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PRELIMINARY DESIGN ON THE ACCELERATOR OF AN INFRARED FREE ELECTRON LASER OSCILLATOR*

Ruixuan Huang†, Qika Jia, Zhouyu Zhao, Heting Li, Zhigang He, Shancai Zhang, Guangyao Feng
University of Science and Technology of China, Hefei, China

Abstract

We are proposing a new infrared (IR) Free Electron Laser (FEL) facility in China which will produce intense laser beam covering the spectral range from 2.5 µm to 200 µm. It is made up of two oscillators generating middle infrared and far infrared laser respectively, which are driven by a single RF injector with a tunable beam energy from 12 MeV to 60 MeV. According to the requirement of the FEL physics, the linac is designed with an rms energy spread of less than 0.5%, a transverse rms emittance of less than 40 mm · mrad and a micro bunch length of 4-10 ps with a charge of 1 nC launched. In this manuscript, we present the preliminary design of the accelerator, from the electron gun through the transport line's terminus.

INTRODUCTION

The Free Electron Laser (FEL) oscillator, a well-established facility of intense and tunable radiation source, is widely applied at the wavelength ranging from infrared (IR) to terahertz. A lot of IR-FEL oscillators operating as user facilities have been built in the world, such as CLIO [1] in France, FELIX [2] in the Netherlands, KU-FEL [3] in Japan, and FELiChEM [4] in China.

We are giving a preliminary design on the accelerating system for a newly-proposed IR-FEL facility. The basic layout of the IR-FEL is shown in Fig. 1. It consists of two oscillators driven by the same electron source (injector) with different beam energies. The two oscillators are resonating at mid-infrared (MIR) (2.5-50 µm) and far-infrared (FIR) (40-200 µm), respectively. The injector consists of a 100 keV DC electron gun to launch the electron beam, the RF bunching system with a pre-buncher cavity and a buncher section to compress the bunch lengh, and two RF linear accelerators (linacs) to boost the beam energy. There are several solenoids and quadrupoles along the beamline, which are used for emittance compensation and transverse focusing to match between the laser and electron beams inside the undulator. Between the injector and the FEL oscillators, the achromatic transfer lines are designed, in which energy slits will be inserted to eliminate the electrons with large energy spread. A beam dump is placed at each beamline end, while the dumps at the end of oscillators (BD2 and BD3) are below the beamline plane guided by the vertical bending magnets (D5 and D7).

The overall dimension of the IR-FEL facility is 11 m ×10 m. Compared with FELiChEM facility [5], the primary difference is that this FEL leaves out the magnetic compressor (chicane) and redesign the buncher section while retaining the feasibility of output a high-peak-current electron beam.

On the basis of the requirement of FEL physics, the norminal parameters of the electron beam are listed in Table 1.

Table 1: Norminal Parameters of the Electron Beam

	Parameter	Specification
	Energy (E)	12-60 MeV
	Energy spread (Δ E)	<0.5%
	Emittance (ε_{xn})	<40 mm · mrad
Micropulse	Charge (Q)	1 nC
	Peak current (I_p)	>95 A
	Pulse length (FWHM)	4-10 ps
	Reptition rate	119, 59.5, 29.75 MHz
Macropulse	Pulse length	3-10 µm
	Max. avg. current (I)	>100 mA
	Reptition rate	10 Hz

THE INJECTOR DESIGN

As the electron source, the thermionic triode electron gun can emit 100 keV energy and 1 ns pulse width electron beam with 1 nC bunch charge. The micro-pulse repetition rate is optinal according to subharmonic of the RF frequency. The pre-buncher is a standing wave cavity operating at 476 MHz with a gap voltage of 40 kV, which will give the beam en energy chirp and then make the beam compressed in the following drift space. The electron pulse could be compressed by about 17 times in 24 cm long drift space. The buncher section is a travelling wave tube operating at 2856 MHz, which is comprised of input and output couplers, five low-beta cells (phase velocity of 0.63, 0.8, 0.9, 0.95 and 0.98) and 19 cells at phase velocity of 1.0. With a maximum gradient of 9.0 MV/m, the electron beam could be further compressed to 4-10 ps in FWHM and also be accelerated to about 6 MVat the end of buncher. Two 2-meter-long travelling wave linacs are also operating at 2856 MHz, each of which consists of 57 cells, the input and output couplers. According to the analysis of beam loading effect in Ref. [5], one linac can offer about 30 MeV energy gain with 20 MW power input for a 300 mA current beam.

