

# Study on Thermionic RF Electron Gun after Retuning Process

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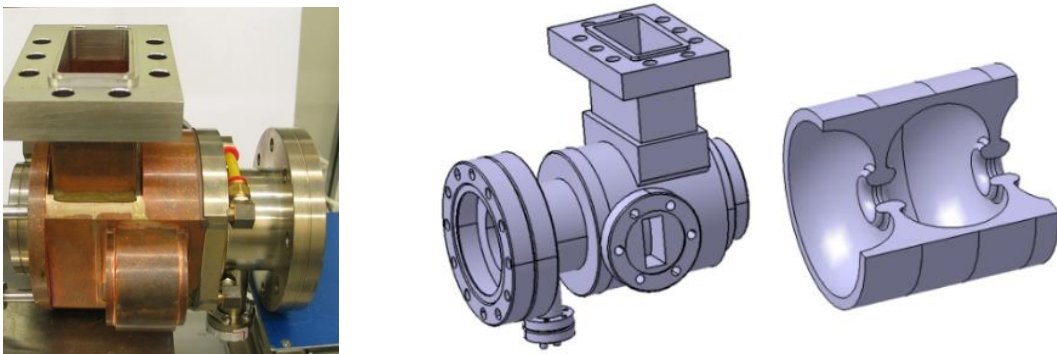
**Abstract.** Relativistic femtosecond electron bunches can be produced from the electron accelerator system at the PBP-CMU Electron Linac Laboratory of the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University (CMU). A thermionic radio-frequency (RF) gun is used as an electron source for this accelerator. The RF gun has a 1.6-cell standing-wave structure with side-coupling cavity. The 2856 MHz RF wave is transmitted from the klystron to the gun through a waveguide system. So far, two RF guns have been used at our laboratory. The first gun was designed and constructed mostly in Thailand. The second one was constructed at the National Synchrotron Radiation Research Center (NSRRC), Taiwan, R.O.C. It was then transported from the NSRRC to our laboratory and was tested after the cavity retuning process. The low-level and high-level RF measurements were conducted. This gun has a resonant frequency of 2855.68 MHz at 26.2°C with a quality factor of 12264. The high-power RF measurements showed that an optimal operating temperature of the gun was 34°C. The electromagnetic (EM) field distribution inside the gun was simulated by using the 3D-model created with program CST Microwave Studio 2012<sup>®</sup>. Study of electron beam dynamics in the gun using program PARMELA was done to estimate the beam properties at the gun exit. Moreover, measurements of the beam properties were performed. The results showed that at optimal conditions the RF gun could produce the beam of  $\sim 2 \mu\text{s}$  (FWHM) pulse width with a charge of  $850.1 \pm 34.7 \text{ nC}$ . The major fraction of the beam has an energy in the range of 1.5-2.5 MeV.

## 1. Introduction

The injector system for the PBP-CMU electron linac consists of a thermionic RF electron gun, an alpha magnet for electron bunch compression, quadrupole focusing magnets, beam steering magnets, and several diagnostic components. A thermionic cathode is installed at the rear wall of the first standing-wave cavity. The RF wave is transmitted to the gun via a rectangular RF waveguide that is connected to the gun at the radial wall of the second cavity. The RF wave from the second cavity is coupled to the

first one through a side-coupling cavity. Opening holes between the main cavities and the RF input-port as well as the side-coupling cavity cause asymmetric electromagnetic (EM) field distribution inside the gun.

There are two RF guns have been used at our laboratory. The first one was designed and fabricated mostly in Thailand, except for the brazing process. The commissioning of this gun was done with reliable performance. Then, it was dismantled from our accelerator system and the second RF gun was installed in July 2011. This gun was constructed at the HOPE Laboratory, National Tsing Hau University and the National Synchrotron Radiation Research Center (NSRRC), Taiwan, R.O.C [1]. It has some different features from the first gun, which are a nose-cone cathode, an adjustable tuning plug and a smaller opening hole of the RF input-port. Moreover, cooling channels are located inside the gun's wall for better gun temperature control. The actual picture, 3D drawing and inner cut-view of the gun are shown in figure 1. All information presented in this paper is for this second RF gun.



