

STUDIES ON ELECTRON BEAM INJECTOR SYSTEM FOR LINAC-BASED COHERENT THz SOURCE IN THAILAND

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Abstract

Main components of a linac-based THz source at the Plasma and Beam Physics Research Facility, Chiang Mai University, Thailand, are a thermionic cathode RF electron gun, an alpha magnet and a linear accelerator. The electron beam produced from this system is currently used to generate a coherent transition radiation in FIR and THz regimes. To increase the capability of the accelerator on production of the THz radiation, it will be upgraded to be a future THz free-electron laser (THz-FEL) by adding a magnetic bunch compressor, an undulator magnet and an optical oscillator. To investigate the optimal performance of the injector system, beam dynamic simulations are performed by using computer codes PARMELA and ELEGANT. The input 3D field distributions of the RF-gun for PARMELA simulations are obtained from the RF modelling program CST Microwave Studio 2012. The beam transport calculation using the program ELEGANT is performed to study behaviour of the electron beam from the RF-gun exit through all components until it reaches the undulator entrance. Energy slits inside the alpha magnet vacuum chamber are used to select electrons with desired kinetic energies. The alpha magnet compresses electron bunches with certain bunch length before the beam entering the linac to obtain minimum energy spread at the linac exit. Then, the electron bunches are further compressed by the magnetic bunch compressor to have a bunch length in order of picosecond at the undulator entrance. Preliminary results of electron beam optimization with appropriated conditions for the THz-FEL are reported and discussed in this contribution.

This system will be used as a magnetic bunch compressor with energy spread conservation. The second component is an undulator electromagnet. The third one 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.

Beam dynamic simulations are performed in order to investigate the electron beam properties, which can be produced from the accelerator. Preliminary goal parameters for the electron beam at the undulator entrance for this study are shown in Table 1. At this period, the start-to-end beam dynamic simulations without space charge effect were conducted. The study results are presented and discussed here. Some information related to the undulator magnet will be briefly mentioned in the last section of this paper.

Table 1: Preliminary goal parameters of the electron beam properties for the future THz-FEL injector system at Chiang Mai University.

Parameter	Value
Beam energy	10 MeV
Energy spread	$\leq 1\%$
Bunch length	~ 1 ps
Bunch charge	~ 50 pC
Normalize transverse emittance	≤ 3 mm-mrad
RMS transverse beam size	≤ 0.5 mm

METHODOLOGY

In this study the start-to-end beam dynamic simulations were performed for the injector system of the future THz-FEL. Firstly, the 3D electromagnetic (EM) field distributions inside the RF-gun are obtained from the RF modelling program CST Microwave Studio 2012 [3]. The computer code PARMELA [4] is used to simulate electrons' motion through the EM fields in the gun. The particle distribution at the RF-gun exit is transformed to be the input distribution for the code ELEGANT [5] which is used to investigate the electrons' motion from the RF-gun exit to the undulator entrance.

The electron beam exiting from the RF-gun has large energy spread, thus energy slits inside the alpha magnet vacuum chamber are used to filter electrons with desired kinetic energies. The alpha magnet gradient is adjusted for compressing the electron beam to have an appropriated bunch length for acceleration in the linac structure.

INTRODUCTION

Properties of radiation from any accelerator-based light source depend greatly on the qualities of the electron beam produced from the accelerator. Thus, the optimization of the injector system is an important issue for all light source. Development of a THz-FEL light source is planned 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 preliminary schematic diagram of the future THz-FEL at Chiang Mai University is shown in Fig. 1. Three new main components will be installed downstream the linac structure. The first component is a 180° achromat system, which consists of four dipole magnets with 45° deflecting angle and three doublet quadrupole magnets.

