DUOPLASMATRON-TYPE ION SOURCE WITH IMPROVED TECHNICAL AND OPERATIONAL PERFORMANCE FOR LINEAR ACCELERATOR

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Duoplasmatron type ion source as injector for RF linear accelerators has been developped and investigated. The structure of ion source comprisis cold hollow cathode with sign-alternating magnetic field which allows to use any plasma-creating gas. This ion source has an improved air cooling system with average discharge current up to hundreds mA. There is possibility to operate this device as a duopigatron with the insertion of an extra electrode. The beam currents of H_1^+, He^+, N_1^+ ions up to 20 mA were obtained with accelerating voltages up to 70 kV. The results of the experimental tests of this ion source combined with the RF compact proton accelerator with energy 1 MeV are presented.

1. INTRODUCTION

1 MeV proton linear accelerator URAN-1 has been built in 1986 at MEPhI. The URAN-1 accelerator for material science experiments has following main parameters: injection energy 60 keV, output energy 1,1 MeV, peak value of beam pulse current 6 mA, pulse RF power 85 kW, frequency 150 MHz [1]. Specific option conditions for accelerating channel with alternating-phase focusing lead to the definite requirements to the injector ion beam parameters. As calculations show it is necessary to have 50 mA proton beam with 3 mm radius in the crossover and normalized emmitance less than 0,15 cm mrad in the region of the first accelerating gap. In this paper the injection system of accelerator, including duoplasmatron-type plasma generator and einzel lense is discussed. Some improvments of the technical and operational performance of ion injector are presented. Modifications of the geometry of extraction region and of the proton beam formation system are discussed.

2. PLASMA GENERATOR

Duoplasmatron having high technical and operational performance was choosen as the efficient ion beam source [2]. Hollow cold cathode and permanent magnets for the discharge magnetic contraction system are used with the purpose to decrease power consumption. Air cooling (in some cases forced) was choosen keeping in mind industrial applications of the ion source. As a result of calculations and experiments ion source shown on Fig.1 was developped.

Working gas is introduced through the hole in the cathode's cover 1 and gas distributor 2 into the aluminium hollow cathode 3. The cathode is situated in th alternating sign magnetic field created by the permanent ring BaFe magnets 4 [3]. The cathode is cooled by air flow by means of radiators 5.

Experimentally measured dependence of longitudinal magnetic field on axis of cathode system with alternately installed magnets is given on Fig.1.

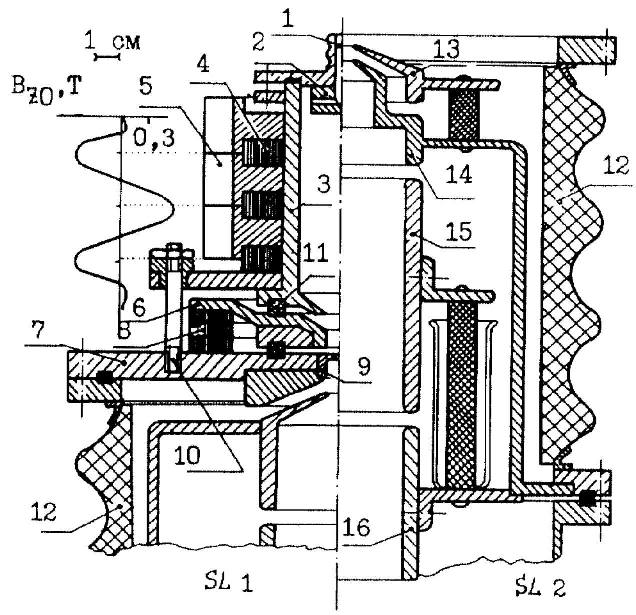


Fig.1. The geometry of plasma generator and of ion-optical system (the details see in text).

Specific desing decision is used in one of modifications of cathode duoplasmatron system [3]. This system is equipped with the cylindrical magnesium alloy insertion with the purpose to increase the lifetime and to improve termal conditions of the cathode as a result of the lower discharge voltage. The insertion is installed in the closed end of the cathode cavity in the way that these plane insertion's butt-end disposes in the middle plane of the first magnet pair nearby the deaf butt-end. In this region the conditions for the closed drift of electrons in the crossed electric and magnetic fields are satisfied so that the density of the ion current going to the insertion is increased. Additional increase of the electron emission from the surface of insertion is achieved by proper choice of materials with the low work function, e.g. magnesium alloy. Voltage-amper caracteristic of this cathode system is shown on Fig.2. The discharge voltage in the wide range of discharge current without insertion has the value 320-350 V (the working gas - argon, gas pressure in discharge chamber 5-10

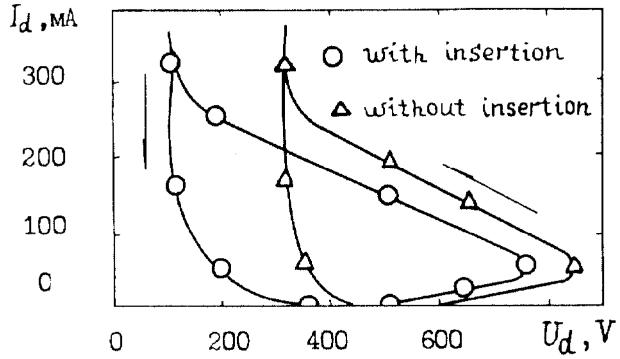


Fig.2. Dependence of discharge voltage Ud on discharge current Id for modified cathode system.

