ELECTRON INJECTOR BASED ON RESONANCE SYSTEM WITH EVANESCENT OSCILLATIONS

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The article presents the design and simulated performances of an electron gun and a bunching system of the S-band injector based on a coupled cavity chain. Amplitude of the on-axis field varies substantially from the cell to the cell in the bunching system. The cell lengths are chosen to get the effective bunching and accelerating of the beam from the initial energy of 25 keV to the energy of about 1 MeV with the current up to 300 mA. The bunching system can be used in electron linacs both for fundamental researches and for radiation technologies.

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1. INTRODUCTION

An injector substantially defines beam characteristics at the linac exit. It is known, that the increasing of amplitude of an accelerating field at the initial stage of acceleration when the phase motion of particles is not frozen allows receiving a small phase length of bunches at a low energy spread [1]. Bunchers, which use such a principle, are described, for example, in [2-4]. Resonant systems of the first and the second papers are a section of the non-uniform biperiodic waveguide with magnetic coupling and the third one uses the section of a non-uniform disk loaded waveguide (DLW) with the large attenuation of a counter-propagating wave. In [5,6] it was offered to use for this purpose a section of homogeneous DLW exited on the frequency that lies beyond the pass-band of the corresponding infinite waveguide.

Development of the S - band electron injector consisting of a diode low-voltage (25 kV) gun and bunching system with evanescent oscillations is the result of our recent researches in this direction. The estimated performances and outline of such an injector are presented below. This injector has been designed for an electron linac with output energy of 100 MeV and current of 100 mA.

2. BUNCHING SYSTEM

The buncher consists of a chain of five coupled cavities with coupling through central holes for beam passing. The sizes of the holes were selected equal to each other. For realization of required on-axis field distribution, the operation frequency of a buncher, which was close to the eigen frequency of the last cell, was selected higher than the frequency of the "π" mode of oscillations of a remaining part of the buncher. In this case the phase advance of the field per the cell equals π.

The preliminary calculations of the bunching system were made on the basis of the self-consistent model of weakly coupled cavities [7]. Further simulation of the system was carried out with the SUPERFISH code [8]. To do so the configuration of a resonant system obtained as a result of the preliminary calculations, was somewhat changed in view of a finite thickness of disks and fringing fields at the entrance and the exit of the buncher that were not taken into account in the preliminary calculations. The purpose of calculations and simulations was the definition of the lengths of the first and the last cells providing the required characteristic of a beam. The period of cells located between the first one and the last one were chosen equal to 0.22 λ according to the preliminary calculations. The computational electrodynamic characteristics of the bunching system are shown in table 1.

Table 1. Electrodynamic characteristics of the bunching system

Parameter	Value
Operating frequency, MHz	2797.15
Quality factor	12300
Shunt impedance, MOhm/m	18
Input power, MW	up to 2
Power losses in wall, MW	0.44
Maximal field on the axis, MV/m	36

To reduce influence of a space charge on the transversal emittance, a distance between the electron gun and the bunching system should be made as short as possible. Therefore in the developed buncher the inlet opening for injection of a beam is an anode iris of the gun.

One of the important stages at creation of a buncher is the development of a technique of adjusting of the resonant system for obtaining necessary distribution of the on-axis field on the operating frequency. The technique of the adjusting consists in the following. At first the frequency of the "π" mode of a homogeneous segment of the system (cells number two, three and four) is found by the SUPERFISH code. Then the stack of three identical cavities, restricted with cavities of half-length, is adjusted to obtain the "π" mode on this frequency. Then the first half-length cavity of the stack is changed with the first cavity of a buncher and its diameter is adjusted to restore the frequency of the "π" mode of the stack. After that the last half-length cavity is swapped with the fifth cavity of the buncher. By changing its eigen frequency the stack is adjusted on the operating frequency of 2797.15 MHz. In such way the required on-axis field distribution on the operating frequency can be obtained.

