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OPTIMAL RF-PHOTOGUN PARAMETERS FOR THE NEW INJECTION LINAC FOR USSR PROJECT

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Abstract

The beam dynamics analysis of the RF-gun with photocathode for Russian 4th generation light source Ultimate Source of Synchrotron Radiation (USSR-4) was done to chose the optimal length of the section and cell's number and also to define optimal accelerating gradient and injection phase. The simulation of electrodynamics characteristics and fields distribution in the RF-gun based on 3.5-, 5.5- and 7.5-cell π-mode standing wave accelerating structure at operating frequency 2800 MHz was done. The influence of the beam loading effect on the field amplitude and beam dynamics was the main purposes of study also. The beam dynamics simulation results will present in the report and optimal RF-gun parameters will discuss.

INTRODUCTION

The scheme of the proposed linear electron accelerator which will be used as an injector to the main ring (top-up injection) is similar to the structure of the injector for the CERN FCC-ee: two RF-guns (with a photocathode and a thermionic cathode) and several tens of identical regular sections (see Fig. 1) [1-2]. The development was carried out within the design framework of the 4th generation Ultimate Source of Synchrotron Radiation (USSR-4) for the National Research Center "Kurchatov Institute". In this paper beam dynamics simulation results in RF-gun with photocathode are presented. The beam dynamics analysis in the accelerator was done by using of BEAMDULAC-BL code [3]. The program allows to take into account the beam loading effect and quasi-static components of the beam self-coulomb-field.

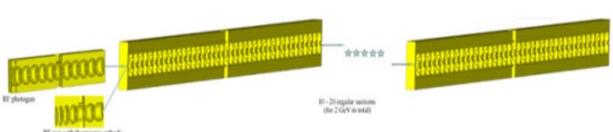

Figure 1: Possible scheme layout of linear accelerator-injector.

BEAM DYNAMICS SIMULATION IN RF-PHOTOGUN

Beam dynamics simulation in RF-gun with photocathode with intensity of 250 pC per bunch for duration of 10 ps was carried out. To achieve the minimum energy spectrum, the parameters of several versions of the photogun (3.5-, 5.5- and 7.5-cell) were optimized (see Fig. 2). Simulation results depending on the field amplitudes in the cells (E_1 – E_4, kV/cm) are presented in Table 1, and taking into account the beam loading in Table 2.

Table 1: Simulation Results Depending on the Field Amplitudes in the Cells

E_1, kV/cm	E_2, kV/cm	E_3, kV/cm	E_4, kV/cm	$\frac{\delta W}{W}$, %	Max E_{out}, MeV
1000	1000	1000	1000	2.5	9.439
900	**1000**	**1000**	**1000**	**1.7**	**9.438**
800	1000	1000	1000	2.2	8.678
750	1000	1000	1000	2.2	8.437
700	1000	1000	1000	2.2	8.181
900	900	1000	1000	3.0	8.390
800	**900**	**1000**	**1000**	**2.0**	**8.808**

According to results the 5.5-cell photogun provides the required minimum value of the energy spectrum for bunches with a charge of 250 pC per bunch and duration of 10 fs.

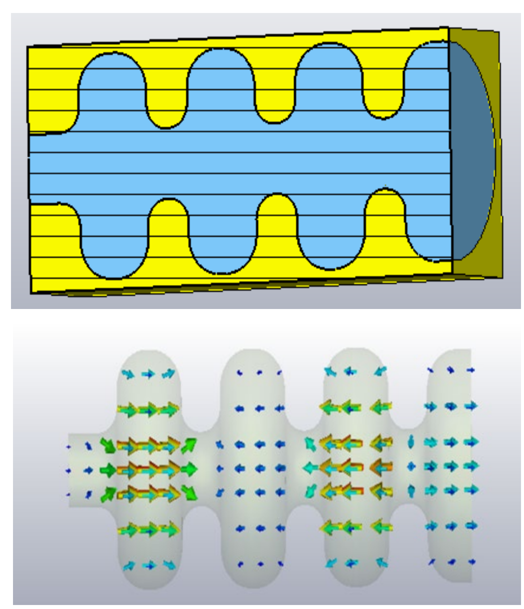

Figure 2: 3.5-cell RF-gun view and electrical field distribution.

The output beam spectrum at different electric field amplitudes (700-1000 kV/cm) in the cells of RF-photogun are shown in Fig. 3. Output longitudinal emittance and beam cross section are shown on Figs. 4 and 5.

