THE FIRST OPERATION OF THE HEAVY ION BEAM PROBING DIAGNOSTIC (HIBP) ON THE URAGAN-2M TORSATRON

A.I. Zhezhera, A.A. Chmyga, G.N. Deshko, L.I. Krupnik, A.S. Kozachek, A.D. Komarov, S.M. Khrebtov, S.M. Maznichenko, Yu.I. Tashchev, G.G. Lesnyakov, I.K. Tarasov, S.V. Perfilov[1]

Institute of Plasma Physics of the NSC KIPT, Kharkov, Ukraine
[1]*Institute of Tokamak Physics, NRC Kurchatov Institute, Moscow, Russia*

The Heavy Ion Beam Probing (HIBP) diagnostic system has been installed and operates now on the Uragan-2M torsatron for the first time in Ukraine. The cesium ion beam with energy range of 17…120 keV and ion current of 10…150 μA was used in the first experiments for tracing the probing beam through torsatron magnetic field (0.39…0.4 T). The secondary ion beam with intensity in the range of 30…100 nA was detected on the first deflecting plate of the secondary beam-line according to preliminary calculations by using 80 keV primary beam energy and 100 μA of primary ion current. The primary beam with energy range of 17…20 keV (I_{beam}≈10 μA) was traced through torsatron magnetic field towards the analyzer detection plates.

PACS: 52.70.Nc.

INTRODUCTION

This paper presents the Heavy Ion Beam Probing (HIBP) diagnostic system for torsatron Uragan-2M, its capabilities for the plasma parameters measurements and the first experiments for tracing cesium probing ion beam through torsatron magnetic field.

Uragan-2M is the flexible torsatron with small helical ripples and considerably high parameters (R_0=170 cm, <a>=22 cm; B_0 = (0.8…2.4) T; l=2, m=4). It was put to operation at the end of 2006.

The direct measurements of the electric potential and its oscillatory component in the core plasma are of primary importance for understanding the role of the radial electric field E_r in confinement improvement mechanisms [1, 2]. Heavy Ion Beam Probe (HIBP) is a unique diagnostic to study directly plasma electric potential and turbulence characteristics in toroidal plasmas from the core to the edge [3]. It can give also the information about space distributions (profiles) of plasma density n_e, electron temperature T_e and poloidal magnetic field B_θ (or the axial plasma current). HIBP is used in a number of existing devices with magnetic plasma confinement to study the plasma parameters with high spatial (<1 cm) and temporal (1 μs) resolution. This method is based on the change of probing ion beam parameters (charge, intensity and pathway).

At the beginning of this diagnostic project the necessary numerical calculations were performed in order to optimize the diagnostic systems placement on Uragan-2M torsatron. Trajectories of the probing heavy Tl^+ and Cs^+ beams were calculated for the various diagnostics ports and for the two values of the confinement magnetic field: B_0=0.4…0.8 T (first stage of the device operation) and 2.4 T (the second one). The covered measurable radial range is 0.1<r/a<1. Necessary energy range of the probing beam is 70…950 keV. The Uragan-2M torsatron operates now with confinement magnetic field values 0.39…0.5 T, so the necessary Cs^+ primary beam energies are 70…90 keV. The calculated detector grid for magnetic field strength 0.8 T and by using of Tl^+ as primary beam ions is shown on Fig. 1. According to the numerical trajectories calculations to trace the primary probing beam through existing magnetic field towards energy analyzer it is necessary to use Cs^+ beam with energies 17…20 keV.

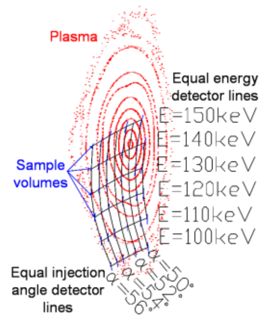

Fig. 1. Calculated detector grid for B_0=0.8 T, E_{beam}=150 keV, Tl^+ probing beam

