HIBP RESULTS ON THE WEGA STELLARATOR

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The heavy ion beam probe (HIBP) is a non-perturbing diagnostic, which allows to determine the spatial distributions of the main plasma parameters such as plasma potential, density, electron temperature and poloidal magnetic field in magnetically confined fusion plasma devices. The heavy ion beam probe plasma diagnostic system has been installed and tested on the WEGA stellarator in Greifswald, Germany in 2006-2007. The HIBP on WEGA is planned to be used for the basic investigations of the plasma confinement in a different magnetic configurations. Also, power deposition region will be investigated in experiments with modulated gyrotron heating power. In this work, the first plasma potential and total secondary current profiles measurements results are presented in a comparison with Langmuir probes data.
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1. INTRODUCTION

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

The diagnostic is based on the difference in the Larmor radii of highly energetic heavy ions with different ionization states. A singly charged ion beam (or primary beam) is injected across the confinement magnetic field. Due to collisions with plasma particles (mainly electrons) probing beam 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 and thermal noise of the current to voltage converters, which are used for the secondary ions current registration. The spatial resolution depends on the beam width inside plasma region and the geometry of each particular installation.

The HIBP has been installed and tested on the WEGA stellarator in collaboration with the Institute of 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.

Plasma experiments with the HIBP diagnostic system were carried out at a toroidal magnetic field strength of B_0=0.489 T. with Argon or Helium as working gas and ECR plasma heating at 28 GHz.

2. HIBP ON WEGA STELLARATOR

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 for the standard operation regime. The beam width is ~5 mm, which along with the geometrical position of WEGA ports and diagnostic equipment provides the spatial resolution of ~7 mm. The time resolution is about 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 electrostatic energy analyser (Fig.1).

In the primary beam line, Na^+ ions are produced from the heated sodium thermoionic emitter and accelerated by the electrostatic acceleration tube. The point and angle of
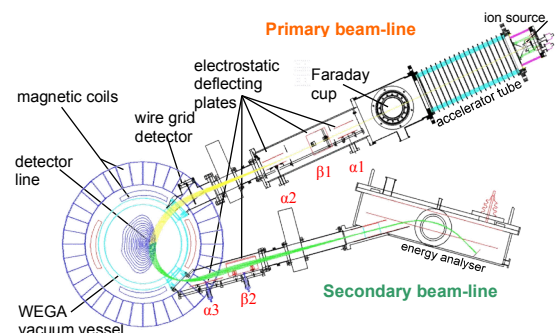

Fig.1. Scheme of the HIBP on the WEGA stellarator

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incidence in the plasma is controlled by the 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 Proca-Green design [2] electrostatic 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.

3. COORDINATE MAPPING VALIDATION

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

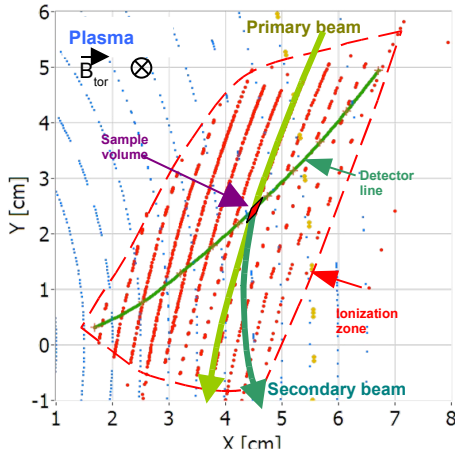In Fig. 2 the result of these calculations is shown. In

Fig .2. Detector grid

the ionisation zone, each point represents the position where the sample volume could be located for corresponding voltages on the 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 $(0.4 < r/a < 1)$. However, we are free to choose any detector line within the bounds of the total possible coverage zone.

The precision of numerical coordinate mapping method is limited by the assumptions included in the model (homogeneity of the electric and magnetic field, geometrical misalignment of the primary and the secondary beam-line is not taken into account). To increase the mapping precision, the measured data could be compared with the 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 1 A

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.

