LINAC DESIGN OF THE IR-FEL PROJECT IN CHINA*

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Abstract

We are building an infrared free-electron laser (IR-FEL) facility that will operate from 5 µm to 200 µm. This FEL source is drived by a linac, which is composed of a triode electron gun, a subharmonic prebuncher, a buncher, two accelerators, and a beam transport line. The linac is required to operate from 15 to 60 MeV at 1 nC charge, while delivering a transverse rms emittance of smaller than 30 mm-mrad in a 5 ps rms length, smaller than 240 keV rms energy spread bunch at the Far-infrared and Mid-infrared undulators. In this article, the preliminary Linac design studies are described.

INTRODUCTION

The basic layout of the FEL facility is shown in Fig. 1. The accelerating system consists of a 100 kV triode electron gun, a bunching system, and two accelerators. The energy range between 15 and 25 MeV will be covered with the first accelerator (A1) for the far-infrared radiation, and the range between 25 to 60 MeV with the second accelerator (A2) for the middle-infrared radiation. As to the requirement of the FEL physics [1], the electron beam characteristics are listed in Table 1.

Table 1: Electron Beam Characteristics

	Energy (E)	15-60 MeV
	Energy spread (δE)	< 240 keV
	Emittance (ε_n)	< 30 mm-mrad
micro pulse	Charge (Q)	1 nC
	Peak current (I_p)	> 95 A
	Pulse length (σ_t)	2-5 ps
	Repetition rate	$\frac{476}{n(=1,2,3,4,5)}$ MHz
macro pulse	Pulse width	5–10 µs
	Average current (I)	~300 mA
	Repetition rate	20 Hz

DESCRIPTION OF THE LINAC

As shown in Fig. 1, the Linac consists of a:

- 100 keV electron gun
- 476 MHz subharmonic standing wave pre-buncher
- 2856 MHz fundamental frequency traveling wave buncher
- two 2856 MHz fundamental frequency traveling wave accelerators
- set of solenoid focusing coil from the gun exit to the end of the first accelerator
- magnetic compressor (chicane)
- two beam transport systems

The triode gun can be driven by the grid for the pulsed mode. A 476 MHz signal during 10 µs is carried to the HV deck. A frequency divider is used to control the repetition rate of the micro pulses. The electron gun pulser could offer the pulsed signal of up to 200 V/1 ns every 2, 4, 8, 16, or 32 ns. We expect to obtain micro pulses of 1-2 A/1 ns at the gun output. The operating mode of the electron gun is similar to the gun of the CLIO FEL [2, 3], while RF gated electron guns are adopted by the FELIX FEL [4, 5] and FHI FEL [6].

The pre-buncher will be a 20 cm long stainless steel re-entrant standing wave cavity operating at 476 MHz. With a gap voltage of 40 kV, the bunch length could be compressed by about 20 times in 24 cm long drift space downstream from the pre-buncher exit at the entrance of the buncher.

For further bunch length compression, a traveling wave buncher operating at 2856 MHz is used, which consists of an input coupler, 11 cells , and an output coupler. The phase velocities β_ϕ of the fist four cells are 0.63, 0.8, 0.915, and 0.958 respectively, and that of the rest of the cells is 1. With a 9 MV/m gradient (about 5 MW input power), the bunch length can be compressed to 4.5 ps (rms) and the beam energy is about 3.1 MeV at the exit of the buncher.

The two 2 meters long traveling wave accelerators are also operating at 2856 MHz, which consists of input and output couplers and 57 cells. Because of the high average current, the beam loading effect should be considered in the accelerators. As to our design structures, the acceleration gradient of the cells are shown in Fig. 2. When the beam current is 300 mA, one accelerator can offer about 30 MeV beam energy increase with 20 MW input power.

To improve the gain of the short wavelength radiation, a higher peak current bunch may be required. The chicane could be as a backup apparatus to obtain a shorter bunch. Because the peak current is above 100 A at the exit of A1, the magnetic compressor is not used normally.

The main functions of the beam transport systems are beam matching and beam energy filtering. Energy slits will be used in the dispersion section to filter out the electrons with great energy spread.

BEAM DYNAMICS

The code PARMELA is used for beam dynamics simulation. The initial beam current and bunch length are 1.5 A and 1 ns respectively.

