INJECTOR OF ELECTRON LINAC FOR NESTOR STORAGE RING

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Abstract

The design of the compact S-band injector and the results of particle dynamics simulation are presented in the report. The injector consists of the low-voltage diode electron gun and a bunching system based on the resonant system with the evanescent oscillations. RF field increases in amplitude along the axis in such bunching system. RF power is supplied to the injector through a coaxial coupler. The injector can be supplied with two types of the guns: 25 kV, 250 mA and 25 kV, 1.1 A. The first gun will provide the linac with the electron beam in a long pulse regime (1500 ns) while the second one will be used in a short pulse regime (40 ns). The resonance system of the injector has been optimized to obtain the electron bunches with energy about 1 MeV, phase length less than 20° and energy spread less than 5% (for 70 % particles) at the linac input. The coaxial coupler allows applying the solenoid magnetic field along the bunching system. Influence of magnetic field configuration on beam parameters is described.

INTRODUCTION

The development of the Compton back-scattering X-ray source in NSC KIPT [1] demanded designing of an electron storage ring and a proper linear accelerator-injector with energy of particles 60 - 100 MeV., We decided to use the traditional linac on the stage of storage ring commissioning. The linac consists of an injector and two accelerating sections. The first accelerating section is the Kharkov-85 type section [2] and the second one is the similar section as the section of the LU-60 linac [3]. We have chosen an injector that is similar to the injector described in [4]. This injector consists of the 25 kV diode electron gun and a bunching system based on a chain of five coupled resonators which are excited out of a wave pass band of this system. Due to the certain choice of resonator sizes, such system allows effective bunching and accelerating particles to relativistic speeds. The injector described here differs from the prototype [4] by higher efficiency of bunching due to the careful calculation of the resonance system [5] and by the coaxial coupling with RF power source. The features of injector design and feature of beam dynamics are resulted below.

BEAM PARAMETERS

For calculations of the resonance and magnetic systems of the injector the POISSON/SUPERFISH [6] group of codes, has been used. Simulation of particle dynamics in the diode gun and the resonance system was performed with the EGUN [7] and the PARMELA [8] codes. Optimization of on-axis field distributing of the resonance system by the technique [9] has been carried out for the increase of particle bunching efficiency. The optimization was performed for the electron gun with current of 250 mA without imposition of the solenoid magnetic field. Beam parameters on the injector exit with final configuration of the field are resulted in table 1 for two types of guns.

Table 1

Name	Values	
Gun current, A	0.25	1.1
Normalized emittance, $\varepsilon_{\text{rms}\ x,y}$, π·mm·mrad, (1 σ)	9	45
Beam size ($4\sigma_{x,y}$), mm	2.5	5.4
Bunch phase length for 70% of particles, °	7.7	13.7
Energy spread for 70% of particles, %	3.9	4
Beam energy, keV	1012	980

The gun with a current of 0.25 A will be used for work in the long pulse mode (1500 ns), and the gun with a current of 1.1 A can be used for the generation of short pulses (40 ns) at application of a proper high-voltage modulator. A current on the exit of the injector can reach 90% of gun current in both cases. Although bunch phase length at gun current of 1.1 A is almost two times higher than that at gun current of 0.25 A because of space charge forces, the injector provides the quite good beam parameters at use of the both guns.

COAXIAL COUPLER

For diminishing transients in the injector and for providing effective acceleration of beam with current up to 1 A, coupling coefficient of the resonance system with a feeder has been chosen about 4. The prototype of the injector described here has coupling with waveguide through opening in the side surface of a resonator with the maximum field (fifth resonator). At such high coupling coefficient the coupling aperture breaks the axial symmetry of the injector and scatters energy into the higher order multi-pole modes of the RF field [10]. Because of a large enough field on the axis of the fifth resonator the beam particles get transversal impuls which results in displacement of beam centroid from an axis of the linac. Owing to particles finite energy spread the beam transversal emittance gets worse when it is steering back to the linac axis. One of the methods diminishing this phenomenon is application of RF power coaxial coupling into the system. Thus a coaxial waveguide, which axis coincides with the beam axis, provides the field symmetry in a resonator [11, 12]. RF power is fed from rectangular waveguide to a coaxial line through the doorknob mode transformer. To suppres the propagation of higher order waves in a coaxial line, their cut-off frequencies must be much higher than working frequency of the linac [12].

