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DESIGN OF PULSED HV AND RF COMBINED GUN SYSTEM USING GRIDDED THERMIONIC-CATHODE

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Abstract

We propose a simple and compact electron gun system with a control grid, which can provide a low emittance of a few mm mrad. The system is composed of a 50-kV thermionic-gun with a gridded cathode and a 238-MHz rf cavity, each of which is manufactured by extending the well-established technology. The rf cavity accelerates the extracted electrons from the thermionic-gun up to 500 keV to preserve the low emittance. Using the CST and PARMELA particle tracking simulation codes, the proposed system can generate a beam with a low emittance of 2 mm mrad by an extraction charge of 0.6 nC by optimizing voltage parameters of the 50-keV thermionic-gun and the 238-MHz rf cavity.

INTRODUCTION

As a low emittance electron source, a photocathode rf gun [1], or a 500-kV thermionic-gun with a single crystal cathode [2] are usually used. Each electron gun system has own strong and weak points. The rf gun system is rather compact but it requires a large and complicated laser system to obtain highly stable beam. On the other hand, the 500-kV thermionic-gun is almost maintenance-free. However, the weak point of the thermionic-gun is to prepare the large and difficult high voltage system.

In order to remove the above-mentioned weak point, one of the authors (Otake) proposed a robust, compact and low-cost electron gun system, while keeping the low emittance and an electron energy above 500 keV. The system comprises of a thermionic-gun with a charging voltage of 50-kV and a 238-MHz rf cavity in order to increase beam energy up to 500 keV. This system adopts a commercially available gridded cathode. An electron pulse length of less than 1 ns extracted from the cathode is sufficiently short to be captured by the phase space of the following acceleration rf. These combining instruments can eliminate the laser system.

Concern in the above-mentioned idea is an emittance growth by the distorted electric field (lens effect) in the grid [3]. It is well-known effect depends on the electric potential shape and strength on the grid wire and the space-charge field strength of the beam [4]. There is the cancelling point of both electric field strengths between the lens effect and the space charge effect. In order to improve this emittance deterioration, we have investigated the optimum condition of this cancellation by using computer simulation. In this paper, we describe basic design of the gun system and the optimized parameters of a beam transport to keep the low emittance.

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DESIGN OF PULSED HV AND RF COMBINED GUN SYSTEM

The low-emittance pulsed HV and rf combined gun system just consists of extension of the established technology. To generate the pulsed beam without the laser system, the 50-kV thermionic-gun with a gridded cathode is employed. The gridded cathode is Y845, which is manufactured by CPI Corporation. To extract beam with a pulse length of 600 ps from the Y845, a fast pulser drives a voltage between a cathode and a grid mesh. Furthermore, the 238-MHz rf cavity is placed as close as possible to its acceleration gap and just behind of the 50-kV thermionic-gun for obtaining a relativistic beam energy of over 500 keV. This positioning is indispensable to reduce the emittance growth by the space charge effect, as which means quickly accelerating to a high β the electron. Furthermore, we consider rf leakage from the rf cavity to the grid and the cathode surface. The acceleration phase space of the 238-MHz rf cavity can capture the pulsed beam, which is beam acceleration scheme similar to a rf gun. In this case, nonlinearity of a rf voltage curvature is one of cause of the emittance growth. When the energy spread of the beam caused by the rf nonlinearity is less than a few percent, there is slight the emittance growth. It is acceptable for our design.

In the 50-kV thermionic-gun, a high-voltage instruments can operate in the atmosphere without insulation oil. Furthermore, a solid-state device can be handle this voltage for a pulser and a power supply. On the other hand, the device installed in a rf amplifier, which has long lifetime and lower failure, and can also drive the 238-MHz for the rf cavity. These are advantage of the gun system. This advantage is not only cost saving, but also improving maintainability.

