OPTIMIZATION OF ELECTRON BEAM PARAMETERS OF LIA-10M ACCELERATOR

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A numerical simulation of the LIA-10M accelerator was carried out. It is shown that at the existing configuration of the diode unit and maximal for LIA-10M injection parameters (3 MeV, 50 kA) significant (up to 40%) beam losses in the accelerating channel are possible. As a result of calculations the injector cathode geometry was optimized what permitted to avoid beam electron leakage onto the walls of accelerating channel and to improve significantly output parameters of the LIA-10M accelerator.

PACS: 29.17.+w; 41.20.Bt

INTRODUCTION

More than 3000 working pulses were produced on the linear induction accelerator LIA-10M [1, 2] since it was created and up to now. In the course of accelerator testing it was emerged, that the injected beam was surrounded by halo from electrons, emitted from the cone part of cathode. Its diameter is rather large, about 160 mm, what is comparable to aperture of the accelerating channel (∅200 mm). In the process of acceleration there was observed an increase of beam transverse dimensions and the accompanying halo. This led to electron hitting the accelerating tubes of several last inductors what initiated electric breakdowns over the surface of their insulators.

To suppress parasitic emission it is necessary to optimize distribution of magnetic field in the injector as well as the geometry of cathode. When optimizing, together with a study of the electron beam dynamics in the injector one should study the processes of its acceleration and transport along the accelerator due to possible losses of the beam charge on the walls of vacuum tube.

The paper presents the results of injector cathode optimization taking into account the beam dynamics in the accelerating channel. Calculations were carried out on an accelerator full-scale model using electromagnetic code BEAMS25 developed in RFNC-VNIIEF [3].

1. CALCULATION MODEL

LIA-10M accelerator consists of injector, 16 identical inductors, transporting channel (TC) consisting of three sections of 1-m length and an output unit (OU) (Fig.1). When constructing the calculated model there is taken into account both the region of formation and acceleration of the beam as well as the high-voltage pulse forming systems of injector and inductors. Calculations are carried out on the square non-uniform mesh whose dimensions are: along the z-axis $k_z = 1250$, along the r-axis $k_r = 100$. Average mesh length along the z-axis $h_z \approx 12$ mm, along the r-axis $h_r \approx 6$ mm.

High-current electron beam formed in the injector (1) moves along the accelerating channel (2) of 16 inductors. After acceleration the charged particle beam falls in TC (3) and further – in OU (4) where it is compressed in the radial direction in the growing magnetic field, after that it falls on the target (5).

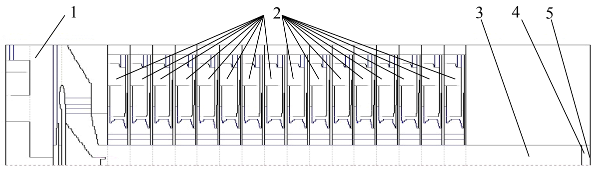

Fig.1. Calculation scheme of LIA-10M accelerator

The processes of acceleration and transport were studied at beam current duration of ~ 20 ns (FWHM) that some less than accelerating voltage pulse duration (~ 22 ns) in inductors. In this case, at good match of the on-time program of inductors one manages to prevent the beam charge loss on the negative polarity of accelerating voltage and acceleration without change of beam current pulse shape is possible. Therefore, accounting of particles lost on the walls of accelerating channel is facilitated.

High-current beam of relativistic electrons in the accelerator LIA-10M is accelerated in the pulsed guiding magnetic field. Distribution of magnetic field along the axis is non-homogeneous, the average value of magnetic field in the accelerating channel and TC is ~ 0.5 T. In OU the field grows up to the value ~ 1 T. In the accelerator design model the distribution of magnetic field is set at the facility axis. At the points outside the axis the magnetic field is calculated by formulae of paraxial expansion with precision $O(r^4)$ [4].

2. SIMULATION OF LIA-10M WITH NON-OPTIMIZED CATHODE

Calculations with non-optimized cathode were carried out for the diameter of its cylindrical part $d_c = 80$ mm. For the amplitude of accelerating voltage $U_D \approx 3$ MV (calculation No. 1) in the injector there is formed a beam of diameter 170 mm, which increases up to 200 mm (Fig.2) in the acceleration process. While it moves along the accelerator the beam loses a part of its charge. The current amplitude in the injection section ($z = 2.63$ m) equals 51 kA, at the juncture cross-section of the sixteenth inductor with TC ($z = 11.83$ m) – 41 kA and on the target ($z = 15.11$ m) is 35 kA (Fig.3). Current widths in all sections remain practically the same: the current width in the injection cross-section is 20 ns and on the target is 19 ns.

