

THERMIONIC RF GUN WITH HIGH DUTY FACTOR

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Abstract

Back bombarding limits wide usage of thermionic RF guns. The article presents one of the possible field distribution on-axis of a RF gun, which allows to reduce back bombarding power of a cathode. Simulation predicts 20 kW of pulsed back bombarding power on the LaB₆ cathode under 0.51 A of output current and 0.908 MeV of maximum energy of electrons. Average current can be increased until average power of back bombarding reaches the initial filament power of a cathode. Therefore it is expected to reach at least 0.5 mA of average output current. Energy spectrum and bunch phase length are suitable to inject the beam directly into the accelerator structure with the phase velocity equal to the velocity of light. Ramp of the cathode temperature during RF pulse and long time stability of output current are discussed.

1 INTRODUCTION

It is well known, that beside providing high quality beams RF guns allow to simplify the injector part of resonant linacs. This fact caused our interest to use RF gun as injector of linacs for a wide application. In particular, it would allow to eliminate such a complicated and unreliable device as a high voltage power supplier of a DC gun. However, such linacs operate with a high duty factor. In this case an application of RF guns is limited due to the following reasons:

i) for the photo-emission RF guns: huge cost of a laser system and short life time of the efficient photo-cathodes.

ii) for the thermionic RF guns: the back bombarding effect as well as wide energy and phase spectra.

The work was aimed at a search of such an on-axis electric field distribution that would allow to reduce back bombarding power and would provide suitable energy and phase spectra of electrons to inject the beam directly into the acceleration structure with the phase velocity v_p equal to the velocity of light.

2 RF GUN WITH LOW BACK BOMBARDING POWER

Back electrons increase cathode temperature of thermionic RF gun. To compensate this increase it is necessary to reduce filament power of the cathode. It is obvious that it can be done until average power of the back bombarding exceed the initial filament power. The pulse power of back bombarding electrons is about 100 kW for single cell RF gun [1] and about 50 kW for

double-cell RF gun [2]. Filament power of the latter one is about 12 - 15 W (pressed oxide Ba-Ni cathode). Filament power for a RF gun that is similar to the gun described in [1] is about 30 W [3] (LaB₆ cathode). It is clear, that these guns can not operate with a high duty factor, for example, of 0.1%.

On the basis of the RF gun design experience it is possible to formulate some criteria of a field distribution search. The electric field that accelerates electrons about 1 MeV per cell is rather high for space charge that is characteristic for thermionic RF guns, so to reach the beam energy about 1 MeV it is necessary to use several cells. The length of the first cell should be chosen in such a way that it would be possible to deliver a substantial part of electrons emitted from the cathode to the entrance of the second cell. The second cell is not to make a considerable acceleration of the electrons. The fundamental acceleration should be made at the next cells. In such a way it is possible to reduce back bombarding and to provide suitable bunching to inject the beam directly into the acceleration structure.

Simulation of the RF gun was made on basis of SUPERFISH [4], PARMELA [5] and the simple edint codes. The edint code allows to simulate two-dimensional electron motion in RF guns taking into account influence of the Schottky effect on the cathode emission. It was used to calculate the back bombarding power of a ring cathode. To simulate a thermionic RF gun with PARMELA the input0 was used. The diout file was prepared by addition code which changed "superparticle" charge according to the Schottky effect.

The design of the RF gun which consists of three accelerating cells was chosen on the basis of the mentioned criteria. On-axis field distribution is shown in Fig. 1. Fields in the adjacent acceleration cells have opposite phases, that is π -mode. Electrons were emitted

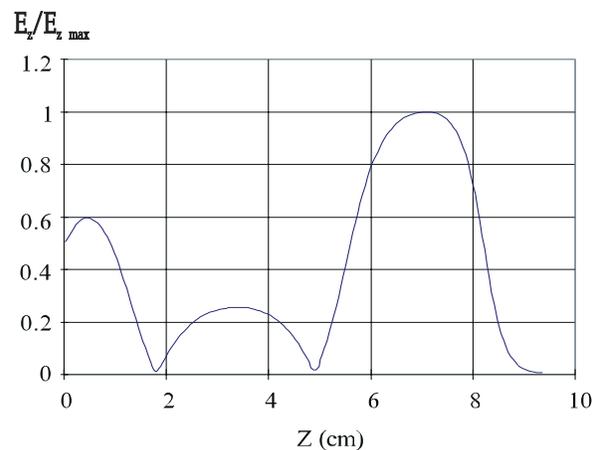


Fig. 1

by LaB₆ cathode with diameter 5 mm. Simulation results of electron motion for maximum value of on-axis field $E_{z,max} = 30$ MV/m are the following. Maximum energy of electrons W_{max} at the gun exit is 908 keV while their average energy W_{av} is 760 keV. The RF gun exit is reached by 51% of particles emitted from the cathode. 70% of particles at the RF gun exit are within the phase interval $\Delta\phi = 43^\circ$ and have the fractional energy spread $\Delta W/W_{av} = 35\%$. The root mean square normalized emittance $\epsilon_{n,rms}$ is 21 mm-mrad. The pulse power of back bombarding electrons P_{back} is 20 kW for 0.51 A of the output current. The back bombarding electrons have average energy $\overline{W}_{back} = 49$ keV. Fig. 2 shows phase and energy spectra of output beam while Fig. 3 shows phase-energy and $x - x'$ distributions of the particles. It follows from above mentioned data and figures that output beam is bunched enough, so it can be injected directly into the acceleration structure with $v_p = c$.

