HIBP DIAGNOSTIC INJECTORS FOR URAGAN - 2M AND TJ-II STELLARATORS

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The testing and first operations of the Heavy Ion Beam Probe (HIBP) plasma diagnostic injectors for stellarator Uragan-2M and TJ-II is presented in this work. The increasing of plasma density in modern fusion devices up to $(3...7)\times10^{19}\,m^{-3}$ (TJ-II and T-10) leads to huge probing ion beam absorption in central plasma area. One way to obtain the HIBP information from plasma centre is the increasing of primary ion beam current. A new modification of HIBP injectors for TJ-II and Uragan 2M stellarators was developed and tested in IPP NSC KIPT with energy up to 100 keV and ion current up to 300 µA.
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INTRODUCTION

The Heavy Ion Beam Probing (HIBP) diagnostics is known as a unique tool for the direct contact less measurements of plasma electric field potential [1-3]. Its ability to measure plasma density, temperature and plasma current profile distribution is well known also. 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. The collisions of primary and secondary probing ions with plasma electrons also lead to their absorption in areas of large plasma density. Fig. 1 illustrated this process in TJ-II stellarator. The total current to analyzer detector plates (black lines) and average plasma density (red) are presented at Fig. 1 for primary beam current of 58 µA. One can see the 5–6 times decreasing of total secondary ion current value from central plasma area (grey liners) with average plasma density increasing from 1 to $2{,}5\times10^{19}m^{-3}$.

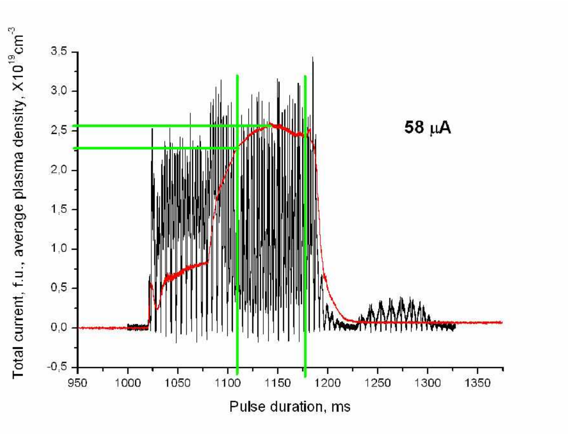

Fig. 1. Total detector current and plasma density values for primary ion beam current of 58 µA

So it is necessary to increase the primary ion probing current in 5–6 times or more for better secondary beam detecting.

NEW MODIFICATION OF HIBP INJECTOR

In order of primary ion current increasing a new HIBP accelerator was developed in IPP NSC KIPT. This accelerator has a three-electrode lens for primary ion beam focusing before entrance to sections of accelerating tube. Extracting electrode was done flat, not conical, as usually in these systems. This lens design showed at Fig. 2.

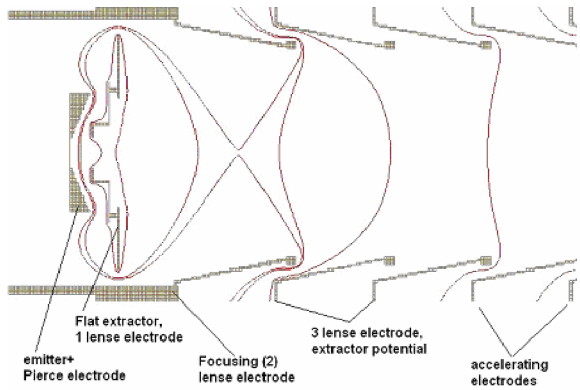

Fig. 2. Three-electrode lens for primary ion beam focusing

This addition lens permits us to increase the extracting voltage and extracting ion current comparatively to previous accelerator designs [3] from 100 to 300 µA. The focusing electrode potential is equal to emitter potential in this system and focusing distance may be controlled by extracting potential value. In order to have the remote control of extracting voltage and ion beam focusing distance we applied extracting voltage control system. This system based on MJ10N1500 Glassman power supply ((-10) kV; 1,5 mA) for extracting voltage producing. This power supply placed under accelerating high voltage and is feeding from (+36) V batteries. This system allows controlling extracting voltage and focusing distance for ion beam current values from 10 to 300 µA and from 2 to 4 m. New injector system was tested in IPP NSC KIPT, for beam energy up to 110 keV. Test results are shown at Figs. 3–5. Fig. 3 presented the dependence of ion beam current on beam energy (accelerating voltage) with fixed thermo-ion emitter temperature.

