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Experimental Study of a Multi-Cavity RF Gun with Thermionic Cathode

Tang Chuanxiang, Lin Yuzheng, Wu Yuanming[2], Wang Youzhi[2], Zhao Xinqiao[2], and Xie Jialin[2]

(Department of Engineering Physics, Tsinghua University, Beijing, China)
[2](Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China)

A novel multi-cavity RF thermionic gun with very weak back bombardment effects has been designed, manufactured, tested, and subjected to experimentation. In this paper, we focus on the experimental results of this RF gun. From the current pulse shapes of BCT at the gun exit and the energy spectra at different positions of the macro-pulse, we can see that the back bombardment effects are suppressed greatly. A current of about 200 mA, a maximum electron energy of 1.8 MeV and a geometric RMS emittance of about 20—30 πmm · mrad are obtained at the entrance of the linac.

Key words: RF thermionic gun, back bombardment, current pulse, emittance, energy spectrum.

1. INTRODUCTION

The Beijing Free Electron Laser (BFEL) facility is a Compton regime IR FEL oscillator, which has obtained its saturated oscillation at a wavelength of 10.68 μm [1]. However, due to the back bombardment effect of its single-cavity RF thermionic gun, the BFEL facility is now operating at a repetition rate of less than 10 pps and a macro-pulse width of about 4 μs. Therefore, a novel multi-cavity RF thermionic gun [2] with much weaker back bombardment effects was designed, built, and subjected to experimentation at the RF gun testing stand of the BFEL laboratory in a collaborative effort by Tsinghua University and the BFEL laboratory, IHEP.

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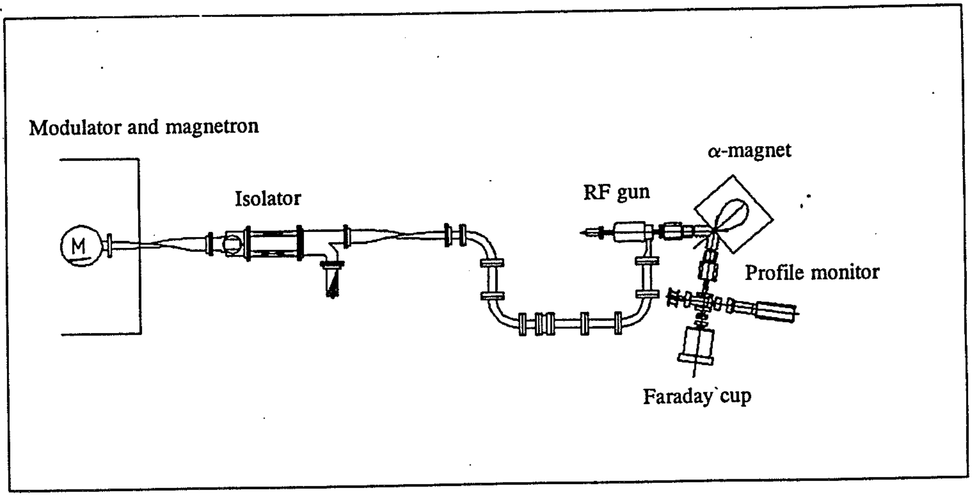

Fig. 1
Layout of the RF gun testing stand in the BFEL laboratory.

This RF possesses bi-period configuration, working at $\pi/2$ mode and a frequency of 2856 MHz. The first accelerating cavity is shortened and a short drift is added between the second and the third accelerating cavities in this RF gun, so that the back bombardment power can be reduced and the longitudinal properties of the electron bunch can be adjusted properly to meet the α magnet requirement [6].

The RF gun testing stand was built to carry out the RF gun studies, including the emission abilities of cathodes, the back bombardment effect, and the beamline research. It consists of a modulator and a magnetron, a microwave transmission system, a beamline, a control system, and a RF gun. The layout of the RF gun testing stand is shown in Fig. 1. Its microwave power source can provide microwave pulses with a width of about 4.1 μs, a flat top of about 2.7 μs, and the ripple at the top of less than 3%. The frequency of the microwave can be set by the adjustment rod of the magnetron. It is capable of stably working at frequency of 2856 $\pm$ 4MHz with the repetition rate of 3.125Hz, 6.25Hz, 25Hz, and 50Hz, respectively.