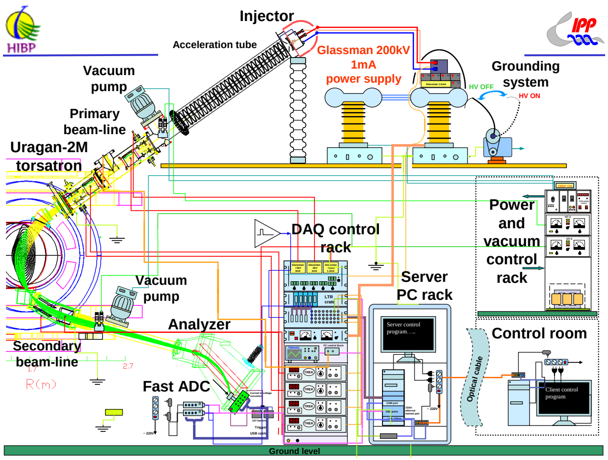

Fig. 2. Schematics of the HIBP diagnostics system for Uragan-2M

1. URAGAN-2M HIBP DIAGNOSTIC SYSTEM

Diagnostic system includes: - Primary ion beam injector with Cs^+ or Tl^+ ion source capable to produce ion current up to 200 μA, accelerating tube up to 1 MV with extractor and focusing systems.

- Primary beam-line with two electrostatic deflecting plates units, ion beam current (Faraday cup) and profile (wire grid) detectors.

- Detecting system for secondary ion beam which consists of the secondary beam-line with electrostatic deflecting plates used for beam correction towards the detector entrance aperture. The traditional 30^0 electrostatic energy analyzer with parallel deflecting plates (Proca-Green analyzer) used as a detector.

- Vacuum pumping and vacuum measurement systems.

- Electrical HIBP components power supplies system with necessary output parameters (voltage, current, stability, level of ripples, rise time, etc).

- Computer systems for probing beam control, data acquisition system and data processing, Fig. 2.

Primary ion beam injector based on the solid-state thermo-ion emitters of alkali ions (from Li to Tl). These emitters were developed and manufactured in IPP NSC KIPT. Cs^+ ion emitter was used for these experiments. Typically probing ion beam parameters shown on Fig. 3.

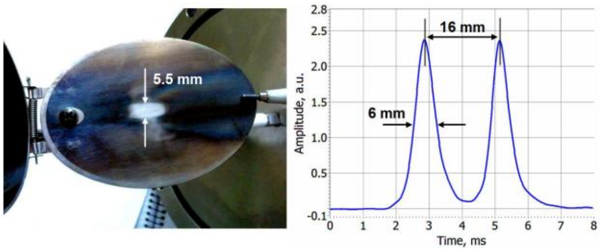

Fig. 3. The footprint of the primary ion beam on the movable collector cover of the Faraday cup after test-bench experiments (left). Ion beam space profile distribution at the distance 3.5 m from emitter (right), E_{beam}*=90 keV;* U_{focus}*=3.5 kV;* I_{beam}*=160 μA*

Our HIBP team has designed, developed and installed injector system capable for producing ion beam current up up 200 μA with diameter less than 6 mm at distances from emitter for point measurements in the area inside torsatron plasma. This was done by implementing of precise adjustments of potential distribution along the accelerator tube according to prior SIMION 3D numerical calculations and test-bench experiments with several beam diameter detectors installed along the primary beam trajectory and by using of HV separated remote extracting voltage control.

The measurements of secondary (double charged) ion beam current and energy originating from the interaction of the primary probing ion with plasma are carried out by means of the traditional 30^0 electrostatic energy analyzer with two entrance slits. This double-slit analyzer design allows obtaining information of plasma potential from two separated plasma sample volumes simultaneously, so direct information about local value of the radial plasma electric field with spatial resolution approximately 1 cm and its fluctuation can be obtained. The plasma potential in the ionization point is measured as a difference between the primary and secondary beams energies; the local plasma density is proportional to the total secondary ion beam current to the all analyzer detector plates.

The HIBP diagnostic system is now installed on the Uragan-2M torsatron, Fig. 4. The ion beam injector operated with Cs^+ ion beam energies 17…120 keV and ion currents 10…200 μA.

In order to rotating the analyzer around the secondary beam-line axis, which is important as the secondary beam fan according to the trajectories calculations is inclined to the horizontal axis (about 30^0), the analyzer is supplied with rotation system for turning of the analyzer around a longitudinal axis, Fig. 5.

