BEAM DYNAMICS IN AN INITIAL PART OF A HIGH BRIGHTNESS ELECTRON LINAC

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The paper is focused on problems of obtaining a bright electron beam in a system that includes a grid-controlled electron gun, a klystron type subharmonical buncher, a standing wave fundamental buncher with increasing accelerating field and a short travelling wave accelerating section. Beam focusing is provided by a longitudinal solenoidal magnetic field. It was shown that the proposed system can provide electron bunches with a peak current more than 100 A and normalized r.m.s. emittance no more than 12 π·mm·mrad.

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1 INTRODUCTION

It is planned to create several free electron lasers under implementation of Dubna synchrotron radiation source [1] on the base of its linac. To obtain laser radiation in visible and ultraviolet ranges of wavelength it is necessary to upgrade an injector part of the linac. After upgrading of the injector the linac should provide the following beam performances: normalized r.m.s. emittance of the beam no more than 20 π·mm·mrad; peak current no less than 100 A; energy spread no more than 0.1%. Lasers radiating at a wavelength of about 300 nm can de obtained with using a convenient injector that consists of a triode electron gun and subharmonic and fundamental harmonic bunchers [2].

Our paper is devoted to simulation of a convenient injector that can be used to upgrade the linac of the Dubna synchrotron radiation source. Simulations of bunching and accelerating elements as well as a focusing system of the injector were performed with SUPERFISH/POISSON [3]. Simulation of beam dynamics in the injector was performed with PARMELA [4].

2 INJECTOR OUTLINE

An outline of the injector is shown in Fig. 1. As an electron source it is planned to use an 100 kV electron gun that will be designed on the base of the CPI Eimac cathode – grid unit. An enough low subharmonic frequency of 142.8 MHz (20th subharmonic of the fundamental linac frequency) was chosen to diminish a cathode load.

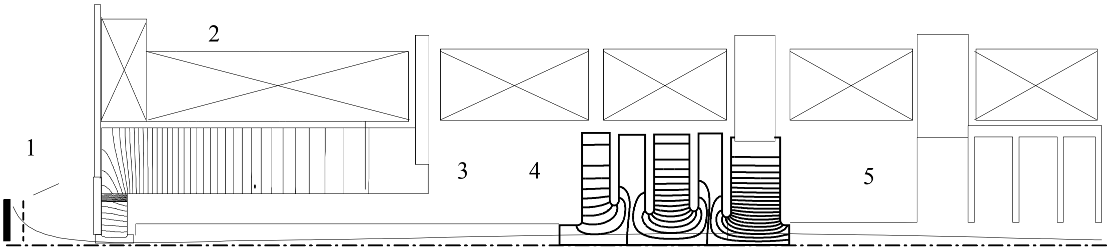

Fig. 1. Injector outline.
1 – triode electron gun, 2 – windings of the solenoid, 3 –subharmonic buncher, 4 – fundamental frequency buncher, 5 – short travelling wave section.

To provide efficient bunching the triode gun will generate a train of cut cosine current pulses that will be phase locked to the RF field in the subharmonic buncher. Bunch length will be 1.75 ns and each bunch will contain a charge of 1 nC. An average current of the gun will be 143 mA while the maximal current will be about 1 A. Needed beam characteristics at the gun exit are summarized in the Table 1.

A quote wave coaxial cavity was chosen as the subharmonic buncher. A general outline of the buncher is similar to the buncher that was described in [5]. A length of a modulation gap taken into account fringing fields will be 60 mm.

Table 1

W, keV	100
τ_{pulse}, ns	1.75
Q_{pulse}, nC	1
F_{pulse}, MHz	142.8
$\varepsilon_{n\ rms}$, π·mm·mrad	2

To decrease wake fields that will be excited by a bunched beam in the cavity and to diminish a time of a transient response the buncher will be made of stainless steel. SUPERFISH evaluated characteristics of the cavity are presented in Table 2.

The beam, preliminary bunched in the subharmonic buncher, undergoes the additional acceleration bunching in the fundamental frequency buncher. It is known that beam acceleration in the electromagnetic field increasing along the buncher allows to diminish a phase length of bunches effectively [6, 7].

