APPLICABILITY OF HEAVY ION BEAM PROBING (HIBP) SYSTEM FOR STELLARATOR WEGA

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The applicability of the HIBP for stellarator WEGA is described in this article. It is possible to use such diagnostics for local plasma parameters measurement. Calculations of probing Na^+ beam trajectories were done for WEGA magnetic configuration with $\mathbf{B_0}$ = 0.5 T. The trajectory optimization aiming for the maximal plasma observation was done for chosen entrance and exit port combination. The calculation shows that HIBP allows getting radial profiles of plasma parameters. The detector line of equal entrance angle connects the central area and the edge of the plasma column for beam energy **E** =30-60 keV. The detector line of equal energy **E** = 40 keV allows to obtain series of radial profiles during single shot by changing of the beam entrance angle with the scan of control voltage.

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INTRODUCTION

The Heavy Ion Beam Probing (HIBP) diagnostics is known as a unique tool for the direct contact less local measurements of plasma potential. Its ability to measure plasma density, temperature and plasma current profile distributions is well known also.

The operation of the HIBP is based on the injection of primary single-charged ion beam into the plasma across the maintaining magnetic field and the registration of the double-charged secondary particles, born due to the collisions with plasma electrons. The region of secondary ionization in plasma, called the sample volume, is the local region of the plasma potential measurements. Position and size of the sample volume are determined by calculation of the probing particles trajectories.

The applied equipment for a variety of magnetic confinement devices (tokamaks, stellarators, bumpy torii, tandem mirrors) has common features but differ in beam energies and ion beam species. The geometry of the confining magnetic field and the size of confinement device determine the energy requirements of the ion beam used for any HIBP application [1, 2]. The applicability of HIBP for WEGA stellarator is described in this article.

1. CALCULATIONS

There are physical limitations of HIBP measurements for all plasma cross-sections consisting in that the ions' Larmor radius should be larger than radius of magnetic field area. Besides, there are geometrical limitations, which are determined by design of vacuum chamber (arrangement of entrance and exit ports), arrangement of magnetic coils, bearings and already installed diagnostic equipment. They greatly narrow down the size of plasma investigated area

The WEGA stellarator isn't very comfortable for HIBP diagnostics because of it has quite large empty magnetic field volume, compared with a plasma volume. Also, already installed diagnostic ports have small inner diameters to provide wide fan of primary and secondary ion beams across them. 3D nature of ions trajectories diminishes the HIBP measurement area and complicates the beam pass through the installation.

Determination of position and size of studied area in the plasma is possible only by a computational way. First, the magnetic field was calculated for a special 3-dimensional grid that covers some of the stellarator working volume. The resulting magnetic field from all magnetic elements of WEGA stellarator was used for a calculation of primary and secondary ions' trajectories.

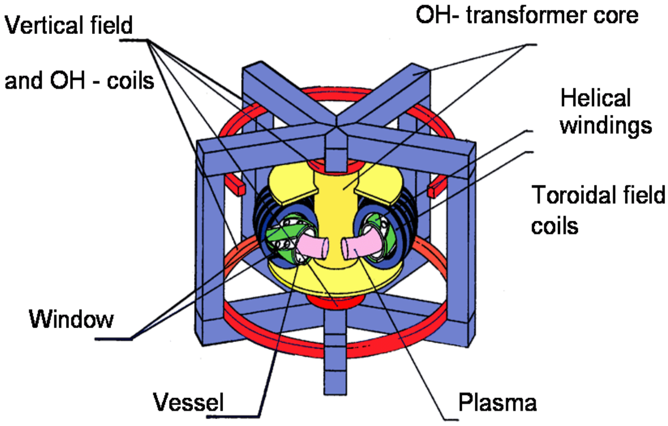

*Fig.1. WEGA stellarator · **L** = 2, **m** = 5, · R=72 cm, **a** = 19 cm, **B (0)** up to 0.5 T*

