EXPERIMENTAL STUDY OF INJECTOR BASED ON THE SPARK SOURCE WITH TITANIUM CATHODE SATURATED WITH HYDROGEN

A.A. Vasiliev, D.D. Iosseliani, V.V. Kushin, S.V. Petrenko, S.V. Plotnikov, D.N. Seleznev, V.V. Zubovsky
State Scientific Centre of Russian Federation "Institute of Theoretical and Experimental Physics", 117259, Moscow, 25, B.Cheremushkinskaya, plotnikov@vitep1.itep.ru
E.P. Bogolyubov, V.T. Bobylev, V.A. Kuznetzov, V.I. Ryzhkov, Yu.K.Presnyakov, V.A.Samarin
All-Russian Scientific Institute of Automatics, 101000, Moscow, Mospochtamt, b/o 918

The results of experimental study of short-pulse proton injector for various variants of construction of pulse spark ion source are considered. The experimental results of study of regimes of both ignition and discharge support within the source with stabilized pulse feeding (~10 µs, 5 Hz). Of special concern the increasing of the cathode electrode life-time. The results of measurements of both absolute and partial (in spices) density of ion beam are presented.

PACS: 29.25.Ni

1. INTRODUCTION

Some applied tasks deal with the use of accelerator beams for remote non-destructive identification of materials state a specific problem of generation and acceleration of extremely short-pulse beams of light ions (*p* or *d*) with a high repetition rate. The first test works on applying the ion beam formation system used in the vacuum neutron tube TNT-147 for proton or deuteron injection into the RF linac structure showed its promises in comparison with traditional gas-based ion source injectors such as compact sizes, low gas load on the linac vacuum system, etc. At the same time, measurements of ion beam parameters revealed some additional possibilities for upgrading of beam parameters for both linac structures and neutron generators. In particular, there is a possibility for regulation of the beam generation and formation system as well as improving of the operating longevity by the use of a multiple cathode construction of the extraction system and a multiple channel system of beam acceleration up to 100 keV.

It is supposed that the use of a lot of cathodes is potentially able to improve both the stability and the service life of the neutron generator and the RF linac injector. Besides, if the cathodes are turned on simultaneously when operating on separate targets there is a possibility of significant increasing of neutron flux intensity of the neutron generator. The use of the multiple channel injection system for RF linac can increase both the intensity and the phase density of the beam.

At present, at ITEP the experimental studies of a multiple channel system of beam formation are under way. In particular, the model of 19-channel system for proton injection of 100 keV (fig. 1) is developed and assembled. Various variants of the cathode block design suitable for multiple channel system beam formation and acceleration are developed.

The promising variant of the short-pulse plasma emitter construction both for linacs and compact neutron generator based on the vacuum tubes is supposed to be a modular model of a multiple-beam ion source. In this system every of multiple beams is generated in its personal cell with the separate cathode and the system for ignition and supporting of the discharge (fig. 2).

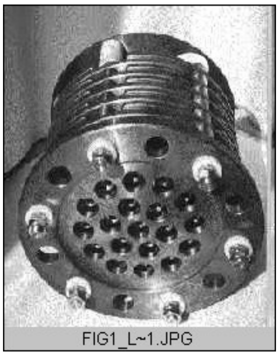

Fig.1. Model of the multiple channel system for ion beam formation

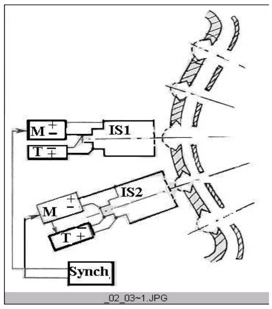

Fig.2. Scheme of multiple channel ion gun

2. SPARK ION SOURCE

Principle of work of spark ion sources is based on the attribute of some metals (Ti,Zr,Sc) heated up to 1000^0C in hydrogen (or its isotopes) surroundings to be transformed into metal hydride due to the exothermic reaction. This process leads to saturation of a metal disc with hydrogen (or deuterium) up to the concentration of about two atoms of hydrogen (deuterium) per 1 atom of metal.

The important advantage of such kind of ion sources is gas storage within electrodes as a metal hydride while the discharge begins with no initial gas concentration.