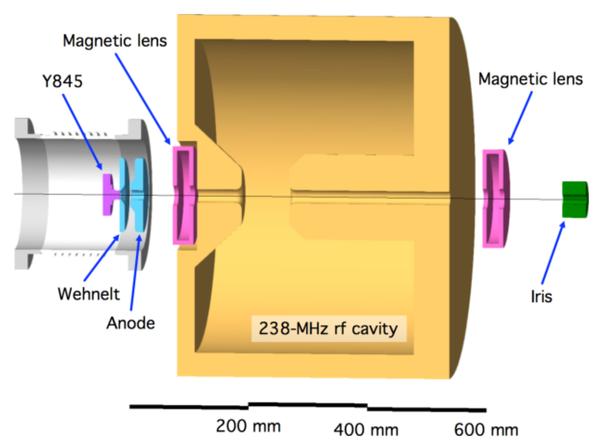

Figure 1: Schematic drawing of the low-emittance pulsed HV and rf combined gun system.

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Based on the design, we finally decide the configuration of the low-emittance pulsed HV and rf combined gun system, as shown in Fig. 1. In this system, there is still a problem, which is the emittance deterioration by the lens effect in the grid. This point is crucial for deciding the feasibility of this system. In the next section, we mainly concentrate this discussion.

LOW-EMITTANCE BEAM GENERATION

Cancellation of Lens Effect

In order to improve the emittance deterioration, the electric field and electron trajectories near the grid are simulated using the CST code. Figure 2 illustrates the electric field strength and the electron trajectories near the grid. Individual drawings in the figure correspond to the grid voltage conditions of 35 V, 45 V and 55 V, respectively. When the grid voltage is 35 V, the electric field distortion gives a transverse kick to the electron passing through the grid mesh, as shown in Fig. 2 (a). Increasing the grid voltage, the transverse kick decreases, as shown in Fig. 2 (b) and (c). There is the optimum voltage so as to balance the space charge force of the beam and the focusing force, which is generated by the lens effect, as shown in Fig. 2 (c).

Based on the above results of the lens effect, the relation between emittances and beam charges, and the dependence on the grid voltages are simulated in order to find the minimum emittance. In the cases of the anode voltages of 50 kV, 60 kV and 70 kV, Fig. 3 shows the emittances and beam charges at the exit of the thermionic-gun, as functions of the grid voltage. The normalized emittance reaches 1 mm mrad with the beam charge of 1 nC (1.7 A / 0.6 ns) in the grid voltage of around 70 V. It is turned out that a normalized emittance of less than 1 mm mrad is obtained, even though the beam charge is increased. It means that this is the emittance is insensitive to the region of this anode voltage change.

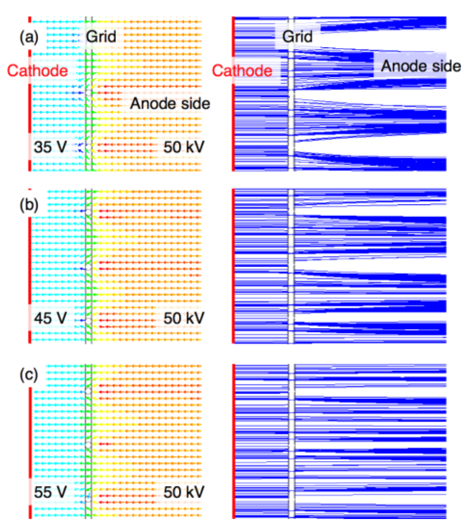

Figure 2: Electric field strength (left) and beam trajectory near grid of Y845 (right) simulated using CST code. (a), (b) and (c) correspond to the grid voltage conditions of 35 V, 45 V and 55V, respectively.