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† rxhuang@ustc.edu.cn

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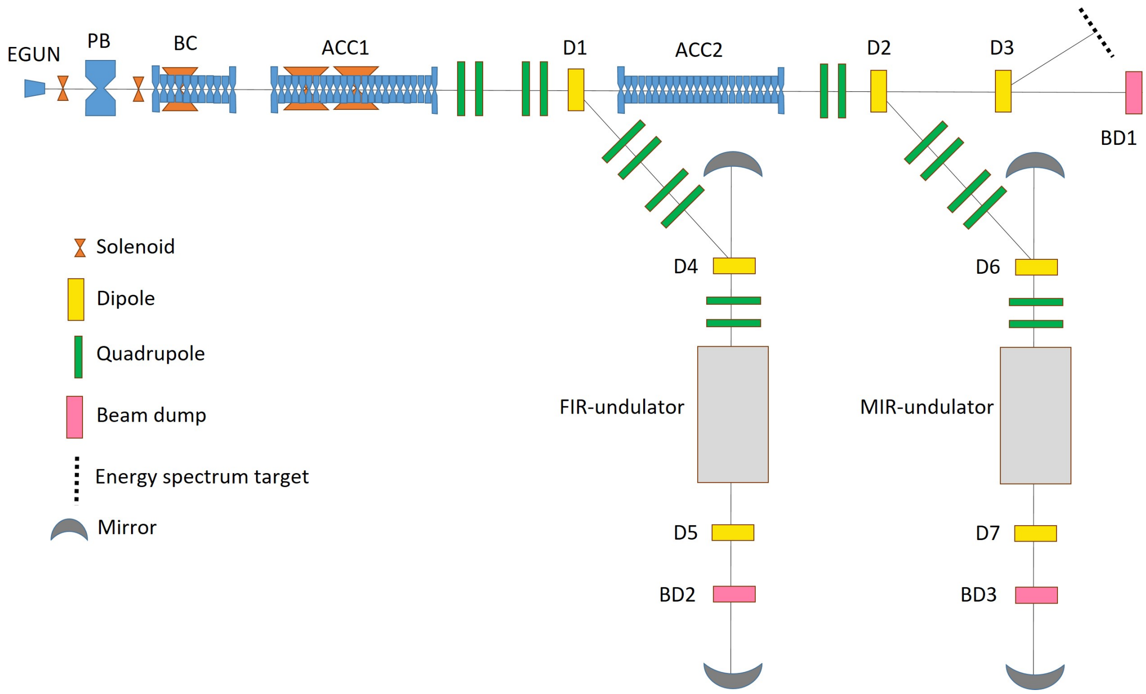

Figure 1: Schemetic layout of the IR-FEL facility.

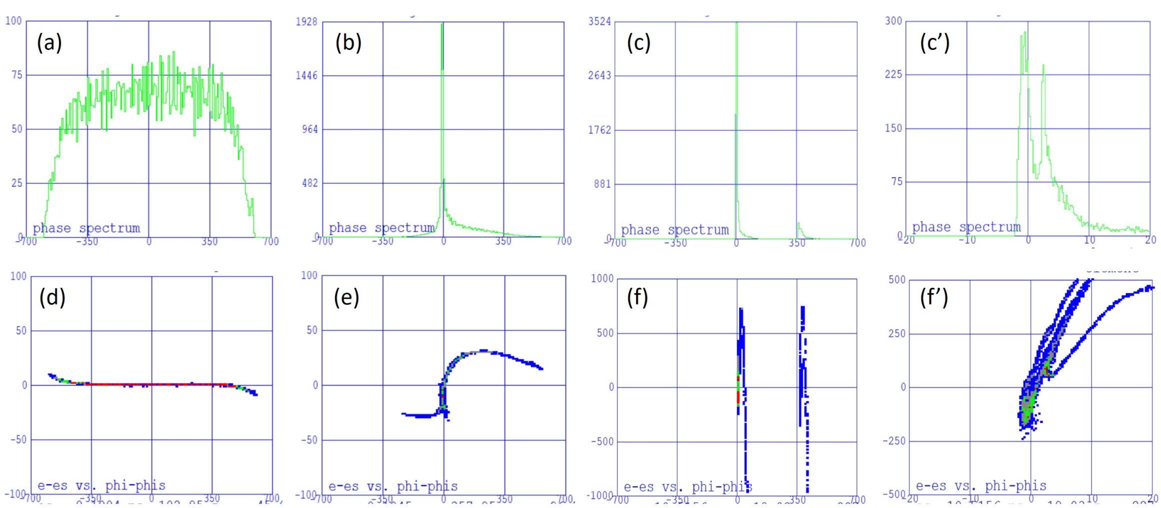

Figure 2: Longitudinal beam distributions (upper) and phase spaces (lower) at entrance of pre-buncher (a, d), entrance of buncher (b, e), and exit of buncher (c, f). (c′, f′) are the locally amplified images of (c, f).

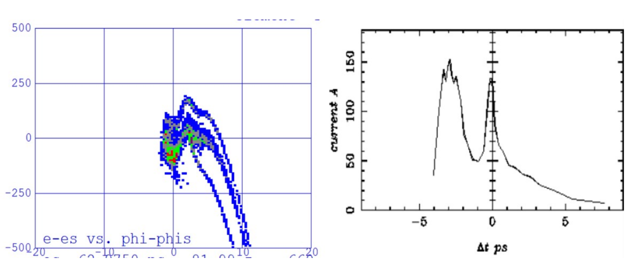

Figure 3: Longitudinal phase space and current distribution of the beam at exit of ACC2.

