NUMERICAL AND EXPERIMENTAL STUDIES ON ELECTRON BEAM PROPERTIES FROM ASYMMETRIC RF-GUN*

S. Rimjaem#, N. Chaisueb, N. Kangrang, E. Kongmon, K. Kosaentor, J. Saisut, C. Thongbai, W. Thongpakdi, P. Wichaisirimongkol

Plasma and Beam Physics Research Facility, Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand

Abstract

The electron linear accelerator at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University (CMU), Thailand, is used to produce femtosecond electron bunches for generation of THz radiation. The main components of the PBP-CMU linac are a thermionic RF electron gun, an alpha magnet, an S-band travelling-wave linac structure, quadrupole lens, steering magnets, and various diagnostic components. The RF-gun consists of a 1.6 cell S-band standing-wave structure and a side-coupling cavity. The 2856 MHz RF wave is transmitted from the klystron to the gun through a rectangular waveguide input-port. Both the RF input-port and the side-coupling cavity cause an asymmetric electromagnetic field distributions inside the gun. This leads to asymmetric transverse shape with larger emittance value. Beam dynamic simulations were performed to investigate the effect of the asymmetric fields on the electron properties by using the code PARMELA. Simulation results suggest that the beam with a maximum kinetic energy of 2.51 MeV, a bunch charge of 0.21 nC and horizontal and vertical emittance values of 20.43 and 19.55 mm-mrad can be achieved. The experiments to investigate the performance of the RF-gun were performed. The results show that at optimal condition the gun can produce the beam of about 2 μs (FWHM) pulse width with a maximum kinetic energy of ~2.8 MeV and a macropulse charge of 850.1±34.7 nC.

INTRODUCTION

A linac-based THz radiation source at the Plasma and Beam Physics (PBP), Chiang Mai University, consists of an S-band thermionic RF electron gun, an alpha magnet, a travelling-wave linac structure, quadrupole focusing magnets, beam steering magnets, transition radiation stations and several diagnostic components. An electron source is a 1.6-cell S-band standing-wave RF-gun. A thermionic cathode is installed at the center of the rear wall of the first half-cell. A WR-284 rectangular RF waveguide is connected to the RF-gun at the radial wall of the full-cell. The RF wave from the full-cell is coupled to the half-cell 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 field distributions inside the gun. In order to study the effect of this feature on the electron beam properties, 3D RF and beam dynamics simulations of the first PBP-CMU RF-gun were performed. The study results show that electron beams produced from asymmetric RF-gun have asymmetric transverse shape and larger transverse emittance than the beams produced from the symmetric one [1]. This RF-gun was dismounted from the PBP-CMU linac system. Then, the new RF-gun was installed in July 2011. It has both common and different features with the previous one. Numerical and experimental studies were conducted to investigate the characteristics and the performance of the new RF-gun.

*Work supported by the CMU Junior Research Fellowship Program.
#Corresponding author: sakhorn.rimjaem@cmu.ac.th

PRESENT PBP-CMU RF-GUN

The current RF electron gun in the PBP-CMU linac system was constructed at the High-energy Optics and Electronics (HOPE) Laboratory, National Tsing Hau University and the National Synchrotron Radiation Research Center (NSRRC), Taiwan, R.O.C [2]. The design of this gun is similar to the first PBP-CMU RF-gun with some different features, which are a nose-cone thermionic cathode, an adjustable tuning plug, a smaller opening hole of the RF input-port on the full-cell radial wall. Moreover, cooling channels are located inside the wall of the gun cavities for better gun temperature control. The 3D drawing and the inner cut-view of the present PBP-CMU RF-gun are shown in Fig. 1.

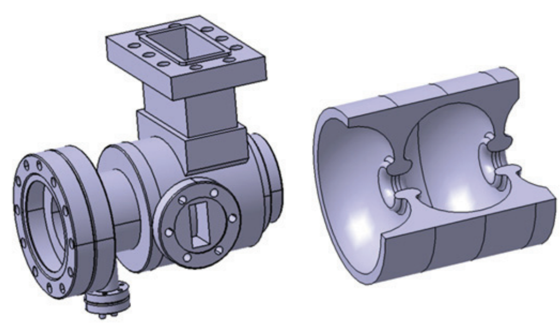

Figure 1: 3D drawing and inner cut-view of the present RF-gun at the PBP-CMU linac facility.