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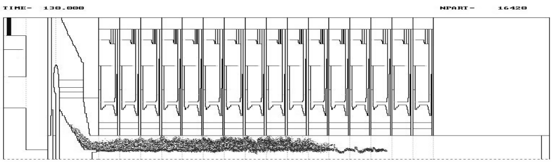
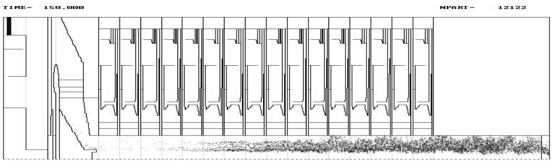


t = 130 ns



t = 150 ns

Fig.2. Distribution of particles in the plane r-z (calculation No. 1)

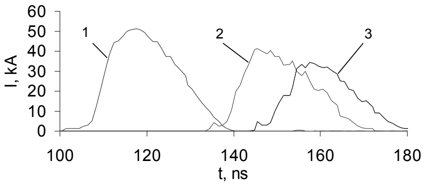
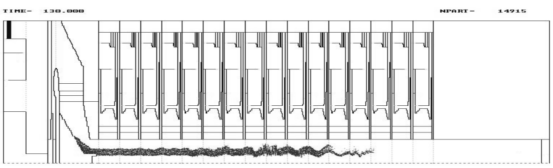
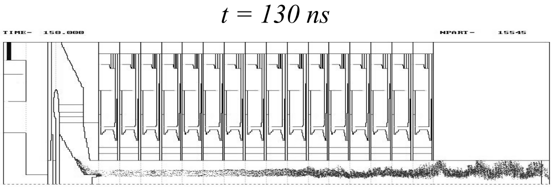


Fig.3. Beam current pulses in different cross-sections (calculation No. 1): 1 – z = 2.63 m, 2 – z = 11.89 m, 3 – z = 15.11 m

In order to reduce the charge loss in the accelerating channel, currently the injector operates with lowered accelerating voltage in the diode ($U_D \approx 2$ MV). In this case in the injector there is formed a beam of diameter 120 mm (calculation No. 2) which in the acceleration process increases up to 200 mm in the transporting channel (Fig. 4).



t = 130 ns



t = 150 ns

Fig.4. Distribution of particles in the plane r-z (calculation No. 2)

While beam moving along the accelerating channel its peak current lowers slightly from 20 kA up to 19 kA (Fig.5). The current pulse width decreases from 20 ns in the injection cross-section up to 17 ns on the target.

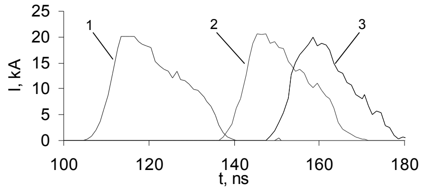


Fig.5. Beam current pulses in different cross-sections (calculation No. 2): 1 – z = 2.63 m; 2 – z = 11.89 m; 3 – z = 15.11 m

The work with lowered voltage in the injector leads to a significant, about two-fold decrease of accelerator output parameters: the total charge on the target lowers from $6 \cdot 10^{-4}$°C for the mode $U_D \approx 3$ MV up to $3.1 \cdot 10^{-4}$°C for $U_D \approx 2$ MV and the total energy on the target – from 12.3 up to 6.3 kJ, correspondingly.

In an effort to eliminate the parasitic emission and to raise the output parameters of accelerator, one should optimize the injector cathode geometry and distribution of magnetic field in it. Change of magnetic field distribution in the injector requires its solenoids alteration what leads to significant material expenses and outlays on calculation and design works. The simplest decision is cathode geometry optimization at the given distribution of the magnetic field in the injector.

To suppress the parasitic emission one should change the cathode geometry so that the electric field strength on its cone surface does not exceed some threshold value $E_{th} = 100$ kV/cm. When optimizing the cathode geometry there was increased an angle between the generatrix of its cone part and the symmetry axis – α_0. With increase of α_0 the maximum strength decreases and for some α_{0opt} it becomes lower than E_{th} for all diameters d_c (Fig.6).

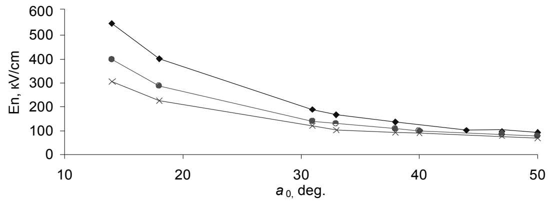
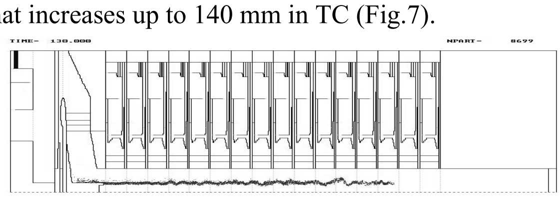


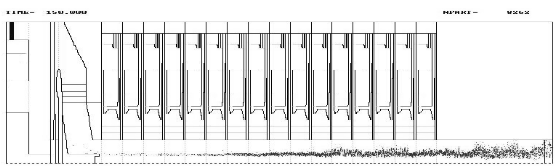
Fig.6. Dependence of maximal field strength on the conical cathode surface on α_0 at different d_c:
♦ – 40 mm; • – 80 mm; x – 120 mm

3. SIMULATION OF LIA-10M WITH OPTIMIZED CATHODE

In the case of $d_c = 80$ mm, $U_D \approx 3$ MB (calculation No. 3) the injector forms a beam of diameter ~ 80 mm that increases up to 140 mm in TC (Fig.7).



t = 130 ns



t = 150 ns

Fig.7. Distribution of particles on the plane r-z (calculation No. 3)

Amplitude of beam current pulse in all cross-sections is ~ 36 kA, duration – ~ 20 ns (Fig.8). The beam

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charge on the target is $6.4 \cdot 10^{-4}$°C, the total particle energy is 13.7 kJ what exceeds the corresponding parameters for the accelerator with a non-optimized cathode.