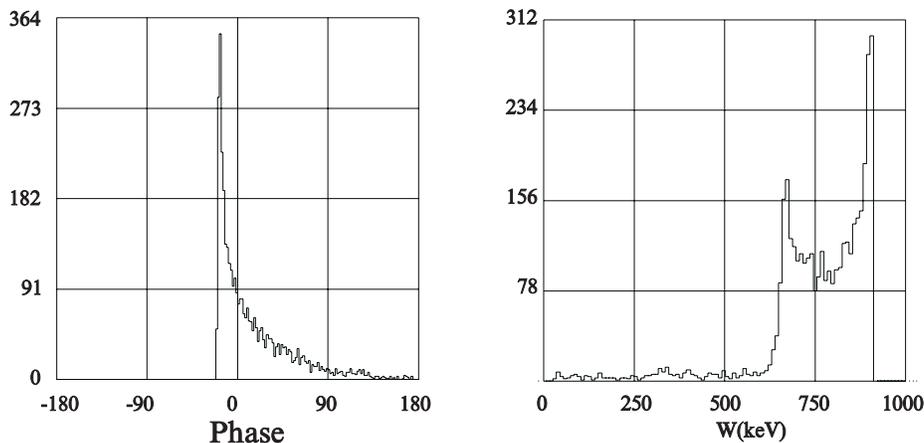


Fig. 2

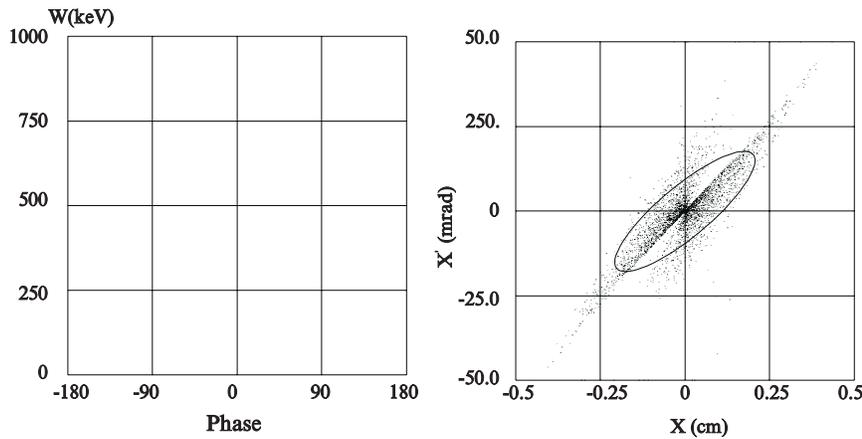


Fig. 3

For duty factor of 0.1% (300 pps and pulse duration $\tau_p = 3,3 \mu s$) average power of the back bombarding takes a considerable part of filament power. There is an experience of RF gun operation with increased pulse repetition rate under switching off filament power [3,6], but in both cases the steady state cathode emission was too high. It is necessary to use a ring cathode to eliminate this effect. The simulation performed for the

ring LaB₆ cathode with an outside diameter of 5 mm and an inner diameter of 2 mm showed that cathode back bombarding power was 13 kW. The part of back bombarding electrons which passes through the inner hole of the cathode can be dissipated inside the cathode housing unit. Of course, the ring cathode increases the beam emittance in 1.5 times, but it is still less than the emittance of a great number of convenient injectors. A ring cathode allows to obtain the necessary output current for operating with a high duty factor by changing the inner diameter.

It is necessary to note that increasing the average temperature of the cathode is not the only harmful factor. A ramp of the cathode temperature that occurs during RF pulse can also cause some troubles. To estimate the temperature ramp with good accuracy it is necessary to take into account energy and spatial spreads of back bombarding electrons as well as spread of heat. For rough estimation of the temperature ramp very

simple approaches were used. Let's assume that all back electrons have the same energy which is equal to \overline{W}_{back} and they are uniform distributed on the cathode surface. Let's also assume that power of back electrons dissipates within the slice of the cathode the depth l of which is equal to the extrapolated penetration length of electrons with energy \overline{W}_{back} , spread of the heat is

neglected. In this case the ramp of the temperature ΔT is equal:

$$\Delta T = \frac{P_{back} \tau_p}{c_p S l \rho},$$

were c_p -- thermal capacity, S -- square, ρ - density of the cathode.

For the solid and the ring cathodes the temperature ramps are 44°K and 34°K, respectively. These ramps increase emission of the cathodes to the end of RF pulse on 70% and 40%, respectively. The temperature ramps are overestimated in this approximation because for the pulse duration the heat spreads on the length that is comparable with a penetration length of electrons.

The main question is how to provide long time stability of the output current when back bombarding power takes a considerable part of filament power. It can be done by using negative feedback on cathode temperature and making RF gun slightly undercoupled with a waveguide for operation current. For undercoupled cavity system a change of the cathode emission causes the opposite change of accelerating field and, consequently, a change of back bombarding power is less than that for the overcoupled cavity system. So it can stop runaway of cathode temperature. Of course, long time stability is an enough complicate question and ultimate answer can give experimental test of the real RF gun.

3 CONCLUSIONS

The on-axis field distribution in a thermionic RF gun has been found that allows to reduce considerably the back bombarding power and providing suitable bunching to inject the beam directly into the acceleration structure. It

is expected to reach at least 0.5 mA of average current at the gun exit. Long time stability needs further experimental study.

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