BEAM INJECTION SYSTEMS FOR THE HIBP PLASMA DIAGNOSTICS OF THE IPP NSC "KHARKOV INSTITUTE OF PHYSICS AND TECHNOLOGY"

I.S. Bondarenko, A.A. Chmyga, G.N. Deshko, N.B. Dreval, S.M. Khrebtov, A.D. Komarov, A.S. Kozachek, L.I. Krupnik
Institute of Plasma Physics, National Scientific Centre "Kharkov Institute of Physics and Technology", 61108 Kharkov, Ukraine
I.S. Nedzelskiy
Associação EURATOM/IST, Centro de Fusão Nuclear, Instituto Superior Técnico, 1049-001 Lisboa, Portugal

PACS: 52.70.Nc

1. INTRODUCTION

Among a lot of contactless methods the plasma corpuscular diagnostics one takes from leading places. With the help of plasma probing by ion and neutral beams it is possible to receive information about space distribution of a potential, density, plasma electron temperature, impurity ions and poloidal magnetic field (axial current) space distributions in plasma of modern fusion devices. Now we have two main directions of plasma corpuscular diagnostics – heavy ion beam probing (HIBP) [1] and light atomic beam probing diagnostic systems (BES) [2].

The heavy ion beam probing diagnostic systems allow obtaining information about the plasma potential space distribution, density, and electron temperature and plasma axial current distribution. This method is based on the heavy ion (Cs or Tl) beam injection in a plasma volume and the secondary ion beam current and energy registration usually by means of a 30^0 Proca–Green electrostatic energy analyzer. This diagnostics required high accuracy of primary and secondary ion beams energy measurements and high stability (not less than 10^{-5}) of ion beam energy, so the injector and analyzer power supplies voltage.

The easy neutral beam diagnostics based on Li or Na beam injection in plasma volume and registration a spectral characteristics of a probing beam radiation allows investigating plasma and impurity ions density space distribution in peripheral area of modern thermonuclear devices. This method has a potential possibility to measure poloidal and toroidal magnetic fields. This diagnostics required high intensity of the probing beam (up to 10 mA), but not so high stability of beam energy.

The corpuscular diagnostic systems consist of two main parts – an injector of a primary beam and analyzing device of a secondary signal from plasma. A main task of an injector, for all types of diagnostic complexes, is to supply a probing beam density in researched area of plasma sufficient for reliable registration of a secondary signal. The injector is also consists of two parts the emitter-extractor unit (ion source) and a shaping-focusing system.

2. EMITTER-EXTRACTOR UNIT AND SHAPING-FOCUSING SYSTEM

The emitter-extractor unit scheme is shown at Fig.1. This quasipierce emitter-extractor unit was elaborated in IPP NSC KIPT and is using now (with not significant modifications) in injectors of HIBP diagnostic complexes of modern fusion devices, such as TJ-II (CIEMAT, Spain), T-10 (RSC, Russia), TUMAN-3M (PhTI, Russia), ISTTOK (CFN/IST, Portugal), and in light neutral beam injector (BES) at ASDEX Upgrade tokamak, (IPP, Germany).

This design allows rather simple changing of the emitter (3) and heating filament (4).

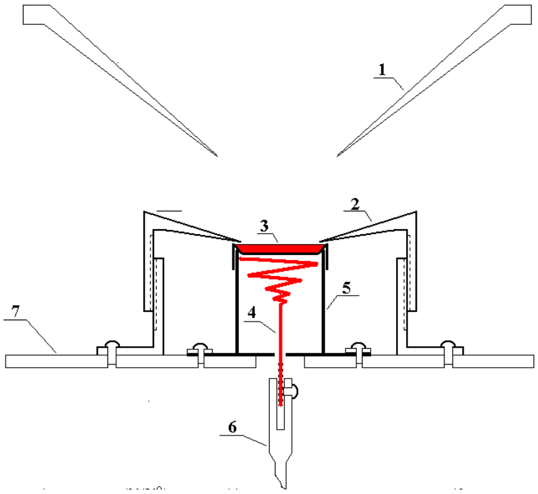

Fig.1. Ion injector emitter–extractor unit:

