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SYSTEMATIC STUDY OF ELECTRON BEAM MEASURING SYSTEMS AT THE PBP-CMU ELECTRON LINAC LABORATORY

K. Techakaew*[1], S. Rimjaem†[2], PCELL, PBP, Faculty of Science,
Chiang Mai University, Chiang Mai, Thailand
[1]also at Ph. D. Program in Physics (Intl. Program), Chiang Mai University, Chiang Mai, Thailand
[2]also at ThEP Center, MHESI, Bangkok, Thailand

Abstract

The linear accelerator system at the PBP-CMU Electron Linac Laboratory (PCELL) is used to produce electron beam with suitable properties for generating coherent teragertz (THz) radiation and mid-infrared free-electron laser (MIR FEL). Optimization of machine parameters to produce short electron bunches with low energy spread and low transverse emittance was focused in this study. We conducted ASTRA simulations including three-dimentional (3D) space charge algorithm and 3D field distributions for radio-frequency (RF) electron gun and all magnets to develop measuring systems. Electron beam energy and energy spread were investigated downstream the RF gun and the RF linac using an alpha magnet and a dipole spectrometer, respectively. The transverse beam emittance was studied using the quadrupole scan technique. By filtering proper portion of electrons before entering the linac, the beam with average energy of 20 MeV and energy spread of 0.1-1% can be achieved for a bunch charge of 100 pC. The systematic error is less than 10% for measuring average energy and energy spread while it is less than 31% for measuring transverse emittance when placing the screen of at least 1.0 m behind the scanning quadrupole magnet. The results of this study were used to develop the measuring setups in our system.

INTRODUCTION

The aim of research activities PCELL is to develop an electron accelerator and experimental apparatus for producing coherent MIR and THz radiation. The MIR radiation will be generated by using the oscillator FEL technology and the THz radiation will be produced from femtosecond electron pulses via the transition radiation (TR) and the super-radiant undulator radiation techniques. The layout plan of the injector system is shown in Fig. 1. There are two sections for accelerating the electron beam. Firstly, electrons produced from the thermionic cathode are accelerated inside the RF cavities to reach the maximum energy of about 2-2.5 MeV at the gun exit. Secondary, the electrons are accelerated in the RF linac structure to reach the average energy in a range of 10 - 25 MeV depending on the linac accelerating gradient. The considered electron beam properties for generation of high quality radiation in both MIR and THz wavelengths are bunch charge, electron bunch length, energy spread, transverse emittance.

* kittipong_techakaew@hotmail.com
† sakhorn.rimjaem@cmu.ac.th

In this work, we focus on the energy and emittance measurements. The design beam diagnostic setups and measuring procedures for energy and emittance measurement in the injector system were performed based on the results from beam dynamic simulation using A Space Charge Tracking Algorithm (ASTRA) code [1] to obtain the suitable conditions with low systematic measurement error. The 3D electric and magnetic field distributions inside the RF-gun, steering magnets, the alpha magnet, quadrupole magnets, and dipole magnet were obtained from the simulations with software CST Studio Suit [2] and were imported to the ASTRA code. In the simulations, we optimized all magnetic fields to meet the appropriate electron beam properties for producing coherent THz TR at the experiment station, which are the beam average kinetic energy of 20 MeV and a electron bunch charge of about 100 pC [3]. The energy and energy spread of electron beam downstream the electron gun were measured using a low energy slit located inside the alpha magnet vacuum chamber and a current transformer (CT2). The spectrometer system consisting of a dipole magnet (DP1) and a screen station (SC6) was used to measure energy and energy spread of electron beam after the linac acceleration. The beam emittance was measured by using quadrupole scan technique [4-6] utilizing a quadrupole magnet (Q6) and a screen station downstream linac (SC4). The results from the computer simulation can be used to estimate the electron beam properties, which are expected to be produced from the accelerator system.

ENERGY AND ENERGY SPREAD MEASUREMENT

Energy Measurement after RF Gun Acceleration

Energy spectrometer in this section consists of alpha magnet and current transformer. The path length of electrons are different depending on their energy. When they travel through an alpha magnet's field. The maximum distance of the electron in horizontal direction a_{max} can be written as [7]

$$a_{max}[\mathrm{cm}] = 75.051\sqrt{\frac{\beta\gamma}{g[\mathrm{G/cm}]}}, \quad (1)$$

where g is the magnetic field gradient, $\beta = v/c$ is the relative velocity of electron, and γ is the Lorentz's factor.