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3. SIMULATED CHARACTERISTICS OF THE INJECTOR

To get a substantial attenuation of the fringing fields at the entrance of the buncher, a length of a drift pipe between the electron gun and the first cavity should be long enough. On the other hand, it is undesirable to use the magnetic focusing of the beam. Therefore, the geometry of gun electrodes was chosen to get a beam waist as far as possible from the entrance of the buncher. It is known [9], that the allowable length of a drift pipe with the certain radius without the magnetic field depends on a beam convergence angle at the input end of the pipe and a current. There are optimum values of these parameters that ensure the maximal distance to the beam waist. It can be found out from the expression [9]:

$$Z(R_{cr}) = \int_{R_{cr}}^{1} \frac{dR}{\ln^{1/2}\left(\frac{R}{R_{cr}}\right)}, \quad (1)$$

where R_{cr} is the normalized beam radius in the waist and $Z(R_{cr})$ is the normalized distance from the anode iris (i.e. the input end of the drift pipe) to the waist. The normalized parameters are related with physical dimensions by the following dependences:

$$R = \frac{r}{r_0}, \quad (2)$$

$$Z = 174 \cdot \frac{I^{1/2}}{U^{3/4}} \cdot \frac{z}{r_0}, \quad (3)$$

where I is the beam current in A, U is the cathode voltage in V, r.is the radius of the beam envelope, $r_0$is the beam radius in the anode iris.

Dependence (1) has the maximum value Z_{cr}=1.082 at R_{cr} =0.42. Thus the envelope inclination angle in the anode iris R' is 0.92. Using the given dependences, it is possible to estimate the maximal distance from the anode iris of the gun to the waist for the following conditions: a radius of the cathode r_c=r_0=2.5 mm, a beam current of 0.25 A, a cathode voltage of 25 kV. It yields: Z_{cr}=61.8 mm, R_{cr}=1.05 mm that allows transportation of the beam through the buncher without magnetic focusing. However to realize such conditions it is necessary to use a large radius of the Wehnelt electrode and to increase dimensions of the gun according to simulations of the gun with the EGUN code [10]. On the other hand, PARMELA [11] simulation of the beam dynamics with the above-mentioned initial characteristics showed problems of bunch formation in the buncher caused by a space charge. Small beam radius in the waist that was located within the third cavity hampered obtaining necessary longitudinal dimension of bunches. Therefore the final shape and dimension of gun electrodes (see Fig.2) were chosen taking into account beam dynamics in the buncher. Simulating parameters of the gun are listed in table 2.

Table 2. Calculated parameters of the gun and characteristic of a beam

Cathode voltage, kV	-25
Cathode radius, mm	2.5
Normalized beam emittance (1 σ), π·mm·mrad	4.1
Distance from the front cut of the anode aperture to the beam waist, mm	40
The beam radius in the waist, mm	1.2
Beam current, A	0.25

It was mentioned above that the numerical simulations of electron beam dynamics in the buncher was carried out with the PARMELA code. As the buncher is intended for bunching and accelerating of a unmodulated beam, to take into account space charge forces correctly in simulation the input beam was represented by a bunch with the length of $5\beta\lambda$, where β is the initial relative velocity of particles, λ is the operating wavelength.

The optimum lengths of the cells and their frequencies were determined by successive running the SUPERFISH and the PARMELA codes. The design of the injector was developed according to the SUPERFISH data. The outline of the designed injector is shown in Fig. 1. Characteristics of the output beam for a gun current of 0.25 A are shown in table 3.

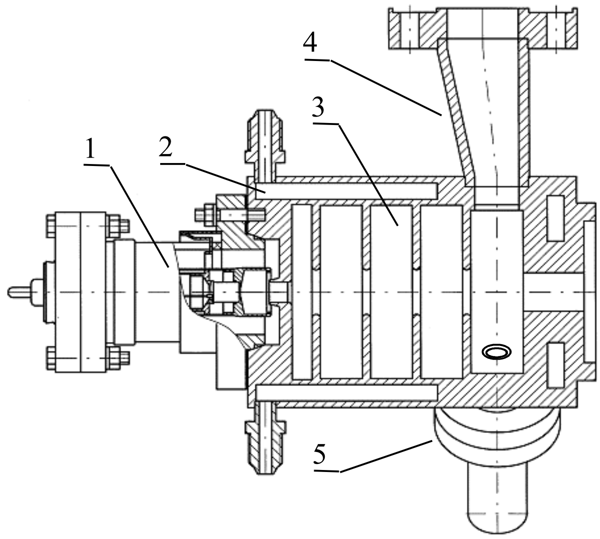

Fig.1. Simplified view of the injector (1 – electron gun, 2 – cooling ducts; 3 – resonant system; 4 – waveguide; 5 - tuning unit)