The single cell is a three-electrode axis-symmetrical design that consists of a cylindrical cathode and a trigger electrode which is insolated from the cathode by means of ceramic spacer with a central emission hole.

The capacity C powered via the resistance R with a direct-current source (S) with a voltage regulated within the range from 0 to 4 kV, is connected to the discharge

PROBLEMS OF ATOMIC SIENCE AND TECHNOLOGY. 2004. № 1.
Series: Nuclear Physics Investigations (42), p.83-85.

gap between the anode and the cathode. The pulse block of spark triggering (T) is connected to the gap with a ceramic spacer (cathode-trigger electrode) (fig.3).

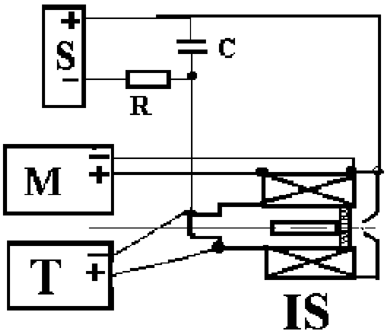

Fig.3. Scheme of ion source feeding

In the variant of the ion source design being considered the anode electrode with a hole for plasma exhaust is arranged at the distance of about 10 mm from the cathode face. The cathode base of the ion source cell is made of Zr (or Ti) treated with deuterium. The locality of the cathode surface is spring-loaded to the ceramic spacer [2]. The solenoid magnetic field is used for plasma axial contraction.

Such kind of the ion source is able to work both under low and high vacuum conditions at a pressure of 10^{-4} Pa.

The ion source operates as follows. Firstly, the magnetic coil modulator M is switched on. When the value of current comes up to maximum value, the high voltage pulse (~15 kV and 10 μs) from the trigger block T is applied to the gap between the cathode and trigger electrode. The surface discharge of the trigger gap along the external side of the ceramic spacer generates the emission centre with the heated surface at the cathode face surface that is accompanied with gas desorption and ionization. Plasma is thrown into the gap between the anode and cathode electrodes that lead to the spark discharge growth in the main gap. The duration of that part of the pulse is about 2 μs while the spark phase duration is 0.4…0.6 μs. During this time the sharp drooping of discharge voltage occurs (~ 2 kV/μs) with simultaneous rising of the spark current up to several hundred A. Then the voltage is falling down smoothly to 100 V and lower.

The emission centre of the spark discharge is generated occasionally at the surface of the cathode electrode turning into the cathode spot that is moving chaotically along the open face of the cathode surface. As a result the sputtering of the cathode electrode occurs that is accompanied with the ionization of Zr (or Ti) vapor and released deuterium (or hydrogen) components [3]. The level of the light fraction ionization is maximal at the spark part of the discharge. In the case of sputtering the cathode is shortening but the spring returns the cathode emission surface back in the initial position leading to the stabilization of discharge conditions. For extra stabilization of plasma beam from the source the spark modulator M with parametric stabilization of the current pulse pick from an inductive store is used.

3. SCHEME OF MEASUREMENTS

The test facility for study of spark ion source parameters comprises the accelerator tube based on the vacuum chamber with pumps, the rack for elements for feeding the ion source and triggering the system, and the system for ion beam formation with the 250 kV transformer and the high-voltage source (+120 kV, 4 mA)(fig. 4). For beam measurements and analysis the measurement channel is used with replaceable diagnostic installations such as phase density analyzer as well as the Thomson analyzer (TA) with a micro-channel plate (MCP) furnished with control diaphragms D and beam current detectors including the Faraday cups (FC) and the inductive transducer - Rogovsky coil (RC)). The working vacuum in the accelerator tube and in the measurement channel is backed at 10^{-4} …10^{-5} Pa.

The diaphragm D is a metal disc of 100 mm in diameter with an axial hole of 20 mm in diameter furnished with a periodically withdrawn Faraday cup FC_1 is located at the distance of 1 m from the beam formation system. Other measuring elements (other FCs and MCP) are located 1.1 meter behind the diaphragm D.

