DEVELOPMENT OF INJECTOR SYSTEM FOR MIR/THz FREE-ELECTRON LASER FACILITY IN THAILAND

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Abstract

Development of a linac-based MIR/THz FEL light source is ongoing at the Plasma and Beam Physics Research Facility, Chiang Mai University. The future facility will consist of an S-band thermionic cathode RF electron gun, a pre-magnetic bunch compressor in a form of alpha magnet, an S-band travelling-wave linac structure, a 180-degree achromat system and two undulator magnets equipped with optical cavities. This research focuses on start-to-end beam dynamics simulations of the injector system. The aim of the study is to produce high quality electron beam at the entrance of the THz undulator magnet. The simulation was conducted by using programs PARMELA and ELEGANT. The program PARMELA was utilized to study the electron beam dynamics inside the RF-gun. Then, the program ELEGANT was used to optimize the injector system parameters. Optimization of physical specifications for the achromat system was performed to obtain short electron bunches with small energy spread at the undulator entrance. In this paper, results of beam dynamics simulations with suitable condition for the THz-FEL beamline are presented and discussed.

INTRODUCTION

Research activities at the PBP-CMU Linac Laboratory focus on the production and applications of the terahertz (THz) radiation and the mid-infrared (MIR) based on coherent transition radiation from femto-second electron bunches and free-electron laser (FEL) technology, respectively. The FEL light source has many distinguish features including high brightness, coherence, short pulse, and tuneable wavelength. Due to the mentioned facts, development of a MIR/THz FEL facility is ongoing at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University. A future injector system will be modified from the existing accelerator system [1, 2].

A schematic diagram of the future MIR/THZ FEL facility at Chiang Mai University is shown in Fig. 1. In this paper, we focus on the development of the injector system for the THz-FEL beamline. Three new main components will be installed downstream the linac structure. The first component is a 180^{o} magnetic bunch compressor that consists of four dipole magnets with 45^{o} deflecting angle, three doublet quadrupole magnets, and steering magnets. The second component is an undulator magnet, which is designed to be an electromagnet with a period length of 64 mm and an undulator parameter of 0.7. Therefore, the undulator radiation with a wavelength of 100 μm is expected to be produced from the electron beam with an energy of 10 MeV. The third component is a set of two concave high reflection mirrors, which will be placed at the two ends of the undulator. This pair of mirrors will be used as an optical oscillator to amplify the undulator radiation.

METHODOLOGY

In the injector system, electrons are emitted from the thermionic cathode and are accelerated through the electromagnetic inside the RF-gun cavities. The electron beam exiting from the RF-gun has large energy spread due to the time-varying RF field feature. The energy slits inside the alpha magnet vacuum chamber are used to select electrons with desired energy range. The alpha magnet gradient is adjusted for compressing the electron bunch to have an appropriated bunch length for further acceleration in the linac structure.

Beam dynamics simulations are performed to investigate the electron beam properties that can be produced from the accelerator. At this early state of the project, the start-to-end beam dynamics simulations without space charge effect were conducted. The study results are presented and discussed here.

In the design of the injector system for THz-FEL beamline, we require different electron beam properties at two locations. First, at the experimental station, which is used to produce transition radiation (TR) from electron beam with a bunch length in femto-second scale. Second, at the undulator entrance for generation of THz free-electron laser. For this radiation we can use electron beams with a bunch length in pico-second scale because the coherent FEL radiation will be produced from the ultra short electron bunches due to the micro-bunching procedure inside the undulator.

In this study, the start-to-end beam dynamics simulations were conducted in 3 steps. Firstly, the 3D electromagnetic field distributions inside the RF electron gun are obtained from the RF model created with the program CST Microwave STUDIO 2012® [3, 4]. Then, the computer program PARMELA [5] is used to simulate electron beam dynamics through the fields inside the RF-gun. Finally, the particle distribution at the RF-gun exit is transformed to be the input distribution for the beam transport code ELEGANT [6], which was used to study the electrons' motion from the RF-gun exit to the undulator entrance without space charge effect.

