HIBP DIAGNOSTIC FOR URAGAN-2M STELLARATOR

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The project of the Heavy Ion Beam Probe (HIBP) plasma diagnostic system for stellarator Uragan-2M is presented. The device Uragan-2M is the flexible torsatron machine with small helical ripples and considerably high size and magnitude of the magnetic field (R = 170 cm, ape = 22 , B0 = 0.8…2.4 T, l = 2, m = 4). Necessary calculations by using the computer code made in HIBP group to optimize HIBP diagnostic set for stellarator Uragan-2M.

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1. INTRODUCTION

The Heavy Ion Beam Probing (HIBP) diagnostics is known as a unique tool for the direct contactless measurements of plasma electric field potential. Its ability to measure plasma density, temperature and plasma current profile distribution 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 point of the plasma potential measurements. Position and size of the sample volume are determined by calculation of the trajectories of probing particles.

The project of the HIBP plasma diagnostic system for stellarator Uragan-2M is presented in this work.

Heavy ion beam probe (HIBP) diagnostic is the most attractive of non-contacting methods, which are not influencing on the plasma parameters and allows to obtain information about space distribution of the plasma electric potential φ, plasma density ne, electron temperature Te and poloidal magnetic field Bθ (or axial current) in the plasma bulk. This method is based on the changing of the primary ion beam parameters (charge, intensity and pathway) when it goes through a plasma volume because of collisions with electrons (mostly) and interaction with a confining magnetic field.

Necessary calculations with using the computer code was made in order to optimize HIBP diagnostic set for stellerator Uragan-2M.

2. CALCULATIONS

There are physical limitations of HIBP measurements for all plasma cross-section consisting in that the ions' Larmor radius should be larger than radius of magnetic field confined 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 investigated area in plasma.

The device Uragan-2M (Fig. 1) was constructed about 1991. It is the flexible torsatron with small helical ripples and considerably high parameters (R = 170 cm, ape = 22 cm, B0 = 0,8…2.4 T, l = 2, m = 4). It was put to operation at the end of 2006.

First calculations for HIBP applications were made at the end of 1980-th [1]. Calculations by modern computer code was made in order to optimize HIBP diagnostic set for stellerator Uragan-2M. 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 Uragan-2M stellarator was used for a calculation of primary and secondary ions' trajectories.

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

Many variants of injector and detector placement were analyzed using different installation positions and angles in order to comply the HIBP diagnostics with existing Uragan-2M stellarator equipment.

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

The special beam-lines for the primaries and the secondaries 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 them to energy analyzer with optimized entrance angle. Such electrostatic control looks to be the necessary elements of the HIBP hardware for stellarators like Uragan-2M.

The calculations of the trajectories were made for singly charged cesium and thallium (Cs^+ and Tl^+) primary ions in the energy range from 150 to 950 keV. Uragan-2M HIBP project uses entrance port 12 for an injection of primary ion beam inside the plasma vessel and exit port 15 for a detection of the secondary ions beams, coming out from the plasma. These ports are placed on a toroidal angle $\varphi = 54^o$ and are almost opposite to each other (Fig.2). Two variants of HIBP diagnostic for different magnetic field values were calculated. At the first stage of the stellarator's operation the Uragan-2M toroidal magnetic field will be 0.8 T (Fig. 3), at the second stage – up to 2.4 T. Detector grid that was calculated for the first stage covers quite large area of the plasma (Fig. 4). It is possible to get the plasma potential profile by fast electrostatic deflection scanning system in the range of $0.1<\rho<1$ with the help of Tl^+ beam of

150 keV. For the second stage it will be necessary to increase the Tl+ beam energy up to 950 keV.

Six types of electrostatic deflection plates of primary and secondary beam-lines were used in calculation for scanning and correcting the beam motion.

