BEAM DYNAMICS SIMULATION AND OPTIMIZATION OF ELECTRON BEAM PROPERTIES FOR IR FEL AT CHIANG MAI UNIVERSITY

S. Suphakul*, S. Rimjaem, C. Thongbai, Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
Thailand Center of Excellence in Physics, CHE, Bangkok 10400, Thailand

Abstract

The linear accelerator system at the Plasma and Beam Physics Research Facility (PBP), Chiang Mai University (CMU), Thailand, is planned to be upgraded to be an injector system for the Infrared Free-electron Lasers (IR FEL). The PBP linac system consists of an S-band thermionic cathode RF-gun, a bunch compressor in a form of alpha-magnet and a 3-m SLAC-type linear accelerator. The current system will be modified to generate the electron beam with properties suitable for the IR FEL. Numerical simulations have been performed to investigate and optimize the electron beam parameters. The planned modification of the system and optimization of the electron beam parameters are presented in this contribution.

INTRODUCTION

The Infrared Free-electron Lasers (IR FEL) facility at Chiang Mai University has been developed under the plan of a new research facility establishment of the Thailand Center of Excellence in Physics. The facility focuses on the production and utilization of the mid- and far-infrared radiation (MIR and FIR) based on femto-second electron pulses and free-electron lasers technology [1]. As shown in Fig. 1, the facility considered in this paper consists of a thermionic cathode RF-gun as an electron source [2], a magnetic bunch compressor in a form of an alpha-magnet [3], a 3-m SLAC-type S-band linear accelerator (linac), a 180^o achromat section, a planar type undulator and an optical resonator.

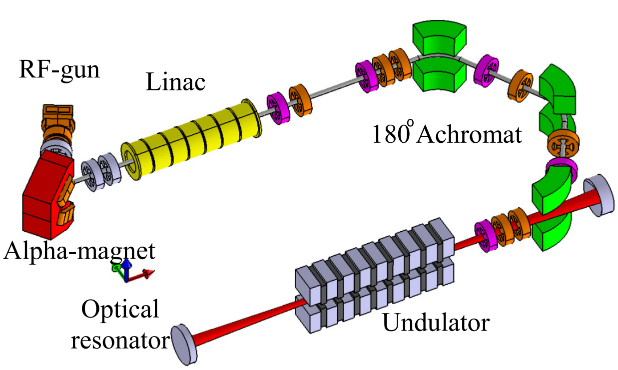

Figure 1: Schematic view of planned IR-FEL at CMU.

The first three components of the existing PBP-CMU linac system are planned for both coherent THz transition radiation from femto-second electron pulses and free-electron lasers. Details of the current PBP-CMU linac system were reported in [4]. The 180^o achromat section is a new component which is under detailed consideration. Therefore, we adopt the magnet lattice of the Kyoto University Free-Electron Lasers (KU-FEL) for initial optimization in this study. The achromat section consists of three 60^o deflecting angle dipole magnets and two sets of doublet quadrupole magnets. Details of KU-FEL achromat system have been described in [5]. Through the achromat, the electron bunch length shortens and the peak current becomes higher for a given bunch charge.

This study investigates and optimizes the electron beam parameters suitable for the IR FEL project at CMU by modifying the PBP-CMU linac driving condition and considering the bunch compression in the 180^o achromat. To investigate the beam dynamics, the computer code PARMELA [6] or the "Phase And Radial Motion in Electron Linear Accelerator" code has been used for simulations of multi-particle beam dynamics from the RF-gun to undulator and optimization of the electron beam lattice parameters.

ELECTRON BEAM OPTIMIZATION

Generally, electron beams for FELs must have high peak current, small emittance, and low energy spread in order to generate intense coherent FEL light in an undulator. For the IR FEL at CMU, some electron beam requirements have been proposed and are shown in Table. 1. In this study, we focus on optimization of longitudinal electron beam dynamics by adjusting the parameters of three main components; the RF-gun, the linac and the 180^o achromat. For the simulation of multi-particle beam dynamics, 30,000 particles per 2856 MHz are assumed to be emitted uniformly from the cathode with current of 2.9 A. One particle represents a charge of 33.85 fC equivalent to 2.12x10^5 electrons .

