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HIBP on WEGA Calibration and Measurements

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INTRODUCTION. The accurate knowledge of the electric field structure and its fluctuations in the plasma is fundamentally important for understanding plasma confinement phenomena. A Heavy Ion Beam Probe (HIBP) is a unique diagnostic, which is able to provide direct non-perturbing plasma electric potential measurements and its fluctuations from the centre to the periphery of the plasma column.

The diagnostic principle is based on the difference in the Larmor radii of highly energetic heavy ions with different ionization states. A singly charged ion beam (primary beam) is injected across the confinement magnetic field. Some probing particles are ionized in the plasma producing double ionized secondary ions (secondary beam). The information about plasma parameters can be obtained from the characteristics of the secondary ions. The main measured parameter is the plasma potential Φ_p. It is obtained by this diagnostics as a difference between primary and secondary beam energies. HIBP can also be used in magnetic confinement fusion experiments to measure the electron density n_e, electron temperature T_e, poloidal magnetic field B_θ as well as their fluctuations with a high temporal and spatial resolution. The temporal resolution is mostly limited by the bandwidth of the current-voltage converters used for secondary ions current measurements. Spatial resolution depends on the beam width and geometry of each particular installation.

A HIBP has been installed and tested on the WEGA stellarator in collaboration with the Institute for Plasma Physics in Kharkov/Ukraine [1]. The main objectives are measurements of electric potential and its fluctuation profiles, its validation with Langmuir probe data, and other diagnostics results.

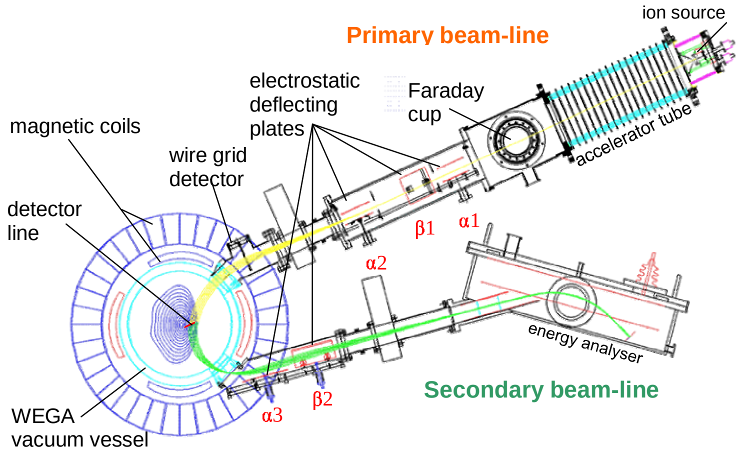

Fig. 1. Scheme of the HIBP on the WEGA stellarator.

HIBP AT WEGA. On WEGA the Na^+ primary ion beam is used with typical current of 35 μA and energy of 39.5 keV. These parameters are optimal for a nominal toroidal magnetic field value of B_0=0.489 T in WEGA. The beam width is ~5 mm, which along with the geometrical properties of WEGA provides the spatial resolution of ~7 mm. The time resolution is 20 μS. The covered radial range of the measurements is $0.4 < r/a < 1$, the plasma centre ($r/a=0$) is not accessible due to geometrical limitations.

The HIBP system consists of the primary beam-line and the secondary beam-line with the energy analyser (Fig.1). In the primary beam line, Na^+ beam is formed and its point and angle of incidence in plasma is controlled by electrostatic deflecting plates. In the plasma, some part of Na^+ ions are ionised and became double-charged Na^{++}. Double-charged ions, which are originated in the sample volume, reach the energy analyser after passing the secondary beam line. In the secondary beam-line voltages on deflecting plates define the position of the sample volume along the primary beam trajectory. In this way, the voltages on all deflecting plates define the position and shape of the detector line (Fig.2) during the profile measurement.

After the secondary beam line, the Proca-Green design [2] energy analyser is installed.

COORDINATE MAPPING. Using the deflecting voltages on plates along with the magnetic field configuration, the trajectories of primary and secondary beams and the position of the sample volume could be calculated. This is done by a trajectories calculation code, which solves the ion equation of motion in electric and magnetic field using the Runge-Kutta method.

In Fig.2 the result of these calculations is shown. In the ionisation zone, each point represents the position where the sample volume could be located for corresponding voltages on deflecting plates. Thus, a HIBP could provide the measurements in any point in the ionization zone. In Fig.2 the detector line is shown which provides the highest radial covering of the plasma

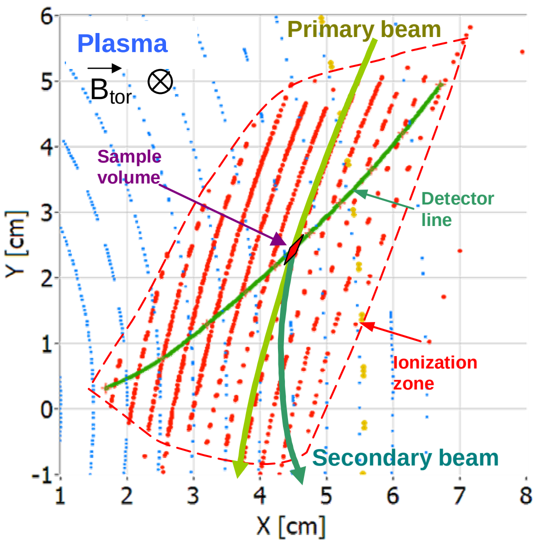

Fig. 2. Detector line obtained from ray tracing calculations of primary and secondary beams.