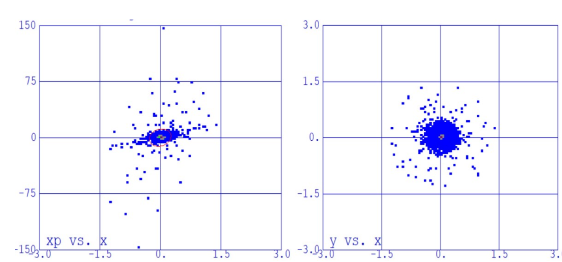

Figure 4: Transverse phase space and beam cross-section at exit of ACC1.

The code PARMELA is used for beam dynamics simulation in the injector. Figure 2 shows the longitudinal beam distributions and phase spaces during the beam compression. The electron bunch is violently compressed from 1 ns

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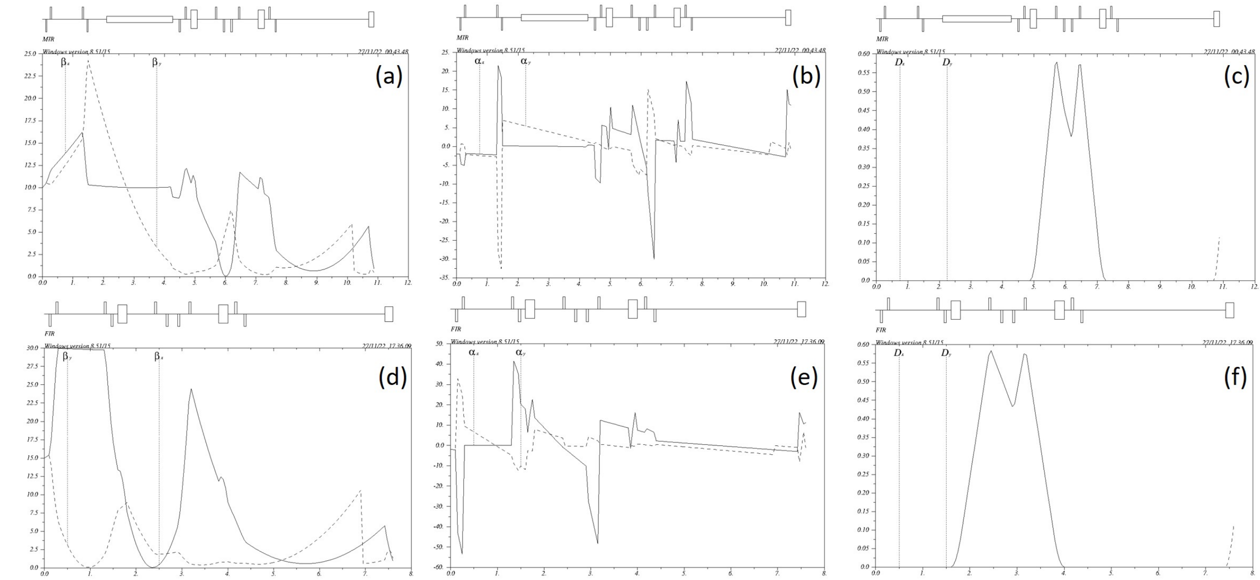

Figure 5: The lattice design for MIR oscillator (upper) and MIR oscillator (lower): the beta function (a, d), the alpha function (b, e), and the dispersion function (c, f).

to 20 ps, where the small pulses may exist by the side of the main pulse while the core part of the main pulse is less than 10 ps with a relatively small energy spread. In the linacs, the electron beam is energy boosted as well as energy spread slightly compensated. As shown in Fig. 3, the core part of electron beam has an rms energy spread of about 200 keV and a peak current of over 120 A at the end of linac ACC2. With a maximum kinetic energy of 60 MeV, the relative energy spread is 0.33‰.

During bunch compression, the transverse emittance of the whole beam is significantly increased from 3.6 to 36 mm · mrad yet under compensation by solenoids. The rms transverse phase space and beam cross-section at the end of linac ACC1 are shown in Fig. 4.

THE LATTICE DESIGN FOR FEL OSCILLATOR

The code MAD is used for lattice design in the transport line. To ensure that the beam optical parameters can match the requirements of the undulator, the focusing system in the transport line should be adjustasble in a certain range. The matching requirements at the entrance of MIR and FIR undulators are mainly listed in Table 2. And the dispersion functions in both cases are zero in two planes. To realize the small energy spread, the dispersion function at the energy slits (in the middel of two 45-degree bending magnets in each transport line) should not be moderately large.

The evolutions of beta, alpha, and dispersion functions for the MIR-FEL and FIR-FEL are shown in Fig. 5. In this example, the initial parameters are $\beta_{x,y}$= 10 m, $\alpha_{x,y}$= −2 m for MIR line and $\beta_{x,y}$= 15 m, $\alpha_{x,y}$= −2 m for FIR line.

Table 2: The Matching Parameters at the Undulator Entrance

Parameter	MIR-FEL	FIR-FEL
β_x	2.1 m	2.45 m
β_y	1.0 m	0.5 m
α_x	1.5	1.8

CONCLUSION

In conclusion, we have introduced a new IR-FEL oscillator in China. Brief physical design considerations and results have been given in this manuscript. On the basis of simulation results, all the main parameters have met the specification requirement.

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