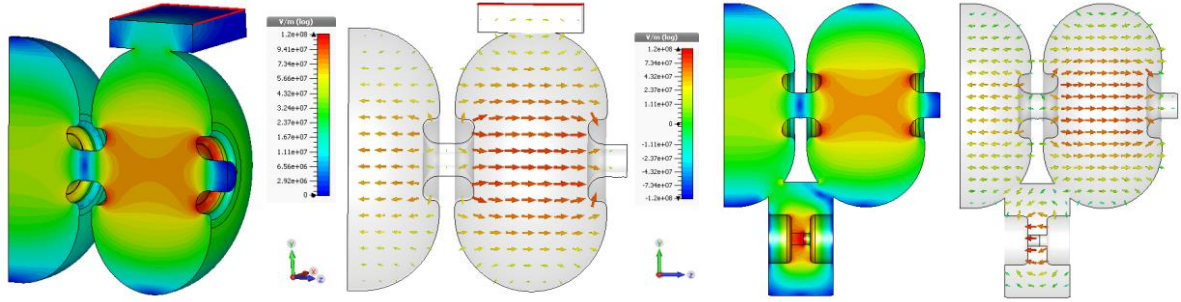
**Figure 1.** Picture, 3D drawing and inner cut-view of the second PBP-CMU RF-gun.

For operation at our laboratory, the flat-cathode is used instead of the nose-cone one to decrease the transverse emittance of electron beams at the RF-gun exit according to the study results in [2]. The gun was then operated to produce the beam with a central kinetic energy of around 1.5 MeV and a pulse current of 400 mA [3]. However, due to the incomplete copper plating at the area around the cathode heat-dam, the leak of the RF wave occurred. This led to the breakdown of the gun operation. Therefore, the repair of copper plating on the heat-dam surface was performed. The resonant frequency retuning process was also done. The 3D RF modeling and beam dynamic simulations were performed. Moreover, the measurements of RF and beam properties were conducted.

## 2. RF simulation and electron beam dynamic simulation

### 2.1. Simulation of electromagnetic fields

A computer program CST Microwave Studio (MWS) 2012<sup>@</sup> [4] was used to create a 3D model of the RF gun for studying RF properties and electromagnetic field distribution inside the gun. Figure 2 shows contour and vector plots of the electric field distribution for the  $\pi/2$ -mode inside the RF-gun in both vertical and horizontal plane. The RF input port leads to asymmetric field distribution in the vertical direction, while the side-coupling cavity leads to asymmetric field distribution in the horizontal direction. The tuning-rod position was varied to obtain the field ratio as close as possible to the measured value. The best simulated peak electric field ratio ( $E_{p2}/E_{p1}$ ) is 2.13 at the resonant frequency of 2855.73 MHz for  $\pi/2$ -mode. Some important RF parameters obtained from the MWS simulations are summarized in table 1.



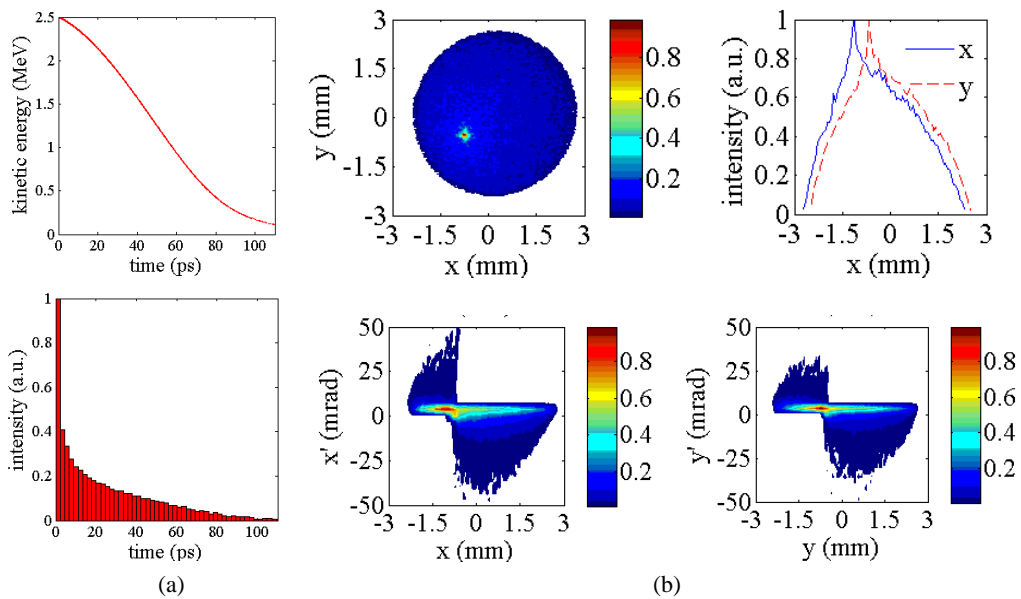
**Figure 2.** Contour and vector plots of the electric field distributions for the  $\pi/2$ -mode RF-gun on the  $y$ - $z$  plane (2 pictures in the left) and the  $x$ - $z$  plane (2 pictures in the right).

