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

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1. Introduction.

A heavy ion beam probe (HIBP) measures a variety of plasma parameters in magnetically confined plasmas, including the electric potential and electron density. In HIBP experiment, a singly charged ions (the primary beam) are injected into the plasma. As they pass through the plasma, a doubly charged ions (the secondary beam) are created due to collisions with electrons. The information about plasma electric potential and density is retrieved respectively from the energy and intensity of the secondary beam collected outside the plasma.

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

A schematic of the HIBP installation on TJ-II is shown in Fig.1. It is composed in three main parts: injection system, detectors, and control and data acquisition system [1]. In the experiments described in this paper, the HIBP operates with a 125 keV Cs^+ beam and EEA to measure the plasma potential. The paper is organised as follows: the principles of the measurements and description of EEA are shortly reviewed in Section 2; the first results of plasma potential measurements are reported in Section 3; the summary is given in Section 4.

2. Plasma potential measurement. Electrostatic energy analyzer.

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

The plasma potential measured by a 30^o Proca-Green EEA with a split plate detector is determined by the relation [2]:

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

where U_a and U_b are the analyzer and accelerator voltages, $\delta i = (i_t - i_b)/(i_t + i_b)$ is the normalised difference of the currents on the top (i_t) and bottom (i_b) detector plates, F and G_a are the analyzer dynamic and gain coefficients, which depend on the analyzer geometry and incident angle of the beam.

The EEA used in HIBP experiments on TJ-II has been described in detail in [1]. Better than 10^{-4} uniformity of the electric field inside the analyzer is achieved with a special configuration of the high voltage (HV) electrode and grounded shield. Both the HV electrode and shield can be shifted toroidally in the range of ± 10 cm inside the analyzer vacuum tank, allowing the 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 optimise the gain G_a. Fig.2 shows the dependence of G_a with the incident angle obtained in calibration experiments on test facility.

3. First results of plasma potential measurements in TJ-II.

TJ-II is a medium size stellarator with 4 periods, major radios of 1.5 m, and 1 T of the typical magnetic field [3]. Its various operational regimes are characterised by strongly different magnetic configurations and large differences of the plasma effective radii.

At the time being, Φ_{pl} has been measured in one point of plasma cross-section (4 cm from the axis) in TJ-II regime with magnetic configuration characterised by 10 kA in the helical coil, 2.8 kA in the hard core, and 6.3 kA in the vertical coil. The average electron density of the ECRH (200 kW) plasmas in this regime has been varied in the range $\langle n_e \rangle = (4\text{-}8)\times 10^{12}$ cm^{-3}, and electron temperature was $T_e = 1$ keV. Fig.3 shows the location of the sample volume and trajectories of the primary and secondary ions in plasma cross-section.

The total current of the secondary ions, i_{stot}, is proportional to the product of $n_e\sigma_{eff}$, where n_e is the local electron density in the ionization point, and $\sigma_{eff} = f(T_e)$ is the effective cross-section of the ionization process. In the range of the electron temperature of TJ-II plasmas σ_{eff} has a weak dependence on T_e, therefore, the intensity of secondary beam should follow the electron density, if the attenuation factor is not strong. It is confirmed by Fig.4, which shows the temporal evolution of the signals of $\langle n_e \rangle$ and i_{stot} in two shots, #5474 (H plasmas) and #5676 (He plasmas).

The signals observed on four collector plates of the analyzer split detector during discharge are shown in Fig.5. Modulation of the beam allows to distinguish the plasma loading offset. Fig.6 presents the temporal evolution of $\langle n_e \rangle$, T_e and Φ_{pl} for two shots, #5474 and #5484 (both of H plasmas). Φ_{pl} exceeds +200 V during stationary part of the low density (4×10^{12} cm^{-3}, shot #5474) discharge. In discharge with a higher, but decreased (from 8×10^{12} cm^{-3} to 6×10^{12} cm^{-3}, shot #5484) density, Φ_{pl} increases from –400 V to +250 V. The increasing of Φ_{pl} has been also observed in series of the flat-top discharges with shot-to-shot decreased electron density. Finally, Fig.7 presents the temporal evolution of Φ_{pl} in hydrogen and helium plasmas of the discharges with close parameters. In helium plasmas the absolute value of Φ_{pl} is about two times lower than in the hydrogen one.

