THE OUTPUT BEAM-LINE AND A NOVEL ION SOURCE OF 2-MEV PROTON RFQ LINAC

B.Yu. Bogdanovich, V.V. Kapin*, A.V. Nesterovich, A.N. Puchkov, V.N.Soloviev, V.P. Zubovskiy, V.V. Yanenko, MEPhI#, Moscow, Russia

Abstract

The 2-MeV 150-MHz proton RFQ linac is set up at the Radiation-Acceleration Center (RAC) of Moscow-Engineering Physics Institute (MEPhI), the State University. It has the output beam-line consisting of a doublet of the electrostatic focusing lenses, the post-accelerating 7-gap two-ridge interdigital H-resonator and a magnetic C-shaped spectrometer with vertical magnetic field. An unconventional design of the electrostatic lens featured by the two-dimensional electric field and wire-meshed beam apertures is implemented. Such lens provides a transverse focusing effect only in one plane, while does not affect on the beam in a perpendicular plane. In the 7-gap post-accelerating structure, the output energy of RF beam-bunches can be monotonically increased within the beam-pulse. It results in an amplification of the peak value of the beam current on a distant target. A novel ion source with an increased life span is developed. It combines the principles of duoplasmatron and RF ion source. In this report, designs and parameters of the output beam-line components and the ion source are described. The beam optics is evaluated with TRACE-3D code.

INTRODUCTION

The 2-MeV 150-MHz proton RFQ linac is set up at RAC of MEPhI. This conventional RFQ [1] serves as a base system for the applied research works. The present report describes the works related to its injection system and its output beam-line components.

The injection system consists of duoplasmatron-type ion source which provides proton beam of the energy up to 100 keV and the current of several tens of milliamperes. The novel design of the ion source combining the principles of duoplasmatron is presented in this report.

The output beam-line consists of a doublet of the electrostatic focusing lenses, the post-accelerating 7-gap two-ridge interdigital H-resonator and a magnetic C-shaped spectrometer with vertical magnetic field. In this report, the features and status of these components are presented too.

THE INJECTION SYSTEM

The source construction

For initial tests of the linac, the duoplasmatron-type ion source shown in Fig.1 had been used. However, this ion source utilizes heated cathode with a rather short life span. In order to increase the life span and reliability of the ion source, a novel design has been proposed. It uses advantages of RF ion sources which work without heated cathode. The elements of the modified ion source has been placed inside the duoplasmatron housing using existing high-voltage and gas supplying systems, while preserving the exterior view of the ion source.

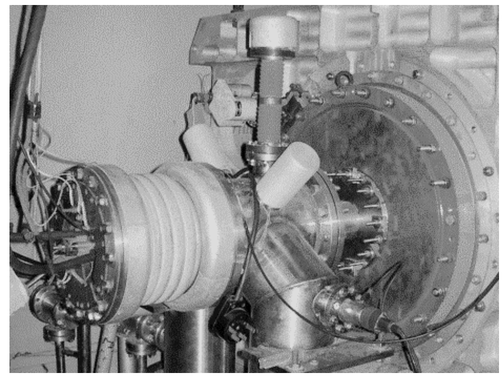

Fig.1 View of the ion source.

The interior construction the ion source is shown in Fig.1. It consists of the helix resonator 1, quartz tube 2 and discharge chamber 3. The gaseous hydrogen passes through quartz tube to the discharge chamber. RF fields in the helix resonator can ionize hydrogen under certain conditions corresponding to some threshold level of RF power. RF discharge charge burned in the tube is extended to the discharge chamber where it can stimulate an arc-discharge.

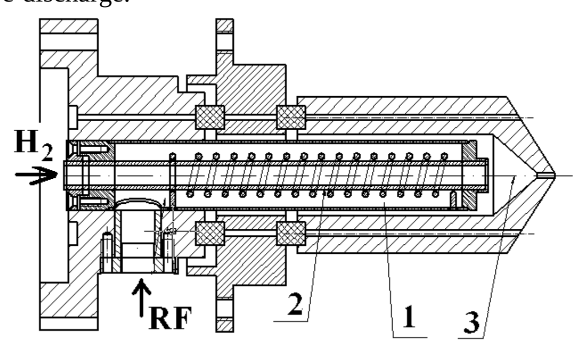

Fig.2 The interior construction of ion source.

