OPTICAL DESIGN OF THE ENERGY RECOVERY LINAC FEL AT PEKING UNIVERSITY*

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Abstract

Peking University is currently designing an Energy Recovery Linac FEL (PKU-ERL-FEL). The system is consisted of a DC-SC photocathode injector, a superconducting linac which is composed of two nine cell TESLA-type cavities, an undulator and beam transport system. The objectives of the PKU-ERL-FEL are providing infrared FEL and building a test-bed for the study of beam dynamics and accelerator technology for energy recovery. In this paper the main parameters of the PKU-ERL-FEL are described and the optical design for the beam transport of PKU-ERL-FEL is presented. The simulation is carried out using the typical particle tracking codes such as *elegant*.

INTRODUCTION

Energy Recovery Linac (ERL) for FEL was approved in Jlab [1]. It is an economical operation mode for widely use in scientific research, industrial and other areas. As the benefit of reducing most of the energy loss, ERL would make it possible to construct large accelerators which need huge power and increase the beam current to a very high level that seems difficult nowadays. Recently many laboratories are developing ERL technology and some facilities are under constructing such as ERLP in Daresbury Laboratory [2][3][4]. Peking University also plan to build an Energy Recovery Linac FEL (PKU-ERL-FEL) based on the research work of RF superconducting technology. This facility will not only provide infrared FEL (IR-FEL) for users but also be used as a test-bed for the study of beam dynamics and superconducting linac techniques for energy recovery. In this paper we mainly discuss the optical issues of the PKU-ERL-FEL.

DISCRIPTION OF PKU-ERL-FEL

Similar with other facilities, PKU-ERL-FEL consists of a DC-SC photocathode injector, a superconducting linac which is composed of two nine cell TESLA-type cavities, an undulator with mirrors in each side and beam transport system. PKU-ERL-FEL is under design and the general parameters are determined. Figure 1 shows the layout and table 1 gives the main parameters of the PKU-ERL-FEL.

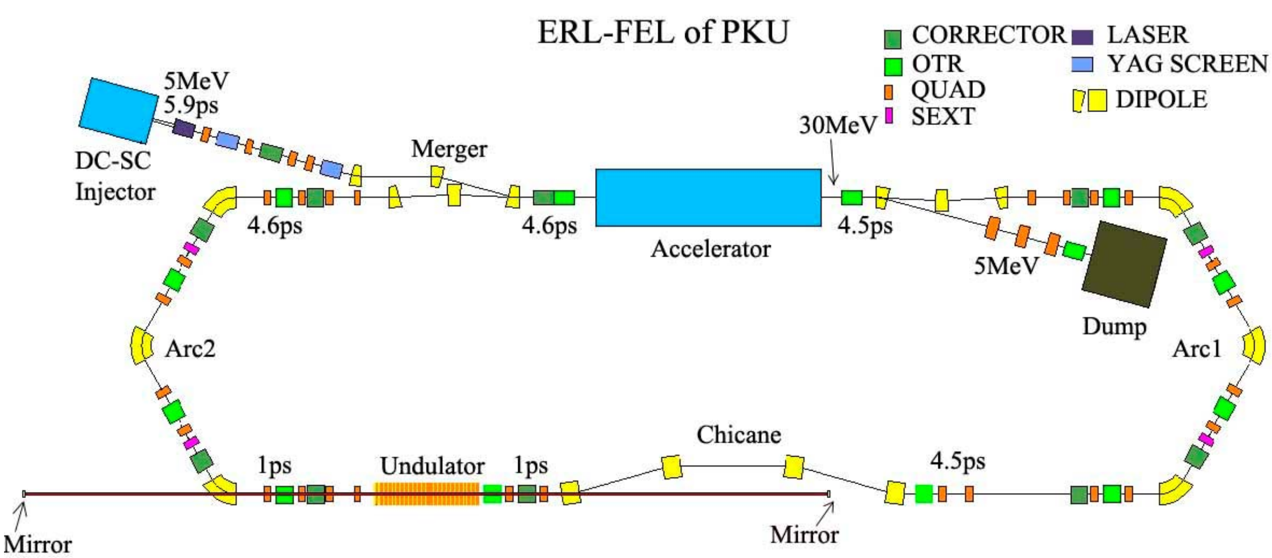

Figure 1: Layout of PKU-ERL-FEL.

