4. Plasma potential time evolution with different average electron density.

Core (r ≈ 0.3)

Edge (r ≈ 1)

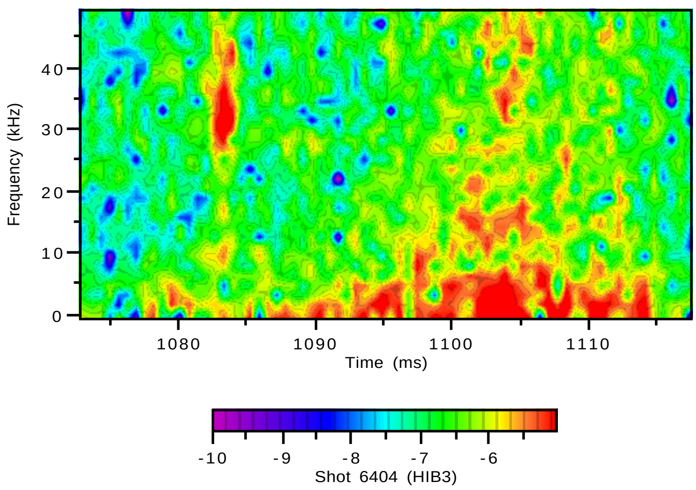

Fig. 5. Frequency spectra of collector plates signal during a temporal scan of the beam from the core region (ρ ≈ 0.3) to the plasma edge (ρ ≈1). A quasi-coherent mode is clearly observed in the plasma core region (ρ ≈ 0.4).