Fig. 4. General view of HIBP system at Uragan-2M torsatron with beam control and data acquisition system (left).Upper platform with primary beam injector, power supply +200 kV, emitter heating and extractor power supplies system, grounding system (right)

The previous experiments carried out by different HIBP diagnostics on stellarator TJ-II and on tokamak T-10 showed that this rotation system can significantly reduce the measurement errors especially for double or multi-slit analyzer designs.

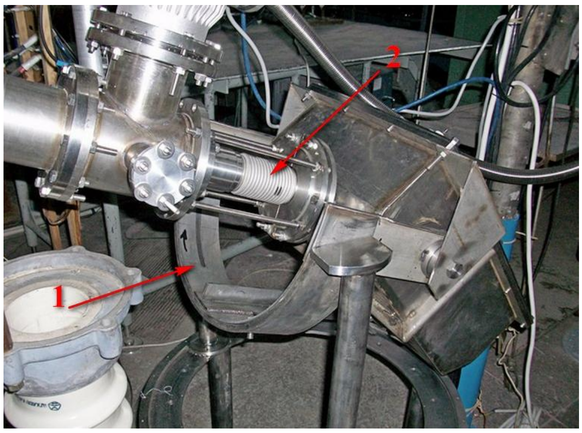

Fig. 5. The electrostatic analyzer of a secondary ion beam is supplied with system for turning the analyzer round a longitudinal axis 1 – turning mechanism; 2 – rotating below

The data acquisition and control systems of HIBP diagnostics for the Uragan-2M (see Fig. 2) are based basically on “L-Card” company modules and PC DAQ cards. Due to fast (2.5MSPS) operation of the ADC and also by using our self-developed low noise broadband current to voltage converters for the detector plates. It gives a possibility to study the fluctuations of potential and electric field at frequencies up to 1MHz.

To operate on U2-M with HIBP diagnostic the special control and data acquisition programs were made using NI Labview 2011 program package together with the standard software for DAQ equipment

(LGraph2, etc). Control programs allow to manage and to monitor all the necessary parameters of the diagnostics during experiment. These programs include slow signal control and acquisition part which is used to obtain primary beam with required parameters before plasma shot (energy, intensity and focusing), active beam control part, which is used to operate HV amplifiers (TREKs) that control electrostatic deflection plates during plasma shot in order to direct the primary beam in a certain plasma volume and to target secondary beam into analyzer as well as to provide radial scanning of the beam in the plasma. Also, this program software is used for visualizing and for processing of the obtained data during experiment which is very helpful to provide feedback and necessary corrections to the active beam control system in order to get a proper secondary signal in the subsequent Uragan-2M shots.

2. EXPERIMENTAL RESULTS

In the first experiments for Cs^+ ion beam transportation through torsatron magnetic field (B_0=0.4 T) it was found an unexpected large horizontal shift of primary ion beam (rightwards) before the entrance of the torsatron port during magnetic field pulse. This was a result of the stray vertical magnetic field influence on the injector-extractor unit, where the energies of the beam are small. This effect leads to cutting the bulk of primary ion beam by beam-line apertures. Afterwards this effect was omitted by reconstruction the position of the right vertical (beta 1) deflection plate and enlarging the horizontal dimension of previous aperture from 33 to 45 mm. Also, the proper experiments showed that it is necessary to apply correction to the beam position by both beta 1 and beta 2 plates of the primary beam-line during magnetic field pulse. Later, this correction for beam transportation towards torsatron chamber and detection the secondary and primary ion beams to the first deflecting plates of the secondary beam-line acting as a beam detectors (bottom alpha 3 and right beta 3), Fig. 6. The ionization of probing ion beam was done by interaction with neutral hydrogen. The residual gas pressure in torsatron chamber was 9×10^{-5} Torr. The measured secondary ion current on the alpha 3 plate was in the range of 20…100 nA using 100 μA of the primary beam current, beam energy E_{beam}=70…80 keV, torsatron magnetic field B_0=0.39 T (Fig. 7).

In order to prove a possibility of ion beam transportation through the secondary beam-line with a rather narrow coupling tube to analyzer entrance slits the primary ion beam with energy range of 17…18 keV was used according to previous numerical trajectories calculations. The beam current was 10…12 μA. This primary (single charged) beam was detected practically without losses on the alpha 3 plate, Fig. 8.

Then the primary beam was traced to the analyzer deflecting plate (used as a beam collector plate) through analyzer entrance slits by applying of correcting voltages to the primary and secondary beam-lines deflecting plates, Fig. 9.