Table 2

F_0, MHz	*142.8*
Q_0	*960*
R_s, kOhm	*126*
P_{rf} ($E_{z\,max}$ =1.4 MB/м), kW	*25*
E_{max} on the surface, MV/m	*10*

We propose to use a chain of inhomogeneous on-axis coupled cylindrical cavities to create such field distribution. Characteristics of the cavities are chosen in that way to obtain the $\pi/2$ mode at the operating frequency so the five-cavity buncher consists of three accelerating cavities and two coupling cavities. Needed on-axis field distribution is reached by variation of iris diameters and length of cavities on the base of the best bunching. Initial configuration of the buncher was synthesized on a base of results of PARMELA beam dynamics simulations in a simplified model that consisted of separated cells and drifts.

This initial configuration was slightly changed during optimization of the injector. The main electrodynamics characteristics of the buncher are presented in Table 3.

Table 3

f_0, MHz	2856
Q_0	10800
R_s, kOhm	301
P_{rf} ($E_{z\,max}$ =20.5 MB/м), kW	153
E_{max} on the surface, MV/m	30

Stability of a field configuration under frequency variation of a RF supply generator is a very important for a resonant system that is used for accelerating the intensive current. This variation is necessary to compensate a beam loading effect [8]. Fig. 2 shows a family of on-axis field distribution in the buncher for several frequencies within a range of ±3 MHz relatively to the resonant frequency. Field amplitudes were normalized to obtain an average on-axis field equal to 1 MV/m for each frequency. One can see that curves almost overlapped and look like as a single curve. This is evidence of good field stability. Estimation shows that the maximal deviation of the average field amplitude in the first cell is no more than 6.5% as well as it is no more than 2.5% in the last one.

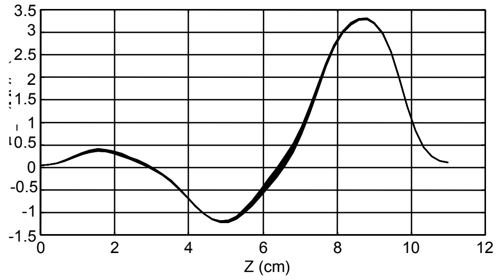

Fig. 2. A family of on-axis field distribution in the buncher.

Final beam bunching is realized in a drift space between the buncher and the accelerating section as well as in the accelerating section. As the accelerating section we are going to use a part of a $2\pi/3$ disc loaded waveguide with constant impedance and phase velocity that is equal to the velocity of the light. Characteristics of the accelerating section is given in Table 4.

Table 4

f, MHz	2856
Mode	$2\pi/3$
β_{ph}	1
a/λ	0.1013
t/λ	0.0191
β_g	0.0123
α, 1/m	0.166
R_s, MOhm/m	64.4
Number of cells	19
P, MW	2

3 BEAM DYNAMICS

The research of beam dynamics in the injector was conducted in several stages. At the first stage the optimized values of amplitude and phase of a field of a subharmonic buncher and value of drift space were determined. Optimization was carried out by minimization of a product of beam emittance on bunch phase length. Obtaining the minimal value of the product that depends on the drift space length and phase and amplitude of field in a modulating gap of the subharmonic buncher allows to determine the optimal length of the drift space (70 cm) and average field amplitude (0.9 MV/m). Investigation shows that values obtained are stable with respect to the change of the solenoid magnetic field in the range from 0.02 to 0.05 T. It was also found that at optimal injection the phase average energy of particles decreases by 20 keV after interaction with the field of the subharmonic buncher that allows effective bunching at an enough short distance.