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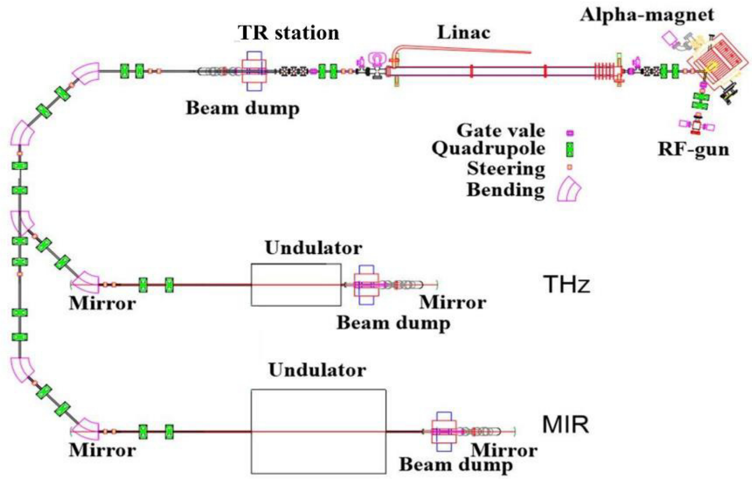

Figure 1: The planned layout of the electron beam injector system and the linac-based MIR/THz FEL Beamlines at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University, Thailand.

RESULTS AND DISCUSSION

A. Gun-to-Linac (GTL) Section

In our accelerator system, a section called gun-to-linac (GTL) is considered from the electron gun to the entrance of the linac. The electron gun in this system is a 1.6-cell S-band standing-wave RF-gun with a thermionic cathode of 6 mm diameter. The 2856 MHz RF wave is transported from a 7-MW klystron to the electron gun via a WR-284 rectangular waveguide system. The waveguide is connected to the gun at the radial wall of the full-cell cavity. The RF wave is then coupled from the full-cell to the half-cell through a side-coupling cavity. An opening aperture of the RF input-port and the coupling holes between the side-coupling cavity and the two main resonant cavities cause asymmetric electromagnetic field distributions inside the RF-gun. The simulation results show that electron beams produced from the RF-gun have asymmetric transverse shape and larger transverse emittance than the beams produced from the symmetric RF-gun [4]. The transverse beam distributions and the energy spectrum at the RF-gun exit are shown in Fig. 2.

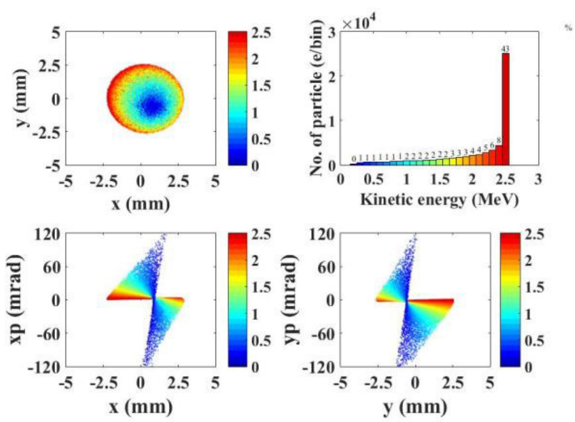

Figure 2: Simulated transverse phase space distributions and energy spectrum at the RF-gun exit. Different colors in the plots represent the particles with different energies in MeV unit.

Simulation results show that the beam has a bunch charge of 227.9 pC at the gun exit. The center of the beam is not at the middle of the reference trajectory, which is clearly seen in Fig. 2. Thus, a steering magnet is used to steer the beam back to the center before it travels to the alpha magnet. In this study, the energy slits inside the alpha magnet were used to filter out the electrons with kinetic energy of less than 2.47 MeV. This leads to the average kinetic energy of 2.55 MeV with 1.2% energy spread at the exit of the alpha magnet. An optimal gradient of the alpha magnet in this study is 213 G/cm. After that, the electron beam is accelerated by the linac with an accelerating electric field of 3.65 MV/m and an RF phase of 90° to reach the average kinetic energy of 10.16 MeV with the energy spread of 0.2% at the TR experimental station. The particle distributions are presented in Fig. 3.

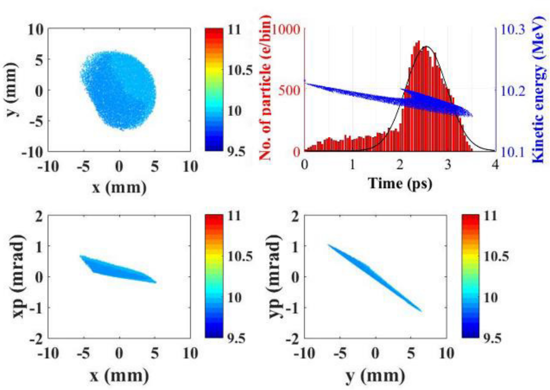

Figure 3: Simulated transverse and longitudinal particle distributions at the TR experimental station.