The system of equations for particles motion in electromagnetic field was solved by the Runge-Kutta method with certain accuracy:

$$\frac{\partial v_y}{\partial t} = \frac{q}{m}\left[-v_x H_z + v_z H_x\right] + \frac{q}{m}E_y ,$$

$$\frac{\partial v_x}{\partial t} = \frac{q}{m}\left[v_y H_z - v_z H_y\right] + \frac{q}{m}E_x ,$$

$$\frac{\partial v_z}{\partial t} = \frac{q}{m}\left[v_x H_y - v_y H_x\right] + \frac{q}{m}E_z ,$$

Many variants of injector and detector placement were analyzed using different installation positions and angles in order to comply the HIBP diagnostics with existing WEGA stellarator equipment.

The trajectory optimization aiming for the maximal plasma observation was done for chosen port combinations.

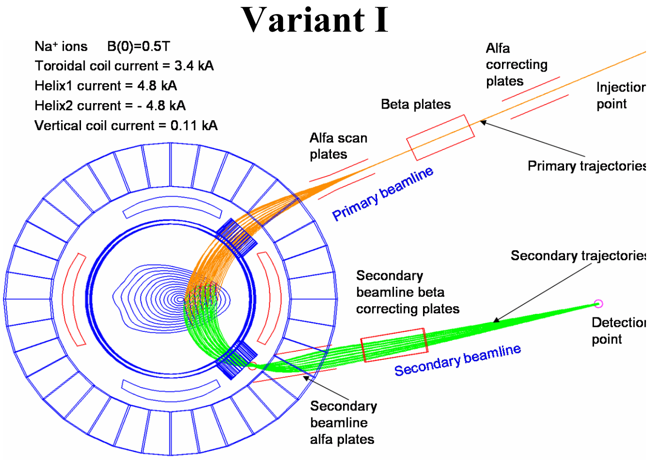

Fig.2. WEGA HIBP diagnostics scheme (XY plane)

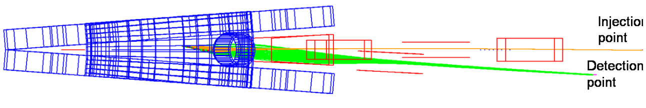

Fig.3. WEGA HIBP diagnostics scheme (XZ plane)