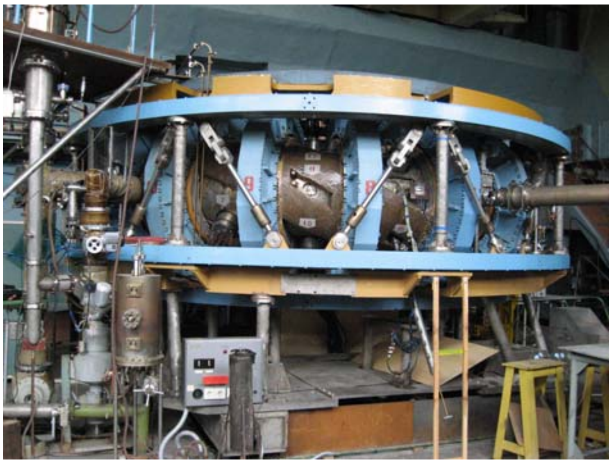
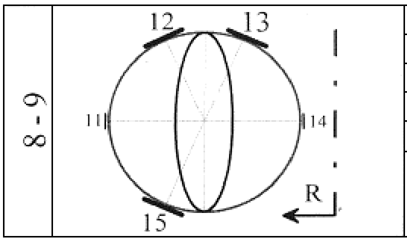


Fig. 1. Uragn-2M device.
Large radius R=1.7 m, averaged plasma radius – ape = 22 , toroidal magnetic field – B0 ≤ 2.4 T



11	ϕ40
12	ϕ160
13	ϕ100
14	ϕ40
15	ϕ140

Fig.2. HIBP ports

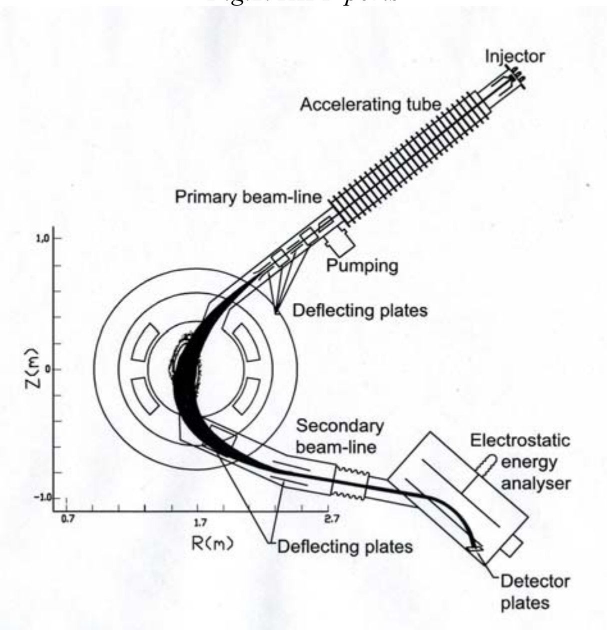


Fig.3. HIBP system for Uragan-2M stellarator

3. HIBP CONSTRUCTION

On the basis of trajectories calculations the diagnostic complex which consists from injector, diagnostic tube, primary and secondary beam-lines, the analyzer, has been developed. The high-voltage power supply has been developed for a feed of injector and an accelerating tube with a voltage up to 200 kV and a current 1 mA (Fig.5, 6). Industrial power supply IVN-100 (Fig. 7) (100 kV, 1 mA) is used for a feed of the analyzer.

