SIMULATION OF S-BAND RF GUN WITH RF BEAM CONTROL

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Abstract

The RF gun with RF control is discussed. It is based on the RF triode and two kinds of the cavities. The first cavity is a coaxial cavity with a cathode-grid assembly, where beam bunches are formed, the second cavity is required for the beam acceleration. The features of the gun are the following: bunched and relativistic beams in the output of the injector, absence of the back bombarding electrons, low energy spread and short length of the bunches. The scheme of the injector is shown. The electromagnetic field simulation and beam dynamics are presented.

INTRODUCTION

The RF gun with a thermionic cathode can be used as the injector. It is based on the cavity joint with the cathode-grid assembly [1, 2]. Emitted by the cathode electrons are accelerated by the cavity electric field. The main advantages of this system are the following. Firstly, the beam is immediately formed to the bunches that follow with the cavity frequency. Secondly, the particles can become relativistic at the output of the injector. This beam can be directly injected to the linear accelerator regular accelerating structures operating with a frequency of the injector cavities. But if the thermionic cathode without an additional control of the beam current is used, the electrons are emitted continuously. In this case some negative effects occur: wide energy spread of the particles at the injector output, back bombardment of the cathode and the cavity walls by the electrons, additional heating of the cathode. Besides that, output bunches have significant “tails”. Then, during the acceleration, these “tails” are usually lost. If they are of a high energy, an additional radiation background can occur when “tails” hit the inner walls of the accelerator channel.

To avoid disadvantages of the conventional RF gun the additional control cavity can be used. This cavity is coaxial type cavity with capacitance, which is based on the RF triode [3, 4]. Generating the necessary phase shift between the controlling RF signal (which is applied to the cathode-grid gap) and the electric field in the accelerating cavities, one can reduce the output bunch duration and decrease the particle spread. In case of a sufficient RF power in the accelerating cavities, particles at the injector output have ultrarelativistic velocities.

In this paper a principle scheme of the injector with a frequency of 2856 MHz is discussed. The control system of the beam current is described. Results of the output beam dynamics simulations with an emission current of 10 A are presented. The most attention is paid to the longitudinal beam dynamics. The beam emittance is unconsidered in the paper.

SCHEME OF THE INJECTOR

General scheme of the controlled RF gun is presented in Figure 1. RF power from the klystron which can also be used to feed the regular accelerating structures is transmitted to the gun accelerating cavities along the waveguide section through the isolator and the vacuum window. Part of the klystron power is derived to the coaxial cavity which is a part of the RF triode. The triode grid is the continuation of the accelerating cavity end wall. To tune the voltage amplitude on the cathode-grid gap and the phase delay relative to the accelerating cavities in the RF section of the coaxial cavity, an adjustable attenuator and a phase shifter are used. Cathode heating is realized by the power source through the inner conductor of the coaxial cavity. To compensate the accelerating cavity field which penetrates to the cathode-grid gap due to the grid transparency, an additional bias voltage can be applied.

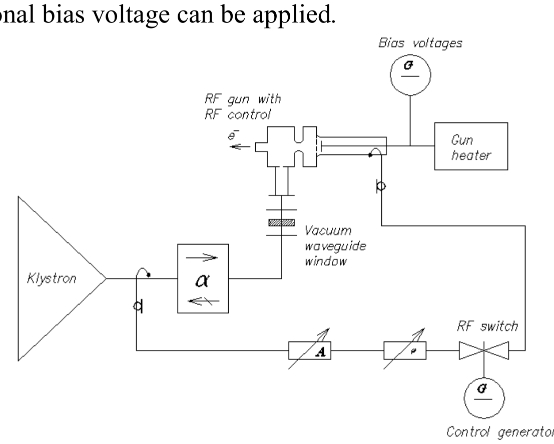

Figure 1: Scheme of the RF gun with RF control.

In the scheme of the RF gun with RF control presented in Figure 1, the common RF power generator is used to feed the accelerating cavities and the control coaxial one. In this case the beginning of the beam current pulse and its duration are always connected with the common RF pulse of the generator. For the independent control of the beam current duration without using an additional RF power source, it is proposed to use the coaxial RF switch at PIN diodes developed before [5-6]. By means of the control voltage on the diodes, one can let pass a RF signal through the coaxial line or provide its full reflection. The RF pulse edges have the duration of about 50 ns, so one can form the current with a pulse base duration of 100 ns. Also the independent RF power source for the control cavity can be

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used. In this case the generator has to have an output RF power not less than 1.5 kW.