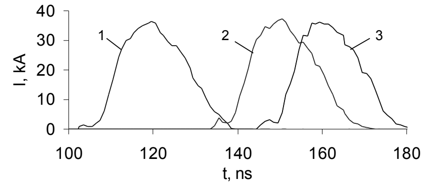


Fig.8. Beam current pulses in different cross-sections (calculation No. 3): 1 − z = 2.63 m; 2 − z = 11.89 m; 3 − z = 15.11 m

Fig.9 presents the charge Q_L loss in the accelerator sections for optimized and non-optimized cathodes with d_c = 80 mm. The losses are normalized with regard to injected charge $Q_{inj.}$ Sections 1−16 correspond to inductors, sections 17−19 – to sections TC, section 20 – OU. When working with non-optimized cathode with $U_D \approx 3$ MV (1) the charge loss starts from the third inductor, the total charge losses on the accelerating tubes is 20% from the injected charge, the total losses – 36%. For $U_D \approx 2$ MV there are practically no charge losses in inductors, the main losses are in TC and OU (2), the total charge losses are 10%. When working with optimized cathode with $U_D \approx 3$ MV no charge losses in inductors take place, the main losses are in the last section TC (3), the total charge losses – ~ 1.5% from the injected charge.

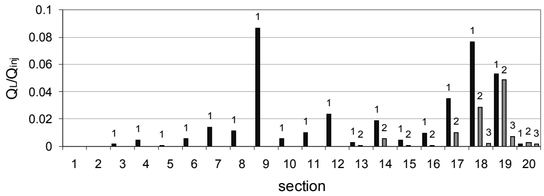
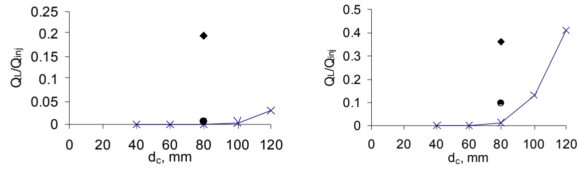


Fig.9. Charge losses in the accelerator sections: 1 - calculation No. 1; 2 − calculation No. 2; 3 - calculation No. 3

There was performed simulation of the accelerator with the optimized cathode with d_c from 40 to 120 mm (Fig.10). For cathodes with diameter ≤ 100 mm the main charge losses are on the walls of TC and OU. In case of 120-mm cathode, the beam losses inside the accelerating channel are 5% of the injected charge and they fall on several last inductors of the accelerator. The total losses are ~42% of the injected charge. For comparison this figure presents the charge losses in the accelerator by the non-optimized cathode.



a *b*

Fig.10. Charge losses on the accelerating tubes (a), total losses (b): calculation No. 1 (♦), calculation No. 2 (●), the optimized cathode (x)

When working with optimized cathode, the main losses of beam charge take place in the transporting channel and output unit of LIA-10M. Therefore, these accelerator units need in modernization to provide required magnetic field distribution in them.

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ОПТИМИЗАЦИЯ ПАРАМЕТРОВ ЭЛЕКТРОННОГО ПУЧКА УСКОРИТЕЛЯ ЛИУ-10М

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Проведено численное моделирование ускорителя ЛИУ-10М. Показано, что при существующей конфигурации диодного узла и максимальных для ЛИУ-10М параметрах инжекции (3 МэВ, 50 кА) возможны значительные (до 40%) потери пучка в ускорительном тракте. В результате расчетов оптимизирована геометрия катода инжектора, что позволило избежать утечки электронов пучка на стенки ускорительного тракта и существенно улучшить выходные параметры ускорителя.

ОПТИМІЗАЦІЯ ПАРАМЕТРІВ ЕЛЕКТРОННОГО ПУЧКА ПРИСКОРЮВАЧА ЛІП-10М

В.С. Гордєєв, Є.С. Михайлов, Г.А. Мисков, І.В. Вікторов, І.В. Паршина

Проведено чисельне моделювання прискорювача ЛІП-10М. Показано, що при існуючій конфігурації діодного вузла і максимальних для ЛІП-10М параметрах інжекції (3 МеВ, 50 кА) можливі значуі (до 40%) втрати пучка в прискорюючому тракті. У результаті розрахунків оптимізована геометрія катода інжектора, що дозволило уникнути витоку електронів пучка на стінки прискорюючого тракту і суттєво поліпшити вихідні параметри прискорювача.