In this study, we used the alpha magnet's low energy slit with known calibrated energy to select a part of electron bunch and used the current transformer CT2 to measure the

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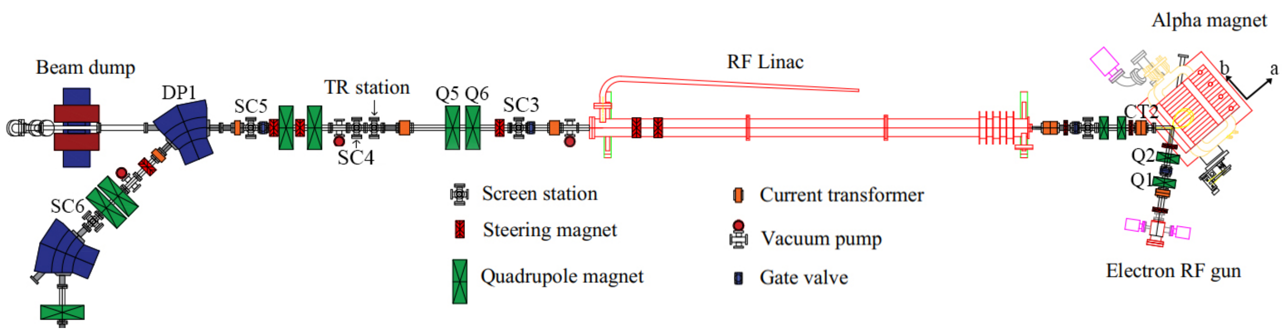

Figure 1: A layout of the injector system for generation of coherent MIR and THz radiation at the PBP-CMU Electron Linac Laboratory (PCELL).

electron current. Consequently, the electron energy spectrum was obtained as shown in Fig. 2. The quadrupoles Q1 and Q2 were used to maintain the total electron charge during the transportation while measuring the electron energy. The alpha magnet gradient was set at 2.1 T/m. The appropriate step of the charge slicing for measuring electron energy is 30 slices. The average kinetic energy and energy spread from this optimization were calculated to be 2.11 MeV and 387 keV, respectively. The average kinetic energy and energy spread obtained directly from simulation at CT2 are 2.16 MeV and 385 keV, respectively. The results from the electron energy spectrum yield that the average kinetic energy was estimated to be 2.3% lower than the direct simulate value and the energy spread was estimated to be 0.5% higher than the simulated actual value.

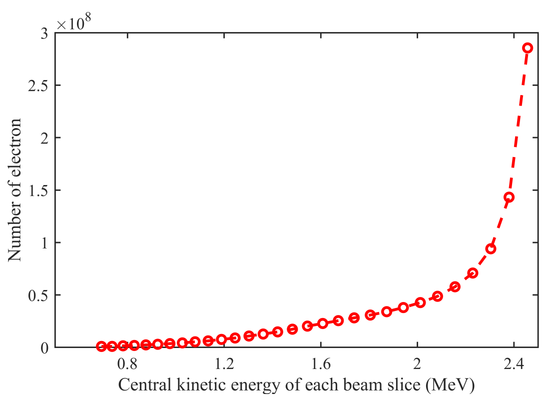

Figure 2: The energy spectrum of electron bunch using alpha magnet and current transformer CT2.

Energy Measurement after Linac Acceleration

Energy of electron beam after the linac acceleration is measured using dipole magnet DP1 and screen station SC6. The energy of an electron travelling through the dipole magnetic field can be calculated using the formula with practical units as [8]

$$E[\mathrm{GeV}] = \frac{0.2998 \int B_y(z)dz[\mathrm{T \cdot m}]}{\beta\alpha[\mathrm{rad}]}, \qquad (2)$$

where $\int B_y(z)dz$ is the integration of the magnetic field along the electron path and α is the deflection angle.

The distance between the observation screen and the camera was set to be at 1.2 m corresponding to the resolution of 0.1 mm/pixel. The optimization result showed that the horizontal beam size before entering the dipole magnet should not be larger than 3 mm to minimize the systematic error. The suitable electron beam properties for generating THz TR was used in this optimization. The electron beam at the TR station has a bunch charge of 117.6 pC, a bunch length of 0.36 ps and an average kinetic energy of 20.07 MeV with an energy spread of 0.55% (111 keV). The horizontal and vertical beam size are 3.45 and 3.60 mm, while horizontal and vertical emittance are 0.41 and 0.25 mm.mrad ,respectively. Figure 3 shows the energy spectrum of electron beam using dipole magnet DP1 and screen SC6. It was found that the kinetic energy of 20.06 MeV can be measured with the systematic error of 0.05% and the energy spread of 95 keV can be measured with the systematic error of 14%.

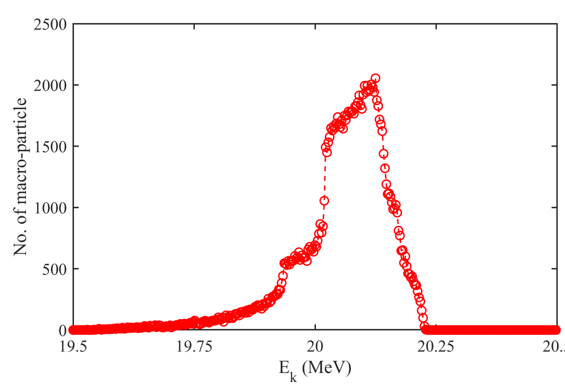

Figure 3: The simulated energy spectrum of electron beam using the dipole magnet BD1 and the screen station SC6.