*sikharin.sup@gmail.com

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Table 1: Required Electron Beam Parameters for IR FEL at CMU

Parameters	Value
Energy	~ 15 MeV
Relative energy spread	0.5 - 1%
Peak current	~ 30 A
Total charge	~ 30 pC
Bunch length	1 - 2 ps
rms emittance	3 mm-mrad

RF-gun

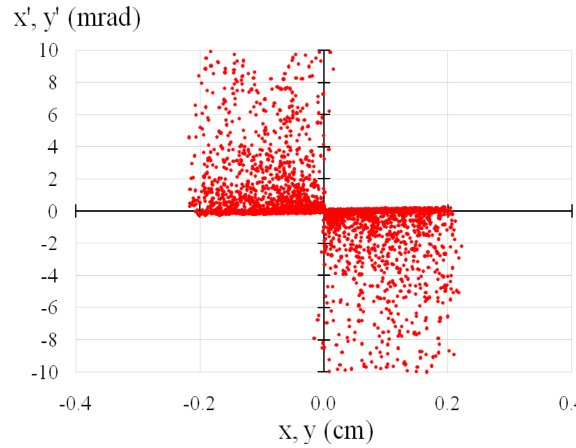
To optimize the RF-gun, the accelerating field gradients of both half- and full-cell cavities were adjusted to produce an electron bunch with low energy spread, especially at the head of the bunch, which will be used for FEL lasing. The ratio of the accelerating field amplitudes at the cathode plane of the half-cell and at the center of the full-cell are defined as the field ratio. With the field ratio of 1:2 and the accelerating field of 35/70 MV/m, the RF-gun provides a beam with low energy spread at the head of the electron bunch. The electron beam distributions at the RF-gun exit are shown in Fig. 2 and 4.

The electron bunches exiting from the RF-gun are filtered by an energy slit inside the alpha-magnet vacuum chamber to remove low energy particles. For the RF-gun condition noted above, we set the energy filter level at 3.81 MeV. The maximum energy is 3.91MeV and energy spread of the useful electrons is 0.82%. Because of very low energy spread, the bunch compression due to the alpha-magnet will be neglected in this study.

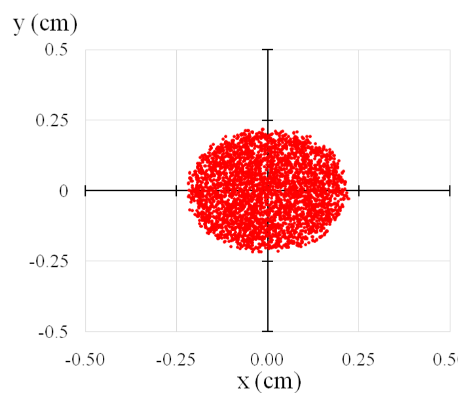
Linac

To get an electron bunch with low energy spread, the linac initial phase was varied between 0 and -90 degree relative to the reference particle phase at the entrance of the linac. Then, the number of particles is counted within the desired energy bin (1% in this study). Higher number of electrons means higher beam current. The number of particles within 1% energy spread normalized to the total number of the particles entering the linac is shown in Fig. 3.

The energy gain from the linac can be adjusted by optimizing the product of the accelerating field (E_0) and the transit time factor (T). This product is linearly proportional to the electron energy at the linac exit. The longitudinal and transverse phase space distributions of the particles at the RF-gun and the linac exit for the linac initial phase of -53.7 degree are shown in Fig. 4 and 5 respectively. The product of accelerating field and transit time factor (E_0T) is equal to 4 MV/m, which provides the final maximum electron energy of 15.6 MeV.



a) Particle distributions in transverse phase space in x-x′ and y-y′ plane.



b) Particle distributions in x-y plane.

Figure 2: Particle distributions at the RF-gun exit for the field ratio of 1:2 and the accelerating field of 35/70 MV/m.

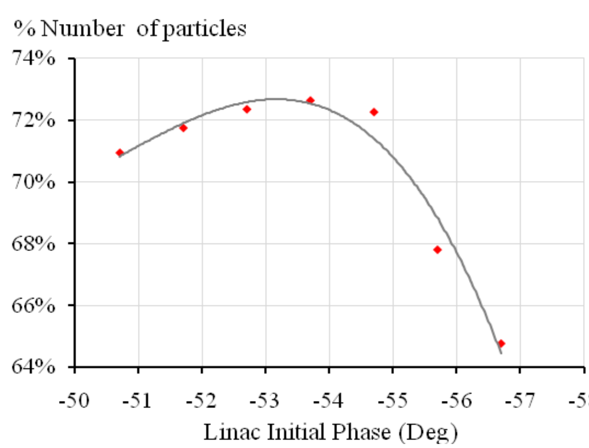


Figure 3: The number of particles within 1% energy spread normalized to the total number of the particles entering the linac as a function of the linac initial phase respect to the reference particle phase entering the linac.

