ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA08

BEAM DYNAMICS SIMULATION IN A LINEAR ELECTRON ACCELERATOR – INJECTOR FOR THE 4TH GENERATION SPECIALIZED SYNCHROTRON RADIATION SOURCE USSR

I. A. Ashanin[1], S. M. Polozov[1] A. I. Pronikov[1] , Yu.D. Kliuchevskaia
National Research Nuclear University MEPhI, Moscow, Russia
[1]also at National Research Center "Kurchatov Institute" Moscow, Russia

Abstract

USSR project (Ultimate Source of Synchrotron Radiation, 4th generation synchrotron light source) is being developed in the NRC «Kurchatov Institute». This Light Source will include both storage ring and soft FEL (Free Electron Laser) and one linac with an energyof 6 GeV, which is planned to be used both for beam injection into storage ring (top-up injection) and as a high-brightness bunch driver for FEL. It is suggested to use two front-ends in this linac: RF-gun with thermionic cathode with adiabatic buncher for injection into storage ring and RF-gun with photocathode will use to generate a bunch train for FEL. The purpose of this work was to development a general layout of the top-up linac with the aim of minimize of the beam energy spread and transverse emittance at the exit and analysis the front-to-end beam dynamics in this linear accelerator.

INTRODUCTION

The 4th generation synchrotron light source called Ultimate Source of Synchrotron Radiation (USSR-4) is under construction at the moment in Russia [1-2]. New 4th generation source design will require the innovations and evolution in the domestic technologies of magnetic and vacuum systems, the solution of new problems in materials science and instrument engineering. New facilities will become one of the biggest world scientific centres conducted researches in a variety of disciplines spanning physics, chemistry, materials science, biology and nanotechnology.

General facility layout includes 6 GeV main storage ring and top-up injection linac. The top-up injection scheme into USSR main storage synchrotron is preferable. Thus it is proposed to use the same linac with two RF-guns. First of them will RF photogun and can be used to generate the drive beam for FEL. The second one will RF-gun with thermionic cathode can be used for injection into storage ring. Such layout leads to two linacs operation modes: 6 GeV beams for injection and 6-7 GeV high-brilliance bunches for FEL. It leads to the same for-injection scheme as it was used for SuperKEK-B and MAX-IV and is proposed for FCC-ee [3-4]. Both injectors will operate with the same regular part of the linac which consists of 80-90 identical sections (see Fig. 1). The planning transverse emittance is 70-100 pm·rad. The length of the circumference of the main storage ring is about 1300 m, it will consist of 40 super periods, including two asymmetric magnetic arches and a gap of about 5 m for the placement of plugg-in devices between them.

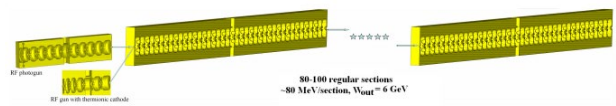

Figure 1: Expected scheme of the 6 GeV top-up injection linac.

The "front-to-end" beam dynamics simulation results in this linear accelerator will discuss in the paper.

All results of the beam dynamics simulation carried out using the BEAMDULAC package developed at the Department of Electrophysical Facilities of NRNU MEPhI [5]. The BEAMDULAC-BL code version was designed to study the beam dynamics in high-intensity electron linacs, it is discussed in detail in [6] and it was tested for a number of e-linac designs [7-8].

RF-GUN'S PARAMETERS COMPARISON

The beam dynamics simulation was done both for RF-guns with photocathode and thermionic cathode (see Table 1) [9]. The beam dynamics simulation in the RF-photogun shows that 250 pC and 10 ps bunch can be easily accelerated by 5.5-cell accelerating structure with comparatively low accelerating gradient of 600 kV/cm [10]. RF-gun with thermionic cathode is a classic adiabatic buncher consists of 26 accelerating cells and 25 coupling cells. First 4 cells are the bunching cells and the phase velocity and the RF field amplitude growth here cell-to-cell. In the other 22 cells this parameters are constant.

Table 1: Comparison of the RF-gun's Parameters

Parameter	Photogun	Thermogun
W_{inj}, keV	100	100-120
E_{acc}, kV/cm	450-600	150
W_{out}, MeV	10.5	10.3
Transmission coeff., %	100	85-90
FWHM, %	±1	±2 %
B, T	0.1	0.035

As the regular section, it is proposed to use a biperiodical accelerating structure (BAS) on a standing wave with a high coupling coefficient in the magnetic field, comparison

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA08

of simulation results for structures on standing and travelling wave is held below.

