RF gun for an intense THz radiation source*

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Abstract A new facility is under construction at the Shanghai Institute of Applied Physics, to generate femto-second electron bunches and intense coherent THz radiation pulses. A thermionic RF-gun is used to be the electron source of the linac, which is 1.6 cell, $\pi/2$, side coupled in design. In the following of this paper, the design, manufacture and beam operation of this gun are presented.

Key words thermionic RF gun, femtosecond electron beam

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1 Introduction

There are two approaches for generating ultra-short electron bunches. One is a thermionic RF gun with an α magnet, and the other is a photo-cathode RF gun with a chicane magnet compressor. The former solution was adopted for the intense THz radiation source under construction at the Shanghai Institute of Applied Physics (SINAP)[1].

A 1.6 cells thermionic RF gun has been developed and operated successfully at APS[2, 3], SUNSHINE[4] for ultra-short electron bunches. At SINAP, a 1.6 cell, $\pi/2$ mode with a side couple bi-period structure has been developed. The RF gun has been designed and manufactured with the collaboration with the Accelerator Lab of Tsinghua University and Beijing Vacuum Electronics Research Institute. During the commissioning, the achieved average accelerating gradient in the gun is more than 60 MV/m and the beam energy is about 3 MeV.

2 Cavity design and manufacture

The RF gun should generate a beam with a high linearity of bunch energy to bunch length at the high energy part which can be compressed by an alpha-magnet from few tens of picoseconds to few hundreds of femtoseconds. We use the simulation codes such as SUPERFISH[5], PARMELA[6], and ELEGANT[7] to get the beam profile and the cavity dimensions.

The most import thing to be optimized of the RF gun is the field ratio of the first accelerating cell and the second accelerating cell. Simulations show that at a given input RF power, with the increasing of the field ratio, which equals the peak field of the second accelerating cell divided by that of the first accelerating cell, the back-bombardment decreases, while the beam energy decreases and the slope of the linearity part increases.

Another important thing is that when the field ratio increases, the energy divergency increases as well, which means one needs to install an alpha magnet with a big good field region to compensate the lengthening in the drift space. Finally 1.7 was chosen for the field ratio. The bunch compressing system consisting of the alpha-magnet with various strengths and drift space with various lengths giving different results for the beam compression, which is shown in Fig. 1(a). From this figure, one can find an alpha-magnet with the strength of 3.5 T/m and a drift space of 250 cm is a better choice, because the strength of 5 T/m is too high for an alpha magnet.

To check the beam compression, a tracking code was used to simulate this without the space charge. The result is shown in Fig. 1(b). This is a more ideal

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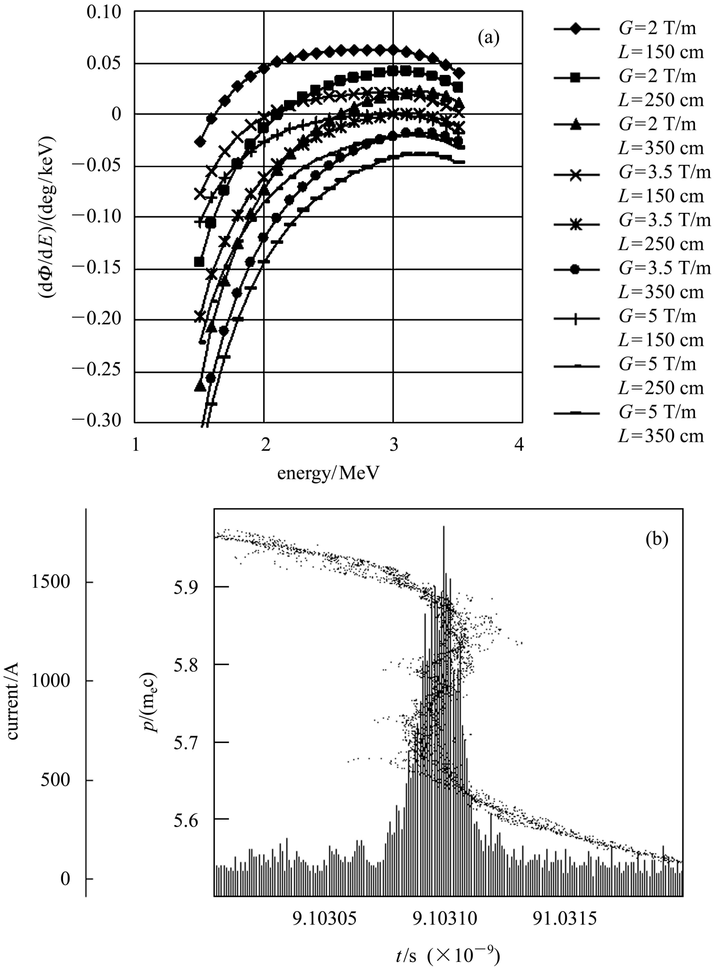

