DEVELOPMENT OF LIGHT ATOMIC INJECTOR FOR BEAM EMISSION SPECTROSCOPY (BES) DIAGNOSTIC OF URAGAN-2M TORSATRON

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The improvement of the light atomic injector for beam emission spectroscopy (BES) diagnostic for Uragan-2M was held. The investigation was carried out with the energy of the sodium ion beam was 20…25 keV, the ion current up to 2 mA, and the beam diameter of 15…20 mm with 2 types of neutralizers. Neutralization of the beam was carried out on sodium vapor at an evaporator temperature of up to 300 ^{0}C. The neutralization efficiency is now near 60…80 % for Na ion current 1.5…2 mA and 20…25 keV beam energy.

PACS: 52.70.Nc

INTRODUCTION

The main idea of this study is an upgrade of the light atomic injector for BES diagnostic for modern fusion devices [1-3]. BES diagnostic consist of the neutral beam injector, including the ion beam accelerator and neutralizer (Fig. 1) and the secondary light signal registration system. Diagnostic is used to study space plasma density profiles, impurity ions distribution and magnetic field distribution in the edge zone of fusion plasmas. This method is based on the detection of the probe beam radiation of atoms excited by the plasma electrons. This report describes the investigation of two types of neutralizers – with open and closed evaporators. Based on the tests of 2 types of neutralizers, a new closed type design was developed. Such a neutralizer can work with a flowing stream of sodium vapor or supersonic. The best light neutral atom is Na [1], due to it yellow bright lines in comparison with Li dark red line.

EXPERIMENTAL RESULTS

The accelerator ion optics system is based on 5-electrode lens [4]. This system allows the ion beam focusing to the neutralization area in the case of lower beam energy and higher current in comparison with the classic 3-electrode system [5].

Fig. 2 illustrates the sodium ion current depending on extracting voltage for different emitter heating power. The investigation was carried out with the energy of the Na ion beam 20…25 keV, the ion current 1…2 mA and the beam diameter 15 …17 mm (Fig. 3). Neutralization of the beam was carried out on Na vapor with evaporator temperature up to 300 ^{0}C.

Two designs of neutralizers were tested. First neutralizer on a supersonic jet of sodium vapor [4] with the possibility of overlapping a jet was investigated (Fig. 4).

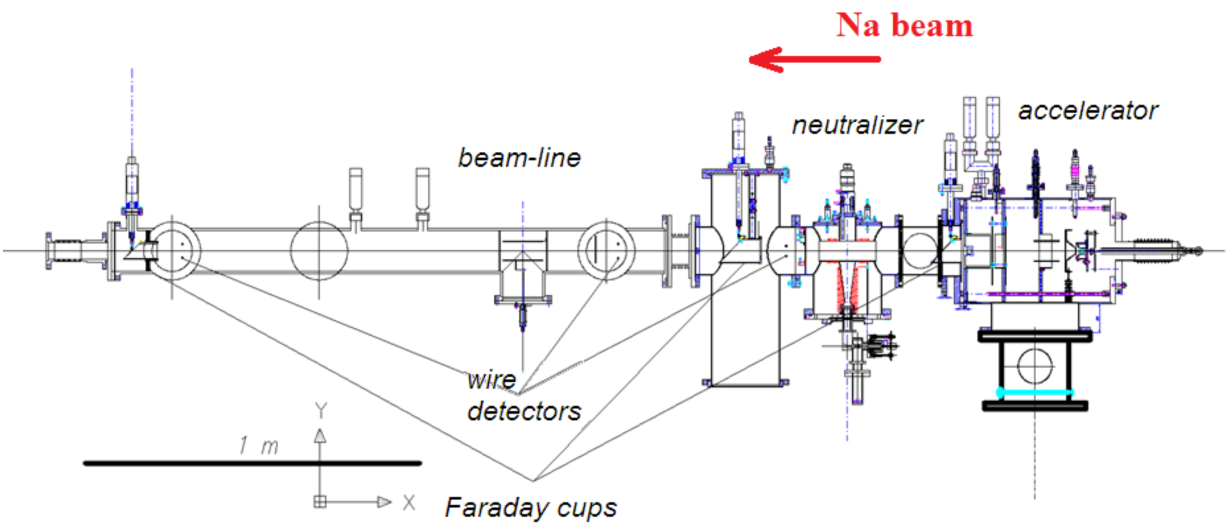

Fig. 1. Sodium atomic injector for BES plasma diagnostics at the torsatron Uragan-2M

ISSN 1562-6016. ВАНТ. 2019. №1(119)
PROBLEMS OF ATOMIC SCIENCE AND TECHNOLOGY. 2019, № 1. Series: Plasma Physics (25), p. 252-255.