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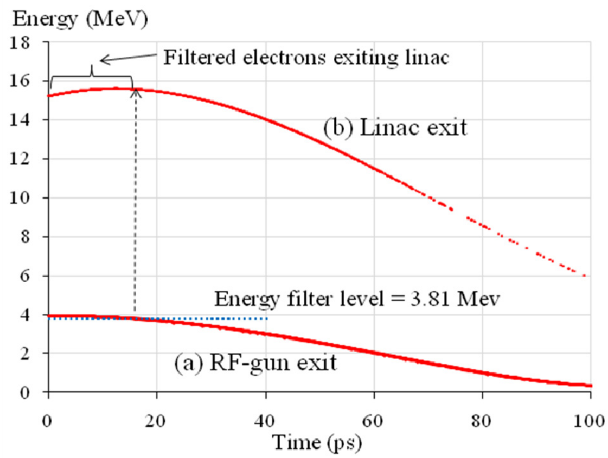

Figure 4: Particle distributions in longitudinal phase space for all particles at a) the RF-gun exit for the field ratio of 1:2 and the accelerating field of 35/70 MV/m and b) the linac exit with the linac initial phase of -53.7 degree and the product between accelerating field and transit time factor (E_0T) is 4 MV/m.

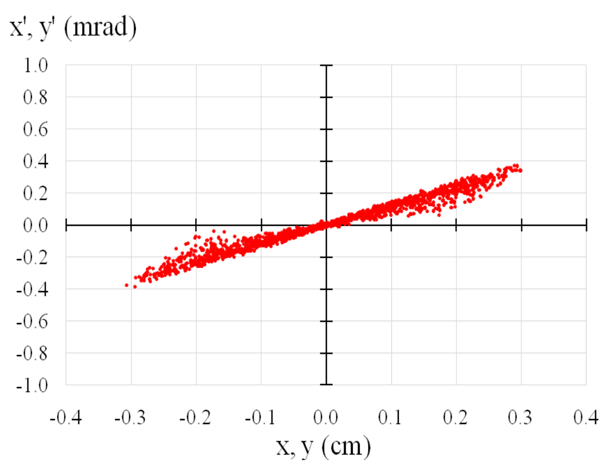

Figure 5: Particle distributions in transverse phase space in x-x′ and y-y′ of filtered particles at the linac exit for the linac initial phase of -53.7 degree, the product between accelerating field and transit time factor (E_0T) is 4 MV/m and the energy filter level is 3.81 MeV.

180° Achromat and Bunch Compressor

The 180° achromat and bunch compressor is a triple bend type. The electron bunch exiting this section becomes shorter with no change of energy spread. The doublet quadrupole gradient is adjusted to have the minimum bunch compression condition. The electron bunch properties at the 180° achromat exit under the minimum bunch length condition are shown in Fig. 6, 7 and 8. Summary of the preliminary injector and electron beam parameters are listed in Table 2.

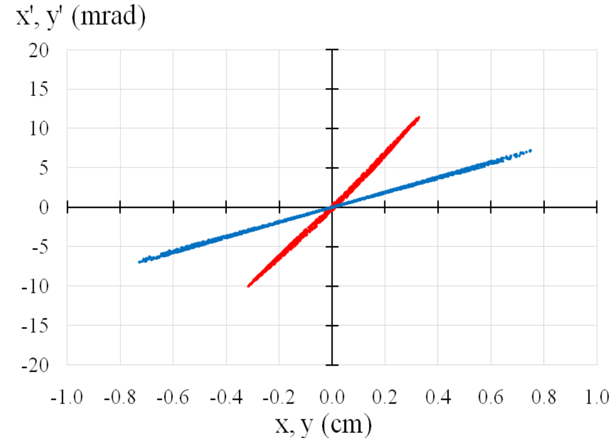

Figure 6: Particle distributions in transverse phase space in x-x′ and y-y′ plane at the 180° achomat exit under the minimum bunch length condition.

