ERROR ANALYSIS FOR THE LATTICE OF FELICHEM*

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Abstract

FELiChEM is a new experimental facility under construction at University of Science and Technology of China (USTC).The facility consists of the middle-infrared (MID-FEL) beam line for 2.5-50 um and the Far-infrared (FAR-FEL) beam line for 40-200um. To achieve the design FEL performance of IR-FEL, the beam with 30 mm-mrad emittance, 5 ps rms length and 1nC bunch charge is required. We conduct error analysis in order to evaluate the tolerances of machine parameters and alignments. In this paper, we simulate the orbit corrections and emittance growth under exist of misalignments and strength errors of magnets. The simulation results show that the trajectory errors can be corrected to mm levels in the whole lattice and the emittance increase is acceptable. At the entrance of undulator, the position and angular errors can be corrected very well. So the trajectory can be controlled in the undulator to meet the requirement of FEL.

INTRODUCTION

The basic layout of FEL facility is shown in Fig. 1[1]. The 100kV triode gun is driven by the grid for the pulsed mode. A 476 MHz signal during 10us is carried to the HV deck. A frequency divider is used to control the repetition rate of the micro pulses.

The pre-buncher is a 20 cm long stainless steel re-entrant standing wave cavity operating at 476MHz. With a 2856 MHz fundamental frequency traveling wave buncher, 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. Two accelerator tubes accelerate the beam energy up to 60 MeV maximum. Accelerator tube is 2 meters long traveling wave constant-gradient structure and operate at 2856 MHz. The beam energy can change with the demanding of FEL.

A magnetic compressor is designed also to control the bunch length. For different FEL, wavelength, magnetic compressor setting is also different. When chicane is closed, FELs can get enough gain and enough power output also.

Two 90 degree beam transport lines bend beam to middle-infrared and far-infrared undulators. The transport lines consist two horizontal 45 degree bending magnet to form an acromat section. 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 large energy spread. It also match the beam twiss parameters at the entrance of undulator.

Two optical cavities form oscillator with undulator. Middle-infrared and far-infrared FEL are generated separately in the oscillators.

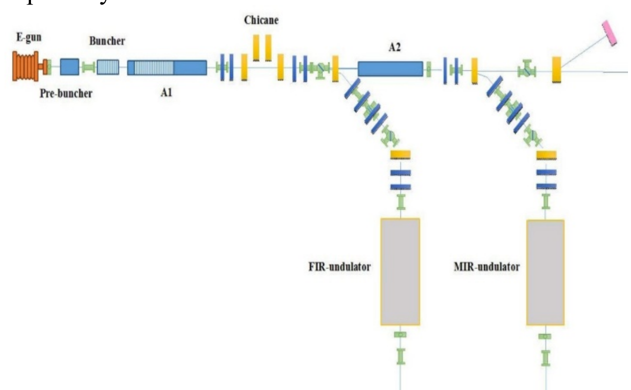

Figure 1: Basic layout of the FEL facility.

Under ideal conditions, beam trajectory passes through the center of the accelerating structure and focus element center. The wakefield effect has little effect on the beam quality. In real installation conditions, alignment errors of elements exist. Magnets also have strength errors, the beam trajectory will deviate from the center of the accelerating structure and focus element center.

In this paper, We used MADX[2] to optimize lattice parameters and conducted error simulations with ELEGANT[3].

FEL LATTICE

FAR-FEL use the first accelerating tube only and it doesn't need CHICANE.

For FAR-FEL, we need match the beam twiss parameters at the entrance of undulator and design an energy slit in the lattice design.

The initial beam twiss parameters which get from parmela simulations are $\beta_{x,y} = 2.5\ m, \alpha_{x,y} = -1, \alpha_x = -1, \alpha_y$=-1. The required twiss parameters of FAR-FEL at undulator entrance is $\beta_x = 2.45, \beta_y = 0.5, \alpha_x = 1.8, \alpha_y = 0, Dx = 0, Dpx = 0, Dy = 0, Dpy = 0.$ The lattice layout and optical parameters are shown in Fig. 2 . The β function in the lattice is controlled within 25 m. The maximum eta function is larger than 0.9 m which meet the requirements of the installation energy slit. The twiss parameters at the entrance of undulator are matched

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to the undulator demanding also.

For MID-FEL, two accelerating tubes are all used. chicane can be used or not for different operating conditions. We need match the beam twiss parameters at the entrance of undulator and design an energy slit in the lattice design also.

The required twiss parameters of MID-FEL at undulator entrance are different to FAR-FEL slightly, which is $\beta_x = 2.1, \beta_y = 1, \alpha_x = 1.5, \alpha_y = 0, Dx = 0, Dpx = 0, Dy = 0, Dpy = 0$. Fig. 4 give a result including chicane. It has similar result with FAR-FEL and fulfill the demanding of MID-FEL.