Fig.2 shows phase and energy spectra, emittance and transversal profile of a beam for this case.

Table 3. Characteristics of the buncher

Input power, kW	630
Current at the injector output, A	0.23
Normalized emittance (1 σ), π·mm·mrad	19
Δφ (for 70 % of particles), degry	19
ΔW/W (for 70 % of particles), %	5
Capture coefficient, %	91.7
Average energy, keV	821
Maximum energy, keV	913
Beam ∅ (for 70 % of particles), mm	1.69
$4\sigma_{x,y}$, mm	3.8

4. CONCLUSION

Thus, the injector system of an electron linac was designed on the basis of the formulated conception on usage of periodic homogeneous structures with evanescent oscillations for bunching and accelerating of an electron beam.

Analysis of the simulated parameters of the injector has shown that the injector can be used both in industrial linacs and in accelerators with precise beam characteristics. Now the injector system is at the stage of manufacturing. We plane to conduct detail experimental research of the designed injector. The considerable practical interest represents, in particular, research of stability of bunching system operation at formation of an intensive beam.

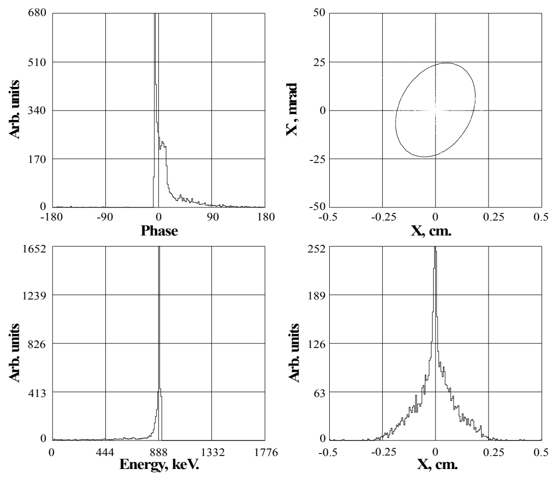

Fig. 2. Beam characteristic at the exit of the injector

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ИНЖЕКТОР ЭЛЕКТРОНОВ НА ОСНОВЕ РЕЗОНАНСНОЙ СИСТЕМЫ С НЕРАСПРОСТРАНЯЮЩИМИСЯ КОЛЕБАНИЯМИ

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Приведены конструкция и расчетные характеристики инжектора 10-см диапазона, основанного на цепочке связанных резонаторов. Амплитуда поля существенно изменяется вдоль оси системы, что позволяет получить эффективную группировку и ускорение пучка от начальной энергии 25 кэВ до энергии около 1 МэВ с током до 300 мА. Инжектор может использоваться в ускорителях электронов как для фундаментальных исследований, так и для радиационных технологий.

ІНЖЕКТОР ЕЛЕКТРОНІВ НА ОСНОВІ РЕЗОНАНСНОЇ СИСТЕМИ З КОЛИВАННЯМИ, ЩО НЕ РОЗПОВСЮДЖУЮТЬСЯ

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Приведено конструкцію та розрахункові характеристики інжектора 10-см діапазону, основаного на ланцюжку зв'язаних резонаторів. Амплітуда поля суттєво змінюється вздовж осі системи, що дозволяє одержати ефективне групування та прискорення пучка від початкової енергії 25 кеВ до енергії біля 1 МеВ при струмі до 300 мА. Інжектор може бути використаний як в лінійних прискорювачах електронів для фундаментальних досліджень, так і в прискорювачах для радіаційних технологій.