EMITTANCE MEASUREMENT

The quadrupole scan technique was chosen for measuring transverse emittance of electron beam downstream the linac. The measurement system consists of two quadrupole magnets Q5, Q6 and an screen station SC4. The first quadrupole

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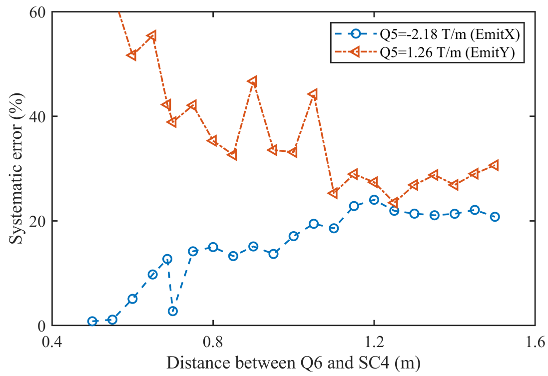

Figure 4: The systematic error of emittance measurement in horizontal (EmitX) and vertical (EmitY) direction.

Q5 is used for controlling the electron beam size, while the second quadrupole Q6 is used for beam size scanning. The principle of this method is to measure the beam size on the observation screen $(\sigma_s)_{11}$ as a function of the quadrupole focal length f which is

$$(\sigma_s)_{11} = D^2(\sigma_q)_{11}\frac{1}{f^2} - 2D[(\sigma_q)_{11} + D(\sigma_q)_{12}]\frac{1}{f} + [(\sigma_q)_{11} + 2D(\sigma_q)_{12} + D^2(\sigma_q)_{22}], \quad (3)$$

where D is the distance between the quadrupole magnet Q6 and the screen SC4 and $(\sigma_q)_{ij}$ are the beam matrix elements at the quadrupole Q6 position. The electron beam size was calculated by using the root mean square method. Therefore, the emittance value (ε) is calculated by

$$\varepsilon = \sqrt{(\sigma_q)_{11}(\sigma_q)_{22} - (\sigma_q)_{12}^2}. \quad (4)$$

In simulation, the distance between the quadrupole magnet and the screen (D) as the strength of quadrupole Q5 were investigated. The systematic error of emittance measurement was estimated and the results are shown in Fig. 4. The systematic errors are less than 25% and 31% for measuring horizontal and vertical emittance, respectively, when the distance between the screen position and the quadrupole Q6 is larger than 1.0 m.

CONCLUSION

The study on energy and energy spread measurement of electron beam after the RF gun acceleration was performed using the alpha magnet and the current transformer. The alpha magnet gradient was set at 2.1 T/m. It was found that the appropriate beam slices for energy spectrum is 30, which provides the measurement resolution of 59 keV/slice. The optimized results suggested that the expected average kinetic energy and energy spread are 2.11 MeV and 387 keV, respectively. These value are respectively 2.3% lower and 0.5% higher than the values obtained from simulated particle distribution. The electron beam and energy spread after the linac acceleration were studied. The optimized results reveal that the estimated average kinetic energy was 20.06, which is 0.05% different from the simulation value at the experimental station. The estimated energy spread was 95 keV, which has a systematic error of 14% for the measurement resolution of 3.5 keV/pixel. The transverse emittance measurement downstream the linac exit was investigated by using the quadrupole scan technique. The proper distance between the scanning quadrupole and the observation should be larger than 1.0 m. The estimated transverse emittances have the systematic error of less than 25% and 31% in the horizontal and vertical axis, respectively. The information from this work is used in the engineering design and construction of the measuring systems for energy, energy spread and emittances in the PCELL setup.

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REFERENCES

[1] A Space Charge Tracking Algorithm (ASTRA), https://www.desy.de/~mpyflo/

[2] Computer Simulation Technology (CST Studio Suit 2022), http://www.cst.com/

[3] S. Pakluuea, "Evaluation of THz transition radiation from short electron bunches at the PBP-CMU electron linac laboratory", M.S. thesis, Chiang Mai Univ., Chiang Mai, Thailand, 2019.

[4] B.-J. Lee, I. Hwang, C. Do Park, C. Kim, and S. Chunjaren, "Beam emittance measurement for the PLS-II linac", *J. Korean Phys. Soc.*, vol. 69, no. 6, pp. 989-993, 2016.

[5] A. T. Green and Y.-M. Shin, "Implementation of Quadrupole-scan Emittance Measurement at Fermilab's Advanced Superconducting Test Accelerator (ASTA)", in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 669–671. doi:10.18429/JACoW-IPAC2015-MOPMA052

[6] R. Chaput, G. Devanz, P. Joly, B. Kergosien, and J. Lesrel, "Emittance measurements of the CLIO electron beam", *Nucl. Instrum. Methods Phys. Res. A*, vol. 393, no. 1-3, pp. 474-478, 1997. doi:10.1016/S0168-9002(97)00549-4

[7] M. Borland, "A high-brightness thermionic microwave electron gun", Ph.D. thesis, Stanford Univ., California, United States, 1991.

[8] H. Wiedemann, *Particle Accelerator Physics, 2nd ed*, Berlin, Germany: Springer, 1999.