Electrodynamic characteristic calculations of the electron gun accelerating cavities were carried out by means of software package CST Studio [7]. The cavity consisting of 1.5 accelerating cells with the oscillation mode of π was used. Coaxial cavity includes the RF triode. As the triode GS-34 (developed in Russia) was used since it has the enough high emission current Pulse characteristics of the triode GS-34 are in [8].

Figure 2 shows the model of the injector with the electric field distribution inside the cavities. Coaxial cavity 1 has an inner diameter of 20 mm and the outer one of 50 mm, the length is 105 mm. Power input is implemented through the coaxial input of N-type 2 with radii of the conductors of 7 mm and 3 mm (outer and inner, respectively). Cathode-grid assembly 3 is inserted into the cathode focusing electrode 4. Parameters of the cathode-grid assembly are the following: cathode diameter is 12 mm, cathode-grid gap is 0.1 mm. Accelerating cavities 5 have a coaxial power input 6 with a waveguide port 7. This input was chosen for the electromagnetic field symmetrization inside the accelerating cavities. Waveguide 8 is an additional matching element and can serve for the vacuum pumping. The lengths of the accelerating cavities equaled 24.8 mm and 52.3 mm for the first cavity and the second one, respectively. Inner diameter of the coaxial input 6 is equal to 14 mm, the outer one is equal to 50 mm.

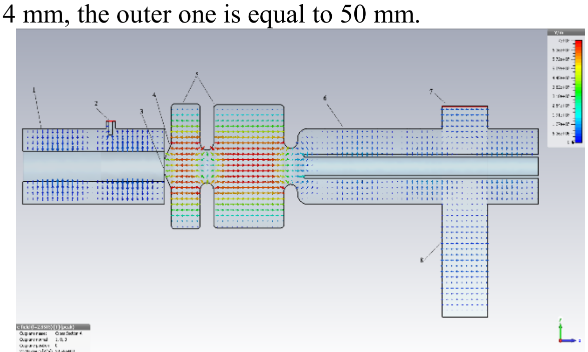

Figure 2: Model of the RF controlled RF gun. Fields agree with the power distribution: 4 MW in the accelerating cavities, 1.5 kW in the coaxial cavity.

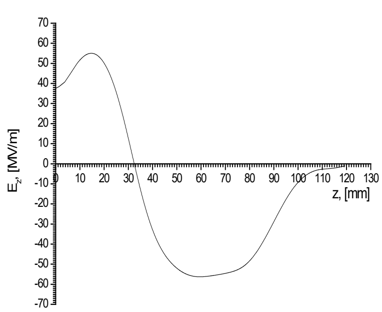

Figure 3: Distribution of the electric field amplitude on the axis of the accelerating cavities at the power of 4 MW.

Electric field distributions on the axis of the accelerating cavity is shown in Figures 3.

Figure 4 shows the electric field amplitude distribution that penetrates from the accelerating cavities to the cathode-grid gap of the coaxial cavity. According to this figure, electric field penetrates from the accelerating cavities to the cathode. Its amplitude there is not more than 2% of the field amplitude at the grid. So, the electric field with the amplitude of about 0.8 MV/m penetrates to the cathode and corresponds to the voltage at the cathode grid gap of 80 V. This additional voltage can be compensated by the bias voltage that, should not exceed 150 W by the absolute value [8].

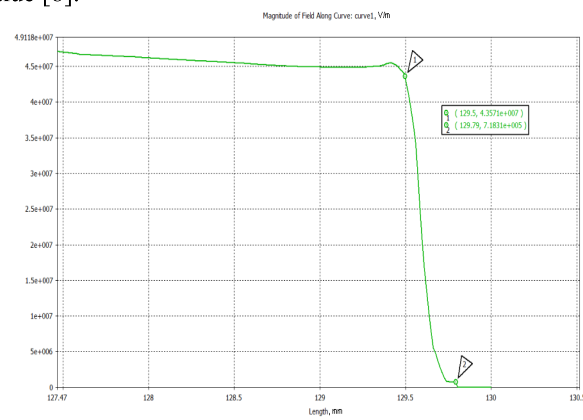

Figure 4: Electric field amplitude distribution penetrating from the accelerating cavities to the cathode-grid gap of the coaxial cavity at the excitation power of 4 MW. Marker 1 corresponds to the cathode position, marker 2 corresponds to that of grid.