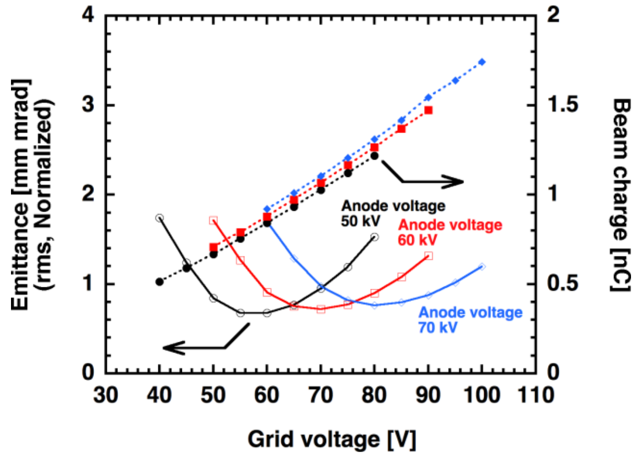

Figure 3: Emittance (solid lines) and beam charge (dashed lines) at the exit of the thermionic-gun as functions of grid voltage simulated using CST code.

50-kV Thermionic-gun

In the design of the 50-kV thermionic-gun, the arrangement and shape of each electrode is optimized by the CST simulation so as to be a collimated beam at the exit of the thermionic-gun. Figure 4 shows the electron trajectories emitted from Y845 to the anode. Figure 5 shows a particle distribution in the horizontal phase space at the exit of the thermionic-gun. Table 1 summarizes the parameters of the gridded cathode and beam characteristics at the exit of the thermionic-gun. As the result, the designed the thermionic-gun satisfy the required specification of the normalized emittance of 1 mm mrad with the beam charge of 1nC.

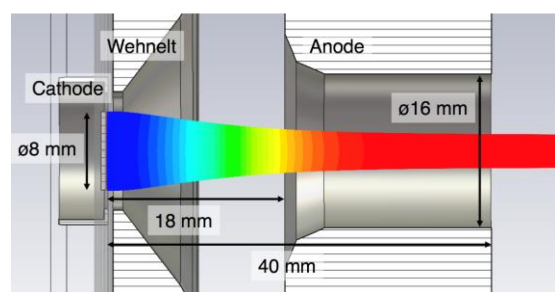

Figure 4: Electron trajectories from Y845 to the anode simulated by CST code. The colormap shows a beam energy change (from the blue: 10 eV to the red: 50 keV).

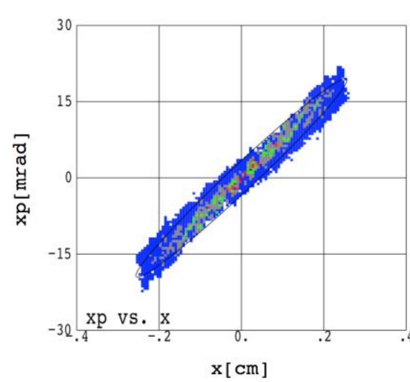

Figure 5: Particle distribution in horizontal phase space at the exit of the 50-kV thermionic-gun.

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Table 1: Main Parameters of the 50-kV Thermionic-gun

Physical parameter of thermionic-cathode (Y845)	
Cathode diameter	8 mm
Distance between cathode and grid	180 μm
Grid spacing	180 μm
Wire diameter of grid	20 μm
Temperature	1000 ˚C
Work function	1.68 eV
Anode voltage / Grid voltage	-50 kV / 70 V
Beam characteristics of 50-kV thermionic-gun	
Charge (current / pulse width)	1 nC (1.7 A / 0.6 ns)
Normalized emittance	1 mm mrad

Beam Transport, Acceleration and Collimation

The distance between the 50-kV thermionic-gun and the 238-MHz rf cavity is shorten as much as possible in order to minimize the emittance growth due to the space charge effect. In order to control the beam envelope, a magnetic lens is located between the 50-kV thermionic-gun and the 238-MHz rf cavity, as shown in Fig. 1. The 50-keV beam is accelerated up to 500 keV on the crest phase of the 238-MHz rf cavity.