**Table 1.** Summary of simulated RF-gun parameters.

Parameter	0-mode	$\pi/2$ -mode	$\pi$ -mode
Resonant frequency (MHz)	2541.80	2855.73	2868.74
Quality factor	6647	16943	13796

## 2.2. Beam dynamic simulations

The program PARMELA [5] was used to study electron dynamics inside the RF gun. In simulations, an electron bunch with a total charge of 0.91 nC per RF period are tracked through the EM field obtained from the CST MWS output. The initial electron kinetic energy of 0.165 eV was used, which corresponds to the cathode temperature of 950°C. The peak electric field at the cathode and at the full-cell center are 30.62 and 64.86 MV/m, respectively. Simulation results in figure 3 show that the longitudinal distribution of the beam has well energy-time correlation with a large fraction of particles accumulated at the head of the bunch. This particle distribution is suitable for the bunch compression using the alpha magnet. Unfortunately, the transverse phase spaces have asymmetric distributions as shown in figure 3(b). At the RF gun exit, the beam has a maximum kinetic energy of 2.51 MeV with a bunch charge of 0.21 nC. The horizontal ( $x$ ) and vertical ( $y$ ) rms sizes are 1.150 and 1.152 mm corresponding to the rms emittances of 20.43 and 19.55 mm.mrad, respectively.



**Figure 3.** (a) Longitudinal distribution and (b) transverse distributions at the RF gun exit.

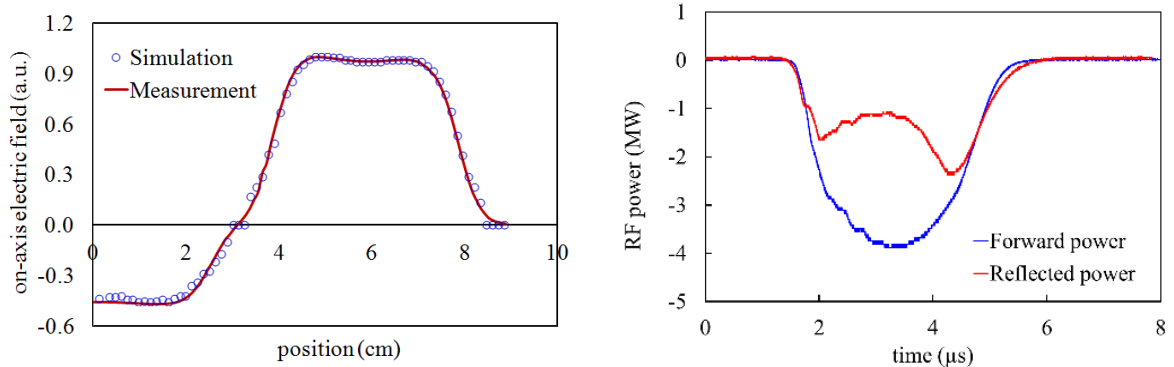
### 3. Measurements of RF properties and electron beam properties

#### 3.1. Low-power RF measurements

The low-level RF measurements in air and room temperature of 26.2°C were conducted to study the RF parameters and the longitudinal electric profile of the gun. Amplitudes of the electric field in the two cells were adjusted by moving the tuning plug inside the side-coupling cavity. The final ratio of the peak electric fields ( $E_{p2}/E_{p1}$ ) is 2.20. The measured resonant frequency and quality factor for the  $\pi/2$ -mode were 2855.68 MHz and 12264, respectively, that are comparable to the simulated values shown in table 1. The measured RF-coupling coefficient was 3.06. Measured electric field profile along the beam propagating path was extracted and the result is agreed well to the simulated data as shown in figure 4 (left).

