STUDY OF CONTROL GRID THERMIONIC CATHODE RF GUN

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Abstract

In this paper, the beam loading effect in the thermionic cathode RF Gun was studyed. To minimize the energy spread in macropulse of RF Gun, a design of Control Grid Thermionic Cathode RF Gun was given. In numerical simulation, the result of this kind RF Gun is: electron beam energy is 2MeV, transverse emittance is 23πmm.mrad, micropulse width is 25ps, micropulse beam current is 12A. The primary experiments has been done. For 1% electron beam energy spread selected by α magnet, the beam current can get 400mA.

1 INTRODUCTION

The thermionic RF-gun has been widely used in FEL experiment. The main problem of thermionic RF-gun is electrons back bombardment.

At CAEP, a L-band thermionic RF-gun was used for the 100um FEL device. To produce 4us macropulse electron beam, the micropulse current in 2% energy spread is limited by effect of back bombardment to 5A. The electron back bombardment change the beam load of thermionic RF-gun, and increase the electron energy spread in beam macropulse. To increase the beam current, the effect of back bombardment must be controlled.

2 EFFECT OF BACK BOMBARDMENT

The standing wave accelerator includes RF generator, circulator, coupler, and cavity (Fig. 1). And its equivalent circuit can be drawn as figure 2.

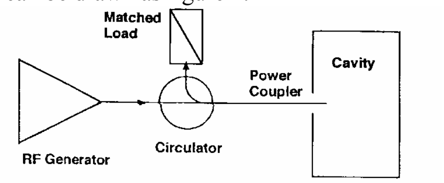

Figure 1: RF system of the standing wave accelerator[1].

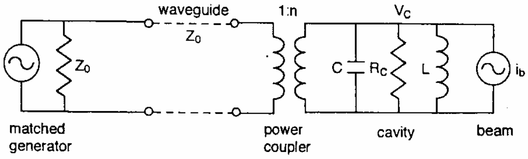

Figure 2: The equivalent circuit of the standing wave accelerator[1].

By the equivalent circuit of accelerator, the stored energy of cavity is

$$\Delta U = CV_c\left(V_{\max} - V_c\right)\frac{\Delta t}{\tau} \tag{1}$$

Where $V_{\max}$ is the maximum voltage of cavity without electron beam, V_c is the voltage of cavity, $U = (1/2)CV_c^{\ 2}$ is the stored energy, and τ is the resonance time constant.

For the steady-state of cavity, the average electron beam power P_b equals to the increasing of stored energy of cavity.

$$P_b = CV_c\left(V_{\max} - V_c\right)\frac{1}{\tau} \tag{2}$$

We express $\tau = 2Q/\omega$ and $Q = \omega U/(P_{ex} + P_c)$, where P_{ex} is the external power dissipated, P_c is the power dissipated in cavity wall. Substituting these expressions into Eq. 2, we can get

$$V_c = V_{\max}\frac{P_{ex} + P_c}{P_{ex} + P_c + P_b} \tag{3}$$

So, the change of cavity voltage can be written as

$$\frac{dV_c}{V_c} = -\frac{1}{1 + \frac{P_{ex} + P_c}{P_b}}\frac{dP_b}{P_b} \tag{4}$$

For the accelerator design, the waveguide-to-cavity coupler is always set to critically coupled with the designed beam current. So Eq. 4 can be written as

$$\frac{dV_c}{V_c} = -\frac{1}{2 + 2\frac{P_c}{P_b}}\frac{dP_b}{P_b} \tag{5}$$

When the beam power is larger compared with the average power dissipated in cavity wall, the change of electron beam load will remarkably influence the beam energy. Figure 3 shows the electron beam waveform of thermionic RF-gun in CAEP.

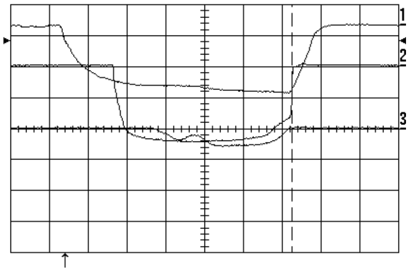

Figure 3: Electron beam waveform of thermionic RF-gun(<ch1>).

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3 CONTROL GRID THERMIONIC RF-GUN DESIGN IDEA

In FEL experiment, the electron beam energy spread must be controlled strictly (always less than 1%). So the main problem of thermionic RF-gun is the effect of back bombardment. The process of the back bombardment is:

- Electrons back bombardment
- The temperature of cathode increasing
- The electron beam current increasing
- The electric field of cavity reducing
- Electron beam energy reducing

So there are many methods to minimize the effect of back bombardment.

- To control the electrons back bombardment, we can carefully design the cavity, use the cathode with a hole in center, use the magnetic field, et al.
- To control the temperature of cathode, a laser can be used to heat the cathode.
- To control the electron beam current, we can use the control grid electron gun.
- To control the electric field of cavity, the power of microwave is needed to be controlled.
- To control electron beam energy, a external electrical source can be used to change the electrical potential of cathode.

In our design of the new RF-gun, the control grid electron gun was used. To minimize the emittence of the electron beam, the grid was put into the first cell. Figure 4 shows the position of the grid and the cathode. The space between grid and cathode is about 0.9mm, the voltage of cathode is 600-1000V. Figure 5 shows the structure of the new RF-gun cavity. .

