THE DEVELOPMENT OF LIGHT ION INJECTOR FOR THE PLASMA DIAGNOSTIC SYSTEM BASED ON BEAM EMISSION SPECTROSCOPY

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The development of light ion injector and neutralizer for the BES plasma diagnostic system and its first experimental results are presented in this work. This injector will be used for neutral beam plasma diagnostic systems. Diagnostic systems based on neutral beams of Li or Na atoms can be used to study the spatial plasma density profiles, impurity ions and magnetic field distribution in the border region of the plasma fusion devices. This method is based on the detection of the probe beam glow of atoms excited by the plasma electrons. These diagnostic systems consist of two main parts – the neutral beam injector (including the ion beam accelerator and neutralizer) and the secondary light signal registration system. Light ion beam accelerator based on the five-electrode ion-optical system, in contrast to the classical three-electrode system, delivers beams of lithium or sodium with current 3…5 mA at a beam energy 20…25 keV. The neutralizer is based on the supersonic jet of sodium vapor formed by Laval nozzle. The first experiments of neutralizing the ion beam with a transverse supersonic atomic jet was done.

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INTRODUCTION

Beam Emission Spectroscopy (BES) is used to study space plasma density profiles, impurity ions and magnetic field distribution in the edge zone of fusion plasmas. This method is based on the registration of optical light radiation from the neutral probe beam exited by the plasma electrons and ions [1]. Diagnostic systems basically based on neutral beams of fast Li or Na atoms [2]. These diagnostic systems consist on two main parts – the neutral beam injector (including ion beam accelerator and neutralizer) and the secondary light signal registration system.

1. THE ION OPTICS SYSTEM FOR LIGHT ION BEAM INJECTOR

The ion accelerating system in this project is based on a five-electrode ion optics system instead of the classical three-electrode [1-4]. Implementation of additional electrodes allows for ion beam focusing regardless from extraction voltage. This design also allows to focus the ion beam with high ion current and relatively low energy beam (up to 35 keV), which is impossible for the classical three-electrode lens. Extractor voltage in traditional systems must be closely related to the energy of the beam in order to focus the beam in the neutralizer. This ratio limits the value of ion current for a given beam energy and focusing distance. In new ion optical system with additional focusing electrode the value of extraction voltage can be increased and the ion current also can be increased while maintaining the beam focal length.

The numerical calculations of the ion and neutral beam trajectories with energy up to 70 keV and the ion current up to 6 mA were carried out by SIMION 3D code in the initial stage of ion optics system elaboration. Main attention was directed to the beam energy of up to 35 keV that is optimal for the beam neutralization. These calculations determine the geometrical parameters of the electrodes and their space locations.

The ion optics system of light ion (Li^+ and Na^+) injector elaboration was based on the calculations of ion beam current lines for the certain energy and current. The main purpose of these calculations is to obtain the ion beam optimally focused in the neutralization area with $0.1…0.3^0$ deviation with a beam diameter 20…40 mm inside the neutralization area. With these parameters we will have a neutral beam focus of 10 mm diameter at a distance of 2.5…3 m from the injector. These calculations and the real experimental design illustrated by Fig. 1.

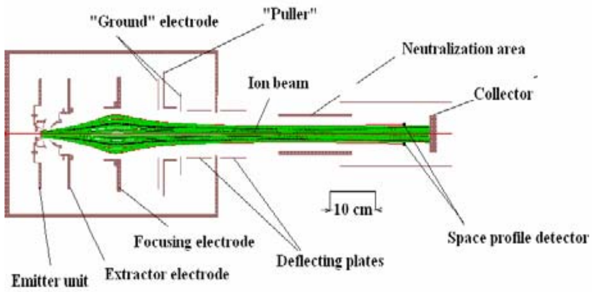

Fig. 1. The calculations of the five-electrode ion-optics system by SIMION 3D code

After ion optics system elaboration, manufacturing and investigations of Li and Na ion beam focusing the system was able to produce the ion beam with an energy 20…25 keV and 3…4 mA of ion current. Ion beam parameters were controlled by the wire detector and additional collector placed in the position instead of the future neutralizer. Space profile distribution of the ion beam from the injector was measured using a four-rods wire detector by ion beam scanning with two pairs of electrostatic deflection plates, placed in the horizontal and vertical positions. The wire detector was placed 30 cm apart from the first scanning plates (in the future neutralizer placement). The distance between wires was 40 mm in the vertical and horizontal positions. The scanning voltage was ± 3 kV, 50 Hz sinusoidal. These measurements were done by scanning of the ion beam using deflection plates across the wire detector and by registration of the additional collector current.