The arc-discharge measurements

The parameters of the arc-discharge are studied using the methods of the “double-probe” [2]. The principal scheme of the measurements is shown in Fig.3. It consists of the plasma emitter made of the helix resonator with the quartz tube, the power supply unit (PSU), two ∅3 mm probes (probe-1 and probe-2), the RF detector, RF power generator, the voltmeter (V) and the amperemeter (A).

The dependence of the electron current on the probe voltage has been measured. It is approximately linear in

* kapin@mail.ru
# http://www.mephi.ru

the voltage range V_{PSU}=0÷20 V, where the electron current I_e increases from 60 μA to 140 μA. The maximum value I_e=140 μA has been reached at V_{PSU}=30 V. The supplied RF power was up to 20 W at the RF frequency of 290-300 MHz.

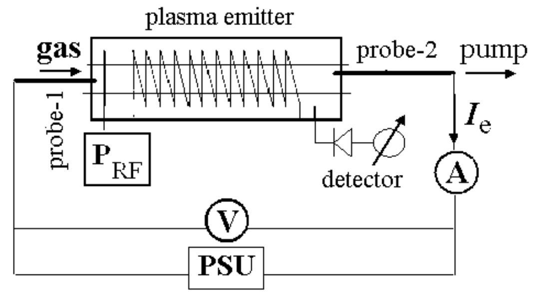

Fig.3 The principal scheme of the measurements.

THE OUTPUT BEAM-LINE

The block-scheme of the output beam-line is shown in Fig.4. It consists of a doublet of the electrostatic focusing lenses, the post-accelerating 7-gap two-ridge interdigital H-resonator and a magnetic C-shaped spectrometer with vertical magnetic field.

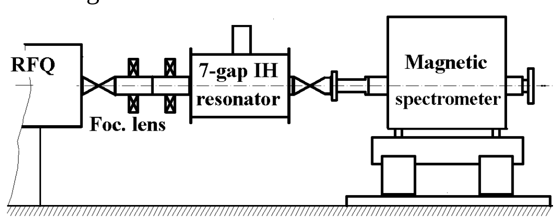

Fig.4 The output beam-line.

The 2-MeV bunched proton beam should be transported to 7-gap post-accelerating IH-structure, and further to the magnetic spectrometer. 7-gap IH-structure can provide an energy gain from up to 500 keV. It also can monotonically increase the beam energy within the 50-100μs beam pulse. It results in an amplification of the peak value of the beam current on a distant target, where beam-pulse will be compressed to several microseconds.

The 7-gap IH structure has no any external focusing elements. This short 0.5m-length structure uses relatively moderate accelerating fields and does not demand the longitudinal focusing, since the length of the beam bunches will be almost preserved within its length at any synchronous phases. Moreover, the structure can operate at synchronous phases ensuring a transverse focusing by RF-fields.

Beam optics evaluations

The beam transport in the output beam line has beam evaluated using the TRACE-3D code [3]. The simulated beam-line consists of two exit RFQ-cells, the two magnetic quadrupoles, the 90°-bending magnet with zero field-gradient index and input and exit edges simulating the magnet fringe-fields, while all components separated with appropriate drift-spaces. In these simulations, the focusing effects of 7-gap IH-stricture are neglected, and structure is simulated by the drift-space. Thus, beam focusing in this beam-line is ensured by magnetic quadrupoles and the magnet fringe-fields.

The phase-space at RF exit has been simulated with PARMTEQ. They are shown in Fig.5. In further simulations with TRACE-code these phase-spaces are replaced by ellipses with the same Courant-Snyder parameters.