Fig. 1. Beam compression through an alpha magnet. (a) Compression of the gun field ratio of 1.7, with various strengths of alpha-magnet and various lengths of drift space. ($d\Phi/dE = 0$ means best compression, G means the strength of alpha-magnet, and the L means the length of the drift space). (b) The particle distribution in longitudinal space after compression by Elegant.

result, because the space charge force will lengthen the beam in fact. And this effect will be shown later in the experiments.

Once the field ratio has been defined, the coupling coefficient between the accelearting cells and the coupling cell can be estimated by the coupling cell theory[8]. The dimensions of the accelerating cell of the RF gun are shown in Fig. 2. The coupling cell is a re-entrance type cavity with small size and low Q.

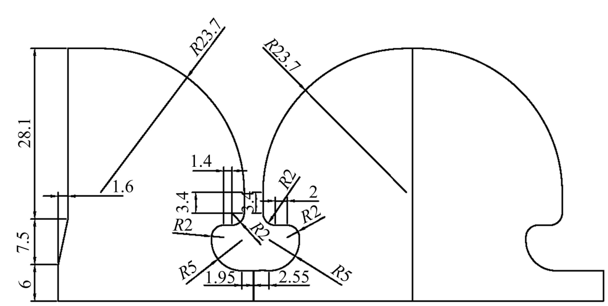

Fig. 2. The dimensions of the accelerating cell of the RF gun.

The RF gun is designed to generate electron bunch trains with macro-bunch current of ∼1 A and energy of ∼3 MeV. The beam loading is about 3 times compared to the wall loss which is estimated by the calculated Q value. So the coupling coefficient from the waveguide to the RF gun is set to 4 to minimize the reflected RF power at the nominal working point.

Two sets of the RF gun parts of have been made, one for the RF cold measurements, and the other for the high power operation.

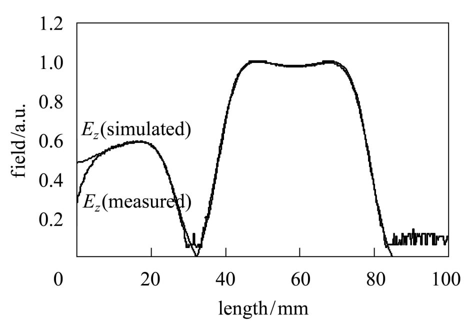

Fig. 3. The field profile of RF gun at $\pi/2$ mode.

Table 1. Measured RF parameters of the gun.

frequency/MHz*		Q value		coupling coefficient	
1st accelerating cell	2855.02	1st accelerating cell	12000	1st accelerating cell to coupling cell	1.99%
2nd accelerating cell	2855.42	2nd accelerating cell	14600	2nd accelerating cell to coupling cell	0.98%
coupling cell	2855.16	Coupling cell	4200	between accelerating cells	0.05%
RF gun	2855.87**	RF gun	15500**	waveguide to gun	4.2**

∗ The measurements are performed at room temperature and with air in the cavity. ∗∗ The measurements are performed after final welding and adjustment, while others are measured before welding.

After modification, the ratio between the peak fields of two accelerating cells is close to the design value 1.7. Fig. 3 shows the field profile of the two accelerating cells. And the RF parameters measured are shown in Table 1.

3 Cathode

Simulation shows that to get 1 A beam at the gun exit, the emitting current of cathode should be larger than 2.5 A which presumes an emitting current density of 35 A/cm^2 on a cathode with a diameter of 3 mm. Both single crystal LaB_6 and BaW cathode can meet the requirement. We use the LaB_6 cathode for its high work function, which can effectively reduce self-heating caused by the back-bombardment.