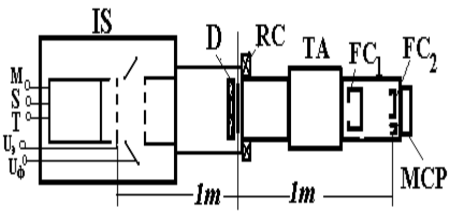

Fig.4. Schematic view of the test facility

The voltage within the range from 0 to 60 kV was applied to the accelerating electrode. The voltage that applied to the focusing electrode as well as to the extracting electrode was varied within the range from 0 to 20 kV. The magnetic coil was feed with the pulse current with the amplitude from 0 to 150 A and duration of 1.5 ms. Voltage at the capacity store C is varied within the range from 0 to 4 kV. The triggering block generated pulses of 10 μs duration with the voltage up to 15 kV. The experimental value of the light ion beam component of the pulse current of 320 mA was measured at the diaphragm D at deuteron beam energy of 60 keV (see fig.6). Optimum values of voltage applied on the extractor electrode and focusing electrode were equal to -3.1 and -1.3 kV respectively. The voltage at the spark capacity store C was equal to 3 kV. The results of spectral parameters measurements by means of the magnetic analyzer showed that the plasma bunch is separated on fractions right away after exhausting them through the anode hole. The beam current of about 2 mA was measured at the Faraday cup FC_2 that is located at a distance of about 2 m from the ion source anode. The shape of the ion beam pulse measured at the FC_2 was analogous to that measured at the diaphragm D. The detection of ions with various values of charge-to-mass (q/m) ratio was carried out by varying the magnetic field amplitude in the gap of TA (fig.7). (The value of magnetic field amplitude is increased from fig.7.1 to 7.4). The measurement results show that the front part of the beam pulse of 2…3 μs consists only of light fractions that are deuterons and molecular deuterium ions in the case when the cathode is treated with deuterium, while the followed part of the beam consists of ions of cathode material metal ions (Zr ions of various charge states) as well as desorbed gases ions.

The average measured value of beam current density at the diaphragm D for light component is 4.5 mA/cm^2, while at its center within the hole of 20 mm in diameter this value is about 8mA/cm^2. The instability value of the beam current amplitude measured at the repetition rate of 1 pps for the light component of beam does not exceed 30% that is much better than the instability measured at the ion source used in the compact neutron generator [4].

The characteristic property of the considered variant of the ion source is the effect of the external coil magnetic field that is used in the ion source design on the light fraction of the output beam. Without magnetic field the deuteron current is very poor while as the magnetic field is increasing, the deuteron beam current amplitude is rising smoothly.

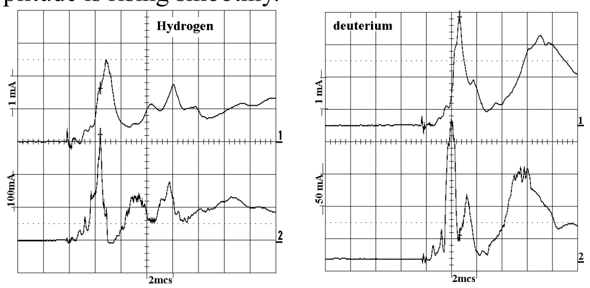

Fig.5. Oscillograms of pulse beam current delays measured by means of theTOF-method for deuterium (left) and hydrogen(right) ions at the flight base of 1.1m

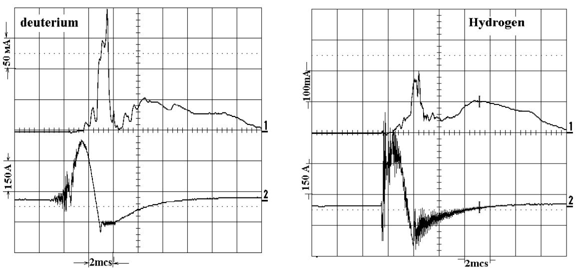

Fig.6. Oscillograms of total ion beam current from the spark ion source at 50 mA/div and 2 μs/div (1) and the amplitude of current in the spark discharge at 150A/div (2)

Deuteron identification within the spectrum was carried out both by means of the Thomson Analyzer with visualization of the spectral picture at micro-channel plate MCP and by the time-of-flight (TOF) method. When the TOF-method was used the base distance was equal to 1.1 meter the moments of ion beam pulse picks coming to the FC_2 related to the moment of detection of pulse beam coming at the diaphragm D (fig.5-7).