Pa, duty factor 1). After the insertion is installed the discharge voltage decreases to about 120-150 V with identical conditions.

Energy price of ion at the first approximation is given by [4] :

$$C_i = f_i^{-1}(C^* p_i^{-1} + f_K U_d) \qquad (1)$$

where f_i - relative number of ions going to the beam, f_K -relative number of ions bombarding the surfaces having cathode potential; C^* -the limit of energy price of ion; P_i -ionization probability; U_d - discharge voltage.

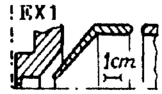
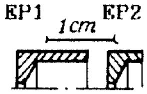
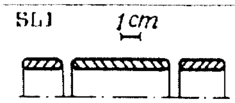
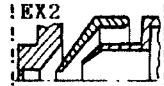
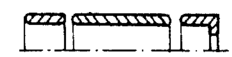
By substitution into (1) the values $f_i = f_K = P_i = 1,0$; $C^*=50$ eV we get the energy price of ion decreased with the use of insertion nearly 2,2 times.

Intermediate electrode 6 and anode 7 are made of ferromagnetic material. There are the poles of ring permanent magnets system 8. The ribbons of the intermediate electrode's external parts and of anode serve to improving the cooling. For the same reason intermediate electrode has copper base. The desing of ion source allows to create high density of plasma in the region of the emission tungstem hole in the anode 9. Because of the long brads 10 there is possibility to install additional electrodes. These electrodes increase ion generation efficiency and at the same time help to produce ion of metals through the cathode sputtering. The hole block of the plasma generator may be dismantled, it uses the ftoro-plastic sealings 11. Ceramic isolator 12 holds on itself ion beam extraction and formation systems and is connected with anode.

3. EXTRACTION AND ION BEAM FORMATION. DISCUSSION.

Various extraction and proton beam formation systems were considered (see table 1). One version of the ion optic systems formed by combination of extractor EX2, expander EP1 and electrostatic lense LS1 is shown on fig.1. If we assume the beam energy in the region of grounded electrode 14 equals eUb and potentials of electrodes 13 26 correspondingly U_1, U_e, U_i, U_a then it's convenient to describe parameters of

Table 1
Ion-optical system of accelerator injector

N	Extractor	Expander	Einzel lense
1	EX1 	EP1 EP2 	SL1 
2	EX2 	EP3 EP4 	SL2 

immersion and einzel lenses by coefficients $K_i=U_i/U_b$; $K_1=U_1/U_b$. Emittance measurements were carried out by two slits method with following computer treatment. Ion beam has smaller angular divergence for curve 2 on fig.3 so emittance is roughly 25% smaller. The electric field at the output of immersion objective is increased in the EX2 system by means of rapprochement of 13 and 14 electrodes so the optical lense parameters are improved [6].

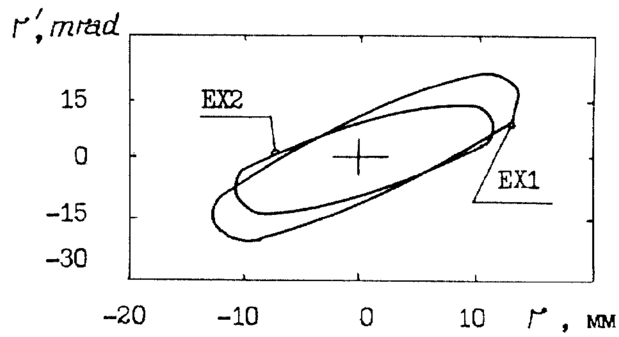


Fig.3. Emittance diagrams of proton beam for EX1 and EX2 extraction systems.

The value of the coefficient Ki strongly influences on the initial space-angle beam characteristics because the form and the position of plasma surface depends on the value of Ki under fixed discharge conditions. There is optimal value of Ki corresponding to the minimal angle divergence and to minimal beam emittance. This situation means an optimal matching of ion beam to the immersion objective output with einzel lense behind (fig.4). Correlation of the results may be achived according to similarity parameter [7]

$$P = 22{,}5 \frac{\pi d^2}{(U_b - U_i)^2} \frac{J}{\sqrt{2e/M}} \qquad (2)$$

where d- the length of extractor's gap; j- the density of the ion beam current; M- the atomic mass.