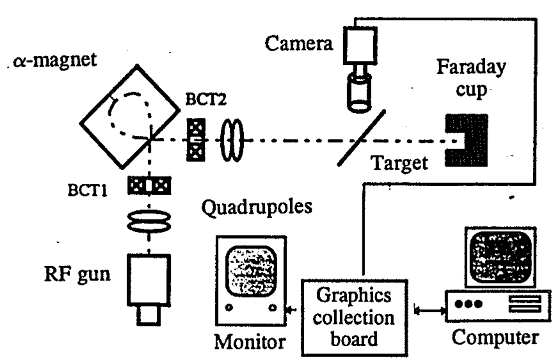

Fig. 2
Sketch of the emittance measurement system.

2. EXPERIMENTAL RESULTS

A single-crystal LaB_6 thermionic cathode with a diameter of 3 mm was used in the multi-cavity RF thermionic gun, which is heated with a tower-shaped tungsten filament. The current pulse shapes and current strength were measured using two BCTs (BCT1 and BCT2) at the exits of RF gun and α-magnet, respectively. The energy spectra were obtained using the α-magnet and the momentum filter in the vacuum chamber. The quality of the electron beam is characterized mainly by its emittance. The variable quadrupole method [3] was adopted to measure the emittance of the electron beam after the α-magnet. A sketch of the emittance measurement system is shown in Fig. 2.

2.1. Current pulses

Figure 3(a) shows the current pulse shape at the RF gun exit under the condition of the input RF power of about 0.8 MW, the macro-pulse current of about 500 mA, and the maximum electron energy of about 1.2 MeV. A close-up view of the top of the current pulses at the RF gun exit is shown in Fig. 3(b), which was obtained with an input RF power of about 1.6 MW. At 1.6 MW power condition, the macro-pulse current is about 800 mA at the RF gun exit and about 200 mA at the exit of the α-magnet, with the maximum electron energy of about 1.8 MeV.

In Fig. 3, the phenomenon of tapered rising in the current pulses at the exit of this multi-cavity RF thermionic gun is seen; such a phenomenon usually happens in other RF thermionic guns because of the back bombardment effects. Furthermore, the ripples of the top of the current pulse in Fig. 3 are consistent with those of the input RF power envelope, with also means the back bombardment effects are very weak in this RF gun.

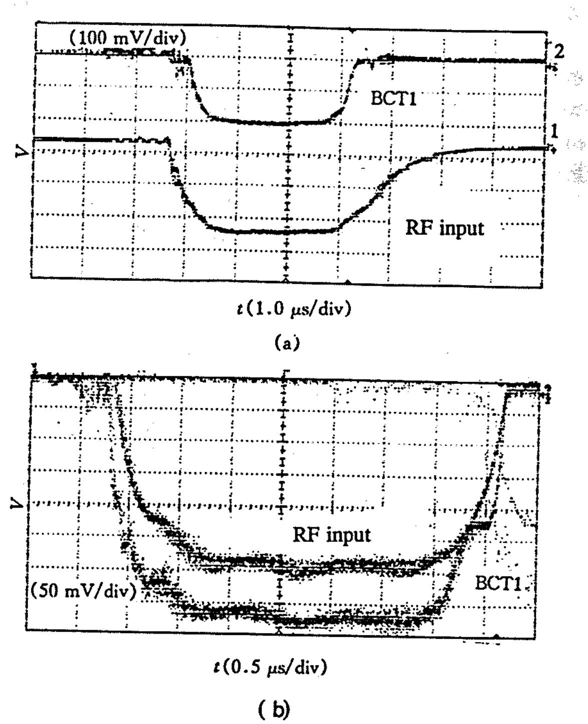

Fig. 3
The current pulse at the gun exit and the envelope of the input RF pulse.
(a) input RF power of 0.8 MW; (b) input RF power of 1.6 MW.

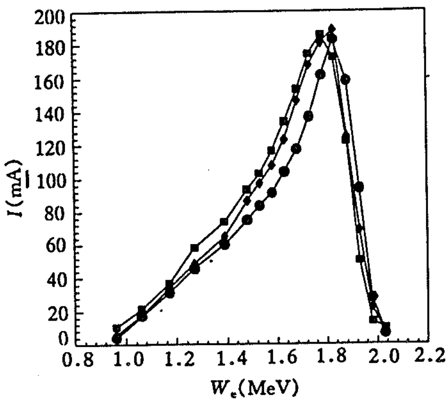

Fig. 4
Electron energy spectra at different time positions of the macro-pulse.
● 1.0 μs; ◆ 2.0 μs; ■ 3.0 μs.