This RF-gun was transported from NSSRC to Chiang Mai University and has been installed as the electron source of the PBP-CMU linac after the cavity re-tuning process. According to the study results in [3], the flat-cathode is used instead of the nose-cone one to decrease the transverse emittance of electron beams at the RF-gun exit. The gun was operated with the forward RF peak power of 3.65 MW and 3 μs (FWHM) pulse width. The

ISBN 978-3-95450-134-2

beam with a central kinetic energy of around 1.5 MeV and a beam macropulse current of 400 mA was obtained [4]. 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 cavity-tuning and low-level RF measurements in ambient air at the room temperature of 26.2°C were conducted to investigate the RF parameters of the gun. In addition, the bead-pull measurements were performed during the cavity-tuning process. Amplitudes of the electric field in the half and full cells was adjusted by moving the tuning plug inside the side-coupling cavity. The final ratio of the peak electric field at the center of the full-cell to that at the cathode position is 2.20. Results of RF measurements are listed in Table 1. The tuning plunger of this RF-gun has special design for allowing the re-adjustment of the field ratio even after the final fabrication and brazing process [2]. Therefore, the dependence of electron beam properties on the field ratio can be studied.

Table 1: Measured RF-Gun Parameters for π/2 –Mode

Parameters	Value
Resonant frequency	2855.68 MHz
Quality factor	12264
RF-coupling coefficient (β_{rf})	3.06
Field ratio (E_{p2}/E_{p1})	2.20

NUMERICAL SIMULATIONS

Simulations of Electromagnetic Fields

A computer code CST Microwave Studio (MWS) 2012@ [5] was used to create a 3D model of the RF-gun (Fig. 2) for studying RF properties and electromagnetic field distributions inside the gun. The tuning-rod position was varied to obtain the field ratio as close as possible to the simulated value. This tuning process was difficult because it required the mesh adjustment for each tuning step. The best simulated peak field ratio (E_{p2}/E_{p1}) is 2.13 at the resonant frequency of 2855.73 MHz for π/2 operation mode. Simulated on-axis electric field profile along the beam propagating path was extracted and the result is agreed well to the measurement data (as shown in Fig. 3). Some RF parameters obtained from the MWS simulations for each mode are summarized in Table 2.

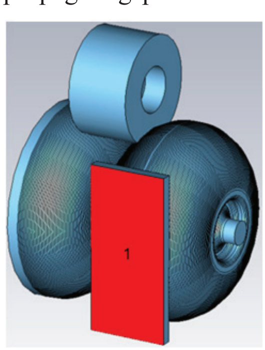

Figure 2: Simulated 3D MWS model of the RF-gun.

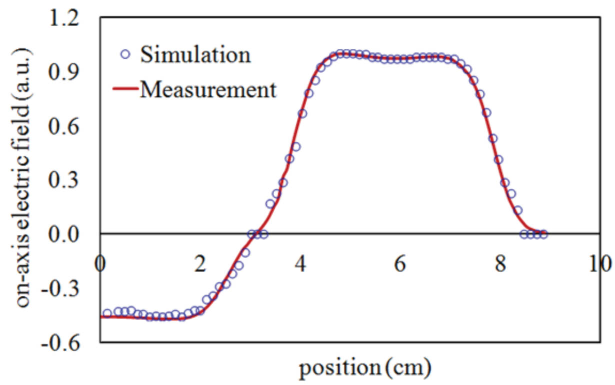

Figure 3: Simulated and measured on-axis electric field distributions inside the RF-gun.