CHOICE OF REGULAR SECTION

Simulations show that TW SLAC section can't be effectively used for injection due to such value of the energy spread and the transverse emittance which will leads to the low injection efficiency. The strong influence of the current loading does not allow accelerating more than 3-5 bunches in one pulse. Comparatively low energy spectrum was obtained in dynamics simulation of the beam at the output of SW BAS [8]. Comparison parameters are presented in Table 2. Beam dynamics simulation results are illustrated in Fig. 2.

Table 2: Comparison of the Beam Dynamics Simulation Results for Regular Part of Accelerator

Parameter	TW SLAC	SW BAS
Length, m	0.305	0.210
Energy gain, MeV/section	91	71
Number of sections	66	86
FWHM, %	±2.5	±0.9
Transverse emittance, nm·rad	1-5	0.3

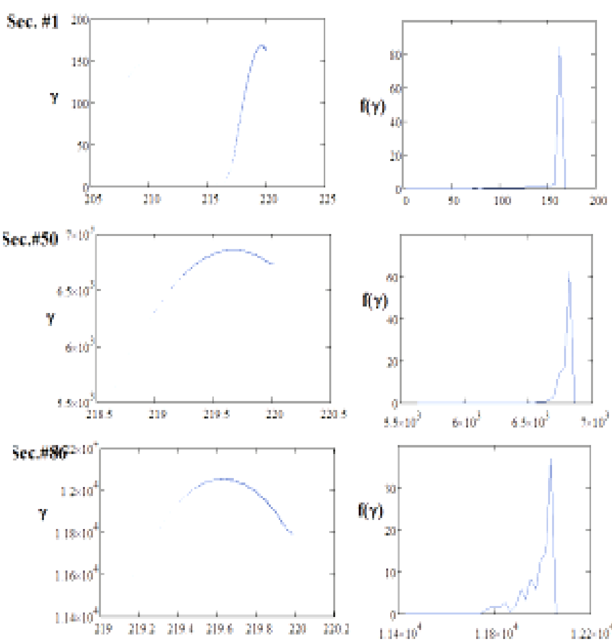

Figure 2: Beam dynamics simulation results for 40-cell BAS: longitudinal phase portraits on the phase plane (γ, z) and the energy spectrum.

ELECTRODYNAMICS CHARACTHERISTICS

Regular part

The BAS structure have the following parameters: $L = 53.45$ cm, coupling coefficient $K_{co} = 11.3\%$, effective shunt impedance $r_{sh.ef.} = 116.2$ MOhm/m, Q-factor is equal 10571, group velocity is equal 0.165c, $E_{max}/E_{acc} = 2.6$. The simulation was carried out in the approximation that an energy of 1 J is stored in the cell. General view of regular section and electric field distribution presented in Fig. 3. Then, the optimization of the structure consisting of 10 regular periods was carried out. Q-factor was increased up to 15385 as expected. Electric field distribution of 10 section's structure presented in Fig. 4.

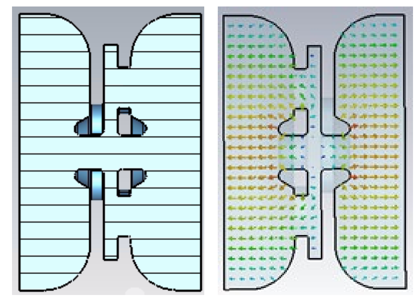

Figure 3: General view of regular section and electric field distribution.

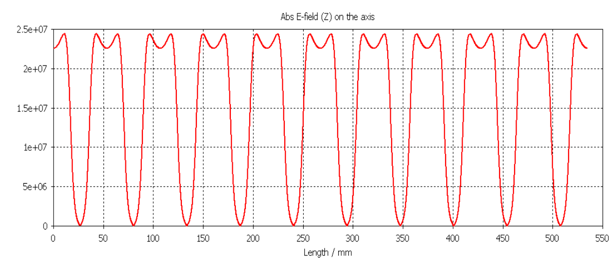

Figure 4: Electric field distribution of BAS structure consists of 10 sections.

Adiabatic Buncher

Also, simulation of the electrodynamics characteristics and optimization of the geometric parameters of the adiabatic buncher and power input were carried out. The buncher cells were configured in layouts identical to the one shown in the Fig. 5. For such cells with a variable length and electric field amplitude, the process of tuning the cells is somewhat different. Here the parameters of one accelerating half-cell are known, and the second is tuned. The ratio of the amplitudes of the accelerating fields in the middle of the half-cells was tuned by changing the solutions of the magnetic coupling gaps in the tuned cell.