The size of an internal conductor of the coaxial line must provide both electric durability at level of the passed power about 1 MW and lossless beam transportation.

The design of the coaxial coupler of the injector (see Fig. 1) is some compromise between the above-described requirements and structural features of the linac. We choose coaxial line with a characteristic impedance of 22.5 Ohm at the diameter of central conductor of 22 mm (at impedance of 50 Ohm working frequency of the linac would lie in the pass-band of the first waveguide mode of such coaxial line). Coax length is 75 mm that provides attenuation of higher order modes no less than 30 dB.

The doorknob mode transformer is designed on the base of 72x34 rectangular waveguide. One end of the waveguide is connected to the RF generator while another one has moveable shorting plane. To match the mode transformer on the stage of preliminary tests, the position of the shorting plane can be fine-tuned. We expect that the mode transformer will provide matching of the waveguide with the coaxial line (VSWR<1.1) in a passband ± 2.5 MHz.

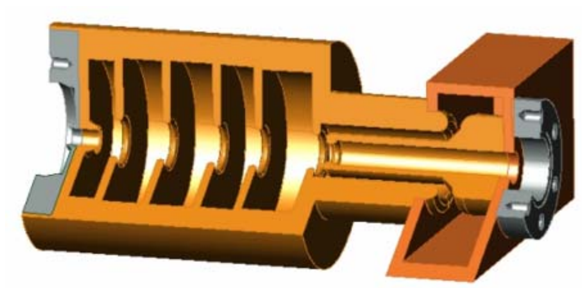

Figure 1: Schematic view of the injector.

The application of the coaxial coupler gives more flexibility at choice of an external magnetic field configuration that allows to control spatial characteristics of beam at particles bunching as well as at their transportation in the linac.

MAGNETIC SYSTEM OF THE INJECTOR

There are two problems that we solve at research of beam dynamics in the external magnetic field. The first problem is the searching such magnetic field configuration that would provide the acceptable beam transportation in the linac. The second problem is the searching of such magnetic field configuration that would provide almost unchangeable transversal beam size at particles bunching. Simulations have shown that at particle bunching in an initial part of the injector, beam size increases substantially due to both space charge and RF field forces. The particles reaching the fifth resonator where they obtain the main energy, also get the increase of radial impulse, which depends on the transversal co-ordinate of particle and its phase relatively RF field in the resonator. Dependence of transversal impulse of particles on a phase results in worsening of actual beam emittance. Therefore small beam size diminishes emittance growth.

Layout of the injector and a transport line to the linac for the first task is shown in Fig. 2.

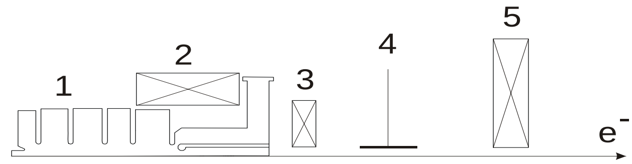

Figure 2: Layout of the injector and a transport line to the linac. 1 is the electron injector; 2 is the solenoid; 3 is the beam current transformer; 4 is the collimator; 5 is the axial magnetic lens.

The adjustable collimator is installed after the injector to provide the required output beam current of the linac. Simulations mainly were carried out for the gun with current of 0.25 A. The size of collimator aperture has been adjusted that the output beam current should not exceed 100 mA. At simulation of beam dynamics with the gun that provided current of 1.1 A the collimator has not been used.

Because of RF focusing provided by the wave type transformer at the entrance of the accelerating section, beam transportation has been jointly studied in the injector and the first accelerating section. The results of calculation of particle dynamics for several configurations of the magnetic field are presented in Fig. 3. Sharp change of beam size for cases 1, 2 and 3 in a point with a longitudinal co-ordinate of 30 cm is due to beam collimation. Beam size decreasing along the section is caused by RF focusing in the wave type transformer.