Table 2: Summary of Simulated RF-Gun Parameters

Parameters		Value
Resonant frequency (MHz)	0-mode	2541.80
	π/2 –mode	2855.73
	π –mode	2868.74
Quality factor	0-mode	6647
	π/2 –mode	16943
	π –mode	13796
Field ratio (E_{p2}/E_{p1})	π/2 –mode	2.13

Beam Dynamics Simulations

A particle tracking code PARMELA [6] was used to study longitudinal particle distributions as well as transverse profiles and phase spaces of the electron bunch. In simulations, an electron bunch with a total charge of 0.91 nC per RF period are tracked through the electromagnetic fields, which were obtained from the RF simulation output from the program CST MWS. Radial and longitudinal mesh sizes used in simulations are 0.42 mm and 0.89 mm, respectively. The initial electron kinetic energy of 0.165 eV was used, which corresponds to the cathode temperature of 950°C.

Simulation results in Fig. 4 show that the longitudinal phase space distribution of the beam has linear 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 (Fig. 5), which leads to a larger emittance value than the beam produced from the symmetric gun. Simulated parameters of the electron bunch at the RF-gun exit are listed in Table 3.

To study the beam transportation from the RF-gun to downstream components, the simple simulations including further drift length of 180 cm were conducted and the results are shown in Fig. 6. It is clearly seen that

ISBN 978-3-95450-134-2

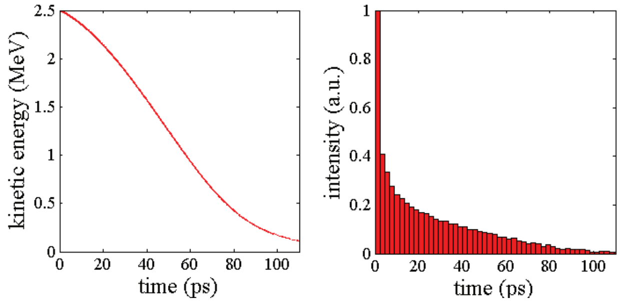

Figure 4: Simulated longitudinal phase space distribution and histogram at the RF-gun exit.

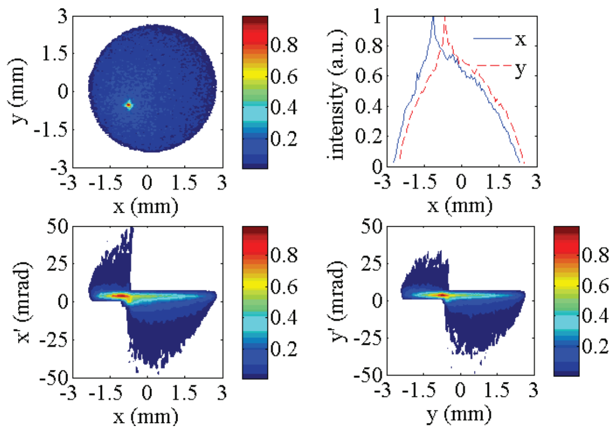

Figure 5: Simulated transverse phase space distributions at the RF-gun exit.

the beam width increases and it is bigger than the diameter of the beam tube (~2.5 cm) at about 70 cm downstream the gun exit. This distance corresponds to the vertex position of the alpha magnet. Energy slits inside the alpha magnet vacuum chamber are used to filter the electrons with low kinetic energies for sufficient post acceleration in the linac and for good beam transportation to the experimental stations. The fraction of useful electrons can be investigated experimentally, which is discussed in the experimental results section. In Fig. 6, the transverse beam emittance decreases when the beam travelling downstream the RF-gun. This is due to the particle lost along the propagating path.

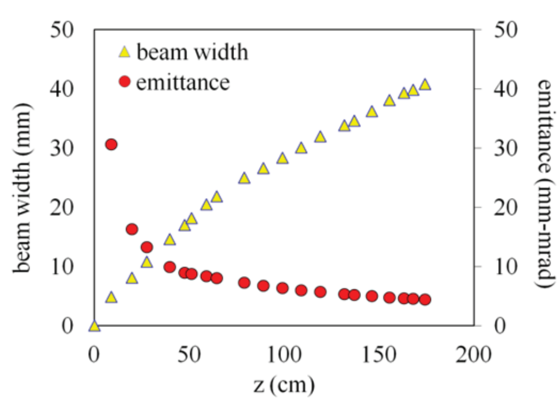

Figure 6: Beam width and beam transverse emittance evaluation from the gun exit through a 180 cm drift tube.