In order to accurately measure the incidence angle of the primary beam the system will be installed that consists of the wire grid detector at the output of the primary beam-line and multi-cell array detector inside the WEGA vacuum vessel.

4. MEASUREMENTS AND RESULTS

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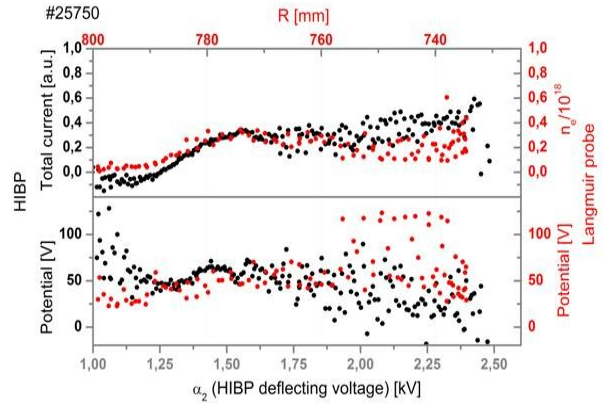

Fig.3. Total current density profile measured by Langmuir probes (top); the same for the plasma potential (bottom)

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 the 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 coefficient 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 volume, which could be obtained from the trajectories calculation code, F_i, and F_S are the primary and secondary beam attenuation factors for, j_i j_s primary and secondary currents.

The ionization cross-section $\sigma_{(i \to S)}$ is a function of the electron temperature distribution. Thus, the full secondary current is proportional to the combination of plasma density and the electron temperature. The 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 the regimes with higher temperature >40 eV and low density the situation could be essentially different 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.

5. CONCLUSIONS

The crosscheck with the Langmuir probes shows a good agreement of the measured plasma potential with the data obtained from the Langmuir probes measurements. In the near future, ECRH power deposition investigation by the HIBP is planned with a modulated gyrotron. Also, potential fluctuation studies could be done in conjunction with the 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

1. L.I. Krupnik et al // *Fusion Science and Technology*. 2006, v. 50, p 276-280.
2. T.S. Green and G.A. Proca // *Rev.Scientific Instr*. 1970, v. 41, p. 1409.

РЕЗУЛЬТАТЫ ЗППТИ НА СТЕЛЛАРАТОРЕ ВЕГА

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Диагностика *зондирования плазмы с помощью пучка тяжелых ионов* (ЗППТИ) является диагностикой, которая не влияет на параметры плазмы и позволяет измерять пространственные распределения главных параметров, таких как потенциал плазмы, плотность, электронная температура и полоидальное магнитное поле в установках с магнитным удержанием. Диагностика плазмы пучком тяжелых ионов была установлена на стеллараторе ВЕГА в г. Грайфсвальде, Германия, в 2006-2007г. ЗППТИ на стеллараторе ВЕГА планируется использовать для исследования процессов удержания плазмы в различных магнитных конфигурациях. Также будет исследована область поглощения ВЧ- мощности в экспериментах с модулируемой мощностью гиротрона. В этой работе представлены первые измерения профилей потенциала и полного тока вторичного пучка в сравнении с данными, полученными от Ленгмюровских зондов.

РЕЗУЛЬТАТИ ЗППВІ НА СТЕЛАРАТОРІ ВЕГА

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Діагностика *зондування плазми за допомогою пучка важких іонів* (ЗППВІ) – це діагностика, яка не впливає на параметри плазми, та дозволяє вимірювати просторовий розподіл головних параметрів, таких як потенціал плазми, густина, електронна температура та полоїдальне магнітне поле у пристроях з магнітним утриманням. Діагностика плазми пучком важких іонів була встановлена на стелараторі ВЕГА у м. Грайфсвальд, Німеччина, у 2006-2007р. ЗППВІ на стелараторі ВЕГА заплановано використовувати для дослідження процесів утримання плазми при різних магнітних конфігураціях. Також буде досліджена область поглинання ВЧ- потужності у експериментах з модульованою потужністю гіротрону. У цій роботі представлено перші вимірювання профілю потенціалу та повного струму вторинного пучка у порівнянні з даними, які були одержані від Ленгмюрівських зондів.