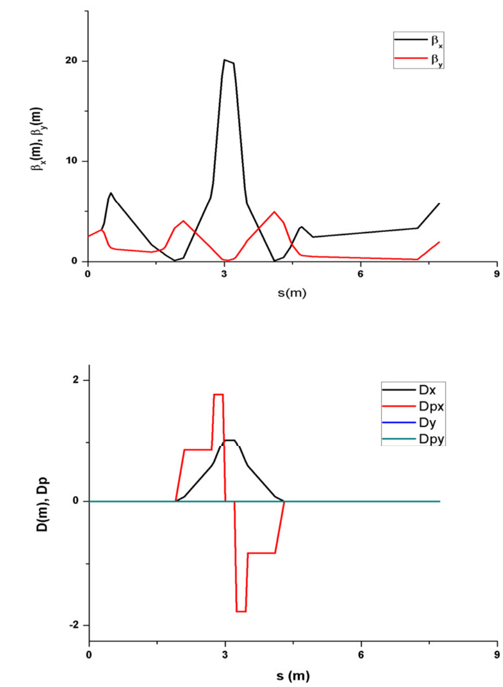

Figure 2: The optics of FAR-FEL transport line.

The beam envelopes under different energy spread for two lattices are shown in Fig. 3 and Fig. 5. The maximum beam envelope is decided by the energy spread, and it is about 6(H)&1.5(V) mm under 0.5% rms energy spread and 3(H)&1.5(V) mm under 0.2% rms energy spread of FAR-FEL. The corresponding values of MID-FEL is about 3(H)&1(V) mm under 0.5% rms energy spread and 2(H)&1(V) mm under 0.2% rms energy spread.

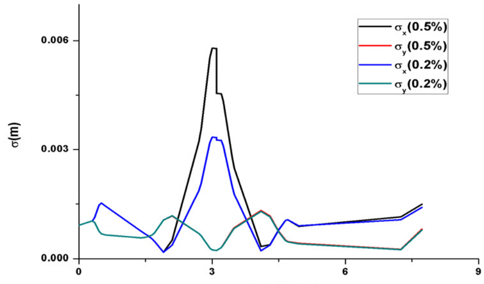

Figure 3: The beam envelope of different energy spread in FAR-FEL transport line.

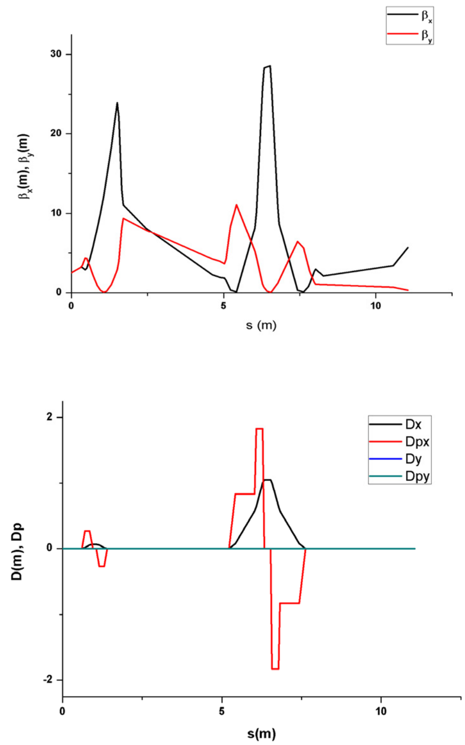

Figure 4: The optics of MID-FEL transport line.

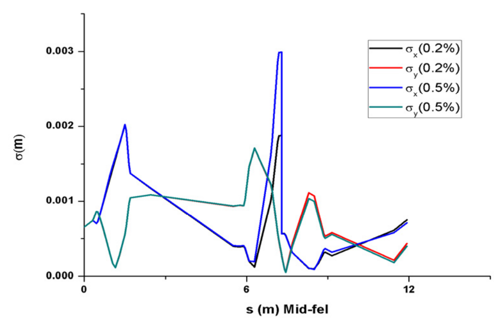

Figure 5: The beam envelope of different energy spread in MID-FEL transport line.

ERROR ANALISIS AND CORRECTION

The alignment errors and strength errors of quadrupoles and bend magnets cause the distortion of beam trajectory. The distortion of trajectory reduces the transfer efficiency of transport line and causes the emittance increasing dramatically. Large residual dispersion at undulator also will cause FEL gain decrease.

The BPM layout principles is that every 2π Betatron Phase Advance should be arranged at least four BPMs. The exact amount and layout are obtained by simulation calculation.

Table 1: Errors Setting of Orbit Correction Simulation

Parameters	bend	quadrupole	cutoff
Dx&dy(mm)	0.15	0.15	3
Rotate error(mrad)	0.5	0.5	3
Strength error	0.1%	0.1%	3

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4 single pass BPMs and 4 correctors for MID-FEL and 5 single pass BPMs and 5 correctors for FAR-FEL are used to control the trajectory of beam line. A BPM is located as close as possible to the undulator entrance. It is used to confirm the final beam parameters from transport line. Beta function is considered also when arranging BPM.