Figure 3 shows the simulated longitudinal distribution state and phase space of the electron bunch at the exit of the

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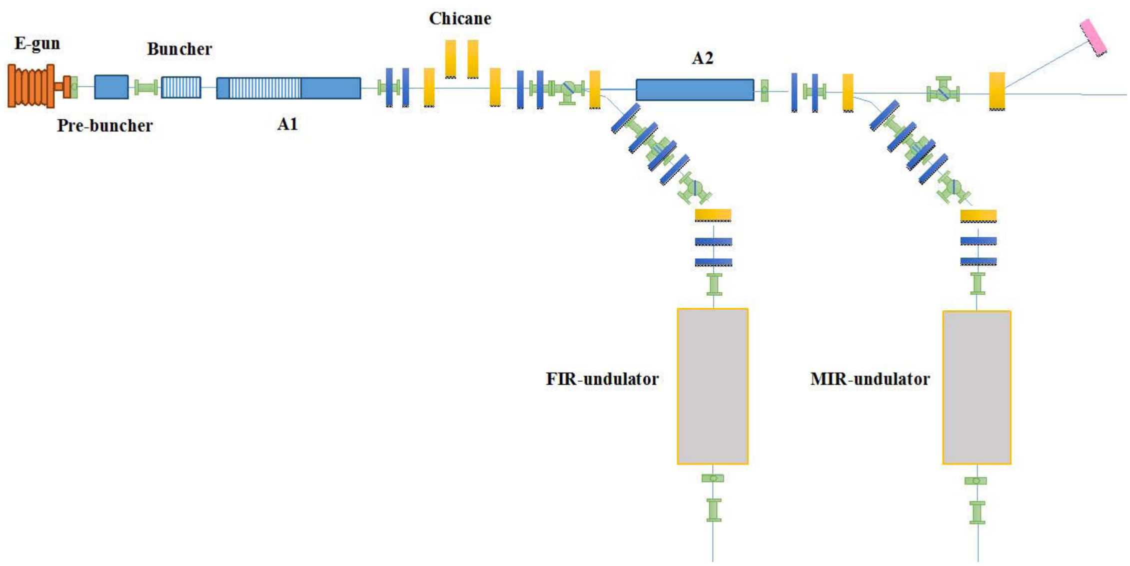

Figure 1: Basic layout of the FEL facility.

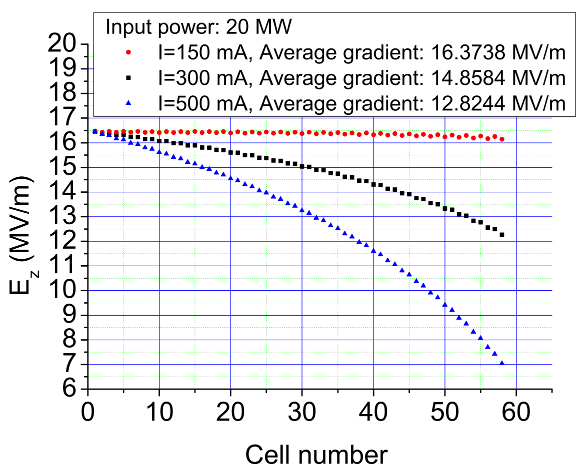

Figure 2: Acceleration gradient of the acceleration cells for different beam currents.

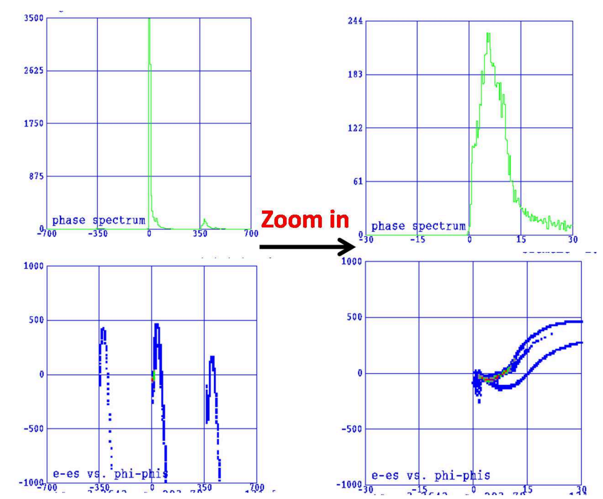

Figure 3: Longitudinal distribution state and phase space of the electron bunch at the exit of the buncher.

buncher. The electron bunch is compressed to about 30 ps width. In the core part, the bunch length is within 15 ps, and the energy spread is also small.

Figure 4 shows the current distribution state and phase space of the electron bunch at the exit of A1. The peak current is up to 120 A, the charge of electrons in the core part is about 1 nC, and the rms bunch length is 4.5 ps. When the beam energy is 20 MeV, the rms energy spread is about 80 keV. When the beam energy is 30 MeV, the spread could be increased to 120 keV, which is the maximum rms energy spread of the whole Linac, however the energy spread caused by errors is not included. The transverse emittances are about 10 mm-mrad in the horizontal and vertical directions, as shown in Fig. 5.