Table 3: Simulated Beam Parameters at the RF-Gun Exit

Parameter	Value
Electric field at cathode	30.62 MV/m
Electric field at full-cell center	64.86 MV/m
Maximum kinetic energy	2.51 MeV
Bunch charge	0.21 nC
Horizontal centroid position	-1.3 mm
Vertical centroid position	-0.7 mm
Horizontal rms beam size	1.150 mm
Vertical rms beam size	1.152 mm
Horizontal rms emittance	20.43 mm-mrad
Vertical rms emittance	19.55 mm-mrad

EXPERIMENTAL RESULTS

During the RF-gun commissioning and the beam characterizations in this study, we used the high power RF pulses with the repetition rate (*ppt*) of 10 Hz and the pulse width of about 3 μs (FWHM). The operating temperature of the RF-gun was controlled by using the cooling system with the precision of the measured temperature around 0.2°C. The high power RF measurements were done to clarify the optimal condition for the RF-gun operation. The RF-coupling coefficient (β_{rf}) was estimated from the amplitudes of forward and reflected RF waves as

$$\beta_{rf} = \frac{1 \pm \sqrt{P_r / P_f}}{1 \mp \sqrt{P_r / P_f}}, \quad (1)$$

where P_f and P_r are the peak powers of the forward and the reflected RF waves, respectively. The PBP-CMU RF-gun is over-coupled to an external RF source, the upper sign in Eq. (1) is used.

Results of high-power RF studies for three gun temperatures are reported in Table 4. It is noted that the forward and reflected RF peak powers (P_f and P_r) in Table 4 were considered at the optimal position, where the most RF absorption occurred.

Table 4: Results of High-Power RF Measurements

Parameters	32°C	34°C	36°C
P_f	3.44 MW	3.86 MW	3.47 MW
P_r	0.96 MW	1.23 MW	1.32 MW
β_{rf}	4.10	4.57	5.24

Current transformers CT1 and CT2 are used to measure electron charge per macropulse at the positions upstream

ISBN 978-3-95450-134-2

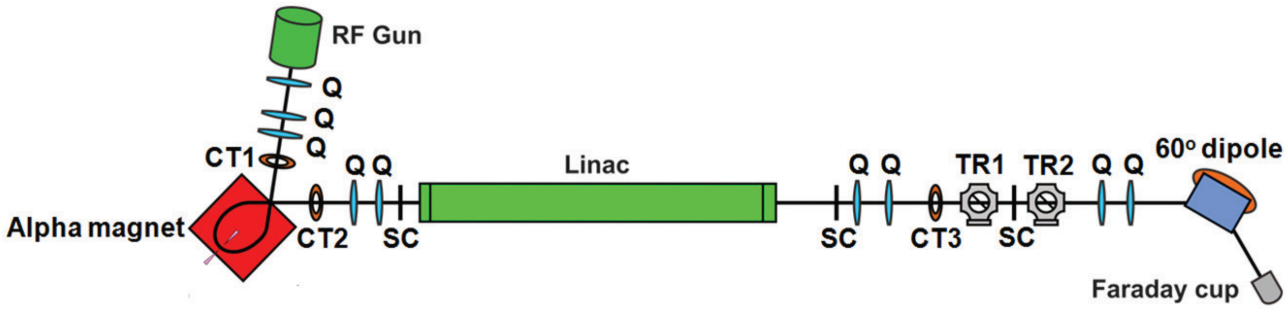

Figure 7: Schematic layout of the PBP-CMU linac system.

and downstream the alpha magnet (as shown in Fig. 7). The CT1 measurement results in Fig. 8 reveal that the RF-gun produced electron beams with the charge almost the same amount for all three considered gun temperatures. The overall results for 22 sets of measurements, which each set has 6 measurement points, show that the beam with the charge of 783.9±63.0 nC, 850.1±34.7 nC and 889.7±79.7 nC were achieved at the gun temperatures of 32, 34 and 36°C, respectively. Although the beam charge values are similar for all three cases, but the gun can produce electron beams with small standard deviation at the gun temperature of 34°C.