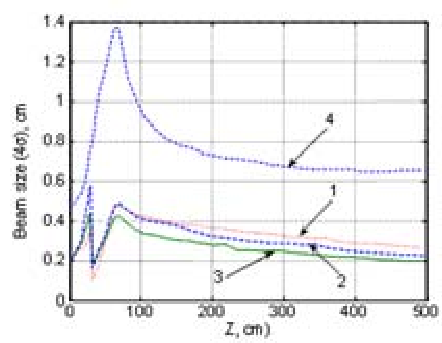

Figure 3: Beam size (4σ) along the injector and the first accelerating section for three configurations of the magnetic system. 1 – only the solenoid is switch on; 2 – only the lens is switch on; 3 – the solenoid and the lens are switch on; 4 – the same as 3 but at gun current 1.1 A.

It is possible to see from Fig. 3 that combination of the solenoid and the lens provides the best transportation of beam in the first accelerating section. Values of magnetic field in the solenoid and the lens practically do not influence transversal emittance of the beam.

At simulation of beam dynamics concerning the second problem we created the magnetic field by five coils placed along the injector. After several iterations needed configuration that provided almost constant beam size in the area of bunch formation and acceleration has been found. This configuration is shown in Fig. 4 (curve 2). Curve 1 there shows the magnetic field distribution of the solenoid that corresponds to the results represented in

Fig. 3. To get sharp fall of the magnetic field in the cathode area, the first coil is connected in opposite direction to others.

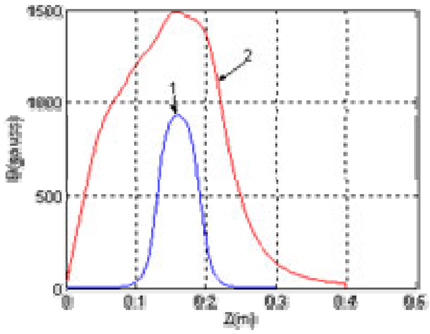

Figure 4: Magnetic field configurations in the injector.

Changes of beam size along the injector and a subsequent drift space are shown in Fig. 5. Curve 1 represents the case when the solenoid is "on" (see curve 1 in Fig. 4). Curve 2 corresponds to the case without the magnetic field. Curve 3 corresponds to the magnetic field of coils (see curve 2 in Fig. 4).

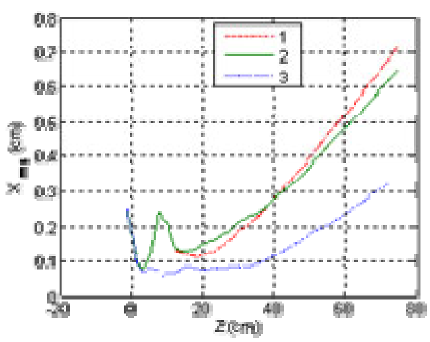

Figure 5: Root mean square beam size (1σ).

The results showed in Fig. 5 were obtained at use of the gun with beam current of 1.1 A. It is clear from the curve 3 in Fig. 5 that beam size is almost constant along the considerable part of the injector (the Z co-ordinates 0 through 14.5 cm). Normalized transversal emittance of ampere range beam at the end of the drift space is three times less (15 π·mm·mrad) in this case than that without magnetic field. At use of the gun with beam current of 0.25 A and the same magnetic field the transversal emittance is two times less than that without magnetic field. Thus, maintenance of a constant beam size in the injector considerably diminishes the transversal emittance. However for application of this technique it is necessary to solve several technical problems, in particular, to provide the magnetic shielding of the electron gun. Therefore at the first stage the magnetic system, represented in Fig. 2 will be used.

CONCLUSION

The injector of the linac for storage ring "NESTOR" is developed. The injector can provide the beam current up to 1 A at energy of electrons about 1 MeV. Use of the coaxial RF coupler will provide the field symmetry in the resonance system of the injector and will improve transversal beam parameters. Research of influence of the solenoid magnetic field on particle dynamics in the injector showed that maintenance of constant transversal beam size on the stage of bunch formation and acceleration considerably diminished transversal beam emittance. Design of the magnetic system which will provide necessary field configuration is under way. On the first stage for providing beam transportation more simple magnetic system that includes the short solenoid and axial magnetic lens will be used.

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