An attention should be shared out to the errors of plasma potential measurements. In general, the sources of the errors may be divided in two groups: the error due to accuracy of the analyzer and accelerator voltages, U_a, U_b, and the errors due to geometrical uncertainties, which influence the analyzer gain coefficient, G_a.

The values of the voltage of the analyzer and accelerator power supplies are known with accuracy better than 10^{-4}. The check of the loading of the power supplies during plasma shots shows 10 V of the maximum change.

To minimise the errors due to geometrical uncertainties, we use G_a values obtained in the experiments with gas target directly on TJ-II, and the value of F determined in the analyzer calibration on test facility. The advantage of the gas target experiments in stellarator is that when the plasma current is small and Φ_{pl} is not too large, the trajectory of the secondary ions from the gas is almost identical to that from the plasma, but with zero potential. In TJ-II a gas target 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 unchanged. At the time being, for rough estimation of the error determined by the geometrical uncertainties we use the difference between the gain coefficients obtained in calibration experiment on gas target and test facility, which gives $\pm 10^{-3} U_b$, or ±125 V of the absolute value.

4. Summary.

A heavy ion beam probe diagnostic starts the measurements of the plasma potential in the TJ-II stellarator using a 125 keV Cs^+ beam. The measurements have been performed in the ECRH (200 kW) plasmas with $\langle n_e \rangle = (4\text{-}8)\times 10^{12}$ cm^{-3} and $T_e = 1$ keV. The first results of the temporal evolution of Φ_{pl} in one point, staying 4 cm from the plasma axis, have been obtained. The results show both positive and negative plasma potential of the values (-400)-(+250) V with the estimated error of ±125 V. The dependence of plasma potential with average electron density is in agreement with the HIBP measurements on the ATF stellarator [4]. The absolute value of plasma potential is lower in helium plasmas, as to compare with the hydrogen one.

References.

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[3] C. Alejaldre et al, Fusion Technology, 17, p.131, 1990.
[4] T.P. Crowley et al, IEEE Transactions on Plasma Sci., 22, p.291, 1994.

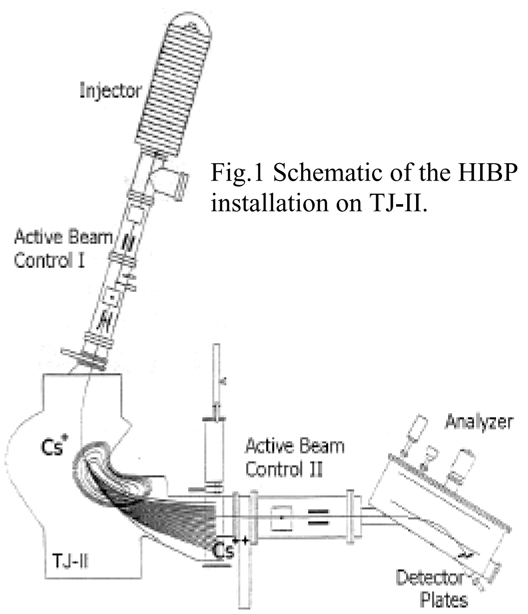

Fig.1 Schematic of the HIBP installation on TJ-II.

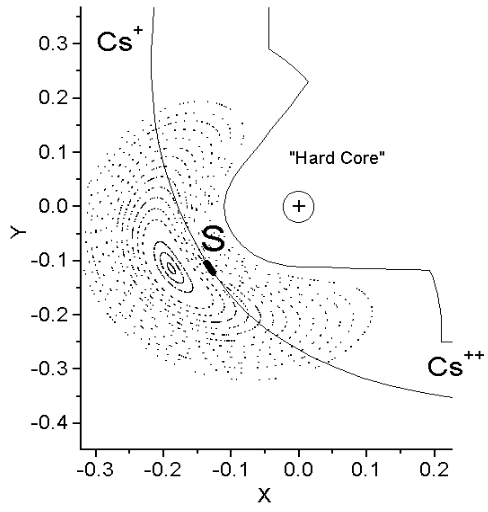

Fig.2 Sample volume location in plasma cross-section.