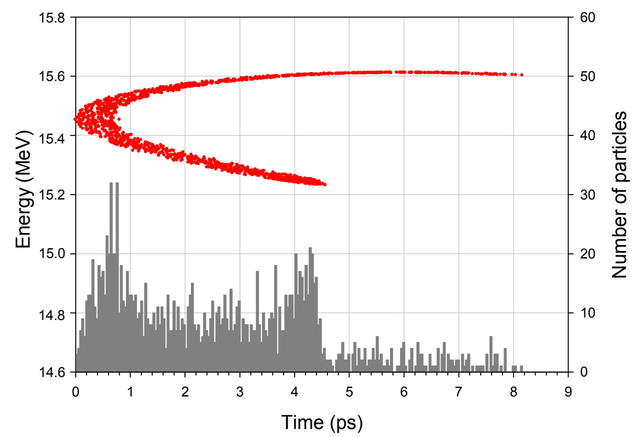

Figure 7: Particle distributions in longitudinal phase space at the 180° achromat exit under the minimum bunch length condition.

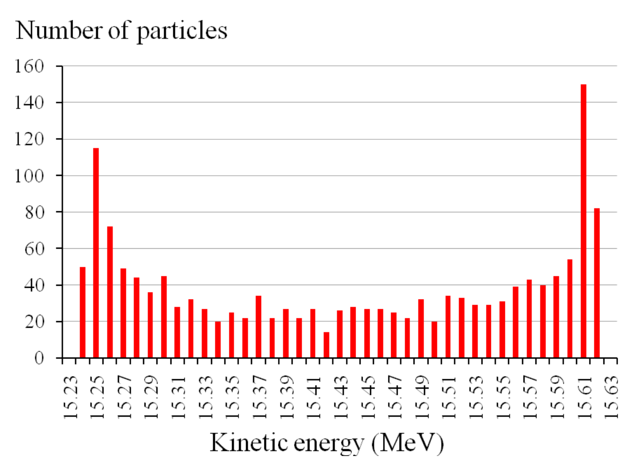

Figure 8: Energy spectrum of the particles at the 180° achromat exit under the minimum bunch length condition.

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Table 2: Summary of Preliminary Injector Parameters

Parameters	Values
RF-Gun	
Type	1.6 cell thermionic cathode with side coupling cavity
Field ratio	1 : 2
Accelerating field	Half-cell= 35 MV/m Full-cell = 70 MV/m
Beam output energy	
- Average	3.91 MeV
- Maximum	3.94 MeV
- Minimum	3.81 MeV
Energy spread	0.82 %
Energy filter level	3.81 MeV
Linac	
Type	S-Band SLAC-type travelling wave linac
Length	3 m
Initial phase	- 53.7 deg. with respect to ref. particle entering linac
Beam output energy	
- Average	15.43 MeV
- Maximum	15.61 MeV
- Minimum	15.23 MeV
Energy spread	0.87 %
Bunch length (FWHM)	14.47 ps
Bunch charge	51.68 pC
Peak current	3.5 A
Emittance (mm-mrad)	
- rms	$\varepsilon_x = 0.04$, $\varepsilon_y = 0.039$
- Normalized	$\epsilon_x = 1.24$, $\epsilon_y = 1.22$
180° Achromat	
Type	Triple bend with doublet quadrupole
Bending magnet	
- Defection angle	60 degree
- Effective length	35 cm.
- Curvature	2.99 m^{-1}
Quadrupole	
- Focusing strength	56.4 m^{-2}
- Defocusing strength	- 44.6 m^{-2}
Beam output energy	
- Average	15.43 MeV
- Maximum	15.61 MeV
- Minimum	15.23 MeV
Energy spread	0.87 %
Bunch length (FWHM)	4.1 ps
Bunch charge	51.68 pC
Peak current	12.61 A
Emittance (mm-mrad)	
- rms	$\varepsilon_x = 0.6$, $\varepsilon_y = 0.299$
- Normalized	$\epsilon_x = 18.86$, $\epsilon_y = 9.31$

CONCLUSION AND OUTLOOK

The longitudinal beam dynamics of the injector system for an IR FEL at CMU has been investigated and optimized by numerical simulation. The electron bunches exiting the 180° achromat have average energy of 15.43 MeV, energy spread of 0.87%, bunch length of 4.1 ps, bunch charge of 51.68 pC and peak current of 12.61 A. Note that, the results are the preliminary study of the injector design. Further studies and optimization by using computer codes and theoretical analysis will be conducted to investigate both transverse and longitudinal electron beam dynamics.

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