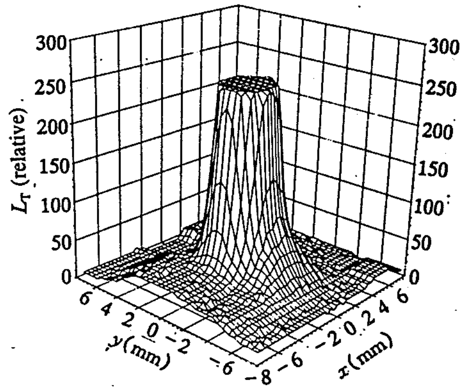

Fig. 5
The brightness distribution of the beam spot.

2.2. Energy spectra

In a RF thermionic gun, the back bombardment of the electrons in the RF thermionic guns causes the increment of cathode's emission current and hence the exit electron energy will droop within the macro-pulse. Then, the electron energy difference in the macro-pulse exhibits the back bombardment effects of the RF thermionic gun. Figure 4 shows the electron energy spectra at different time positions of the macro-pulse with input RF power of 1.6 MW. The origin of the time coordinate is set at the very beginning of the RF envelope. The electron energy at the head of the macro-pulse is about 0.05 MeV higher than that at the tail, which is about 2.5% of the maximum electron energy. The experiment further demonstrates that the effect of electron back bombardment of this RF gun has effectively been suppressed.

2.3. Emittances

The brightness distribution of the spot which was caused by the electron beam hitting a fluorescent target is shown in Fig. 5. The flat top is caused by the saturation of the graphics collection board. The core diameter of the electron beam is about 3 mm. The measured electron beam size in the x direction and its fitted curve as a function of the quadrupole current are shown in Fig. 6. The geometric RMS emittances of the electron beam after the α-magnet are about 28 $\pi \cdot$ mm $\cdot$ mrad in the x direction and 22 $\pi \cdot$ mm $\cdot$ mrad in the y direction, respectively. If only the core of the beam is taken into account, the emittances are about 5 $\pi \cdot$ mm $\cdot$ mrad in both x and y directions.

3. COMPARISON WITH SIMULATION RESULTS

The experimental process of measuring the electron energy spectrum was simulated under almost the same conditions, using the RF thermionic gun dynamics code HOTGUN [4] and beamline simulation code GTL [2]. The simulation and experimental results are shown in Fig. 7. They agree with each other very well.

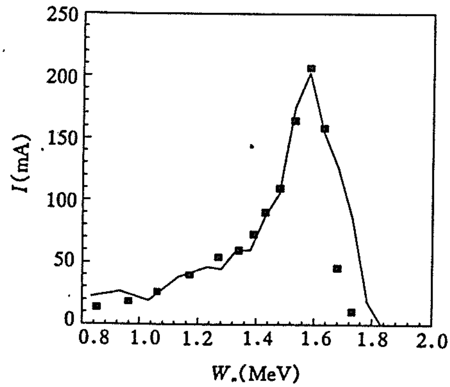

Fig. 6
The horizontal dimension of the beam at the target as a function of the current strength of the quadrupole.

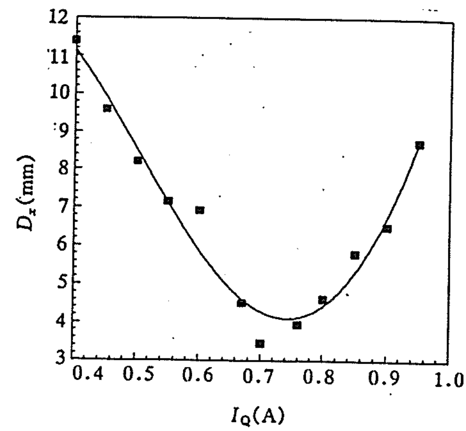

Fig. 7
Experimental and simulation results of the electron energy spectrum.

4. CONCLUSIONS

Experimental studies on the multi-cavity RF thermionic gun for BFEL have been carried out by means of the RF gun testing stand in the BFEL laboratory. The measured results show that the design specification has been reached and the idea [5] adopted to reduce the back bombardment effects is proved to be effective. The back bombardment effects and electron energy spread of the multi-cavity RF thermionic gun are much less than the single-cavity RF thermionic gun used in the BFEL facility now. The maximum electron energy obtained with this RF gun is about 1.8 MeV, about twice that of the original single-cavity RF gun. The transverse emittances also decrease to 28 $\pi \cdot$ mm $\cdot$ mrad in the x direction and 22 $\pi \cdot$ mm $\cdot$ mrad in the y direction, respectively. The macro-pulse current strength is about 200 mA after the α-magnet. This gun would be used in the BFEL facility after further testing.

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