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200 MeV LINEAR ELECTRON ACCELERATOR – PRE-INJECTOR FOR A NEW KURCHATOV SYNCHROTRON RADIATION SOURCE

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Abstract

New linear electron accelerator (linac) with an energy of about 200 MeV (or 300 MeV in a high-energy version) is being proposed for injection into the booster synchrotron, which is being developed for the reconstruction of the SIBERIA-2 accelerator complex with the aim of upgrade to 3rd generation source at the NRC «Kurchatov Institute». A modernized linac and its specific elements layout will described in the report. The modeling of accelerating structure and optimization of electrodynamics characteristics and fields distribution and geometric in order to reduce the beam spectrum at the output of the linac was done. A step-by-step front-to-end beam dynamics simulation results will discuss.

INTRODUCTION

Kurchatov synchrotron radiation source (KSRS) today consists of 80 MeV linac, 450 MeV small booster ring Siberia-1 and 2.5 GeV main ring Siberia-2 [1]. Compact booster ring Siberia-1 uses for intermediate acceleration of electrons from 80 to 450 MeV and injection into the main ring, also a source of synchrotron radiation in the field of vacuum ultraviolet and soft X-ray. At the moment, a 40 keV diode gun and ~ 4 A in a pulse with a duration of ~ 18 ns is used as an injector. The energy spread at the output is about 7%. From the gun electron beam drives to the input of the linear accelerator. Disk-and-washer type accelerating structure has 112 accelerating gaps. After acceleration to 80 MeV, the beam pulse consists of about 50 microbunches following each other at a frequency of 2.8 GHz.

In the version for reconstruction (see Fig. 1), it is proposed to use a classic three-electrode gun with a heated oxide cathode (powered by a single modulator) as an electron source. The linear accelerator will include 4 or 6 sections, each about 2.14 m long, operating on a standing wave (biperiodical accelerating system, BAS) (see Fig. 2). Consequently, after acceleration beam energy will be 200 MeV.

Two bunchers – one short klystron type and one adiabatic – will be placed in front-end of linac, which will include several (4-7) irregular accelerating cells with increasing phase wave velocity and accelerating field amplitude for longitudinal beam bunching.

To increase the current transmission coefficient and to reduce the beam energy spectrum, in addition to the adiabatic buncher, a one- or two-gap buncher can be placed in front of the adiabatic buncher operating at a frequency that is two or four times lower than the operating frequency of the sections [2].

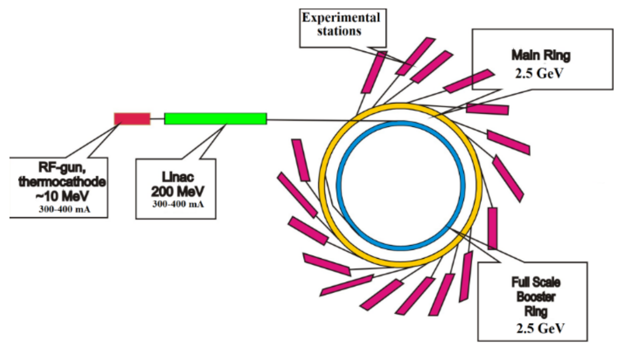

Figure 1: Planned scheme of the accelerator complex.

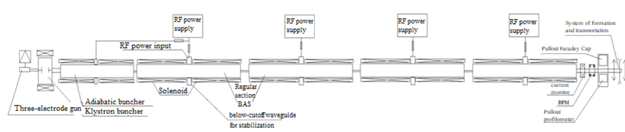

Figure 2: Possible scheme of the linac layout.

All results of the beam dynamics simulation were carried out using the BEAMDULAC-BL code developed at the Department of Electrophysical Facilities of NRNU MEPhI [3-5]. Numerical simulation was carried out in stages, with control of parameters after buncher, after the second, fourth and sixth regular sections.

BEAM DYNAMICS SIMULATION IN THERMIONIC GUN

Simulation shows that the optimal injection energy will be 100–120 keV. The beam current at these parameters was 1.03 A, energy spread 0.76%, beam radius 3.6 mm, transverse emittance 6.5 π (cm-mrad), micropervance 0.03 mkA/B$^{3/2}$ [6]. Transverse beam focusing is carried out using magnetic solenoids on all sections of the linear accelerator and triplets of quadrupole lenses at higher energies.

BEAM DYNAMICS SIMULATION IN ADIABATIC BUNCHER

Linac front-end with a thermionic cathode should provide an energy of ~ 10 MeV. The operating frequency is 2800 MHz. The number of periods is 26.