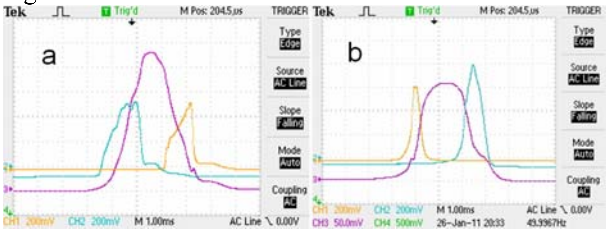

Fig. 2. Ion beam space profile from the wire detector (blue and yellow lines) and additional collector current in the neutralization area (violet line) for Li ion beam with energy 25 keV; (a) - ion current 4 mA, emitter heating power 250 W, (b) - ion current 3 mA, emitter heating power 200 W

So, the ion beam diameter in the neutralizer area increases from 16 mm to 22 mm when ion current grows from 3 to 4 mA. The ion optics system allows us to obtain a slightly converging beam inside neutralizer and so to have the 10 mm diameter neutral beam inside plasma.

2. SODIUM VAPOR SUPERSONIC ION BEAM NEUTRALIZER

The neutralizer is necessary to convert the light ion lithium or sodium beams into fast atomic beams. The neutralizer design with ion beam passing through sodium vapor cloud is operated, in particular, in ASDEX-U [3, 4]. This BES diagnostic system uses 35 keV ion beam and have 97% neutralization efficiency at this energy. The linear density of sodium atoms is $n_l = 1\times10^{15}$ см$^{-2}$ in 120 mm long neutralization tube in this case, so the sodium atoms density is about 8×10^{13} см$^{-3}$. Sodium vapor comes into neutralizer from heated volume (oven) with sodium metal. The sodium temperature in the oven is about 250^0 C. The main disadvantage of this design is that sodium vapor is spreading in bough directions from neutralizer volume along the beam trajectory – towards accelerator and plasma volume. The metal sodium appearance in accelerator leads to decreasing the electric insulation features and possible electrical breakdowns; the sodium appearance in the fusion plasma causes its cooling. The using of transverse sodium stream injection across ion beam will eliminate these disadvantages. Papers [5, 6, 7] shows that transverse supersonic vapor stream of different substances may effectively used to provide the positive ion's neutralization and negative ion beam production without substantially contamination of beam-line by neutralizer substance. The neutralizer design is shown in Fig. 3. Fig. 4 shows expected sodium vapor flux profile from Laval nozzle. To verify the neutralization efficiency of this system the light ion's accelerator based on four-electrode lens was attached to neutralizer entrance port, see Fig. 5. The Faraday cup was installed behind neutralizer for ion current measurements. The 3.5 keV sodium ion beam with ion current up to 40 µA is used in these experiments. The measured ion beam current on Faraday external electrode is less than 2 µA, ion current on Faraday cup inner electrode is up to 40 µA. Fig. 6 illustrates the sodium stream pattern on the cooler surface. This pattern corresponds to the calculated sodium vapor stream space distribution inside neutralizer. Ion current drop on Faraday cup during pulse opening of the sodium stream valve is up to 78%.

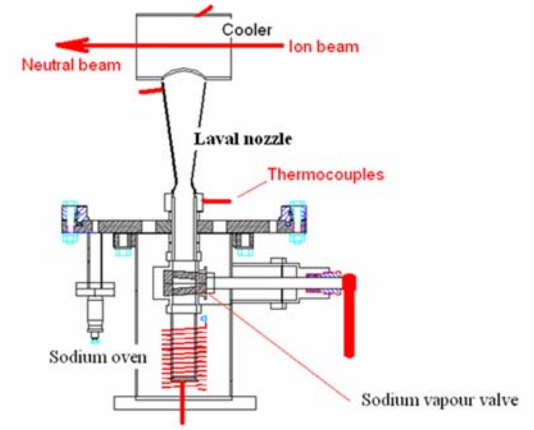

Fig. 3. Sodium vapor supersonic neutralizer design

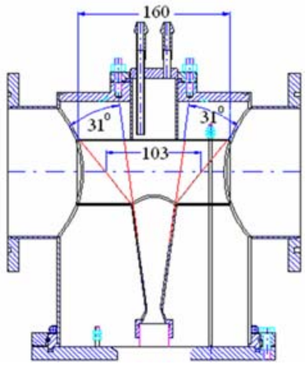

Fig. 4. Sodium vapor stream flux outflow space distribution from Laval nozzle

Fig. 5. Neutralizer testing device with small ion beam accelerator

Fig. 6. Oxidezed sodium vapor stream pattern on the cooler surface during approximately 1 hour air exposition after vacuum chamber opening