1. *Extractor electrode*
2. *Pierce electrode*
3. *Solid state thermo ionic emitter*
4. *Heating filament*
5. *Filament enclose*
6. *Filament holder*
7. *Emitter flange*

The calculations and experimental investigations of this unit shows, that in order to obtain maximum ion current, without ion current to the extractor, it’s necessary to have the following relations between electrode dimensions:

$$\mathbf{D_{extr}} = \mathbf{d_{em\text{-}extr}} \qquad (1),$$

$$\mathbf{D_{ext}} / \mathbf{d_{em}} = \mathbf{1.5} \qquad (2),$$

where

$\mathbf{D_{extr}}$ **-** extractor hole diameter;

$\mathbf{d_{em}}$ – emission surface diameter;

$\mathbf{d_{em\text{-}extr}}$ -emitter-extractor gap.

In this case Chaild – Lengmour law for flat diode can describe the relationship between ion current density and extractor voltage:

$$j = 5{,}54 \cdot 10^{-8} \frac{U^{3/2}}{\sqrt{\mu} \cdot d^2}, \qquad (3),$$

where $d = \mathbf{d}_{em\text{-}extr}$, μ - ion atomic mass.

The optimal extractor cone angle (1) is 90^0, pierce electrode - 120^0. The pierce electrode (2) may have an electrical contact with emitter surface, or may be no – in that case one can apply the positive potential to it (some hundred volts) to plug out the ion beam.

Solid-state thermo ionic emitters (3), elaborated in IPP NSC KIPT consists of metal (Ta, W) support with backing emitter material – alkali ion aluminosilicate (Li, Na, K, Cs) [3, 4], we use also ceolite for Tl, and Cs. These emitters allow obtaining the ion current density in steady state mode up to 10 mA/cm^2 and some A/cm^2 in pulse mode. Working resource – 25 mA·hour/gram.

A shaping-focusing system based on multy-electrode accelerating tube with potential distribution which allows to have soft operation of ion beam focusing point.

3. INJECTOR SYSTEMS

Fig. 2 presents the ion injector for HIBP system of TI-II fusion device [5].

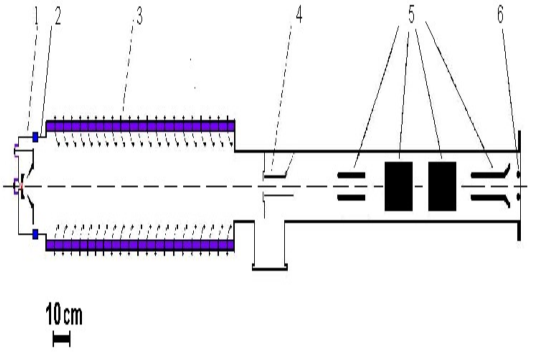

Fig.2. Cs $^+$ HIBP diagnostic system injector of TJ-II stellarator:

1. *Emitter–extractor unit*
2. *Focusing electrode*
3. *Accelerating tube*
4. *Faraday cup*
5. *Deflecting plates*
6. *Wire detector*

The space potential distribution, which necessary for ion beam accelerating and focusing into determined point of stellarator plasma was assigned by resistive divider of accelerating tube. The initial ion beam focusing is carried out by three-electrode lens, consists of extractor electrode, focusing electrode (2), and some first rings of accelerating tube (3), after that the ion beam is accelerating to determined energy. Ion current and focus distance control is carried out by means of extractor potential and emitter temperature (filament current).

Injector power supply, elaborated in IPP NSC KIPT, consists of 4 sources: accelerating voltage (+200кV, 1 mA), extracting voltage (-4 кV, 1 mA), modulation voltage (+600 V, 1 mA), emitter filament heating voltage (12 V, 15 A), assembled in a mutual box. This power supply guarantee high stability of accelerating voltage (not worse than $\mathbf{10^{-5}}$), which is necessary for plasma potential measurements by HIBP method.

Ion current measurements carried out by Faraday cup (4). The FC design allows to measure the ion current between stellarator pulses and to transmit ion beam to plasma in determined period of time. This design prevents ion beam coming into stellarator vacuum chamber during a period of magnetic field arising, then consists a conditions for run away electron current appearance. This current appears due to a secondary ion-electron emission from vacuum chamber wall and leads to plasma discharge breakdown.