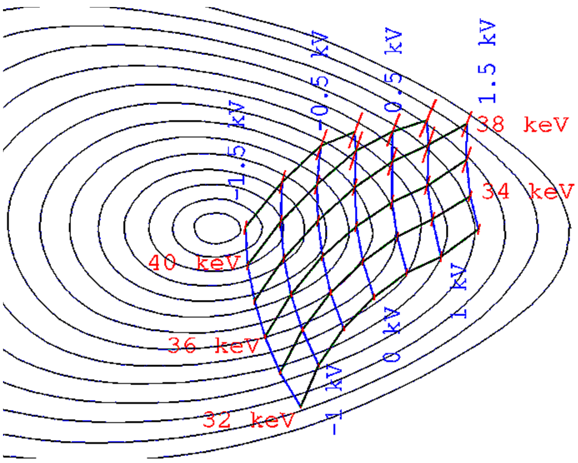

Fig.4. Detector grid

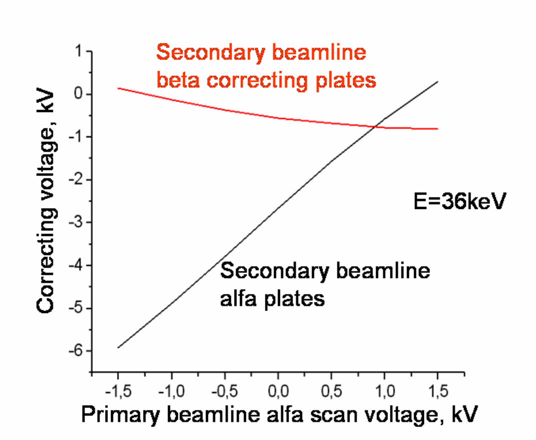

Fig.5. Control voltages for the constant energy detector line E=36 keV

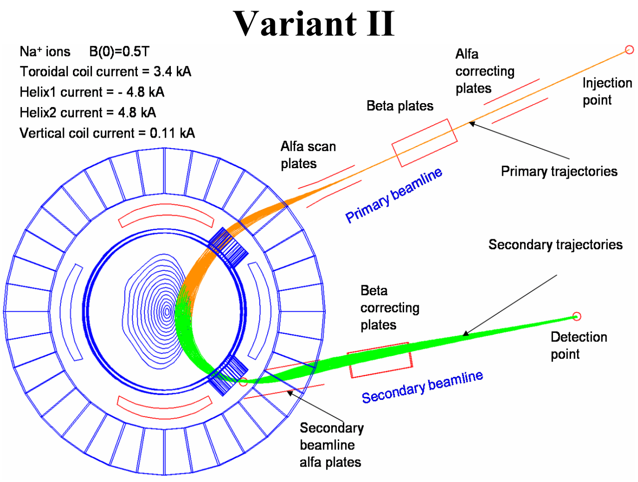

Fig.6. WEGA HIBP diagnostics scheme (XY plane)

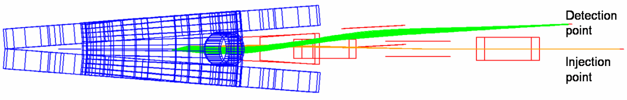

Fig.7. WEGA HIBP diagnostics scheme (XZ plane)

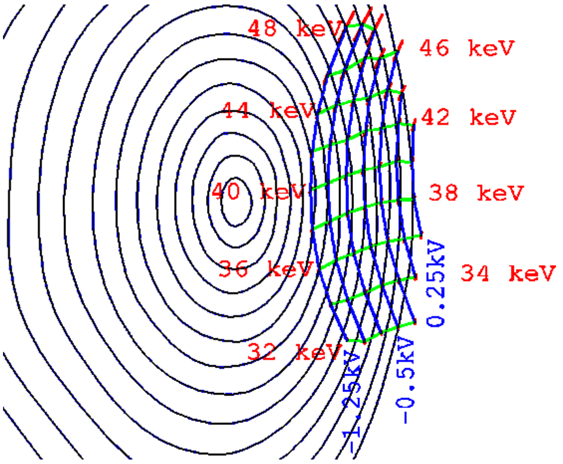

Fig.8. Detector grid

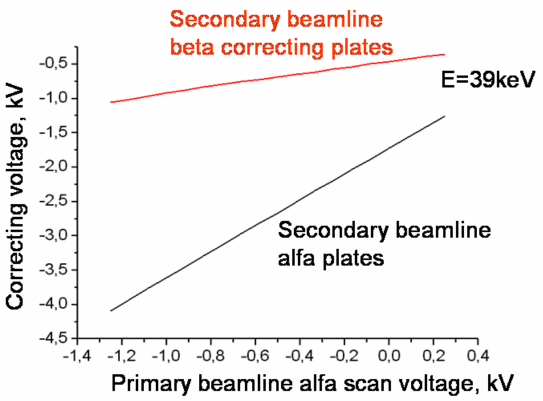

Fig.9. Control voltages for the constant energy detector line E=39 keV

The special beam-lines for the primary and the secondary ions are necessary to transfer the particles from the accelerator to plasma through the area of magnetic field and further to ion energy analyzer. They are also necessary to control the beam trajectory and drive it to energy analyzer with optimized entrance angles. Such electrostatic control looks to be the necessary elements of the HIBP hardware for stellarator like WEGA.

2. RESULTS

The calculations of the trajectories were made using singly charged sodium (Na^+) primary ions in the energy range of 30-60 keV.