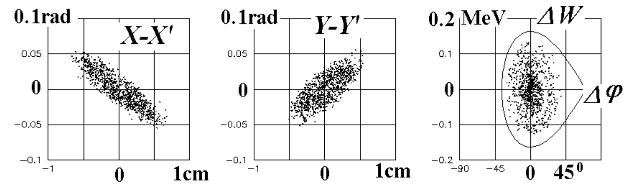

Fig.5 The RFQ phase-spaces by PARMTEQ-code.

The beam dynamics simulations are shown that without any focusing (the magnetic quadrupoles and fringe-filds are off) the beam transmission in the whole output beam-line is very low (about 2.5%). When the fringe-focusing is used, the beam transmission is increased up to 7.5%, which is still very low. Only with usage of quadrupole magnets, it is possible provide the 100% beam transmission. Figure 6 shows the beam phase-spaces at the input and output of the beam-line and the beam envelopes along the beam-line.

In these calculations, the magnet quadrupoles of the length 150 mm are located near to the RFQ-exit at the distance 100 mm. The optimal values of magnetic–field gradients are about 6-7 T/m. These values are quite moderate for a modern technology. However, a fabrication and tuning of such quadrupoles for this experimental installation may require impermissible efforts and resources at university conditions. Therefore, the alternative focusing system has been proposed.

Wire-meshed electrostatic lens

An unconventional design of the electrostatic lens featured by the two-dimensional electric field and wire-meshed beam apertures is proposed. Figure 7,a shows the ideal 2D-layout of such lens, which consists of two plane electrically-grounded wire-meshes located at planes $z=\pm l/2$ and two (upper and lower) high-voltage (Um) cylindrical electrodes of radius R located at distance a from z-axis. The 3D model of the lens and the distribution of electric potential in the lens cross-section at x=0 are shown in Fig.7,b and Fig.7,c, respectively.

In linear this-lens approximation, the focusing distance of this lens can be evaluated as $f_y=W\beta^2 a/U_m$. For 2-MeV protons (the total energy W=940 MeV and β=0.066) the lens with the radius of aperture a=1cm and the voltage U_m=100kV can ensure the focusing distance about 0.4м.

Note, that the lens provides a transverse focusing effect only in one plane, while does not affect on the beam in a perpendicular plane. The pair of such lenses can provide an independent focusing in both transverse planes. Now, these lenses are under fabrication.

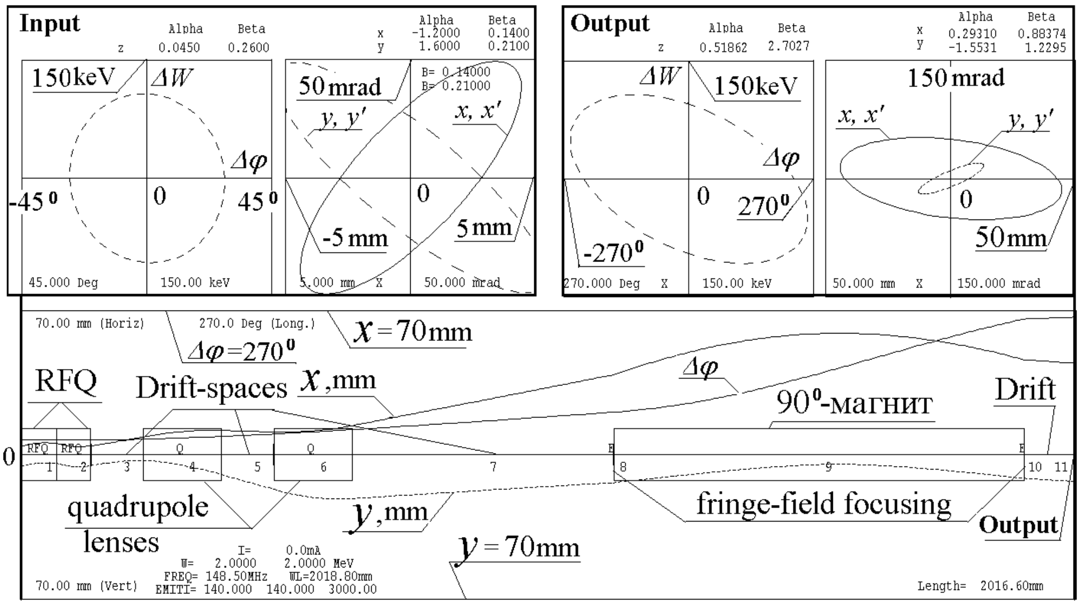

Fig.6 Beam phase-spaces and envelopes calculated by TRACE-code.