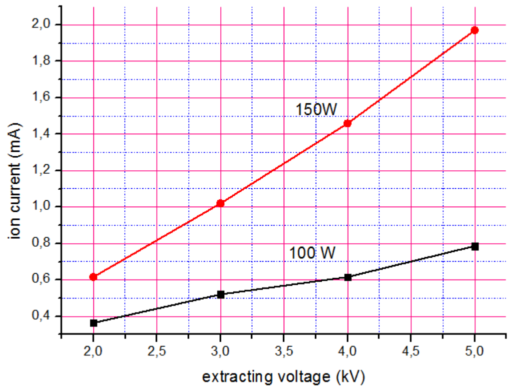

Fig. 2. Sodium ion current depending on extracting voltage for different emitter heating power. Beam energy – 25 keV, emitter heating power – 100 and 150 W

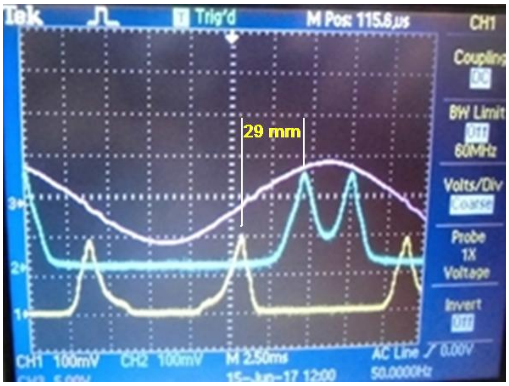

Fig. 3. Ion beam profile observed after the neutralizer measured by wire detector based on 120 mm after neutralizer exit. The neutralizer is cold

Its heating system is based on halogen lamps (3x500 W). Water cooling system on the top of neutralizer surface is used to “freeze” Na vapor stream, That will reduce the vapor spread to the accelerator and torsatron Uragan-2M.

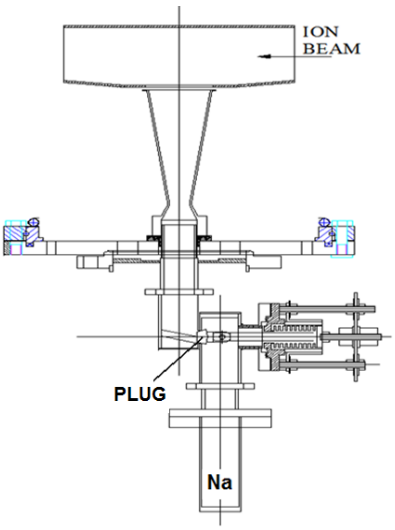

Fig. 4. Neutralizer on a supersonic jet with the possibility of overlapping a stream of vapor

Second neutralizer with a permanently opened Na volume [6] (so called “submarine”) was investigated too. Heating system (Figs. 5,6) based on two heaters (analog first neutralizer).

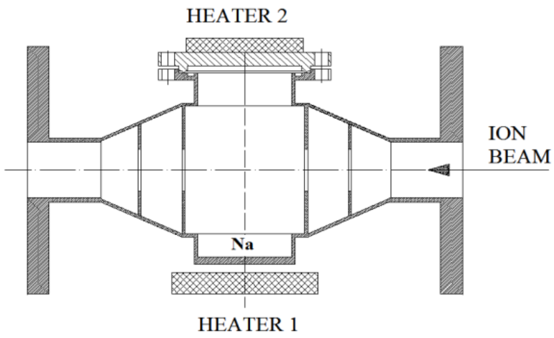

Fig. 5. Neutralizer with a permanently opened Na volume

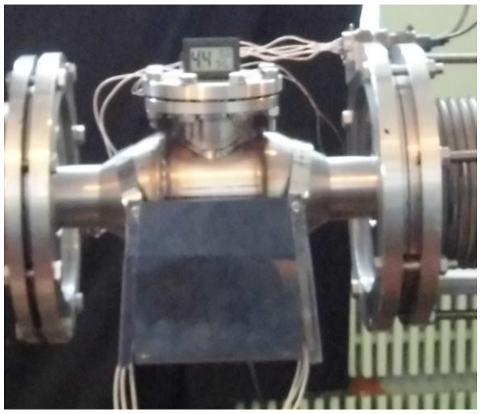

Fig. 6. Photo neutralizer installed on the atomic injector test device with heater 1

The experiments show the necessity of additional heating the upper flange of the neutralizer up to 130…140 °C in order obtaining the suitable beam neutralization (Fig. 7).