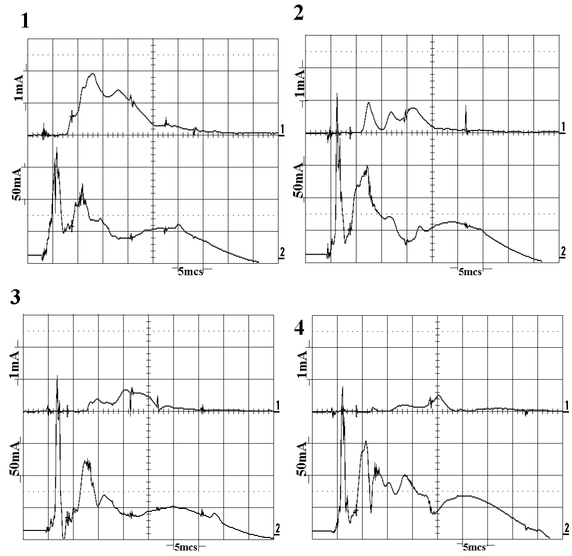

Fig.7. Oscillograms of ion current measured at the diaphragm D (2) and at the Faraday cup FC_2 (1) at increasing of magnetic field in TA

The first experience of works with the spark ion source having the external magnetic field shows that the type of short-pulse source under consideration is promising for linacs as well as for compact neutron generators.

REFERENCES

1. I.Chuvilo et al. Accelerator-based approach experiments for remote identification of fissionable and other materials // *Nucl. Instr. & Meth. In Phys Res*. 1998, v. B 139, p.298-300.
2. A.S.Gilmour, D.L.Lockwood. Pulsed Metallic - Plasma Generators // *Proc. of the IEEE*, 1972, v.60, №8, p.977.
3. S.Anders, A.Anders and I.Brown. Vacuum arc ion sources: some vacuum arc basics and recent results // *Rev. Sci. Instrum*. 1994, v. 65(4), p.1253.
4. V.V.Kushin et al. First experience of works with compact injectors for trials and drills of RF linac structures // *Proc. of the XIX Internat. Linac Conf. (LINAC98).* Chicago, USA, ANL-98/281998, v.1, p.168

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ИНЖЕКТОРА НА ОСНОВЕ ИСКРОВОГО ИСТОЧНИКА С ТИТАНОВЫМ КАТОДОМ, НАСЫЩЕННЫМ ВОДОРОДОМ

А.А. Васильев, Д.Д. Иоссилиани, В.В. Кушин, С.В. Петренко, С.В. Плотников, Д.Н. Селезнев, В.П. Зубовский, Е.П. Боголюбов, В.Т. Бобылев, В.А. Кузнецов, В.И. Рыжков, Ю.К. Пресняков, В.А. Самарин

Представлены результаты испытаний короткоимпульсного инжектора протонов для различных вариантов выполнения конструкции импульсного искрового источника. Приводятся экспериментальные результаты отработки оптимальных режимов возбуждения и поддержания разряда в источнике со стабилизированным импульсным питанием (~ 10 мкс, 5 Гц).

ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ІНЖЕКТОРА НА ОСНОВІ ІСКРОВОГО ДЖЕРЕЛА З ТИТАНОВИМ КАТОДОМ, НАСИЧЕНИМ ВОДНЕМ

А.А. Васильєв, Д.Д. Іоссіліані, В.В. Кушин, С.В. Петренко, С.В. Плотников, Д.Н. Селезньов, В.П. Зубовський, Е.П. Боголюбов, В.Т. Бобильов, В.А. Кузнєцов, В.І. Рижков, Ю.К. Пресняков, В.А. Самарін

Представлені результати іспитів короткоімпульсного інжектора протонів для різних варіантів виконання конструкції імпульсного іскрового джерела. Приводяться експериментальні результати відпрацьовування оптимальних режимів порушення і підтримки розряду в джерелі зі стабілізованим імпульсним живлення (~ 10 мкс, 5 Гц).