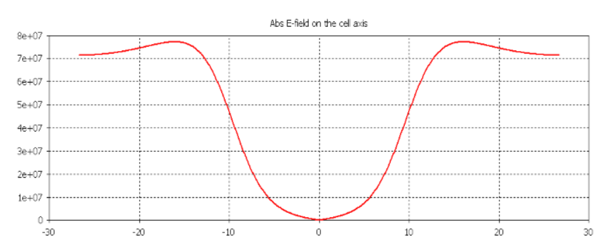

Figure 5: Longitudinal distribution of the electric field on the axis of the structure

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA08

For each of the buncher periods, a resonant model was designed and investigated. To determine the requirements for the accuracy of manufacturing, the variation curves of dependences vs the main geometric dimensions of the each regular period were calculated (see Table 3).

Table 3: Dependences vs the Main Geometric Dimensions of the Each Regular Period

Parameter	**Value**
dF/dR_{ac}, MHz/mm	63.2
dF/dR_{cc}, MHz/mm	0.39
dF/dL, MHz/mm	22.5

Next, the structure, consisting of 4 bunching cells and 4.5 regular cells was optimized. General view of the structure and electric field distributions are shown in Figs. 6 and 7.

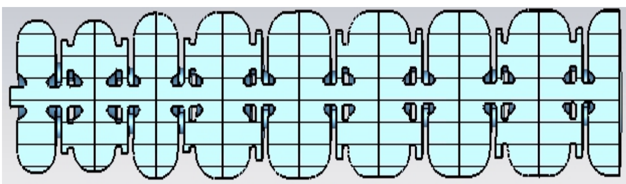

Figure 6: General view of the structure, consists of 4 bunching cells and 4.5 regular cells.

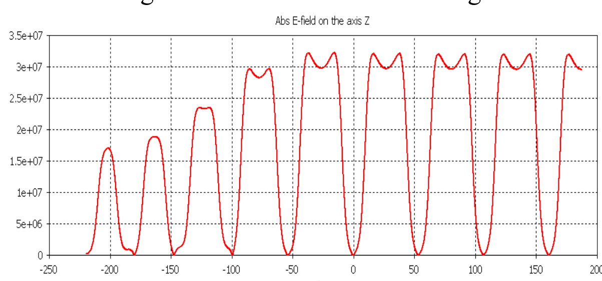

Figure 7: Electric field distribution of 4 bunching cells and 4.5 regular cells.

This structure has the following parameters: L = 407.05 cm, Q-factor is equal 14870, effective shunt impedance $r_{sh.ef.}$ = 103.8 MOhm/m.

RF power input should be injected through the 21st regular cell, therefore the tunable resonant layout consists of a power input cell and two accelerating cells on the sides. On both sides of the cell, rectangular 72x34 mm waveguides are attached for RF power input, connected to the cell by a rectangular window with a variable width.

SPECTRUM OPTIMIZATION

The beam parameters as the geometrical length of the bunch can be reduced and the energy spectrum can be decreased if use the short klystron-type pre-buncher before gentle buncher operating on the half-frequency of 1428 MHz. It was shown that such scheme allows us to control both these parameters using different lengths of short buncher and the different RF field amplitude. Such scheme also provide us also to generate bunches with different geometrical lengths or spectrum [8]. Its application makes it possible to reduce the beam energy spectrum when using RF-gun with thermionic cathode to 0.20 - 0.35%, and the bunch length to 0.8 - 1.0cm. Transverse emittance will be about 1.5 nm · rad, and the beam radius is 0.15 mm (and about 0.25 mm for (4σ)).

The beam dynamics simulation in the regular part of the linac was performed for bunches generated by ptotogun. The current transmission coefficient is near 99.5% after 82th section. In the case of a beam generated by thermogun the current transmission coefficient is near 46.5% after 86th regular section. The beam focusing system is proposed to using solenoids for energies up to 200 MeV, and triplets of quadrupole lenses for higher energies. Front-to-end beam dynamics simulation results are presented in Fig. 8.