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Table 2: Beam Dynamics Simulation Results Taking into Account the Beam Loading at $I = 20$ A

E_1, kV/cm	Cells number	$\frac{\delta W}{W}$, %	E_{max}, MeV	Beam Energy Spread, %
600	3.5	2.0	6.2	1.8
600	**5.5**	**2.7**	**8.1**	**0.9**
700	5.5	2.8	8.2	1.2
600	7.5	2.7	4.8	2.2
600	7.5	2.5	4.8	2.0

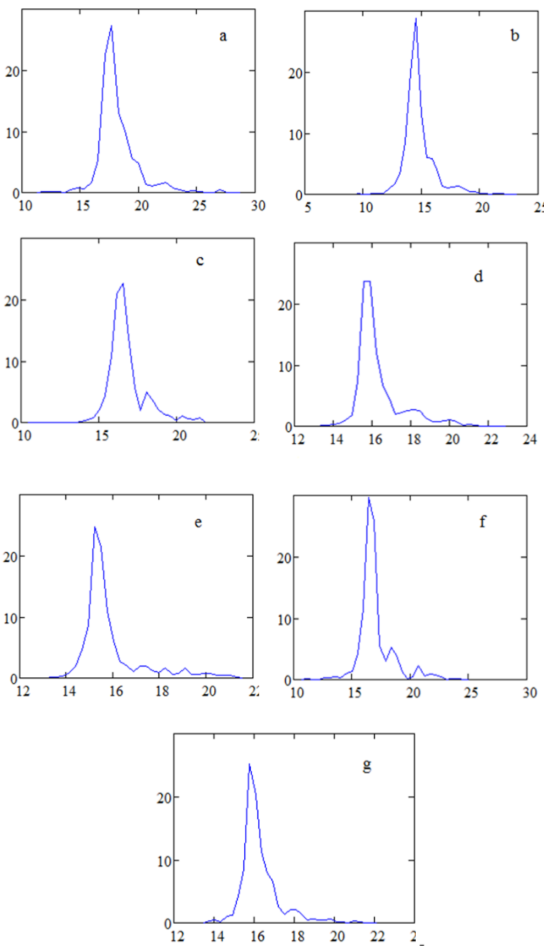

Figure 3: The output beam spectrum at different electric field amplitudes in the cells of RF-photogun.

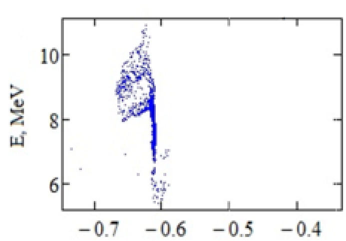

Figure 4: Output longitudinal emittance.

During steps of dynamics simulation preformed electron beam and accelerated in a 5.5-cell photogun was injected into the first regular section and completely captured. Such bunch can be accelerated with an increase of energy slightly higher than for a beam generated by RF-gun with a thermionic cathode.

This is possible because its length less by an order than for a bunch formed by thermionic cathode and the average acceleration rate will be higher.

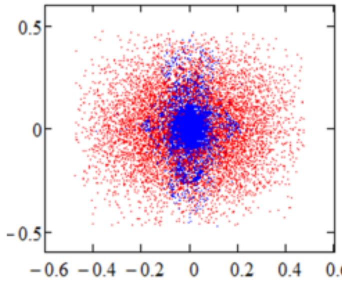

Figure 5: Beam cross section (the initial distribution is shown in red, at the output - in blue).

Table 3: Beam Dynamics Simulation Results Depending on the Field Amplitudes and Injection Phase in the 5.5-cell Photogun

Electric field, kV/cm	Injection phase, $\delta\varphi$	W_{out}, MэB	Transmission coeff., %	Output energy spectrum FWHM %
400	3.0	6.54	100.0	±2.8
500	3.1	8.36	99.9	±4.6
600	3.2	10.46	99.9	±3.1

Thus, the bunch acceleration generated by the photocathode can be performed at field strength of about 575 kV/cm rather than 600, or the output energy will be slightly higher about 6.3 GeV. Beam dynamics simulation shows that the energy spectrum for a bunch with a charge of 250 pC will be very low after the regular part of the accelerator (~ 0.08%) [4]. The transverse emittance will be ~ 0.3 nm · rad. It has also been shown that the current transmission coefficient is ~ 99.5% (see Fig. 6).