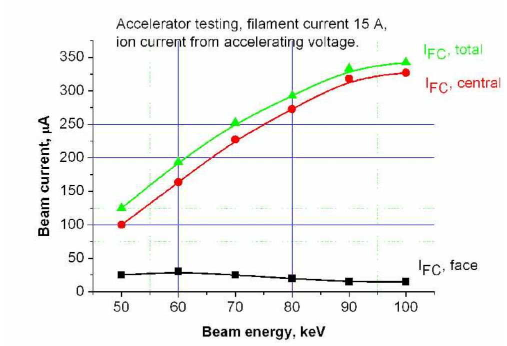

Fig. 3. Ion beam current dependence on accelerating voltage

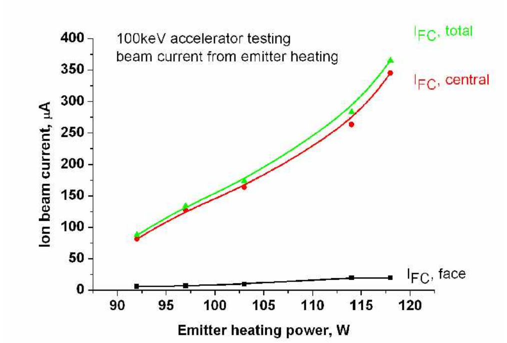

Fig. 4. Ion beam current dependence on emitter heating power. Ion beam energy is 100 keV

At Fig. 4 one can see the dependence of ion beam current on emitter heating power (emitter temperature) for 100 kV accelerating voltage. These measurements were done by Faraday cup at the distance of 2 m from emitter. Fig. 5 illustrated ion beam profiles at various distances from emitter. Ion beam profiles were detected by two wire detectors placed at 2 and 3,5 m from ion emitter and collector with suppressed secondary electron emission placed at 3,5 m. This collector has also a thermocouple for measurements of an input energy of ion beam. Ion beam current measurements by two independent methods give the same values. Beam profiles were obtained by beam sweeping across the detector wires. The distance between wires (and profile peaks) is 20 mm.

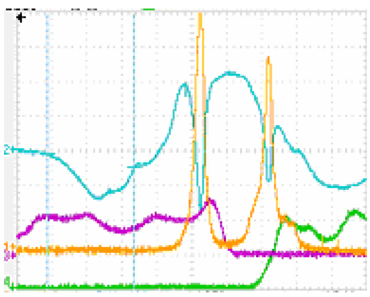

Fig. 5. Ion beam profiles. Faraday cup current (100 μA/div)- blue, ion beam profiles at 3,5 m – yellow, ion beam profiles at 2 m – red & green

New injector system is operating now at diagnostic injector of HIBP system of TJ-II stellarator in CIEMAT, Madrid, Spain during winter 2009 and spring-summer 2010. Operating primary ion beam current was increased up to 150 μA (Fig. 6).

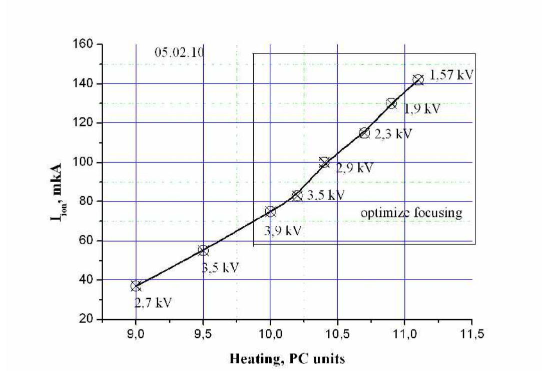

Fig. 6. Dependence of ion beam current to Faraday cup on emitter heating current

Fig. 7–9 shows total detector current, plasma density and electron temperature values for primary ion current 130 μA. These results were obtained at TJ-II stellarator during plasma heating by ECRH and NBI modes. NBI heating switches on at 1070 ms, the average plasma density increases and electron temperature is going down.

During NBI mode of plasma heating the central drop of density profile became deeper, but it may be clear detected by increased primary beam current. Fig. 10 shows total secondary ion beam current dependence on primary ion current. One can see a linear increasing of the secondary detector signal from central plasma with primary beam increasing. So, we have a hope of detecting central plasma area with 300 μA primary ion beam for higher average plasma density.