Needed configuration of on-axis field distribution in the fundamental frequency buncher was determined at a next stage of beam dynamics simulation. After definition of a necessary configuration of the field in the buncher the simulation of dynamics of particles was carried out at different values of strength and phase of the field in it. That has allowed finding their optimal values for obtaining a maximum brightness of a beam at a buncher exit. The analysis of beam characteristics at a buncher exit has shown a capability of a further bunching of a beam in the drift space therefore the accelerating section was established apart 17 cm from the buncher exit. Amplitude of accelerating field in the section was chosen enough low (E_0 = 6.5 MV/m) that allowed additional bunching of a beam. Study of longitudinal motion of particles in bunchers has shown that at optimum phases of a field the center of a bunch is injected in a slowing phase of a field. It results in an effective bunching of a beam and reduces sensitivity of the characteristics of a beam against changes of amplitudes and phases of fields in the bunchers. The research of longitudinal motion of particles shows that in a homogeneous magnetic field of particles betatron oscillations occur because of change of space charge forces during bunching and acceleration. Therefore at an injector exit with a homogeneous magnetic field it was not possible to receive the normalized root mean square emittance (1σ) of a beam less than ~18 π·mm·mrad at 100% passing of particles through the injector. Application of an inhomogeneous magnetic field with taking into account the change of forces of a space charge [2] has allowed reducing the effective emittance growth of a beam during its bunching and acceleration. Beam performances at the exit of the injector with inhomogeneous magnetic field are presented in the Table 5.

Table 5

$\varepsilon_{n\ rms}$, π·mm·mrad (1σ)	11
$4\sigma_{x,y}$, mm	3.4
Δϕ, ° (90% of particles)	10
$\Delta W/W_{av}$, % (90% of particles)	7
W_{max}, MeV	6
W_{av}, MeV	5.58
Maximal Instant Brightness, A/m^2/rad^2	$1.3\cdot10^{10}$
Maximal Instant Current, A	252

Illustration of bunching process in injector is presented in Fig. 3 that shows variation of a maximal instant current of bunches along the injector. Variations of root mean square emittance and radius of a beam along the injector are presented in Fig. 4. Probably it is possible to improve beam emittance using more complicated magnetic system that provides sharp magnetic field changing in a region of the fundamental frequency buncher.

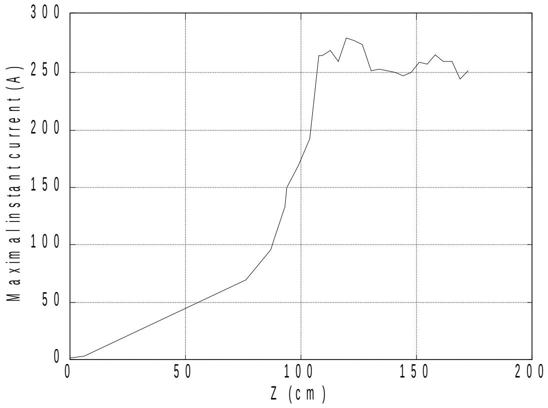

Fig. 3. Variation of maximal instant current of bunches along the injector.

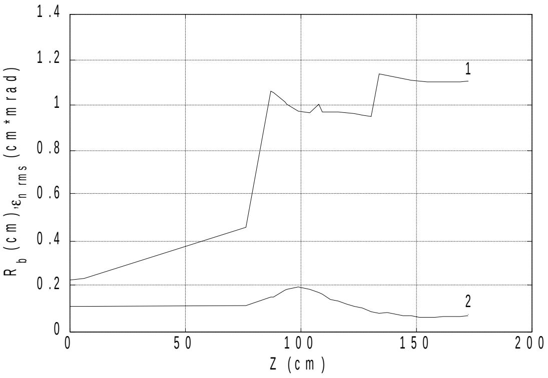

Fig. 4. Variations of root mean square normalized emittance (1σ) and radius of a beam along the injector. 1 – emittance, 2 – beam radius (70% of particles).

4 CONCLUSION

The research carried out has shown that the offered configuration of the injector provides the characteristics of a beam that are suitable for a short-wavelength free electron laser.

The search of minimum value of the product of a phase length of bunches on an emittance of a beam allows to receive optimal values of amplitude and phase of the field in a subharmonic buncher as well as lengths of the drift space.

The injection of bunch centers in a slowing phase of an electrical field in the subharmonic buncher and a fundamental frequency of buncher provide an effective bunching of a beam and reduce the sensitivity of beam characteristics with respect to small changes of phases and amplitudes in bunchers.

The calculations performed allow to proceed to designer development of the injector.

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