The electron beam can be compressed to have a bunch length (σ_z) of 431 fs with the bunch charge of 81.6 pC (35.8% from gun exit). The RMS horizontal and vertical beam sizes are 2.39 and 3.00 mm, respectively. The RMS horizontal and vertical emittance values equal to 4.85 and 2.67 mm.mrad. Thus, the beam at this location has the properties that can be used to produce the THz radiation via transition radiation.

B. Linac-to-Undulator (LTU) Section

For the THz-FEL beamline, the electron beam is transported to enter the undulator entrance by using a magnetic bunch compressor system. Longitudinal and transverse phase space distributions of the electron bunch at the undulator entrance are shown in Fig. 4.

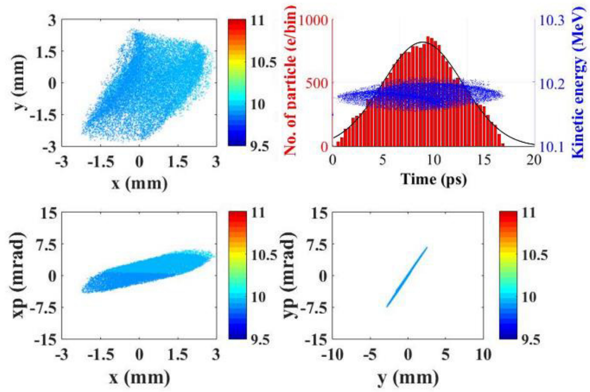

Figure 4: Simulated longitudinal and transverse phase space distributions at the undulator entrance.

The electron beam has a bunch length of 2.97 ps with an energy spread of 20.2 keV (0.2%) at the entrance of the undulator magnet. The RMS horizontal and vertical beam sizes are 0.60 and 0.38 mm, respectively. The normalized RMS horizontal and vertical emittance values equal to 30.5 and 3.2 mm-mrad.

The simulated beta functions along the beam transport line from the RF-gun exit to the undulator entrance in horizontal and vertical axes are illustrated in Fig. 5. Simulated electron beam properties at the undulator entrance are listed in Table 1. Further optimization will be continued to achieve electron beam with shorter bunch length, smaller horizontal emittance and higher charge in order to obtain higher beam brightness and also high THz-FEL power. The simulation including the space-charge effect will also be conducted.

Table 1: Simulated Electron Beam Properties for the Future THz-FEL Injector System Obtained from ELEGANT Simulation

Parameter	Value	
Location	TR experimental station	Undulator entrance
Beam energy	10.2 MeV	10.2 MeV
Energy spread	20.2 KeV	20.2 KeV
Bunch charge	81.6 pC	81.6 pC
Bunch length	431 fs	2.97 ps
Normalize transverse emittance (x and y)	4.85 mm·mrad 2.67 mm·mrad	30.50 mm·mrad 3.20 mm·mrad
RMS transverse beam size (x and y)	2.39 mm 3.00 mm	0.60 mm 0.38 mm

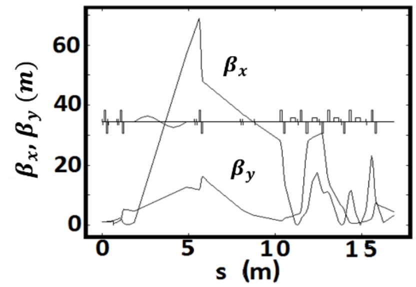

Figure 5: Simulated transverse betatron functions from the RF-gun exit to the undulator entrance.

CONCLUSION

Study on numerical simulations of electron beam dynamics without space charge effect for the future THz-FEL beamline at Chiang Mai University was performed. The study results reveal that the electron beam with the bunch charge of 81.6 pC, the average energy of 10.2 MeV and the energy spread of 20.2 keV can be obtained. The longitudinal bunch length as short as 431 fs is expected to be achieved at the TR experimental station with the RMS horizontal and vertical beam sizes of 2.39 mm and 3.00 mm, respectively. This corresponds to the horizontal and vertical emittance values of 4.85 and 2.67 mm.mrad. At the undulator entrance, the simulated longitudinal bunch length is 2.97 ps. The RMS horizontal and vertical beam sizes are 0.60 mm and 0.38 mm, respectively. This corresponds to the horizontal and vertical emittance values of 30.5 and 3.2 mm.mrad. Further study will be conducted to reduce the horizontal emittance. Moreover, the simulations including the space-charge effects will be done to finalize the start-to-end beam dynamics simulation of the injector system for the THz-FEL beamline.

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