We use numerical simulation to study beam trajectory distortion introduced by installation and alignment. In our simulation, the errors setting is shown in Table 1.

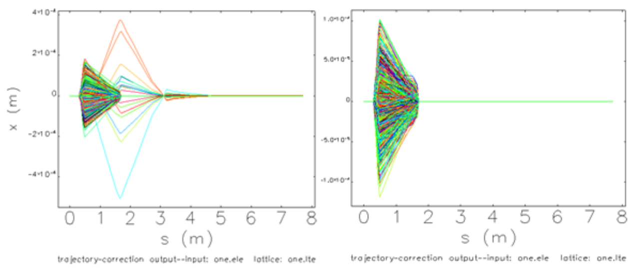

Figure 6: 1000 random seeds simulation of trajectory corrections of FAR-FEL transport line.

Fig. 6 and Fig. 7 give the corrected central trajectories of LINAC to transport line simulated by elegant. In the simulation, the LINAC and the transport line are treated together. The simulations are run by 1000 random seed. The maximum trajectory offset is smaller than 1mm. At undulator entrance, when BPM noises do not be included , the position and angle errors can be compensated perfectly. From the simulation result, the arrangement of BPMs and correctors can control the beam position and angle at undulator entrance precisely.

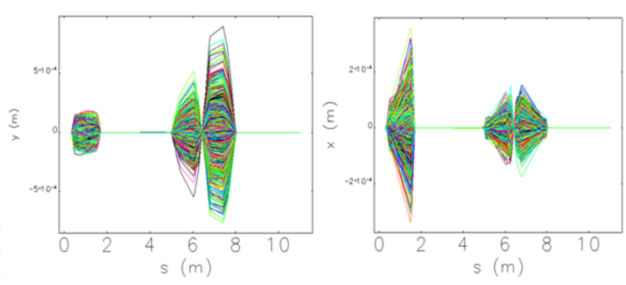

Figure 7: 1000 random seeds simulation of trajectory corrections of MID-FEL transport line.

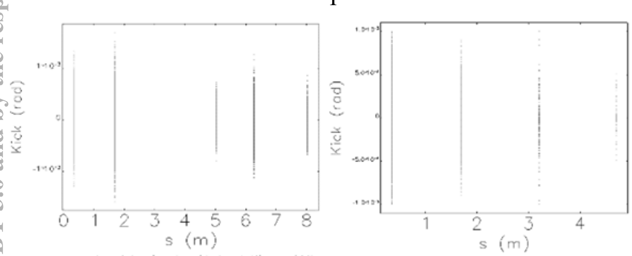

Figure 8: The correctors strength (left: MID right: FAR).

As can be seen in Fig. 8. For FAR-FEL, the maximum strength of correctors is lower than 1mrad. In the case of MID-FEL, the maximum strength of correctors is about 1.5 mrad, but 85 percent strength of correctors is lower than 1 mrad.

The normalized emittance after trajectory corrections at the entrance of undulator is shown in Fig. 9 and Fig. 10. After including the residual dispersion, the emittance fulfil the demanding of FEL.

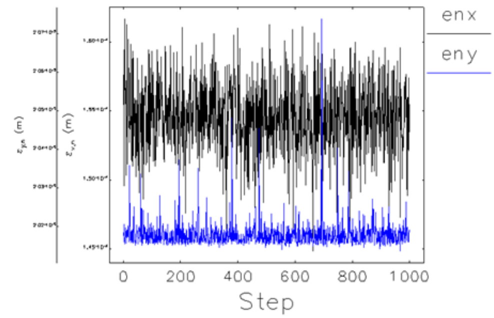

Figure 9: The normalized emittance of FAR-FEL after correction.

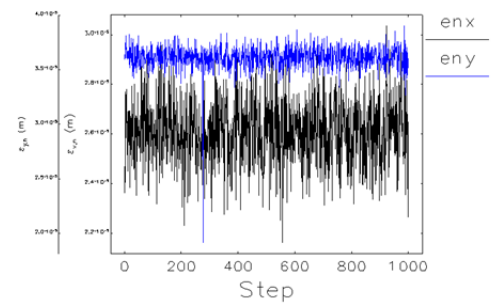

Figure 10: The normalized emittance of MID-FEL after correction.

CONCLUSION

We conducted error analysis and correction of the trajectories of FELiCHEM. The maximum trajectory offset is smaller than 1mm after correction. The beam position and angle at undulator entrance can be controlled precisely. The emittance increase is acceptable also. The strength of correctors is a little bit large. Further work will be processed to decrease the strength of correctors in future.

ACKNOWLEDGEMENT

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