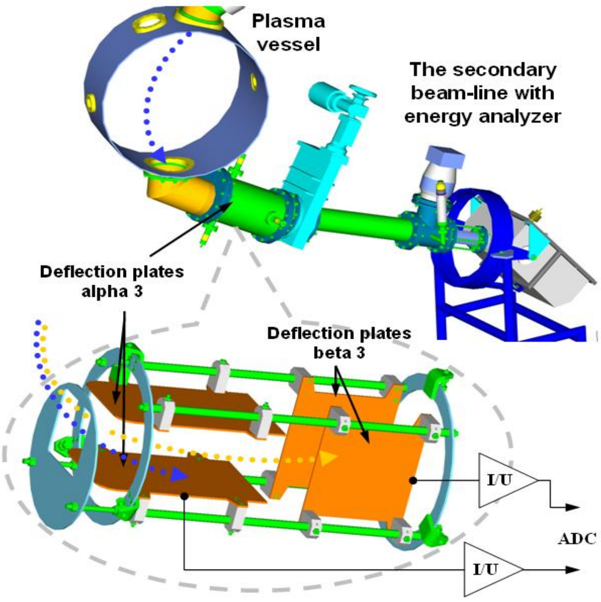

Fig. 6. Secondary beam-line deflecting plates

The hard X-ray radiation was detected during rising and falling of the torsatron magnetic field due to runaway electrons flow formation. It is considered that the source of additional electrons was the secondary electron emission during the interaction between HIBP probing beam with the torsatron constructive elements. This effect was also detected at TJ-II stellarator [4].

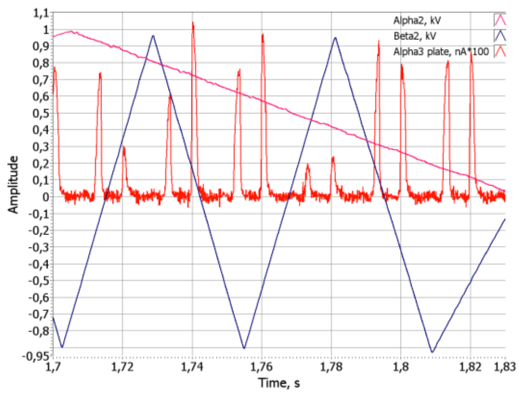

Fig. 7. The secondary beam signals to alpha 3 plate and sweeping voltages of primary beam-line plates

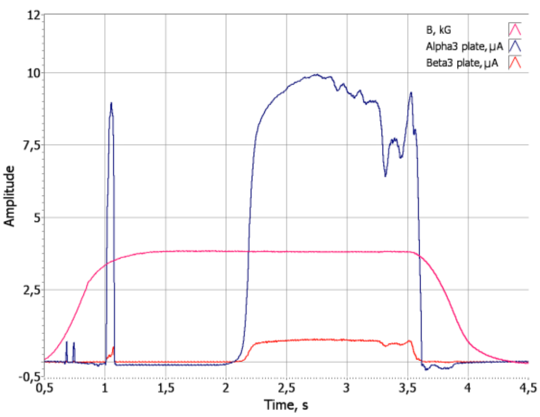

Fig. 8. The primary (single charged) beam signals detected on the alpha 3 and beta 3 plates and the magnetic field value

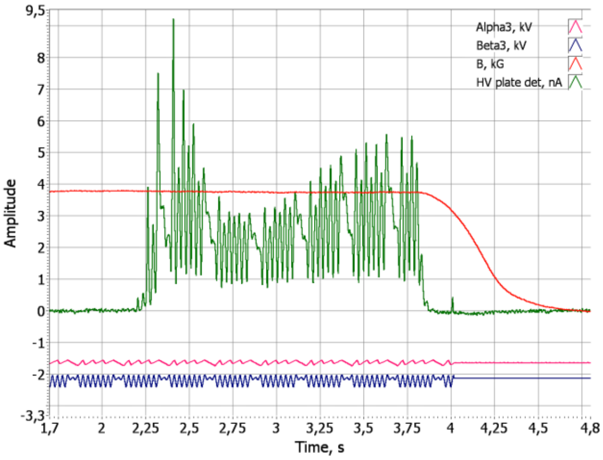

Fig. 9. The primary beam signal from analyzer deflecting plate

CONCLUSIONS

The Heavy Ion Beam Probing (HIBP) diagnostic system operates now at the Uragan-2M torsatron for the first time in Ukraine. The possibility of primary and secondary probing beams tracing trough Uragan-2M magnetic field towards the energy analyzer according to previous calculations was shown.