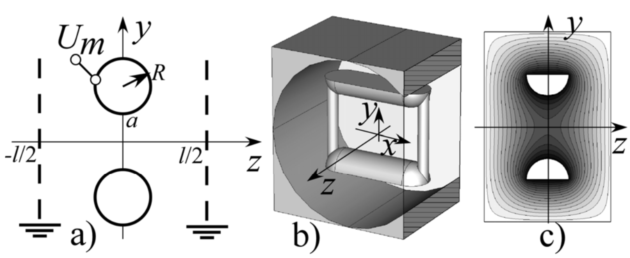

Fig.6 The wire-meshed electrostatic lens: a) 2D ideal lay-out; b) 3D model; c) potential

Tests of the IH-type resonator

Figure 8 shows the 7-gap two-ridge IH-type resonator. The cylindrical tank 1 has the length 540 mm and the internal diameter 500 mm. The plane resonance ridges 2 are located with the angle 120°. The drift-tubes 3 are alternatively connected to the ridges. The coaxial feeder 4 has the vacuum window and supplies RF power using the coupling loop 5. The tank holes and cylindrical tube 6 connect the tank interior to the vacuum pump. The internal cylindrical surface of the tank is cupper-coated, while two bottom flanges are made from the stainless steel.

The sizes of this resonator have been preliminary defined using 3D electrodynamic computer code. This resonator has been tuned to the operating RF frequency of 148.5 MHz. The measured Q-value is about 3500, while such rather low value is due to the usage of stainless steel for both bottom flanges. Coupling loop has been shaped to achieve the voltage standing wave ratio about 1.3 providing the overcoupled regime. Presently, the IH-resonator is under vacuum tests.

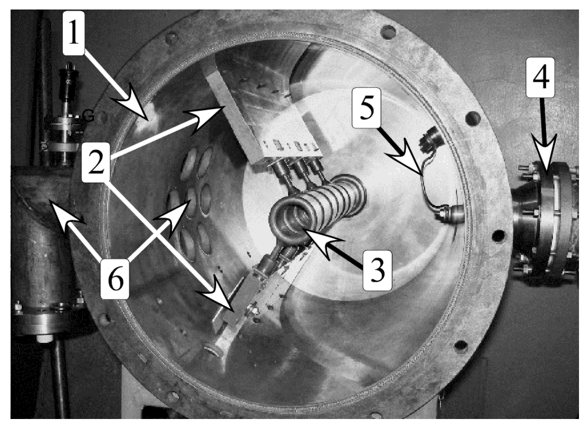

Fig. 8. The 7-gap IH-type resonator.

REFERENCES

[1] O.K.Belyaev, O.V.Ershov, I.G.Maltsev, V.B.Stepanov, S.A.Strekalovskikh, V.A. Teplyakov, A.V.Zherebtsov, “IHEP Experience on Creation and Operation of RFQs”, LINAC’2000*, MOD21, Monterey, pp. 259-262 (2000).

[2] J.D. Swift, M.J.R. Schwar, “Electrical probes for plasma diagnostics”, London.: Iliffe books, 1970.

[3] K.R. Crandall, “TRACE: An Interactive Beam-Transport Program," Los Alamos Scientific Laboratory report LA-5332 (October 1973).

[4] K.R. Crandall, T.P. Wangler, “PARMTEQ – A Beam-Dynamics Code for the RFQ Linear Accelerator”, AIP Conference Proceedings No. 177, pp. 22-28, 1988 by La Jolla Institute.

* Published at http://www.JACoW.org