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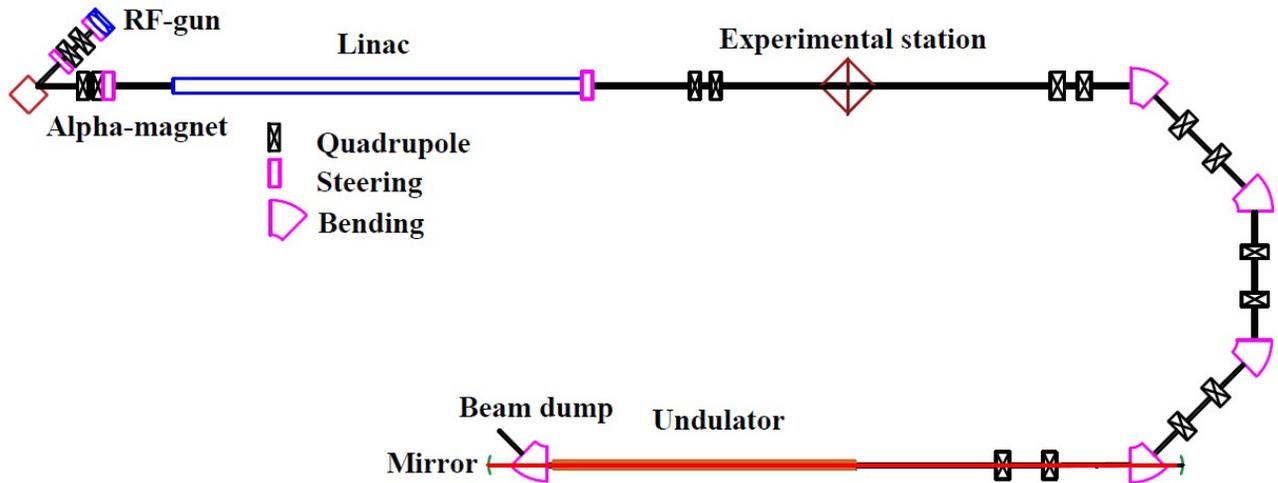


Figure 1: The planned layout of the electron beam injector system for the linac-based THz-FEL at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University, Thailand.

The beam exits the linac with desired energy spread and traverses to the magnetic bunch compressor where it is compressed to have the bunch length in picosecond scale at the achromat exit with unchanged energy spread. Finally, the beam reaches the undulator entrance with optimal beam parameters. The simulation results in each step are presented in the next section.

RESULTS AND DISCUSSION

Beam Dynamic Simulations

The electron source in this system is a 1.6-cell S-band standing-wave RF-gun with a thermionic cathode. The 2856 MHz radio-frequency (RF) wave is transported from a 7-MW klystron with a WR-284 rectangular waveguide system, which is connected to the RF-gun at the radial wall of the full-cell cavity. The RF wave is 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 main cells cause asymmetric electromagnetic field distributions inside the gun [6]. The study 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 one. The longitudinal and transverse beam distributions at the RF-gun exit are shown in Fig. 2.

At the gun exit, the center of the beam is not at the center of the reference trajectory. Thus, a steering magnet is used to steer the beam back to center before it travels to the alpha magnet. In this study, the energy slits inside the alpha magnet are used to filter out the electrons with the kinetic energy of less than 2.55 MeV. This leads to the average kinetic energy of 2.60 MeV with 1.92 % energy spread at the exit of the alpha magnet. An optimal gradient of the alpha magnet is 464 G/cm. Since the magnetic field in the alpha magnet focuses the beam in horizontal axis, it results in non-circular transverse beam size. Quadrupole magnets are used to control the beam size before the beam

enters the linac. The beam is then accelerated by the linac with an optimal phase of 84.81 degree to reach the average kinetic energy of 10.41 MeV with the energy spread of 0.13 % at the linac exit.

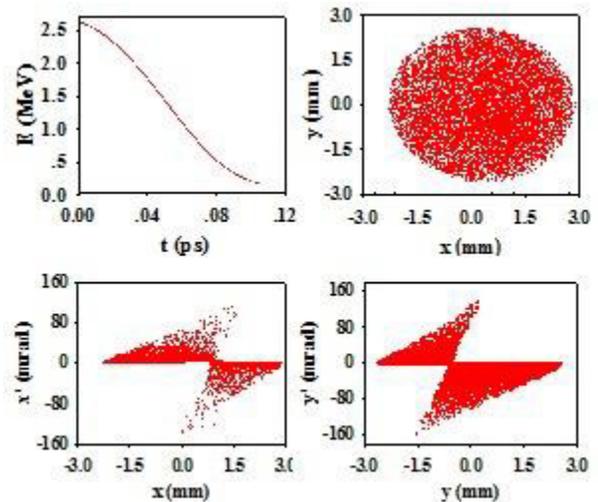


Figure 2: Simulated longitudinal and transverse phase space distributions at the RF-gun exit.