BEAM LOADING EFFECT

One of the purposes of the simulation was study of the beam loading effect on the distribution of the RF field amplitude and the beam dynamics in the «bunch-to-bunch» mode, at which the bunch loads the accelerating structure and the following train of bunches should receive a smaller increase of energy. It was shown that a bunch with a charge of 150 pC (current 15 A with a bunch duration of 100 fs) has no significant effect on the amplitude of the accelerating field. The maximum amplitude decrease is observed in the middle of the accelerating cell, but it is only 1.7% (see Fig. 7).

Simulation also showed that the Coulomb field practically has no effect on the dynamics, leading only to an insignificant increase (up to 0.15 mm or 30%) of the beam envelope in the bunching cells (see Fig. 8).

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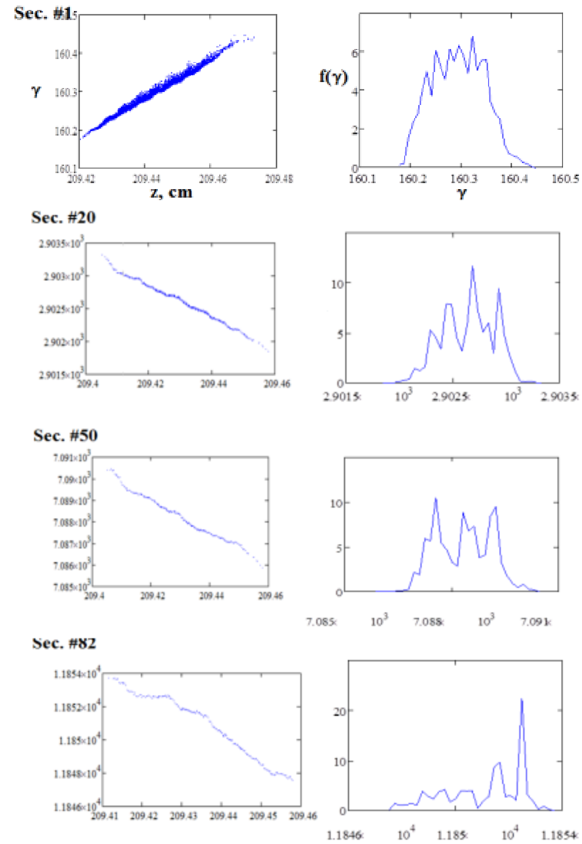
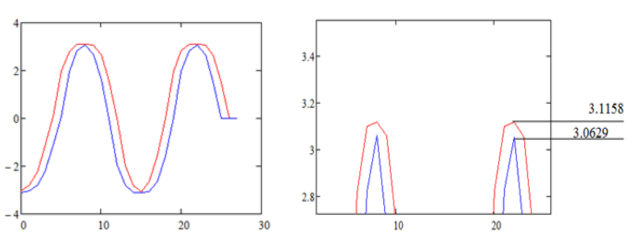


Figure 6: Beam dynamics simulation results in regular part of accelerator-injector for bunch with 250 pC charge, generated by RF photogun. Phase portraits on the phase plane (γ, z) and the energy spectrum.

It has also seen that the size of the envelope differs by 0.0529 mm inside the section, but at the exit the size of the beam is the same.



(a) (b)

Figure 7: Dimensionless amplitude of the accelerating field $\hat{e} = eE / 2\pi W_0$ in the center of the cell before the first bunch pass (red curve) (a) and taking into account the introduced disturbance (b).

For a beam generated by a photogun, it is possible to accelerate up to 12 bunches with a charge of 250 pC per bunch with an energy drop from the first bunch to the last less than 1.5%.

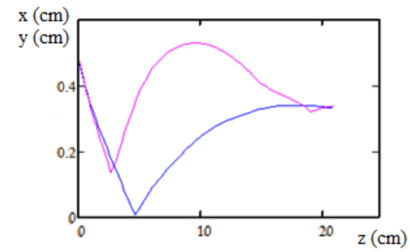


Figure 8: The beam envelope with and without beam loading.

Such beam loading can be compensated, first, by RF power supply system, which makes it possible to pump energy into regular sections, and by a small field's phase displacement, in which a laser pulse is applied to the cathode, from bunch to bunch.

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CONCLUSION

The beam dynamics simulation results of the RF-photogun, as one of the options for the new injection linac was described. Geometric parameters and electrodynamics characteristics were optimized. A 5.5-cell photogun provides the required minimum value of the energy spectrum (~ 0.08%) for bunches with a charge of 250 pC per bunch and duration of 10 fs. It was shown that the beam loading has no significant effect on the beam dynamics.

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