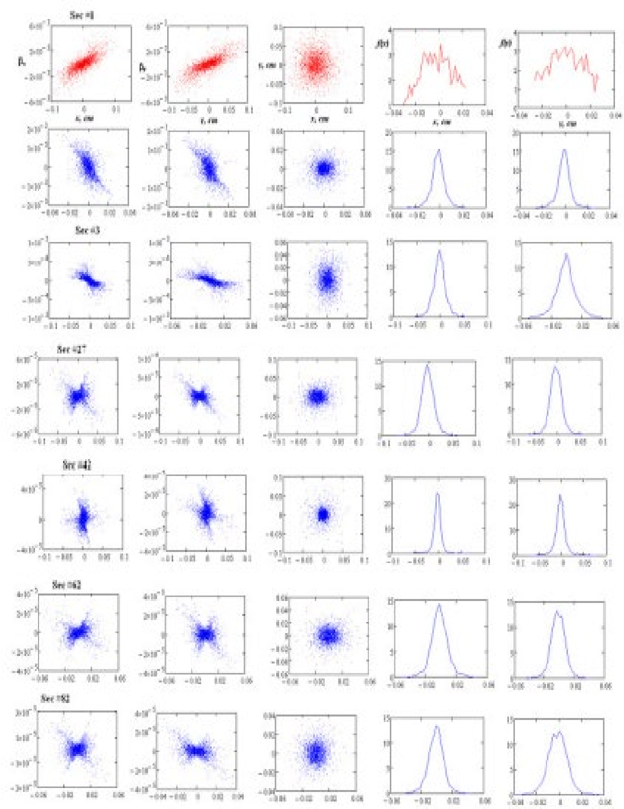

Figure 8: Front-to-end beam dynamics simulation results: beam emittances in both transverse directions, beam cross section and beam distribution along transverse coordinates.

CONCLUSION

The beam dynamics simulation results of two types of RF-gun, of two types of regular part of accelerator were described. Electrodynamics characteristics of adiabatic buncher and regular part were optimized. It was shown that the use of an additional klystron buncher before the adiabatic allows to improve and control the beam energy spectrum and length of the accelerated electron bunch. Front-to-end beam dynamics simulation from the cathode to the exit of the regular part for both variants – with photocathode and thermionic cathode was done.

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA08

REFERENCES

[1] Ye. Fomin, V. Korchuganov, "Kurchatov synchrotron radiation source – from the 2nd to the 4nd generation", in *Proc. RUPAC'2018*, Protvino, Russia, Oct. 2018, paper WEZMH02, pp. 84-87.

[2] I. Ashanin*, et al.* "Conceptual Design of a Dedicated Fourth-Generation Specialized Synchrotron Radiation Source (SSRS-4) at the Kurchatov Institute", *Phy. At. Nuc.* vol. 8, no. 11, 2018.

[3] Y. Papaphilippou, "FCC-ee injector complex including Booster", *FCC Meeting 2016*, Rome, Italy, Apr. 2016.

[4] M. Satoh, *et al.*, "Commissioning of SuperKEKB injector linac", in *Proc. of IPAC'16*, Busan, Korea, May 2016, paper THPOY027, pp. 4152-4154.

[5] E. Masunov, S. Polozov, "BEAMDULAC code for numerical simulation of 3D beam dynamics in a high-intensity undulator linac", *Nucl. Instrum. Meth. A*, vol. 558, pp. 184-187, 2006.

[6] T. Bondarenko, E. Masunov and S. Polozov, "BEAMDULAC-BL code for 3D simulation of electron beam dynamics taking into account beam loading and coulomb field", *Prob. At. Sci. Technologies. Ser.: Nuc. Phy. Investigations,* vol. 6 no. 88, pp. 114-118, 2013.

[7] S. Polozov *et al.*, "New 10 MeV high-power electron linac for industrial application", in *Proc. of IPAC'16*, Busan, Korea, May 2016, paper TUPOW023, pp. 1794-1796.

[8] T. Bondarenko, *et al*., "Commissioning and First Tests of the New Standing Wave 10 Mev Electron Accelerator", in *Proc. of RuPAC'16*, St. Petersburg, Russia, Nov. 2016, paper TUCASH02, pp. 173-175.

[9] S. Polozov, *et. al*., Beam Dynamics Simulation Results in the 6 GeV Top-Up Injection Linac of the 4th Generation Light Source USSR, in *Proc. of RuPAC2018*, Protvino, Russia, Oct. 2018, paper WEPSB05, pp. 285-288.

[10] Yu. Kliuchevskaia and S. Polozov, "Optimal RF-photogun parameters for the new injection linac for USSR project", presented at the RuPAC'21, Alushta, Crimea, Sept.-Oct. 2021, paper TUPSB43, this conference.