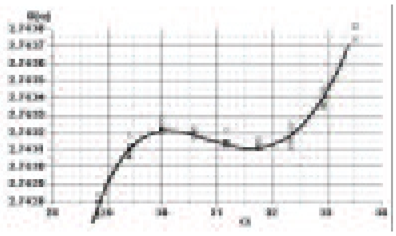

Fig.3 Analyzer gain coefficient G_a

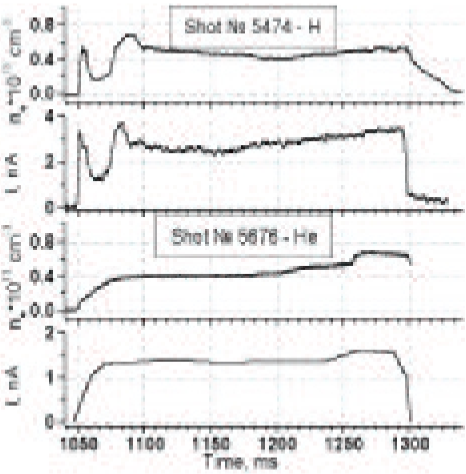

Fig.4 Temporal evolution of the total secondary current Cs^+ and average plasma density in H and He plasmas

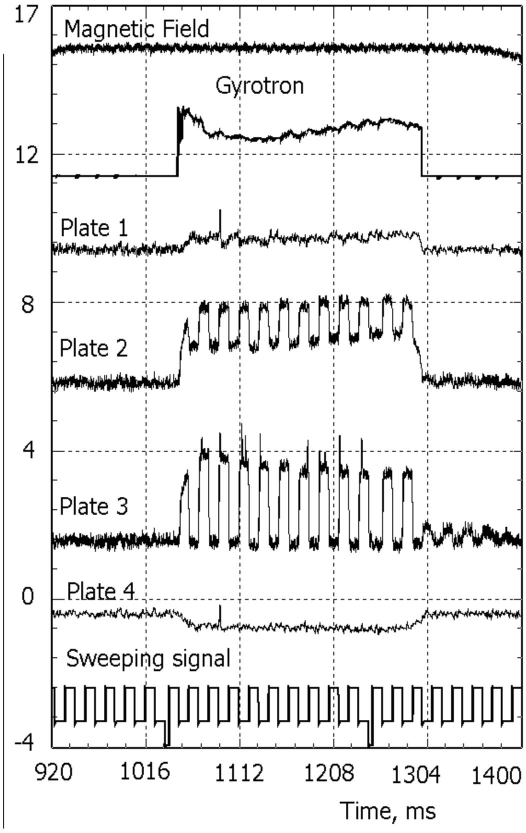

Fig.5 Signals observed during discharge on different collector plates of EEA.

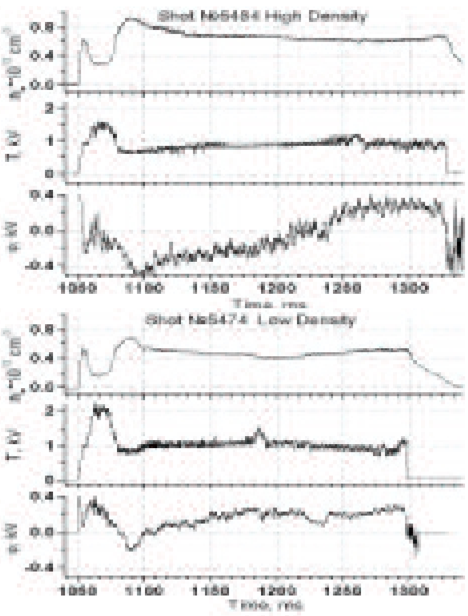

Fig.6 Temporal evolution of plasma potential in shots with different average plasma density.

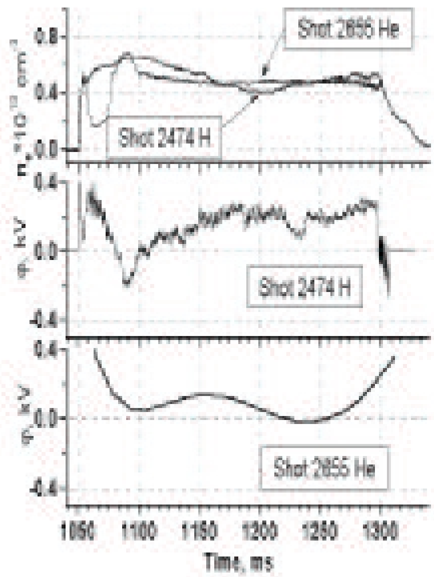

Fig.7 Temporal evolution of plasma potential in hydrogen and helium plasmas.