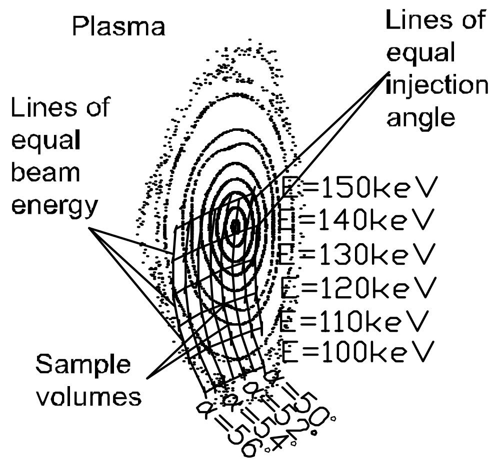


Fig. 4. Calculated detector grid for, B_0 = 0.8 T, E_{beam} = 150 kV, Tl^+ ions

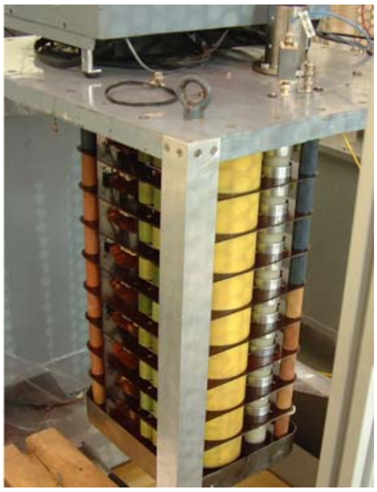


Fig. 5. 200 kV, 1 mA power supply

Fig. 6. Power supply control unit

4. VACUUM TEST-DEVICE

Vacuum stand "HIBP-U-2M" is created for carrying out of adjustment and tests of the diagnostic complex (Fig. 8). The stand represents the vacuum chamber (a breadboard model of 1/9 parts of the stellarator toroidal vacuum chamber) with measurement, control and vacuum systems.

Fig. 7. IVN-100 power supply (100 кV, 1 mA)

Fig. 8. Vacuum stand construction

5. CONCLUSIONS

The applicability of the HIBP for the Uragan-2M stellarator is described. It is possible to use such diagnostics for local plasma electric field potential measurements. The necessary voltages on the primary ion beam accelerator, energy analyzer and deflecting plates are acceptable. The Uragan-2M HIBP system will be consists of two main parts. The first of them is the injector of the accelerated probing beam, consists of:

- Cs^+ or Tl^+ ion source with ion current up to 500 μA;
- accelerator tube up to 1 MeV with extractor and focusing systems;
- primary beam-line.

The second part of the HIBP system is detection hardware for secondary ions registration. It includes:

- traditional energy parallel plate analyzer up to 200keV;
- multi cell array detector;
- secondary beam-line.

These diagnostic system components were used in particular, in HIBP system of TJ-II stellarator [2]. The energy beam operation at the first stage of HIBP operations at Uragan-2M stellarator will be with up to 150keV energy beams, at the second stage – up to 900 keV. All parts of diagnostic set up should be tested on separate device and installed on stellarator.

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ЗППТИ ДИАГНОСТИКА ДЛЯ СТЕЛЛАРАТОРА УРАГАН-2М

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Представлен проект системы диагностики зондирования плазмы пучком тяжелых ионов (ЗППТИ) для стелларатора Ураган-2М. Установка Ураган-2М представляет собой гибкий торсатрон с малыми геликоидальными гофрами, с большими размерами и величиной магнитного поля (R = 170 см, аре = 22 см, B0 = 0.8...2.4 Т, l = 2, m = 4). С целью оптимизации параметров диагностического устройства для стелларатора Ураган-2М проведены расчеты с использованием компьютерных программ, разработанных в группе ЗППТИ-диагностики.

ЗППВІ ДІАГНОСТИКА ДЛЯ СТЕЛАРАТОРУ УРАГАН-2М

І.С. Бондаренко, О.О. Чмига, Г.М. Дешко, О.О. Комаров, О.С. Козачек, Л.І. Крупнік, С.М. Хребтов, О.І. Жежера

Представлено проект системи діагностики зондування плазми пучком важких іонів (ЗППВІ) для стеларатора Ураган-2М. Установка Ураган-2М являє собою гнучкий торсатрон з малими гелікоїдальними гофрами, з великими розмірами й величиною магнітного поля (R = 170 см, аре = 22 см, B0 = 0.8...2.4 Т, l = 2, m = 4). З метою оптимізації параметрів діагностичного пристрою для стеларатора Ураган-2М проведено розрахунки з використанням комп'ютерних програм, які були розроблені групою ЗППВІ- діагностики.