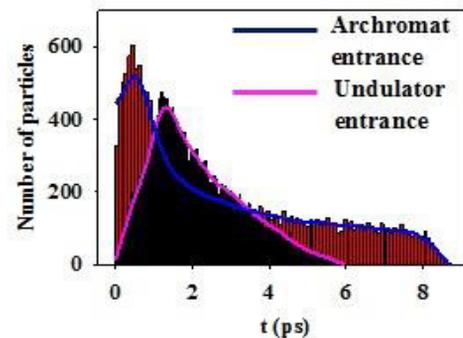


Figure 3: Simulated longitudinal bunch distributions at the entrances of the achromat system and the undulator magnet.

As compared in Fig. 3, the electron beam with broad bunch length of 15.6 ps is compressed in the achromat system with appropriated quadrupole magnet gradients to reach the bunch length of 1.2 ps with the energy spread of 26.6 keV or 0.13 % at the entrance of the undulator. The RMS horizontal and vertical beam sizes are 4.6 and 11.3 mm, respectively. The RMS horizontal and vertical emittance values equal 0.78 and 0.34 mm.mrad. The longitudinal and transverse phase space distributions of the beam at the undulator entrance are shown in Fig. 4.

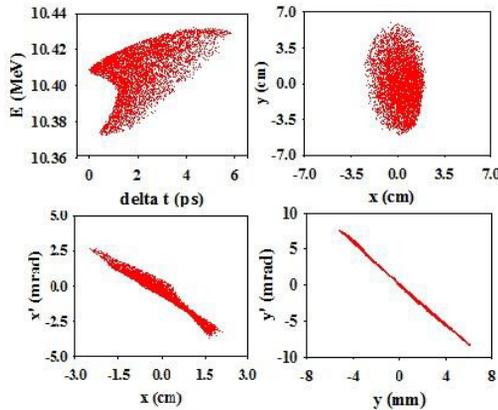


Figure 4: Simulated longitudinal and transverse phase space distributions at the undulator entrance.

The results show that the beam does not enter at the center of the undulator entrance. Further study is needed to steer the beam inside the achromat system. More optimization will be performed in the future to correct the beam trajectory in the achromat system without altering the energy spread. The simulated betatron functions along the beam line from the RF-gun exit to the undulator entrance in both horizontal and vertical directions are illustrated on Fig. 5

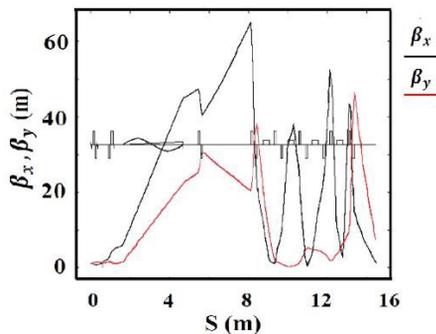


Figure 5: Simulated transverse betatron functions.

Radiation from Undulator Magnet

An undulator radiation wavelength (λ_r) depends on an undulator period (λ_u), an undulator parameter (K) and an electron beam energy (E) as [7]

$$\lambda_r = \frac{\lambda_u}{2n\gamma^2} \left(1 + \frac{K^2}{2} + \theta^2\gamma^2 \right) \quad (1)$$

where $\gamma = E/m_e c^2$ is the Lorentz factor, m_e is the rest mass of electron and c is the speed of light in vacuum. The harmonic number (n) is integer number as 1, 2, 3 ... and θ is the angle of observation related to the average beam direction. For the future THz-FEL, the undulator has a period length of 64 mm and the undulator parameter of about 0.7. Therefore, an expected wavelength of the undulator radiation of 100 μm can be achieved for the electron beam with γ of 20.86.

CONCLUSION

Preliminary study on numerical simulations of electron beam dynamics without space effect for the future THz-FEL at Chiang Mai University was performed. The study results reveal that the electron beam with the bunch charge of 64.8 pC, the average energy of 10.41 MeV and the energy spread of 26.6 keV can be expected at the undulator entrance. The longitudinal bunch length as short as 1.2 ps can be achieved. The RMS horizontal and vertical beam sizes of 4.6 mm and 11.3 mm, respectively, are achieved, respectively. This corresponds to the horizontal and vertical emittance values of 0.78 and 0.34 mm.mrad. The electron beam with these properties can be used to produce the THz undulator radiation with the wavelength of 100 μm when using the undulator parameter of 0.7. Further study will be conducted with the simulations including the space-charge effects and the beam steering in the achromat system.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support by the Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, the Thailand Center of Excellence in Physics and the Development and Promotion of Science and Technology Talents Project of Thailand.

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