WEGA HIBP project will use entrance port C+ for an injection of primary ion beam and exit port C- for a detection of the secondary ions beams, coming out of the plasma. These ports are placed on a toroidal angle $\varphi = 54^o$ and are perpendicular to each other. Two variants of HIBP diagnostic for different direction of helical coil current were calculated, as it can be easily changed. In the first variant plasma have "horizontal" shape, when $I_{helix1} > 0$ and $I_{helix2} < 0$. In the second variant plasma have "vertical" shape, when $I_{helix1} < 0$ and $I_{helix2} > 0$.

Detector grid calculated in the 1st variant covers quite large area of the plasma. It is possible to get the plasma potential profile by fast voltage scan system in the range of $0.1<\rho<0.7$. But in this case the size of a sample volume on the periphery is rather large, thus the spatial resolution of plasma potential measurements in this region will be low (about 1,5-2 cm for a detector with 4 mm entrance slit).

Increasing of the sample volume size on the periphery is quite good because of it helps to maintain the secondary ion current as the density on the periphery of plasma is lower than that in the central area. These variants are differing only in beta placement of secondary beam-line, which can be built on flexible sockets (bellows) to make using the both of these variants possible.

Five pairs of electrostatic deflection plates of primary and secondary beam-lines were used in calculation for scanning and correcting the beam motion. The necessary control voltages on the plates were also calculated.

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CONCLUSIONS

The applicability of the HIBP for the WEGA stellarator is described in this article. It is possible to use such diagnostics for a local plasma parameters measurement. The necessary voltages on the primary ion beam accelerator, energy analyzer and deflecting plates are acceptable. The WEGA HIBP will be consists of a 100 keV sodium ions accelerator, 30° Proca-Green electrostatic analyzer, primary and secondary beam-lines, special equipment for a signal detection and for an active beam control.

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ВОЗМОЖНОСТЬ ПРИМЕНЕНИЯ СИСТЕМЫ ЗОНДИРОВАНИЯ ПУЧКОМ ТЯЖЕЛЫХ ИОНОВ (HIBP) ДЛЯ СТЕЛЛАРАТОРА WEGA

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В статье описана возможность применения HIBP диагностики для стелларатора WEGA. Возможно применения этой диагностики для локальных измерений параметров плазмы. Проведены расчеты траекторий пучка ионов натрия для магнитной конфигурации WEGA с **Bo** = 0.5 T. Проведена оптимизация траекторий с целью получения максимально возможной области наблюдения плазмы при данной комбинации входного и выходного портов. Расчеты показывают возможность получения радиальных профилей параметров плазмы с помощью HIBP диагностики. Детекторная линия для постоянного угла входа касается центральной области и периферии плазмы при энергии пучка **E** =30-60 keV. Детекторная линия для постоянной энергии **E** = 40 keV позволяет получить серию радиальных профилей за один разряд при изменении входного угла с помощью сканирования пучка управляющим напряжением.

МОЖЛИВІСТЬ ЗАСТОСУВАННЯ СИСТЕМИ ЗОНДУВАННЯ ПУЧКОМ ВАЖКИХ ІОНІВ (HIBP) ДЛЯ СТЕЛАРАТОРА WEGA

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У статті описана можливість застосування HIBP діагностики для стеларатора WEGA. Можливе застосування цієї діагностики для локального вимірювання параметрів плазми. Проведені розрахунки траєкторій пучка іонів натрію для магнітної конфігурації WEGA з **Bo** = 0.5 T. Проведено оптимізацію траєкторій з метою одержання максимально можливої області спостерігання плазми для даної комбінації вхідного та вихідного портів. Розрахунки показують можливість одержання радіальних профілів параметрів плазми за допомогою HIBP діагностики. Детекторна лінія для постійного кута входу торкается центральної області та периферії плазми при енергії пучка **E** =30-60 keV. Детекторна лінія для постійної енергії **E** = 40

keV дозволяє одержати серію радіальних профілів за один постріл при зміні вхідного кута за допомогою сканування пучка керуючою напругою.