STUDY ON ENERGY SPECTRUM MEASUREMENT OF ELECTRON BEAM FOR PRODUCING MIR-FEL AT PBP-CMU ELECTRON LINAC LABORATORY

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Abstract

At the PBP-CMU Electron Linac Laboratory (PCELL), we aim to produce a mid-infrared free-electron laser (MIR-FEL) for pump-probe experiments in the future. The electron beam is generated from a thermionic cathode radio-frequency (RF) gun with a 1.5-cell cavity before going to an alpha magnet. In this section, some part of the beam is filtered out by using energy slits. The selected part of the beam is then further accelerated by an RF linear accelerator (linac) to get higher energy. This work focuses on the measurement of energy spectrum of electron beam for producing mid-infrared free-electron laser (MIR-FEL). Since our bunch compressor (BC) for the MIR-FEL beamline is an achromat system, the longitudinal distributions of electron beam at the entrance and the exit of the BC are almost the same. Thus, we can measure the longitudinal properties of the beam before it travels to the BC. By using a dipole magnet and a Faraday cup with a slit, we can measure energy spectrum of electron beam before entering the BC. In this study, the ASTRA code is used to investigate the properties of electron beam as well as to design the measuring system. The design results including systematic error of the measuring system are presented and discussed in this contribution. The results from this work can be used as the guideline for the measuring system construction as well as the beam operation.

INTRODUCTION

At the PBP-CMU Electron Linac Laboratory (PCELL) of the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University (CMU), a mid-infrared free-electron laser (MIR-FEL) has been developed. In the accelerator system, electrons are emitted from a thermionic cathode and are accelerated by a radio-frequency (RF) gun to reach a kinetic energy of about 2-2.5 MeV. Then, the beam passes through the first magnetic bunch compressor in a form of an alpha magnet, which has energy slits for filtering electrons for desired energy and charge. After that, the beam is further accelerated by an RF linac to have the final energy of up to 25 MeV. Then, the beam enters either a dipole beam dump 1 (BD1) or magnetic bunch compressor (BC) for MIR-FEL or THz-FEL beamline. Presently, the commissioning of the electron accelerator is underway at PCELL.

To produce the MIR-FEL, electron beam parameters with proper energy, energy spread, transverse beam size and emittance are required [1, 2]. This work concentrates on the characterization of electron beam energy and energy spread. Since the BC system is an achromat system, the energy and energy spread of the beam upstream and downstream of the BC will be the same. Thus, we can obtain the beam energy and energy spread upstream the undulator entrance by measuring the beam downstream the linac exit.

This research focuses on design of the measuring system for electron beam energy, energy spread and energy spectrum downstream the linac exit. This system should be able to measure the beam with energy of 25 MeV, energy spread of 0.1%, and bunch charge of 60 pC [1, 2].

DESIGN OF MEASURING SYSTEM

To measure electron beam energy downstream the linac exit, we use the beam dump dipole 1 (BD1) and Faraday cup 1 (FC1), which is installed at the end of the straight section beamline as shown in Fig. 1. To measure energy distribution and energy spectrum of the beam with an average energy of 25 MeV and an energy spread of 0.1%, we decided to add a single slit mask in the measuring system for increasing the resolution of the measuring system. To design the slit mask, the following conditions are taken into consideration:

- The slit opening aperture must be small for measuring the beam with energy spread of 0.1%, but it should be big enough to let electrons passing through with the charge higher than the Faraday cup sensitivity.
- The slit thickness must be thick enough to block the electrons, but not too thick to avoid the electron scattering inside the aperture.
- The slit width must be large enough to block the electrons in the horizontal axis, but not larger than the vacuum chamber.

We optimized the slit opening aperture based on following equation [3]:

$$\theta\ [\text{rad}] = \frac{0.2998 \int B_x(z) d_z [\text{T} \cdot \text{m}]}{\beta E_{tot}\ [\text{GeV}]}, \quad (1)$$

where θ is the electron effective bending angle, E_{tot} is the total energy of electron, β is the ratio of the electron velocity