(0.4 < r/a < 1). However, we are free to choose any detector line within the bounds of the ionization zone.

The precision of numerical coordinate mapping method is limited by the assumptions included in the model (homogeneity of the electric and magnetic field, simplified geometry). To increase the mapping precision, the measured data could be compared with results from other diagnostics such as Langmuir probes.

Another possibility of precise mapping is using of high current magnetized electron beam as a reference for exact position mapping. The high current is needed for obtaining of high electrons density in the HIBP measurement region. Estimations show that minimum 1A beam current is needed in order to detect it with our HIBP sensitivity. In these experiments, an electron gun should be installed at the magnetic field line, which crosses the ionisation zone at certain point. If the density of the electrons in the beam is high enough, the HIBP should detect the increase of the total secondary current in this point. The first attempts of this calibration were not successful because of the too low electron beam density. The modification of the electron gun in order to obtain larger electron densities is planned in the nearest future.

MEASUREMENTS AND RESULTS. The measurements of the plasma potential profile and total current of secondary beam were provided in parallel with Langmuir probe measurements. The obtained profiles were compared. The results are presented in Fig.3.

Potential measurement results indicate a positive plasma potential, using the vacuum vessel as the potential reference. This is in reasonable agreement with the data from the Langmuir probes.

The total current of secondary ions could be estimated as,

$j_s = \gamma_e \sigma_{(i \to S)} n_e l_{SV} F_i F_S \, j_i \, q_s / q_i$ where γ_e is the secondary electron emission from the detector plates, $\sigma_{(i\to S)}$ is ionization cross-section, n_e is plasma density, l_{SV} is the length of the sample

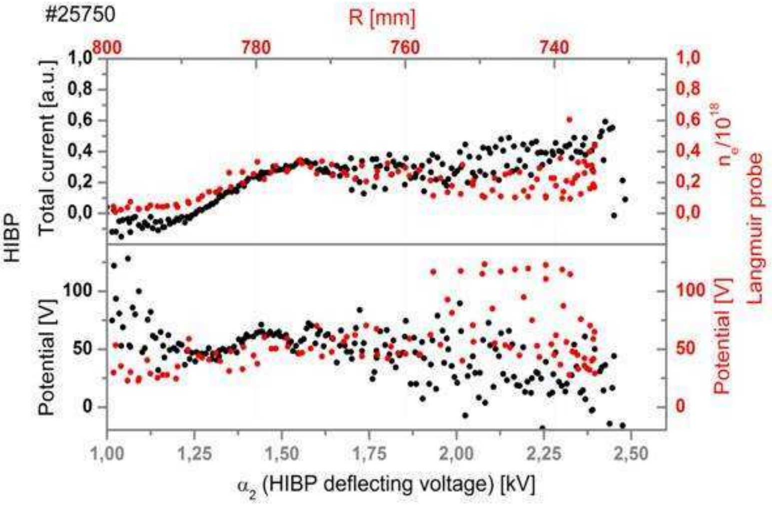

Fig.3. (top) total current profiles and density profile measured by Langmuir probes. (bottom) same for the plasma potential.

volume this could be obtained from the trajectories calculation code calculations, F_i, F_S is the primary and secondary beam attenuation factor for, j_i ,j_s primary and secondary current.

The ionization cross-section $\sigma_{(i\rightarrow S)}$ is a function of the electron temperature. Thus, the full current is proportional to the combination of plasma density and the electron temperature. In measurements shown in Fig.3 the plasma temperature varies in a small range of 10÷20 eV where the influence of the temperature on total current is much smaller than that from the density. However, in some regimes with higher temperature >40 eV the situation could be essentially changed and the influence of the temperature could prevail.

The potential and total current in Fig.3 is plotted over the voltage on the α2 deflecting plates. This corresponds to the scanning of the plasma potential along the detector line shown in Fig.2.

CONCLUSIONS & OUTLOOK. Crosscheck with Langmuir probes shows good agreement of measured plasma potential with the data obtained from Langmuir probes measurements. In the near future, ECRH power deposition investigation is planned with a modulated gyrotron. Also, potential fluctuation studies could be done in conjunction with Langmuir probes. The flexibility of the detector line could be used for investigations of plasma parameters and its fluctuations inside the magnetic islands and in the x-point of WEGA magnetic configurations without changing the magnetic configuration itself.

REFERENCES

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