The adiabatic buncher includes four periods with increasing phase velocity and RF field amplitude. At the

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injection energy of 100 keV in the first four cells, it is necessary to change the phase velocity of the wave from 0.64 to 0.90. In this case, the amplitude of the accelerating field will increase from 90 to 150 kV / cm. In the remaining 22 regular cells of the adiabatic buncher, the phase velocity and the field amplitude are constant. The length of the gaps of the accelerating cells in the regular part is approximately $\beta_{ph}\lambda/4$, but can be adjusted if necessary.

The lengths of the coupling cells are chosen the same and equal to 4 mm. The aperture radius for the entire channel is 5 mm. Beam dynamics simulation results at the exit of the adiabatic buncher are presented in Table 1. Transverse beam focusing is realized by solenoid field.

Table 1: Beam Dynamics Simulation Results at the Output of the Adiabatic Buncher

Parameter	Value
Electric field amplitude, E_{max}, kV/cm	150
Output energy W_{out}, MeV	10.15
Output current I_{out}, mA	447
Current transmission coefficient, %	74.5
Longitudinal losses, %	24.5
Transverse losses, %	0.9
Width of the energy spectrum FWHM, %	±1.5

ELECTRODYNAMICS PARAMETERS OF ACCELERATING STRUCTURE

The biperiodical accelerating structure (BAS) operating on a standing wave was chosen as an accelerating structure. The accelerating cells have an optimized Ω-shape and provide the maximum field on the axis of the structure. Coupling cells have a small longitudinal dimension (4 mm gap). The phase shift per cell is π/2, the phase shift between adjacent accelerating cells is π. Geometry of the regular period of the BAS is shown in Fig. 3.

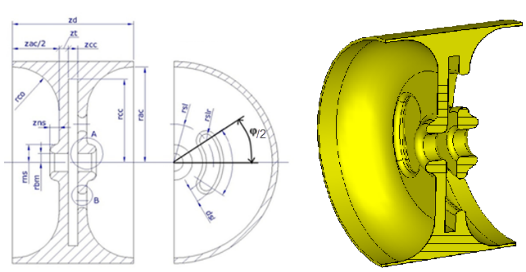

Figure 3: Geometry of the regular period of the BAS.

Electrodynamics parameters of the adiabatic buncher was simulated and geometric parameters was optimized. As a result, the following values of electrodynamics characteristics were obtained: coupling coefficient $K_{co} = 11\%$, effective shunt impedance $r_{sh.ef.} = 96$ MOhm/m, Q-factor is equal 12800, group velocity is equal 0.165c, surface overvoltage $E_{max}/E_{acc} = 3.66$. The accelerating structure model used for simulation consists of one whole accelerating cell, two half cells and two coupling cells. Electric field distribution in the cell for the one period presented in Fig. 4.

It is also proposed to use a BAS as a regular section, but consisting of 40 accelerating cells. The length of the last cell should be increased, since the coupling cell will not be located behind it. The RF power input is also organized into one of the central accelerating cells. Because of the high input power, in this case, it is convenient to use a symmetrical two-way RF coupler, which makes us possible to reduce the field strength in waveguides and high-frequency windows by a factor of four. Electric field distribution in the structure consists of four bunching cells and the first 5.5 regular cells is shown in Fig. 5.

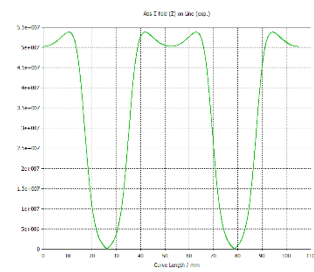

Figure 4: Electric field distribution in the cell for one period.

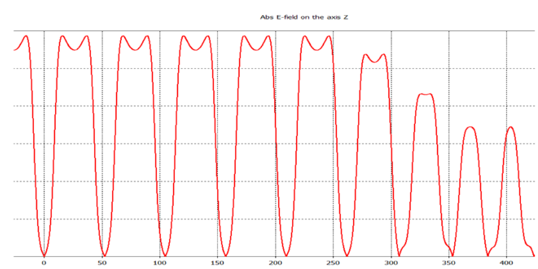

Figure 5: Electric field distribution in the layout of the complete structure (four bunching cells and the first 5.5 regular cells).

BEAM DYNAMICS SIMULATION IN REGULAR SECTION

Beam dynamics simulation results at the exit of the four regular sections depending vs. the injection phase are shown in Table 2. Beam cross and the phase portrait on the phase plane (γ, z) at injection phase -0.75 are shown in Fig. 6. The energy spectrum and beam envelope at the same injection phase are presented in Fig. 7.

Front-to-end simulation leads to following results. The total length of the linac will be about 10 m. The operating frequency is 2800 MHz. Maximum field strength on axis: 450 kV/cm. Output energy is near about 215 MeV. Energy acceleration rate: 50-55 MeV/section. The transverse emittance at the output of the linac will be about 10 nm rad.