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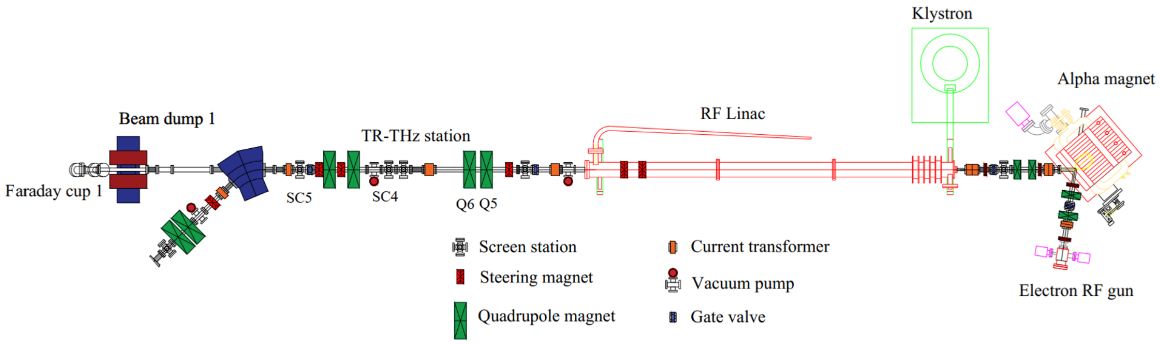

Figure 1: Layout of the PCELL accelerator system.

and the speed of light, and $B_x(z)$ is the dipole horizontal magnetic field along the electron trajectory.

Assign that θ_1 is the physical dipole bending angle, then we obtained the angle $\theta_2 = \theta - \theta_1$, which can be used to calculate the slit opening aperture d from

$$\tan\theta_2 = \frac{d/2}{L}, \tag{2}$$

while L is the distance between the dipole turning point and the slit.

From the calculation, the slit opening aperture is 0.36 mm. With this design, the energy spread of 0.1% (25 keV) is expected for the average energy of 25 MeV. Tungsten with a thickness of 1 mm will be used as the slit due to its suitable properties [4]. The width of the slit is designed to be 28 mm to fit with the space in the vacuum chamber.

SIMULATION METHODS

A Space Charge Tracking Algorithm (ASTRA) [5] is used in this study. In the simulation, we used the Gaussian beam distribution as an input beam. The 3D magnetic field of the dipole magnet BD1 was export from the simulation with the software CST Studio Suite 2022 [6]. The initial beam travels through the dipole magnetic field and be bent with a bending angle of 60°. Then, it passes through the slit and goes to the Faraday cup. To neglect the effect of beam divergence, the electron beam was manipulated to be parallel beam before going into the dipole magnetic field. The distance between the starting point of the input beam and the turning point of the dipole magnet is 35 cm. At this distance, the whole beam is in the dipole's magnetic field along its trajectory and it is still parallel before facing the dipole's fringe field. In this study, the initial input beam and the dipole magnetic field were rotated 60°. The entrance of the Faraday cup is 43 cm downstream the slit.

At our facility, when the electron beam is accelerated through the RF linac, the transverse beam size and the emittance are measured using the combination of quadrupole magnets Q5 and Q6 together with the view screen SC4 via the quadrupole scan technique. By using screens SC4 and SC5, the parallel beam can be adjsuted and observed. The effect of initial beam size and emittance on the energy spectrum was conducted using the beam with average energy of 25 MeV and the total charge of 60 pC, which are the goal parameters for generation of MIR-FEL [1, 2].

After the simulation of the beam energy spectrum complete, we calculated the estimated average energy and the energy spread of electron beam from the simulated energy spectrum by including the sensitivity of the Faraday cup, wich is considered to be 5 pC in this study [7].

RESULTS AND DISCUSSION

The simulation result shows that with our generated input beam distribution both beam size and emittance have no effect on the estimated average energy of the beam. For the energy spread, the beam size has dominant effect on the estimated value than the emittance as can be seen in Fig. 2. Only at the beam size of 0.5 mm that the emittance has little effect on the value of energy spread due to the vary small beam size where the divergence is strong.

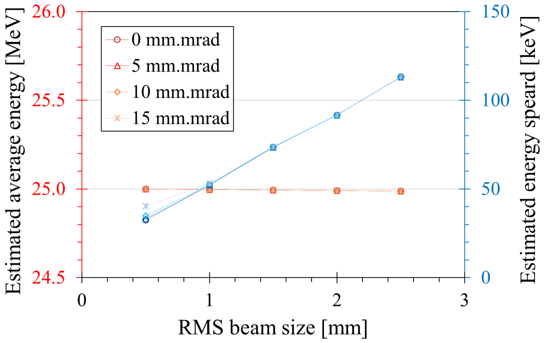

Figure 2: Estimated average energy and energy spread of electron beam with different rms beam sizes and emittances.