ACKNOWLEDGEMENTS

This work was supported by STCU Project #4703.

REFERENCES

1. I.S Bondarenko et al. The First Operation of the Advanced Heavy Ion Beam Probing Diagnostic (HIBP) on the TJ-II Flexible Heliac *// Fusion Engineering and Design*. 2001, v. 56-57, p. 935-939.
2. I.S. Bondarenko et al. Heavy ion beam injection systems for fusion plasma diagnostics // *Rev. Sci. Instrum.* 2004, v. 75, p. 1835-1837.
3. A. Melnikov et al. Plasma potential formation under the edge polarization // *29th EPS Conference on Plasma Phys. and Contr. Fusion*, Montreux, 17-21 June 2002 ECA. 2002, v. 26B, P-1.115 .
4. L. Rodríguez-Rodrigo et al. Runaway electrons control during ramp-up and ramp-down of the magnetic fields in the coils of the TJ-II flexible heliac // *Rev. Sci. Instrum.* 1999, v. 70, p. 645.

Article received 21.11.2014

ПЕРВЫЕ ЭКСПЕРИМЕНТЫ С ПОМОЩЬЮ ДИАГНОСТИЧЕСКОГО КОМПЛЕКСА ЗОНДИРОВАНИЯ ПЛАЗМЫ ПУЧКОМ ТЯЖЕЛЫХ ИОНОВ (ЗППТИ) НА ТОРСАТРОНЕ УРАГАН-2М

А.И. Жежера, А.А. Чмыга., Г.Н. Дешко, Л.И. Крупник, А.С. Козачек, А.Д. Комаров, С.М. Хребтов, С.М. Мазниченко, Ю.И. Тащев, Г.Г. Лесняков, И.К. Тарасов, С.В. Перфилов

.

Впервые в Украине введена в строй система диагностики плазмы с помощью пучка тяжелых ионов на торсатроне Ураган-2М. В первых экспериментах по проведению зондирующего пучка через магнитное поле торсатрона (0,39…0,4 Тл) использовался первичный пучок ионов цезия с энергией 17…120 кэВ и током 10…150 мкА. В соответствии с ранее проведенными расчетами осуществлена регистрация двукратного ионизованного пучка ионов цезия на первую отклоняющую пластину вторичного ионопровода (ток 30…100 нА) при энергии первичного пучка 70…80 кэВ и токе 100 мкА. Осуществлено проведение первичного пучка с энергией 17…20 кэВ (ток 10 мкА) через магнитное поле торсатрона до детекторных пластин анализатора.

ПЕРШІ ЕКСПЕРИМЕНТИ ЗА ДОПОМОГОЮ ДІАГНОСТИЧНОГО КОМПЛЕКСУ ЗОНДУВАННЯ ПЛАЗМИ ПУЧКОМ ВАЖКИХ ІОНІВ (ЗППВІ) НА ТОРСАТРОНІ УРАГАН-2М

О.І. Жежера, О.О. Чмига, Г.М. Дешко, Л.І. Крупнік, О.С. Козачок, О.Д. Комаров, С.М. Хребтов, С.М. Мазніченко, Ю.І. Тащев, Г.Г. Лєсняков, І.К. Тарасов, С.В. Перфілов

Вперше в Україні введено в дію систему діагностики плазми за допомогою пучка важких іонів на торсатроні Ураган-2М. У перших експериментах з проведення зондувального пучка крізь магнітне поле торсатрона (0,39… 0,4 Т) застосовано первинний пучок іонів цезію з енергією 17…120 кеВ та струмом 10…150 мкА. Згідно з попередніми розрахунками проведено реєстрацію вторинного пучка на першу пластину, яка відхиляє іони у вторинному іонопроводі (струм 30…100 нА) а енергії первинного пучка 70…80 кеВ та струму іонів 100 мкА. Здійснено проведення первинного пучка з енергією 17…20 кеВ (струм 10 мкА) крізь магнітне поле торсатрона до детекторних пластин аналізатора.