CONCLUSIONS

The ion-optics system of light ion beam injector for BES diagnostics was developed. This system has five electrodes, instead of three electrodes, which is usually used for this purpose. The additionally electrodes allow to focus the ion beam in the neutralization volume independently from energy of the ion beam and extracting voltage. By using this kind of ion optics it is possible to obtain large values of ion current for smaller ion energies. The possibility of alkali ion beam neutralization by transverse supersonic sodium vapor stream was proved in this experiment, practically for the developed design of neutralizer units. The neutralization coefficient was from 60 to 78 % during the pulse vapor stream operations.

ACKNOWLEDGEMENT

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РАЗРАБОТКА ИНЖЕКТОРА ЛЕГКИХ ИОНОВ ДЛЯ СИСТЕМЫ ДИАГНОСТИКИ ПЛАЗМЫ НА ОСНОВЕ ПУЧКОВОЙ ЭМИССИОННОЙ СПЕКТРОСКОПИИ

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Представлена разработка инжектора легких ионов и нейтрализатора для ПЭС-системы диагностики плазмы и первые экспериментальные результаты. Этот инжектор будет использован для диагностики плазмы с помощью пучка нейтральных атомов. Диагностические системы, основанные на нейтральных пучках атомов Li или Na, могут быть использованы для исследования пространственных профилей плотности плазмы, примесей ионов и распределения магнитного поля в пограничных областях плазмы термоядерных установок. Этот метод основан на регистрации свечения атомов зондирующего пучка, возбуждаемых электронами плазмы. Эти диагностические системы состоят из двух основных частей: инжектора нейтральных атомов (включающего ускоритель пучка ионов и нейтрализатор) и системы регистрации излучения. Ускоритель легких ионов, базирующийся на пятиэлектродной ионно-оптической системе, в отличие от классической трехэлектродной, позволяет получать пучки ионов лития или натрия с током 3…5 мА при энергии пучка 20…25 кэВ. Нейтрализатор основан на сверхзвуковой струе паров натрия, формируемой с помощью сопла Лаваля. Проведены первые эксперименты по нейтрализации пучка ионов с помощью поперечной сверхзвуковой струи.

РОЗРОБКА ІНЖЕКТОРА ЛЕГКИХ ІОНІВ ДЛЯ СИСТЕМИ ДІАГНОСТИКИ ПЛАЗМИ НА ОСНОВІ ПУЧКОВОЇ ЕМІСІЙНОЇ СПЕКТРОСКОПІЇ

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Представлена розробка інжектора легких іонів і нейтралізатора для системи ПЕС діагностики плазми та перші експериментальні результати. Цей інжектор буде використаний для діагностики плазми за допомогою пучка нейтральних атомів. Діагностичні системи, засновані на нейтральних пучках атомів Li або Na, можуть бути використані для дослідження просторових профілів густини плазми, домішкових іонів і розподілу магнітного поля в приграничних областях плазми термоядерних установок. Цей метод заснований на реєстрації світіння атомів зондуючого пучка, збуджуваних електронами плазми. Ці діагностичні системи складаються з двох основних частин: інжектора нейтральних атомів (що включає прискорювач пучка іонів і нейтралізатор) та системи реєстрації випромінювання. Прискорювач легких іонів, який базується на п'ятиелектродній іонно-оптичній системі, на відміну від класичної трьохелектродної, дозволяє отримувати пучки іонів літію або натрію зі струмом 3…5 мА при енергії пучка 20…25 кеВ. Нейтралізатор заснований на надзвуковому струмені пари натрію, формованої за допомогою сопла Лаваля. Проведені перші експерименти з нейтралізації пучка іонів за допомогою поперечного надзвукового струменя.