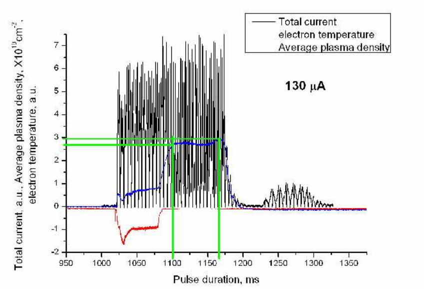

Fig. 7. Total detector current - (black), plasma density - (blue) and electron temperature - (red) values for primary ion current 130 μA

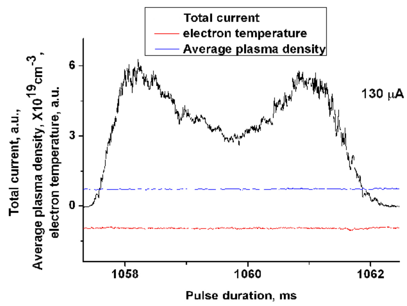

Fig. 8. Total detector current profile- (black), plasma density - (blue) and electron temperature - (red) values for low density (ECRH mode)

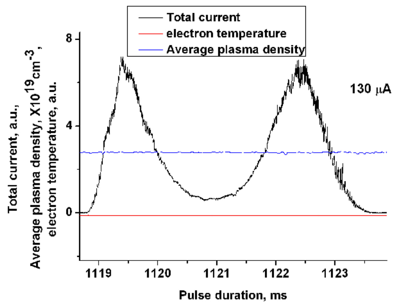

Fig. 9. Total detector current profile - (black), plasma density - (blue) and electron temperature - (red) values for high density (ECRH+NBI mode)

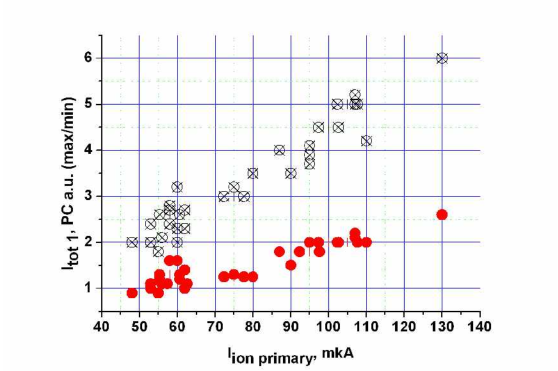

Fig. 10. Total secondary ion beam current depending on primary ion current. Red – central plasma area ρ~0,1, black – maximal current value at ρ~0,5, (ρ is plasma radius)

CONCLUSIONS

New heavy ion beam probe injector design was elaborated in IPP NSC KIPT. This injector was tested for cesium ion beam with energy up to 110 keV and ion current up to 300 µA in Kharkov, PPP-2 stand device, and 125 keV, 150 µA in Madrid, TJ-II stellarator. These testing show a possibility of detecting plasma parameters in the central plasma area by HIBP in high average plasma density conditions. These injectors will be installed in Kharkov to Uragan-2M stellarator and in Madrid to the second HIBP system of TJ-II stellarator.

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ДИАГНОСТИЧЕСКИЕ ЗППТИ-ИНЖЕКТОРЫ ДЛЯ СТЕЛЛАРАТОРОВ УРАГАН-2М и TJ-II

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Представлены конструкция и результаты испытаний инжекторов для зондирования плазмы стеллараторов Ураган-2М и TJ-2 пучком тяжелых ионов. Увеличение плотности плазмы в современных термоядерных установках до уровня (3...7)$\times10^{19}$ м$^{-3}$ (TJ-II и Т-10) ведет к сильному поглощению зондирующего пучка в центральных областях плазмы. В этом случае единственным путем к получению ЗППТИ (зондирования плазмы пучком тяжелых ионов)-информации из центра плазмы является увеличение интенсивности первичного зондирующего пучка. В ИФП ННЦ ХФТИ разработана новая модификация ЗППТИ-инжекторов для стеллараторов Ураган-2М и TJ-2 при энергиях ионов Cs^+ до 100 кэВ и токах пучка до 300 мкА.

ДІАГНОСТИЧНІ ЗППВІ-ІНЖЕКТОРИ ДЛЯ СТЕЛЛАРАТОРІВ УРАГАН-2М ТА TJ-II

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Представлено конструкцію та результати випробувань інжекторів для зондування плазми стеллараторів Ураган-2М та TJ-II пучком важких іонів. Збільшення щільності плазми у сучасних термоядерних пристроях до рівня (3...7)$\times10^{19}$ м$^{-3}$ (TJ-II и Т-10) веде до значного поглинання зондувального пучка у центральних областях плазми. У цьому разі єдиним шляхом до одержання ЗППВІ (зондування плазми пучком важких іонів) інформації з центру плазми є збільшення інтенсивності первинного зондувального пучка. У ІФП ННЦ ХФТІ була розроблена нова модифікація інжекторів для стеллараторів Ураган-2М та TJ-II при енергіях пучка іонів Cs^+ до 100 кеВ та струмах пучка до 300 мкА.