The beam transport and the acceleration in the 238-MHz rf cavity is simulated using PARMELA code. An energy spread by the rf nonlinearity is 2.7% without the space charge effect. An emittance due to the energy spread increases by a factor of 1.1. The simulation results with the space charge effect are shown in Fig. 6. A normalized emittance after the 238-MHz rf cavity is 3 mm mrad with a beam charge of 1 nC. The beam before an iris, which is located after the 238-MHz rf cavity, has a uniform distribution, as shown in Fig. 7. In order to extract the beam core, the iris removes the halo of the 500-keV beam. The extracted beam has a normalized emittance of 2 mm mrad with a beam charge of 0.6 nC, as shown in Fig. 6. Emittances and beam charges can be adjusted by the aperture size of the iris, as shown in Fig. 8.

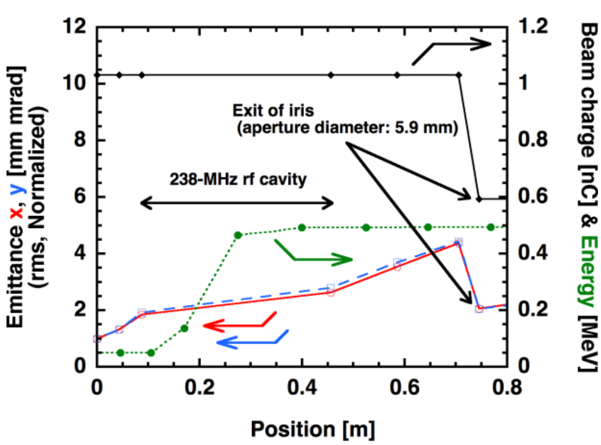

Figure 6: Emittances and beam charges in acceleration process of the gun system simulated by PARMELA code. The origin point is the exit of the 50-kV thermionic-gun.

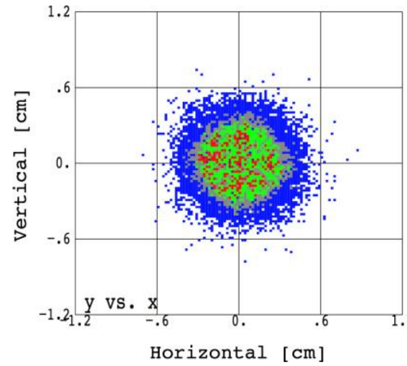

Figure 7: 500-keV beam profile before the iris simulated by PARMELA code.

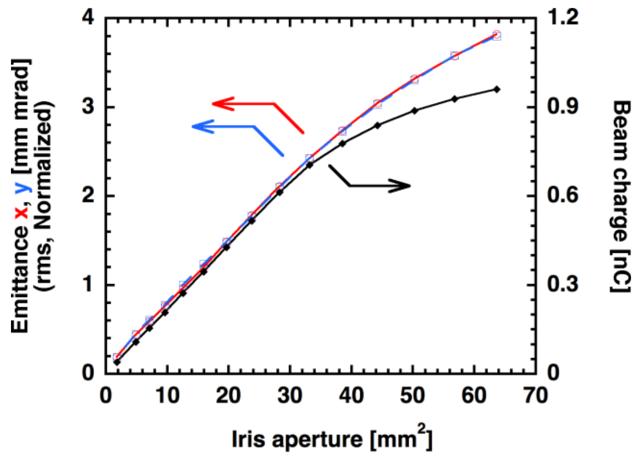

Figure 8: Emittances and beam charges as functions of the aperture sizes of the iris simulated using PARMELA code.

CONCLUSION

We proposed a low-emittance pulsed HV and rf combined gun system composed of a 50-kV thermionic-gun and a 238-MHz rf cavity. The main causes of the emittance deterioration in this system are the lens effect in the gridded cathode, the space charge effect between the thermionic-gun and the rf cavity, and the energy spread by the rf nonlinearity. To improve the emittance deterioration, each component was optimized by the particle tracking simulation. The simulation result shows that an emittance of less than 2 mm mrad is achievable in a beam charge smaller than 0.6 nC/pulse. Currently, the test bench has been constructed to confirm the beam performance including the low emittance predicted by the simulation.

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