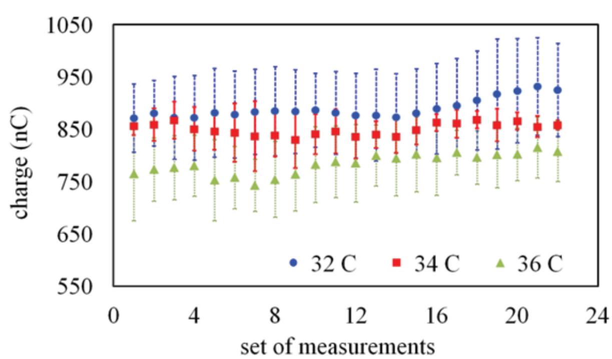

Figure 8: Results of charge measurements.

Electron beam energy was measured using energy slits inside the alpha magnet vacuum chamber. The electron charge values for each energy interval (0.2 MeV bin) for the gun temperature of 34°C are shown in Fig. 9. About 50% beams with the kinetic energy lower than 1 MeV

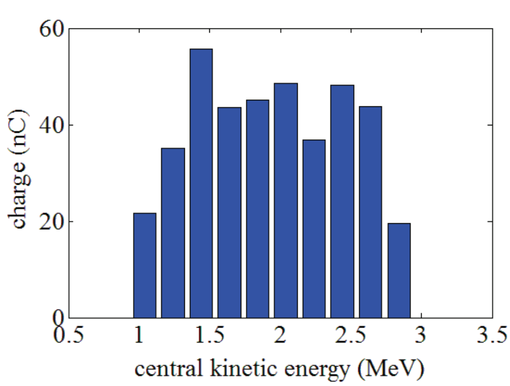

Figure 9: Energy spectrum for the cathode power of 27 W and the RF-gun temperature of 34°C.

was filtered out using the low energy slit. The results in Fig. 9 show that electrons in the main part of the beam have energies in the range of 1.5-2.5 MeV. This beam will be transported further to be accelerated by the linac and will be used as the source of THz radiation.

CONCLUSION

The new RF-gun was installed as the electron source for the PBP-CMU linac system in 2011. Characteristics of this RF-gun are under the investigation. Numerical and experimental studies were performed to study the properties and the performance of the RF-gun. At optimal condition, the beams with maximum kinetic energy of around 2.8 MeV and the macropulse charge of 850.1±34.7 nC were measured at the gun temperature of 34°C. The transverse projected emittance will be measured after the installation of the new diagnostics.

ACKNOWLEDGMENTS

This work has been supported by the CMU Junior Research Fellowship Program and the Department of Physics and Materials Science, Faculty of Science, Chiang Mai University. The authors grateful to the generous support for the RF-gun from the High-energy Optics and Electronics (HOPE) Laboratory, National Tsing Hau University and the National Synchrotron Radiation Research Center (NSRRC), Taiwan, R.O.C.

REFERENCES

[1] S. Rimjaem, K. Kusoljariyakul, C. Thongbai., Nucl. Instrum. Methods Phys. Res. A 736, 10 (2014).

[2] W.K. Lau et al., "*Characterization and Tuning of a Microwave Gun Cavity*", PAC'05, Knoxville, Tennessee, USA, May 2005, p. 1748 (2005); http://www.JACoW.org

[3] S. Rimjaem et al., Nucl. Instrum. Methods Phys. Res. A 533, 258 (2004).

[4] P. Boonpornprasert et al., "*RF Gun Commissioning for PBP-CMU Linac System*", AGRC'12, Chiang Mai, Thailand, p. ST-564 (2012).

[5] Microwave Studio, Computer Simulation Technology, Darmstadt, Germany; http://www.cst.com

[6] L.M. Young, J.H. Billen, *PARMELA*, Technical Note LA-UR-96-1835, Los Alamos National Laboratory (2002).

ISBN 978-3-95450-134-2