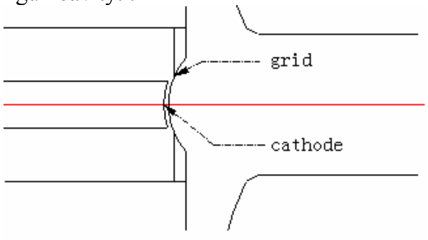

Figure 4: Structure of the RF-gun near the cathode.

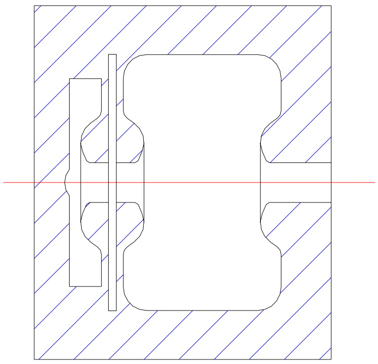

Figure 5: Structure of the RF-gun cavity.

4 SIMULATION RESULT

The first cells of the RF-gun act as a bunching segment too. The bunching segment makes the electron and the microwave synchronize better and more electron will be captured. The SUPERFISH CODE and the GPT CODE has been used to calculate the electron beam. The current of the cathode is 2A. The field ratio of the second cell to the first cell is about 4, the electrons get energy mainly from the second cells.

The simulation result (energy spread 1%) is: beam energy is 2MeV, emittence is 23pi mm*mrad, micropulse width is 25ps, micropulse current is 12A. Some simulation results show in figure 6 and figure 7.

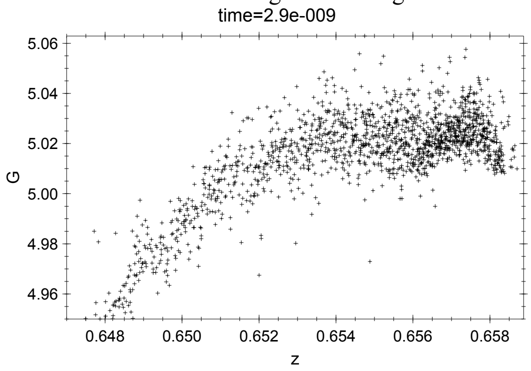

Figure 6: Electron beam energy distribution at the exit.

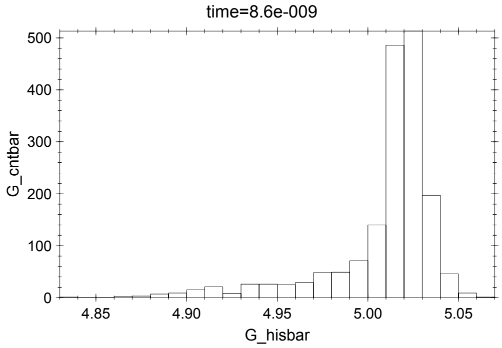

Figure 7: Electron beam energy spectrum.

5 EXPERIMENT RESULT

The characteristic parameters of the control grid RF-gun are measured by net work analyzer: The resonant frequency of the $\pi/2$ mode is 1300.16MHz, the coupling coefficient of the wave guide to the cavity is 5.2. The klystron microwave source is 3.5MW. The voltage between grid and cathode is 400V. The macropulse width is 4μs, the beam current at the a magnet exit during the macropulse up to 400mA. Fig.8, Fig.9, and Fig.10 show some pictures of the new RF-gun and some experiment results.

Figure 8: Picture of control grid electron gun.

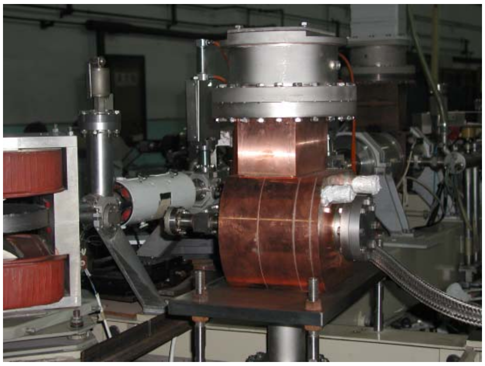

Figure 9: Picture of the new RF-gun.

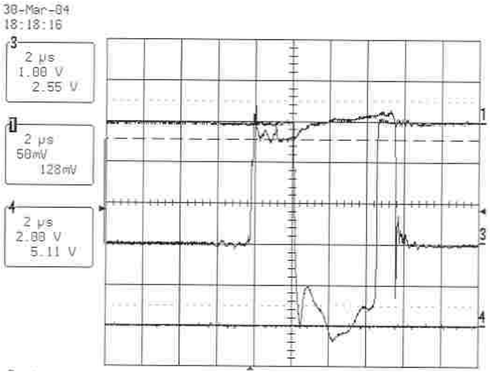

Figure 10: Electron beam waveform of the new RF-gun(<ch1>).

6 CONCLUSIONS

The thermionic cathode RF gun is a kind of excellent electron source. In this work, the control grid electron gun has been used to reduce the effect of back bombardment. The experiment results show that these methods work efficiently. But we also found that the beam emittence is larger than simulation result.

REFERENCES

[1] Wangler T P, Principles of RF Linear Accelerators, New York, J. Wiley & Sons Inc., 1998