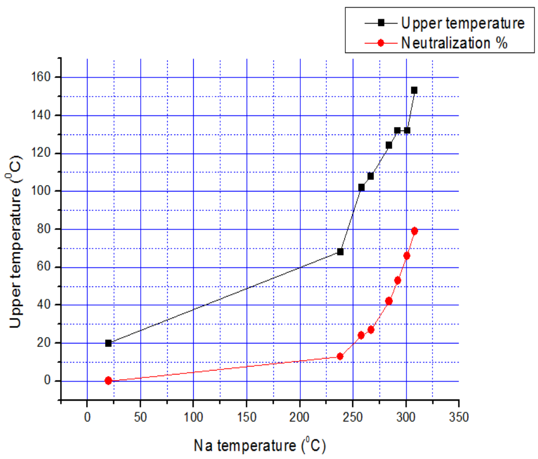

Fig. 7. Dependence of the neutralization efficiency of the ion beam and upper flange temperature versus Na volume temperature

Fig. 8 present the experimental data of the neutralization efficiency of Na ion beamsfor bouth neutralizers. Neutralizers are opened during experiments with ion current of 1…1.5 mA.

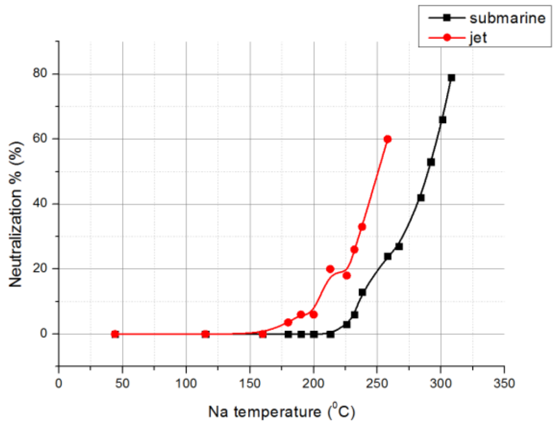

Fig. 8. Dependence the ion beam neutralization efficiency versusNa volume temperature of neutralizers

These dependencies show more effective neutralization for supersonic jet (less temperature for the same efficiency). It may be explained by the less exiting diameter for Na vapor (47 mm instead 66 mm). It leads to more Na vapor density in the neutralization area (about 2 times) in comparison with "submarine".

The estimations of ion beam density n_i, sodium vapor density n_{Na} and the neutral beam density n_0 for supersonic jet neutralizer are next: beam energy E = 25 keV, ion current I_i = 1.7 mA, beam diameter d = 7 mm. Sodium temperature in the neutralizer is 250 ^{0}C, sodium vapor pressure is $2 \cdot 10^{-2}$ Torr with plug is closed (see Fig. 4):

Calculation of ion beam density-

$n_i = I_i / eV_iS_i$, where $V_i = 1.38 \cdot 10^6 (E/A)^{1/2}$,

$n_i = 0.97 \cdot 10^8$ cm^{-3}.

We estimate what Na vapor will expand 4 times when the plug will be opened. So the Na density inside neutralizer will be:

$$n_{a\,Na} = 2.68 \cdot 10^{19} P / 750,$$

$n_{aNa} = 1.78 \cdot 10^{14}$cm^{-3}

The neutralization length L we estimate as 5 cm – as a jet exit diameter, neutralizing cross section σ is $5 \cdot 10^{-15}$ cm^{-2}

$$n = \langle \sigma V \rangle n_a L,$$

$n_0 = 1.97 \cdot 10^8$ cm^{-3}.

This estimation of neutralization efficiency shows a possibility of ion beam neutralization with ion density of $n_0 = 1.97 \cdot 10^8$cm^{-3}andioncurrent up to 3.5 mA.

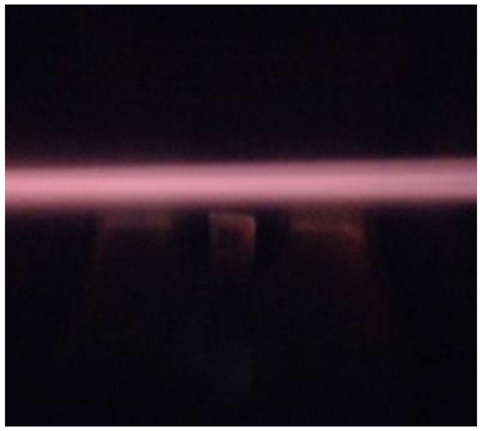

Fig. 9. The ion beam in the neutralizer chamber: beam diameter – 20 mm; current – 1.2 mA; energy – 25 keV; emitter heating power – 150 W; extracting electrode voltage – 22 kV; focusing electrode voltage – 23.8 kV

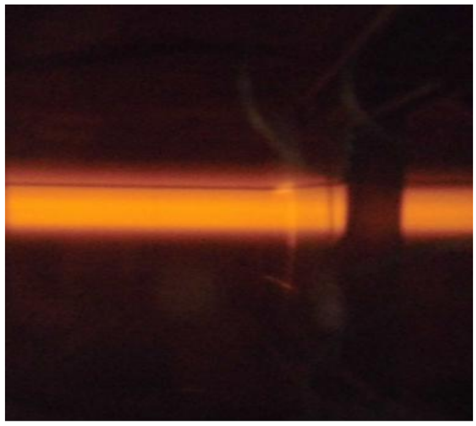

Fig. 10. The neutral Na beam at the distance of 0.5 m after the neutralizer chamber exit: diameter – 20 mm; current –1.7 mA; energy – 25 keV; emitter heating power – 150 W; extracting electrode voltage – 21 kV; focusing electrode voltage – 24 kV

A new type of neutralizer, based on previous experiments was developed. It will have the possibility of pulsed steam supply to the neutralization area.