Since only the transverse beam size has the effect on the measurement of energy spread, the next simulation is to estimate the beam energy from the measuring system when the initial beam travels in to the dipole magnetic field with different beam transverse sizes and energy spreads. According to the results in Fig. 3, it can be concluded that the average energy from the beam measurement is slightly lass than

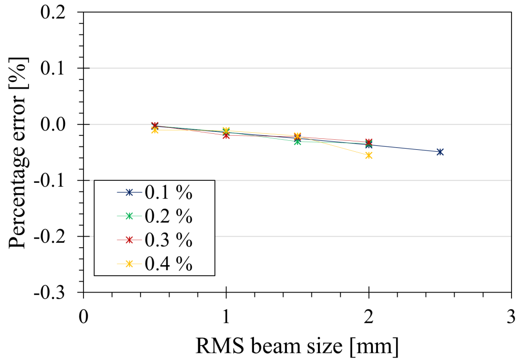

Figure 3: Systematic error of the estimated average energy for different rms beam sizes and energy spreads.

the real value, when the initial beam size value is between 0.5-2.0 mm.

For the measurement of energy spread, the initial beam size and energy spread have significant effect as shown in Fig. 4. When the initial beam size increases for different initial energy spreads, the estimated energy spreads obtained from the design measuring system become similar, and the systematic errors are slightly increasing, except the error for the initial energy spread of 0.1%. For this case, the dispersion of the initial energy spreads is very small so the initial beam size is dominated. These results shows that this measuring system can distinguish the beam energy spread in a range of 0.1-0.4% when the initial beam has the transverse size of less than 1.5 mm.

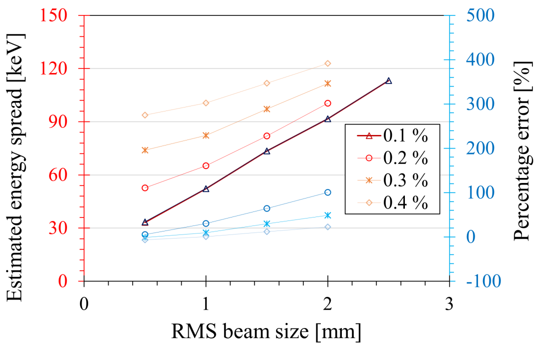

Figure 4: Estimated energy spread and corresponding systematic error for electron beam with different initial beam sizes and energy spreads.

Figure 5 shows the simulated energy spectrum of electron beams with the same beam size but different energy spread. From the same slit opening aperture, the beam with higher energy spread than 0.1% will have higher resolution of the energy spectrum due to high dispersion when the beam passing through the dipole magnetic field. However, with this high dispersion, we may get lower amount of the electrons in each bin. This plot corresponds to the Fig. 4, at the same initial beam size, the beam with higher initial energy spread than 0.1% provides lower systematic error of the estimated energy spread due to higher resolution of the energy spectrum.

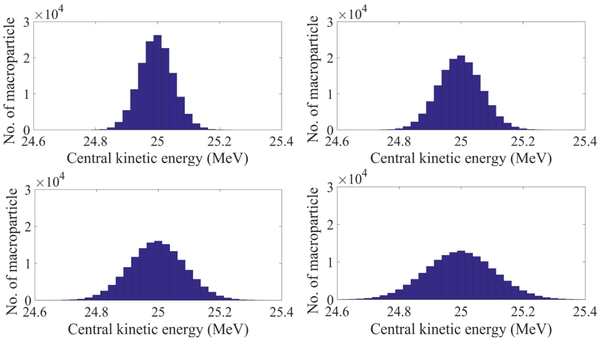

Figure 5: Simulated energy spectrum of electron beams with average energy of 25 MeV, 1.0-mm beam size, and energy spread of 0.1% (top left), 0.2% (top right), 0.3% (bottom left), and 0.4% (bottom right).

CONCLUSION AND OUTLOOK

The design of energy measuring system consists of the dipole magnet BD1 with a bending angle of 60°, the Faraday cup with the sensitivity of 5 pC, and the tungsten slit mask with the slit opening aperture of 0.36 mm. The distance between the BD1 turning point to the center of the slit and the entrance of the Faraday cup are 35 cm and 78 cm, respectively. This measuring system can be used to measure the 25-MeV electron beam with an energy spread of 0.1-0.4%. The system can be used to estimate the average energy of electron with the systematic error of 0.06% less than the actual value. In order to achieve the estimated energy spread of 0.1-0.4%, operators must control the beam to have parallel beam and has the beam size of less than 1.5 mm before the beam entering the dipole magnet BD1. In near future, the energy measuring system will be constructed based on results from this study.

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