#### 3.2. High-power RF measurements

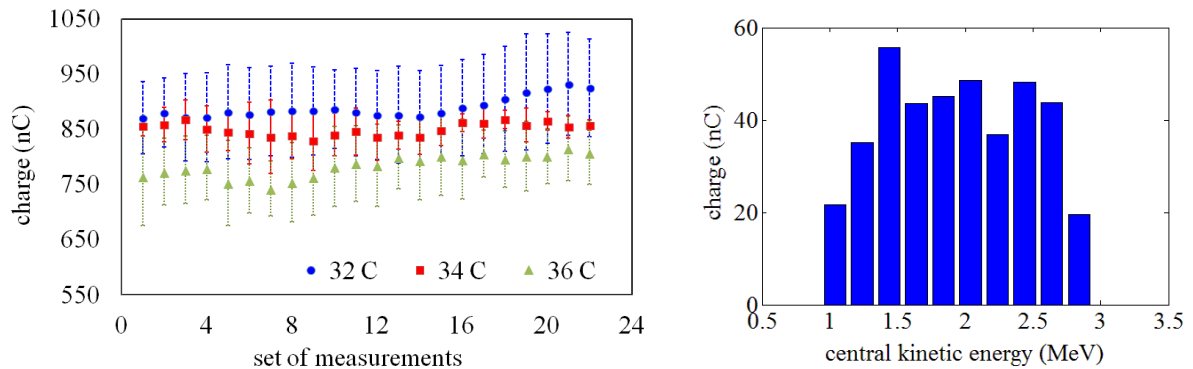
The high-power RF measurements were performed by using the RF wave with the pulse repetition rate of 10 Hz and the pulse width of  $\sim 3 \mu\text{s}$  (FWHM). The operating temperature of the gun was controlled with the water cooling system. Since our gun is over-coupled to an external RF source, the RF-coupling coefficient ( $\beta_{rf}$ ) was estimated from the powers of forward ( $P_f$ ) and reflected ( $P_r$ ) RF waves at the optimal condition, which the most RF absorption occurred as  $\beta_{rf} = \left[1 + \sqrt{P_r/P_f}\right] / \left[1 - \sqrt{P_r/P_f}\right]$ . High-power RF studies for three gun temperatures of 32, 34 and 36°C were done. The optimal operating condition happened at the temperature of 34°C, which is presented in figure 4 (right). The forward and reflected RF powers are 3.44 and 0.96 MW, respectively. This leads to the maximum and average absorb RF power of 2.7 MW and 81 W, respectively.



**Figure 4.** (left) Simulated and measured on-axis electric field profiles inside the RF-gun. (right) Forward and reflected RF powers for the gun with the temperature of 34°C

#### 3.3. Electron beam measurements

A current transformer was used to measure electron pulse charge at the RF gun exit and the results are presented in figure 5 (a). The overall results for 22 sets of measurements, which each set has 6 statistic measurements, showed that the beams with the charge of  $783.9 \pm 63.0$  nC,  $850.1 \pm 34.7$  nC and  $889.7 \pm 79.7$  nC were produced at the gun temperatures of 32, 34 and 36°C, respectively. Thus, this RF gun could produce electron beam with more stable pulse charge with smallest standard deviation at the gun temperature of 34°C and the cathode filament power of 27 W. Electron beam energy was measured using energy slits inside the alpha magnet vacuum chamber. The electron spectrum with 0.2 MeV bin for the gun temperature of 34°C are shown in figure 5 (b). About 50% beams with the kinetic energy lower than 1 MeV was filtered out using the low energy slit. The measured results showed that electrons in the main part of the beam have energies in the range of 1.5-2.5 MeV.



**Figure 5.** Results of charge measurements (left) and energy spectrum measurement (right).

#### 4. Conclusion

RF properties of the second PBP-CMU RF gun were studied. The gun had a measured resonant frequency of 2855.68 MHz at the room temperature of 26.2°C and a quality factor of 16943. Results from beam dynamic simulations using 3D EM field distributions suggested that the gun can produce the beam with a maximum energy of 2.51 MeV with 0.21 nC bunch charge. The beam with maximum kinetic energy of 2.8 MeV and charge of  $850.1 \pm 34.7$  nC was measured at the optimal gun temperature of 34°C.

#### 5. Acknowledgments

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#### References

- [1] Lau W K *et al* 2005 *Proceedings of the PAC2005 Conference* (Tennessee: IEEE Xplore) p 1748
- [2] Rimjaem S *et al* 2004 *Nucl. Instrum. Methods Phys. Res. A* **258** 533
- [3] Boonpornprasert P *et al* 2012 *Proceedings of the AGRC2012* (Chiang Mai: GSCMU) p ST-564
- [4] Microwave Studio, Computer Simulation Technology, Darmstadt, Germany; <http://www.cst.com>
- [5] Young L M and Billen J H 2002 *PARMELA LA-UR-96-1835* (California: LANL Technical Note)