This device was manufactured and installed for vacuum and heating test. The sodium heater may also have a shape of a Laval jet that can be closed from its top.

We also planning an additional pumping of the beam-line near its exit to Uragan-2M and these additional pumping systems will be supplied by liquid nitrogen vacuum traps**.** These measures will improve the vacuum conditions inside the injector.

The degradation of the vacuum conditions up to $(3…5) \cdot 10^{-4}$ Torr in the accelerator volume was observed for bought neutralizer systems at an evaporator temperature of 260…300 °C in experiments. This pressure of sodium vapor leads to unstable operation of the accelerator (breakdowns in the ion beam formation area).

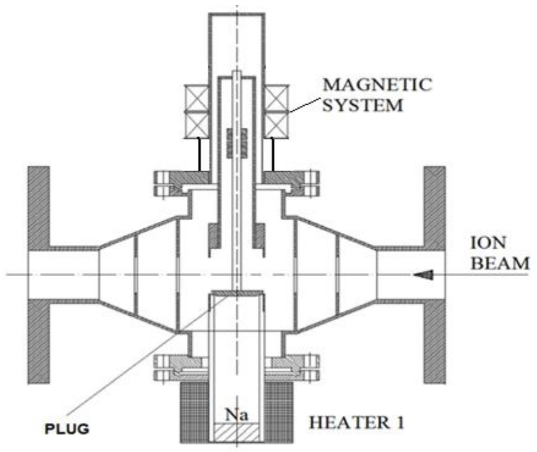

Fig. 11. Neutralizer with plug and its electromagnetic drive

THE MAIN RESULTS

1. Two designs of neutralizers were investigated: first – the neutralizer on a supersonic jet of sodium vapor, second - the neutralizer with a permanently opened Na volume.
2. The Na ion beam with current 2 mA and energy 20…25 keV was neutralized with efficiency near 60…80 % at the neutral beam injector prepared for Uragan-2M torsatron.
3. A new type of neutralizer, based on previous experiments was developed. It will have the possibility of pulsed steam supply to the neutralization area.

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Article received 13.10.2018

РАЗРАБОТКА ИНЖЕКТОРА ЛЕГКИХ АТОМОВ ДЛЯ ПУЧКОВО-ЭМИССИОННОЙ СПЕКТРОСКОПИЧЕСКОЙ (ПЭС) ДИАГНОСТИКИ ТОРСАТРОНА УРАГАН-2М

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Проведены испытания инжектора легких атомов для пучково-эмиссионной спектроскопии (ПЭС) для диагностики торсатрона Ураган-2М. Исследования проводились при энергии пучка ионов натрия 20…25 кэВ ионным током до 2 мА и диаметром пучка 15…20 мм с двумя типами нейтрализаторов. Нейтрализация пучка проводилась на парах натрия при температуре испарителя до 300 °С. Эффективность нейтрализации в настоящее время составляет 60…80 % для ионного тока натрия 1,5…2 мА и энергии пучка 20…25 кэВ.

РОЗРОБКА ІНЖЕКТОРА ЛЕГКИХ АТОМІВ ДЛЯ ПУЧКОВО-ЕМІСІЙНОЇ СПЕКТРОСКОПІЧНОЇ (ПЕС) ДІАГНОСТИКИ ТОРСАТРОНА УРАГАН-2М

О.Д. Комаров, Л.І. Крупнік, О.О. Чмига, Г.М. Дешко, М.Б. Древаль, А.В. Клосовський, О.С. Козачок, С.М. Хребтов, С.М. Мазніченко, В.А. Волков

Проведено випробування інжектора легких атомів для пучково-емісійної спектроскопії (ПЕС) для діагностики торсатрона Ураган-2М. Дослідження проводилися з енергією пучка іонів натрію 20…25 кэВ іонним струмом до 2 мА та діаметром пучка 15…20 мм з двома типами нейтралізаторів. Нейтралізація пучка проводилася на парах натрію за температурою випарника до 300 °С. Ефективність нейтралізації на даний час становить 60…80 % для іонного струму натрію 1,5…2 мА та енергії пучка 20…25 кеВ.