Angular divergence is minimal when P=1. Any variations in injector conditions when parameter P is equal zero lead to the increase of angular divergence of beam. Configuration and dimension of the expander is influenced by the given initial space-angle beam performances (fig.5) Two groups of particles are observed in any cases: 1) the main part of particles focused in the region of the first slit of measurement device (main component); 2)low intensity part

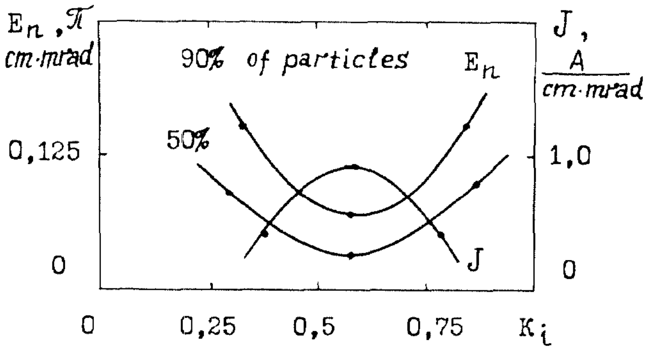


Fig.4. Dependences of normalized emittance En and phase density J of proton beam on coefficient value Ki with EX2 and EP1

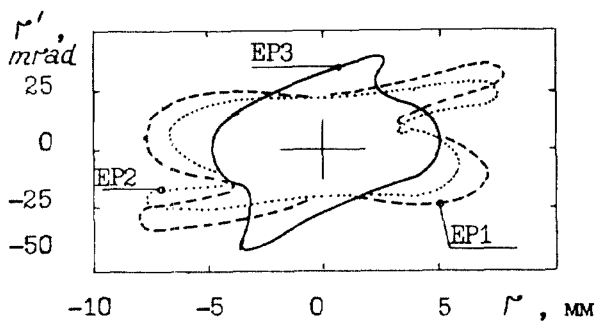


Fig.5. Emittance diagrams of proton beam: Id=10 A; gas pressure 5 Pa; Ki=0,57; Kl=0,964; beam energy 80 keV.

the beam composing halo, which itself is focused in another plane. This part is observed on emittance diagramm as abberation wings (table 2).

Expander EP1 is the best by emission performances as comparised with expanders of another dimensions and configurations (fig.6 a,b). When optical strength of the lense increases the ion beam convergence angle and effective emittance at the lense output increase too. Einzel lense LS2 has smaller abberation level [5] but the last results of its performance improvements are not discussed in this paper. The necessary beam radius in crossover is achieved in the range of coefficient values Kl=0,963-0,965. In this case focuse distance of the einzel lense is equal 280-320 mm.

This experimental data have been used for the matching of injector beam with the acceptance of alternating-phase focusing accelerating channel [1]. Calculated acceptance of accelerating channel is shown by dotted line on fig.5. Matching of the

Table 2
Beam parameters for different expander types

Expander types	En, cm! mrad	Rb, mm	Diverg., mrad	Current, mA	Halo, %
EP1	0,22	4,7	35	75	30
EP2	0,15	3,2	30	54	15
EP3	0,13	3,1	30	52	13
EP4	0,11	2,8	25	45	8

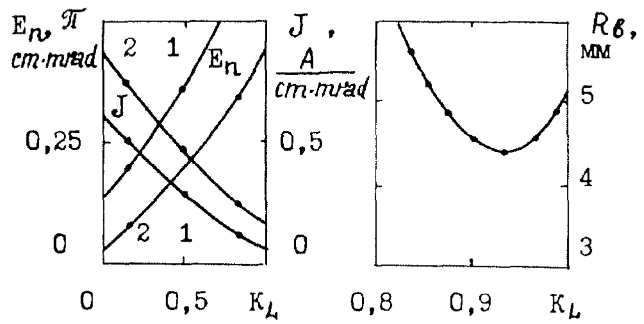


Fig.6. Dependences of En, J and minimal proton beam radius Rb on value Kl: 1-90% of particles; 2-50%; Ki=0,57; for EP1, EX2, SL1.

injector beam by the choice of the design and plasma generator parameters allows to get 30% of efficiency of the capture of injected beam into RF acceleration process.

5. CONCLUSION

Described above ion injector including duoplasmatron-type plasma generator and ion-optical system is characterized by high technical and operational performances in wide range of parameters of the extracted ion beam. Ion beams of H_1^+,He^+,N_1^+ with intensity up to 50 mA (proton equivalent) are obtained in duoplasmatron mode of operation with accelerating voltage up to 70 kV, pulse discharge current up to 30 A and discharge voltage 100-150 V. Furthermore, its exploitation in continuous operational mode with ion current up to 20 mA permits to conclude that this system may be used not only as accelerator injector but also in adjacent branches (low energy ion implantation etc).

6. REFERENCES

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