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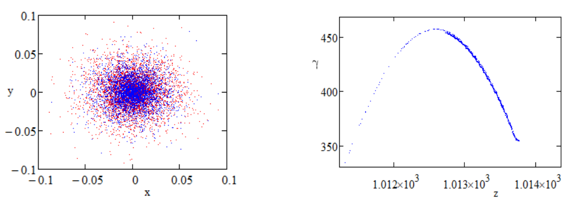
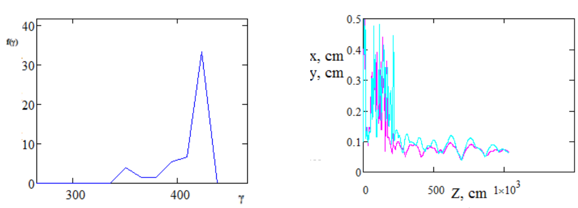
Table 2: Beam Dynamics Simulation Results at the Output of the Fourth Regular Section Depending on the Injection Phase

Parameter	**Value**		
Injection phase, $d\varphi$	0,75	0	-0.75
Full output energy, MeV	196.0	215.7	214.2
Output current I_{out}, mA	354.2	325.3	348.9
Transmission coefficient, %	59.0	54.2	58.2
Longitudinal losses, %	39.7	44.8	40.9
Transverse losses, %	1.2	2.6	1
Width of energy spectrum FWHM, %	±2.6	±2.2	±1.7



(a) (b)

Figure 6: Beam cross section (the initial distribution is shown in red, at the output - in blue) (a) and the phase portrait on the phase plane (γ, z) (b).



(a) (b)

Figure 7: The energy spectrum (a) and beam envelope at injection phase -0.75.

SPECTRUM OPTIMIZATION

The minimal variation of the matching gap's length d_z between the regular sections leads to a significant phase shift of the bunch and can be used for precise tuning of the beam energy spectrum. Variation by 1 mm at a wavelength of 107.14 mm corresponds to a change in the injection phase by 3.4 degrees. With this accelerator adjustment, it is possible to obtain a beam spectrum at the output of less than ± 1% FWHM.

Dependence of the current transmission coefficient and the spectrum width of the beam at the output of the fourth regular section on the length of the matching gap are exposed in Table 3. Phase portraits on the longitudinal phase plane (γ, z) and the energy spectrum after the fourth regular section, depending on the length of the matching gap are presented in Fig. 8. The average output energy also increases due to the shorter and denser bunch, which makes it possible to reduce the amplitude of the accelerating field from 450 to 410 kV/cm. This power reduction consumed by the section, and will create 5% margin for compensating for power losses in the microwave path.

Table 3: Dependence of the Current Transmission Coefficient and Beam Spectrum at the Output of the Fourth Regular Section on the Length of the Matching Map

Length of matching gap d_z, mm	Average beam energy, MeV	Transmission coefficient %	Width of the energy spectrum FWHM, %
164	225.7	54.7	±0.88
165	230.2	54.3	±1.85
166	228.9	54.1	±2.44

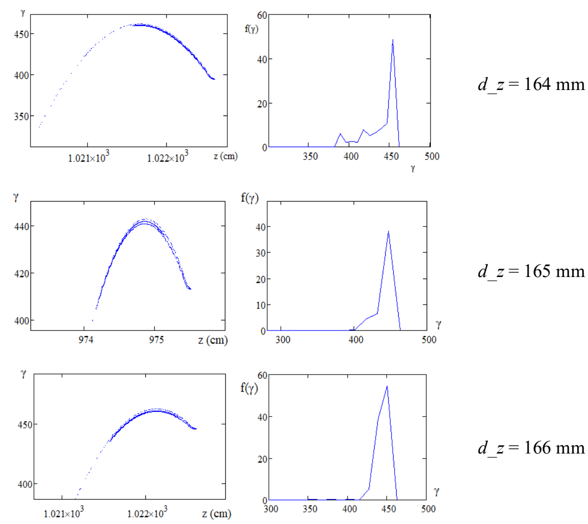


Figure 8: Phase portraits on the phase plane (γ, z) and the energy spectrum after the six regular section, depending on the length of the matching gap.

CONCLUSION

It was proposed to use BAS structures in regular part of the KSRS-2 injection linac and to reach the beam energy of 200 MeV, it will be necessary to use four regular sections. Fine tuning of the length of the matching gap between the sections provide to a significant improvement of the spectrum (less than ± 1% FWHM). The total "front-to-end" beam current transmission coefficient is about 58%, which, at an injection current of 600 mA, makes it possible to obtain at the output about 350 mA of a beam accelerated to the maximum energy.

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