The high work function of the LaB_6 also has one disadvantage, because it works at a high temperature of 1350—1550 ℃. The cathode loader has been carefully designed to minimize the heat leakage from the cathode to the room temperature components, and it is adjustable in the beam direction for setting the right position of the cathode after assembling. An RF choke also was designed to avoid propagating of the microwave power from the cavity to the cathode loader.

During the test, the filament is powered by the filament supply and its temperature is measured by a heat-optical meter via a view port at the vacuum chamber in alpha-magnet. The measured cathode temperature was about 1400 ℃ when the heat power was 30 W.

4 Commissioning of the RF gun

The RF gun and the accelerating tube are powered by one S-band klystron with a nominal output power of 20 MW, via a 6 dB power divider. About one quarter of the output RF power is fed to the RF gun, while the left power is fed to the accelerating tube. The layout of gun, linac, and beam instrumentations setup are shown in Fig. 4.

During the commissioning, the RF power is about 3 μs (FWHM) and the average beam current is about 0.65 A which was detected by an FCT and measured by an oscilloscope. No obvious self-heating was observed, due to the high work fucntion and low back-bombardment design of the RF gun.

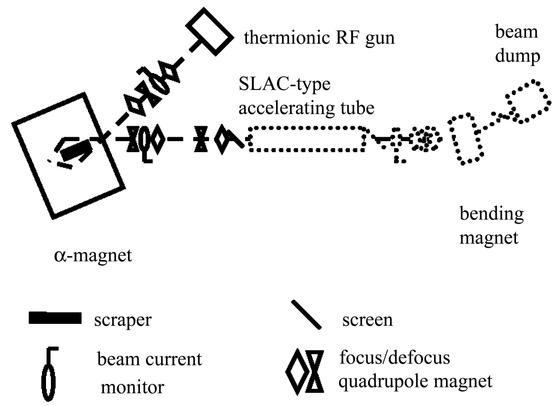

Fig. 4. Layout of RF gun, alpha magnet, and beam instrumentations.

The electron beam from the gun has a low energy and high emittance tail. To measure the energy divergency of the macro-pulse of the electron beam, we use the alpha-magnet and the scraper in the alpha-magnet vacuum chamber as the analyse magnet and slit. And a beam current monitor at downstream section of the alpha-magnet is used to measure the beam current when the scraper moves. Unfortunatley, the scraper could not be located precisely after tens of measurement. As shown in Fig. 5, only low energy beam profile has been measured at the early period of the commissioning. The energy recorded during the operation is ∼3 MeV with an input power of 3 MW.

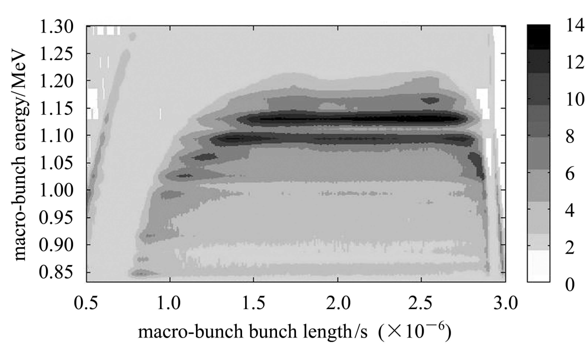

Fig. 5. Measurement of longitudinal profile of the macro-bunch. Different colour stands for different charge density.

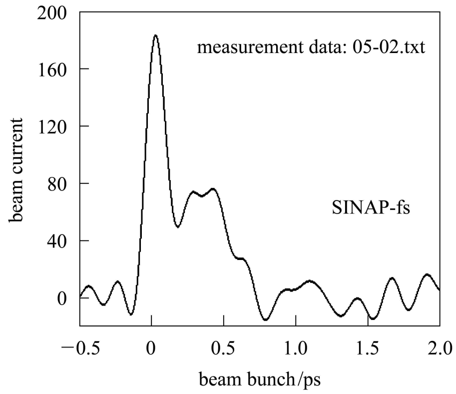

Fig. 6. Reconstructed micro-bunch profile from the corrected autocorrelation.

After the alpha-magnet, the bunch has been compressed to ~250 fs[9], which is measured by a Michelson interferometer. The reconstructed micro-bunch profile is shown in Fig. 6.

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