The lattice of the beam transport line is designed with the code MAD. As an example, the beta and dispersion functions for the MIR-undulator without the magnetic compressor are shown in Fig. 6. At the position of 0.9 m dispersion, the energy slit will be installed for energy filter.

STATUS AND SCHEDULES

The project is under technical design. The first 60 MeV electron beam is scheduled in September of 2017, the MIR laser would operate at the end of 2017, and the FIR laser would be available at the middle of 2018.

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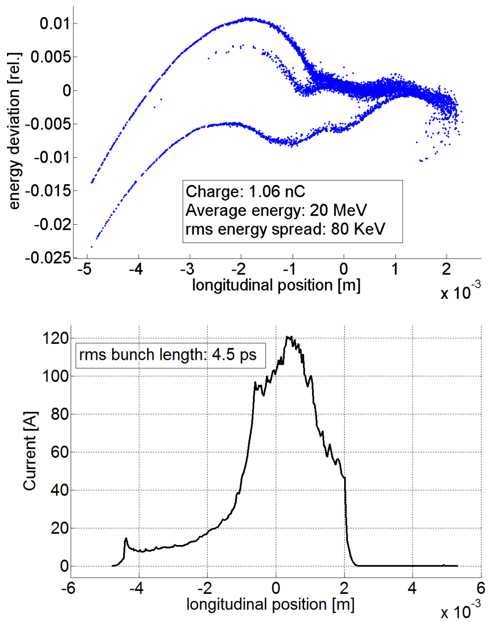

Figure 4: The current distribution state and phase space of the electron bunch at the exit of A1.

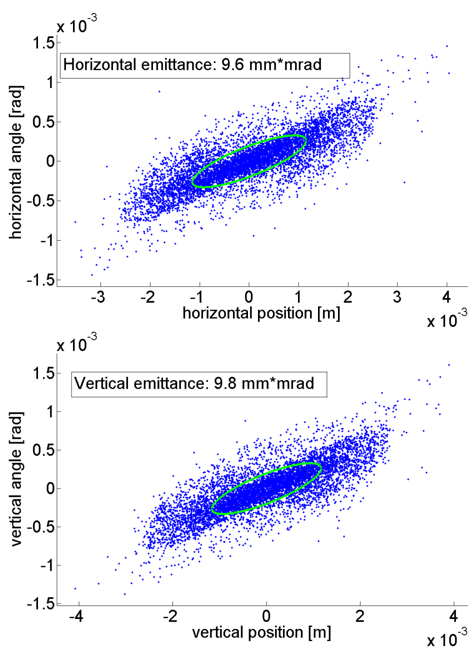

Figure 5: The transverse phase spaces of electron bunch at the exit of A1.

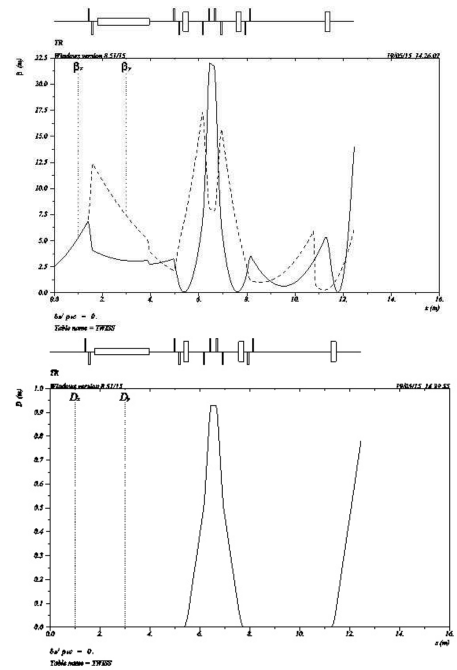

Figure 6: The beta function and dispersion function along the transport line.

REFERENCES

[1] Heting Li, presented at FEL'15, Daejeon, Korea, Aug 2015, paper TUP028, these proceedings.

[2] J. C. Bourdon, R. Belbéoch, P. Brunet, et al., proceeding of EPAC'1988, P. 314.

[3] R. Chaput, proceeding of EPAC'1988, P. 544.

[4] P. W. van Amersfoot, R. W. B. Best, C. A. J. van der Geer, et al., proceeding of EPAC'1988, P. 430.

[5] R. J. Bakker, C. A. J. van der Geer, A. F. G. van der Meer, et al., Nucl. Instrum. Methods Phys. Res., Sect. A **307**, 543(1991).

[6] H. Bluem, V. Christina, B. Dalesio, et al., proceeding of FEL'2010, MOPA09.

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