PARTICLE DYNAMICS

Particle dynamics simulations were also carried out with help of CST Studio [7]. Because of computer ability limitation the accelerating cavity and the exciting one were considered to be independent in terms of the electromagnetic field. The grid was considered to be completely transparent for the beam. Phase shift between the control voltage in the coaxial cavity and the voltage in the accelerating cavities equaled about 120°. Field amplitudes are shown in Figs. 4 and 5. The cathode emission current was chosen 10 A.

Figure 5 shows the diagram of relationship between the beam current at the injector output and time. According to the figure, the beam consists of bunches with a frequency of about 2856 MHz. The phase length of a bunch is about 50°. The average output current is about 5 A that is 50% of the given cathode current. Figure 6 presents the energy spectrum of the beam at the RF power in the accelerating cavities of 4 MW. That shows the average beam energy equaled 3.1 MeV as well as the energy spread is 5% for 98% of the particles. Back travelling or lost in the cavity walls electrons are not observed. The grid influence on the angle distribution was not considered, as was already mentioned.

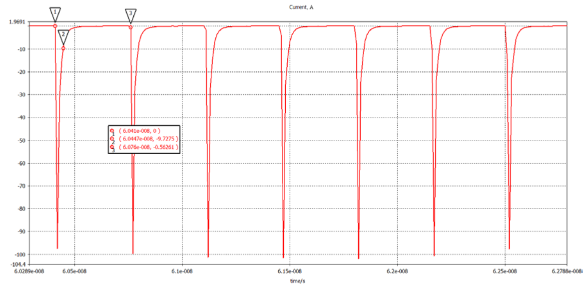

Figure 5: Beam current at the injector output.

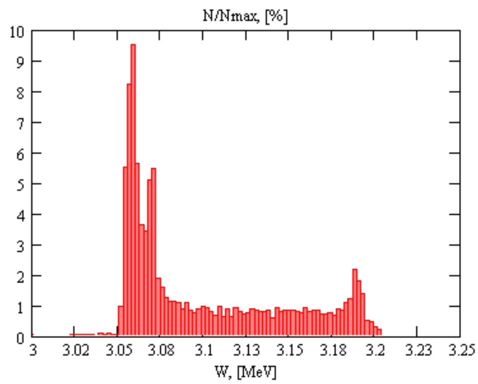

Figure 6: Energy spectrum of the beam.

Figure 7 shows the accelerated beam with the emission current of 10 A in the accelerating cavities at various moments of time. As one can see, the beam is matched with the drift channel due to using the special form of the cathode electrode.

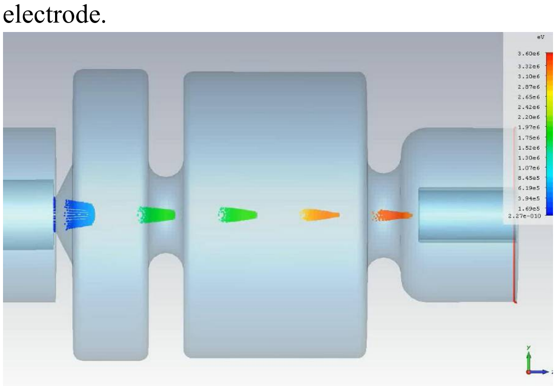

Figure 7: Transverse beam dynamics in the accelerating cavities of the RF controlled RF gun. The bunch is shown in various moments of time.

CONCLUSION

The detailed simulations show that RF gun with the RF control allows obtaining electron bunches with an operating frequency of the accelerator, relativistic velocity and small energy spread in a bunch. Besides, in this model high-energy particles that go back to the cathode or get to the injector walls are absent. The properly chosen profile of the cathode electrode is capable of focusing enough big charges without using an additional external magnetic field. The simulation of the RF power penetrating from the accelerating cavities through the grid to the exciting cavity did not show the significant voltage in the cathode-grid gap and this value can be compensated by bias voltage.

Proposed injector can be used in the complex, when the good emittance of the electron beam is not important, for example, for accelerators with conversion systems. Also this system can be applied for S-band industrial accelerators.

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