The ion beam space control is carrying out by deflecting plates (5), and beam profile measurements - by wire detector (6).

This injector allows to having primary Cs ion beam current up to 100 mkA with beam diameter 4 mm. It’s more than enough for steady secondary ion beam registration. The secondary ion current on analyzer detector plates is now 100 – 300 nA, it’s 2 order of magnitude more than plasma loading.

The same types of injectors are working now at HIBP diagnostic systems of tokamaks T-10 (300 кV, 30mкA, Tl$^+$ beam), TUMAN-3M (80 кV, 80 mкA, K$^+$ beam) and ISTTOK.

Fig.3 shows potential distribution in HIBP injector of ISTTOK tokamak [6], one can see the initial ion beam focusing area by three-electrode lens (I – III) and accelerating area (IV).

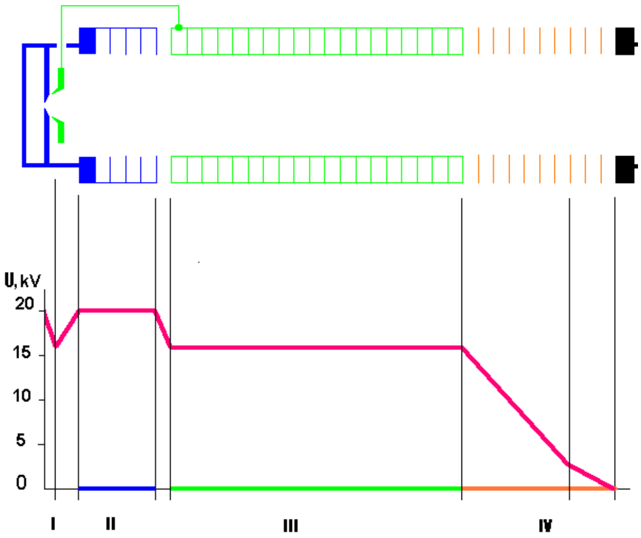

Fig.3. Potential space distribution in ISTTOK tokamak injector

ISTTOK injector system can operate with two mutually replacing ion sources– solid state and plasma sources. Plasma ion source allows injecting into plasma practically any kind of ions and also two or more component ion beams with the aim of plasma electron temperature measurements. With Cs^+ solid-state source this injector produces up to 20 mkA, 20 keV beam with 3mm diameter and 1,7 mrad divergence at 1,3 m from the accelerating tube. It can operate with a mono-cusp plasma ion souce also, and produces up to 40 mkA Xe^+ beam with the same 3 mm diameter but 16-mrad divergence. The respective current-to-voltage characteristics are shown in Fig.4.

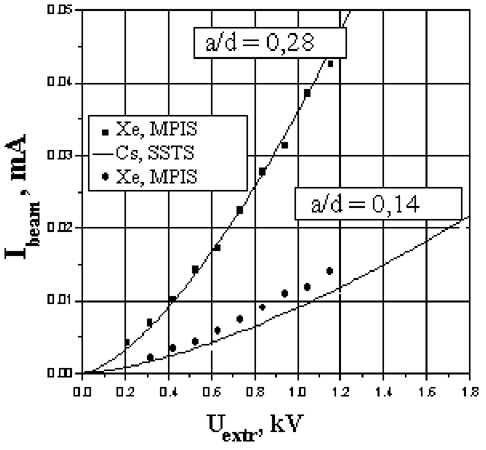

Fig.4. ISTTOK injector current-to-voltage characteristics
MPIS – mono-cusp plasma ion source,
SSTS –solid-state thermo ionic source,
a – emitter diameter, d – emitter extractor gap

4. CONCLUSION

A long – focus primary ion beam HIBP injectors described in this report. They were based on accelerating tubes with resistively dividers. These systems have a possibility of a soft control of focusing distance and primary beam density by means of extractor voltage control. This feature is very important for supplying a probing beam density in researched area of plasma sufficient for reliable registration of a secondary signal.

Now authors are working under new types of emitter – extractor units, based on Li and Na solid state thermo ionic emitters in order to obtain ion current up to several dozen milliamps for beam - emission spectroscopy (BES), and several – component ion beams for plasma electron temperature measurements by HIBP method.

This work was supported by STCU Grant № P-102.

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