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Table 1: Main parameters of the PKU-ERL-FEL

Injection Energy	5MeV
Maximum Energy	30MeV
Bunch Frequency	26MHz
Bunch Charge	~60pC
Bunch length at Entrance of Undulator	~1ps
Macro Pulse Length	2ms
Rep. Frequency of Macro Pulse	10Hz
Energy Spread (rms)	0.24%
Transverse Emittance （rms, n.）	~3μm
Length of Undulator	1.5m
λ_u of Undulator	3cm
K of Undulator	0.5-1.4
Optical Cavity Length	11.52m
Wavelength of FEL	4.7-8.3μm

Injector

The injector is a three and half cell DC-SC photocathode injector working at 2K with a frequency of 1.3GHz. DC-SC photocathode injector has been studied at Peking University since 1999 and demonstrated with a one and half cell model [5]. The accelerating gradient of this three and half cell DC-SC photocathode injector will reach 15MV/m and the transverse emittance of the beam from the photocathode is less than 3.0μm.

Linac

The linac is composed of two nine cell TESLA-type cavities also working at 2K. Electron will be accelerated to 30 MeV from 5 MeV at a gradient of about 13MV/m. Then it goes through the whole loop and back to the linac to be decelerated to 5MeV at 180° phase shift which is exactly achieved by adjusting the length of the whole loop. The linac will be operated in pulse mode due to the limitation of the capability of the cryogenic system.

Undulator

The undulator is 1.5m long and with 50 periods. The wave length of the IR-FEL produced by the undulator is from 4.7μm to 8.3μm. As the bunch frequency is 26MHz, the length of the cavity is currently set at 11.52m. Before the undulator is a magnet compressor to compress the bunch length to about 1.0ps. The bunch length has to be lengthened for effective deceleration. There are two ways to lengthen the bunch after undulator, one is using a decompressing chicane and another is adjusting the R_{56} of return arc. We adopt the second way for saving cost and space. Therefore the undulator is put close to the second arc to make one mirror in the chicane and the other in the outside of the first bending dipole of the second arc.

Transport system

Considering the limited space, the transport loop should be at a smaller scale. The length between the outer side of the outward arc and return arc is near 17 meters and the width of the trajectories is about 4.2 meters. 3 bend merger is adopted for beam injecting to the linac. Following the linac is the extraction chicane which bends the decelerated beam to the dump. After the first arc which contains three 60° bending magnets the beam will be turned 180° to the opposite direction. Then the beam goes through the chicane with a bending angle of 15° and the undulator. The beam comes out from the second arc and goes back to linac through the merger chicane. The energy is recycled and the exhausted electron beam goes to the dump with an energy of about 5MeV.

DESIGN CONSIDERATION

It is well known that the lattice of an ERL-FEL system should be achromatic and the whole loop should be isochronous. Keeping the matrix elements

$$R_{16} = R_{26} = 0 \qquad (1)$$

in each section is necessary to ensure the lattice to be achromatic. Keeping the matrix element

$$R_{56} = 0 \qquad (2)$$

will make the whole loop isochronous. Because we will use the return arc to lengthen bunches, the R_{56} of the second arc should compensate the R_{56} coming from the compression chicane and other parts:

$$R_{56,arc2} = -(R_{56,chicane} + R_{56,other}) \qquad (3)$$

The waist of the beta function should be removable and the beta function should match with the requirements of the undulator.

Energy spread is another important parameter to realize FEL and energy recovery successfully. The beam energy spread is determined by [6]

$$\delta < \frac{1}{4N} \qquad (4)$$

N is the undulator period. The undulator in PKU-ERL-FEL has 50 periods so that the beam energy spread should be less than 0.5%.

Space Charge and Coherent Synchrotron Radiation (CSR) can cause the increase of beam emittance. Therefore they should be taken into account in our design.

In the optical design we also need to consider the second order matrix terms of T_{166}, T_{266} and T_{566}. Sextupoles should be used in the two arcs to reduce the value of second order matrix terms to a tolerable degree.

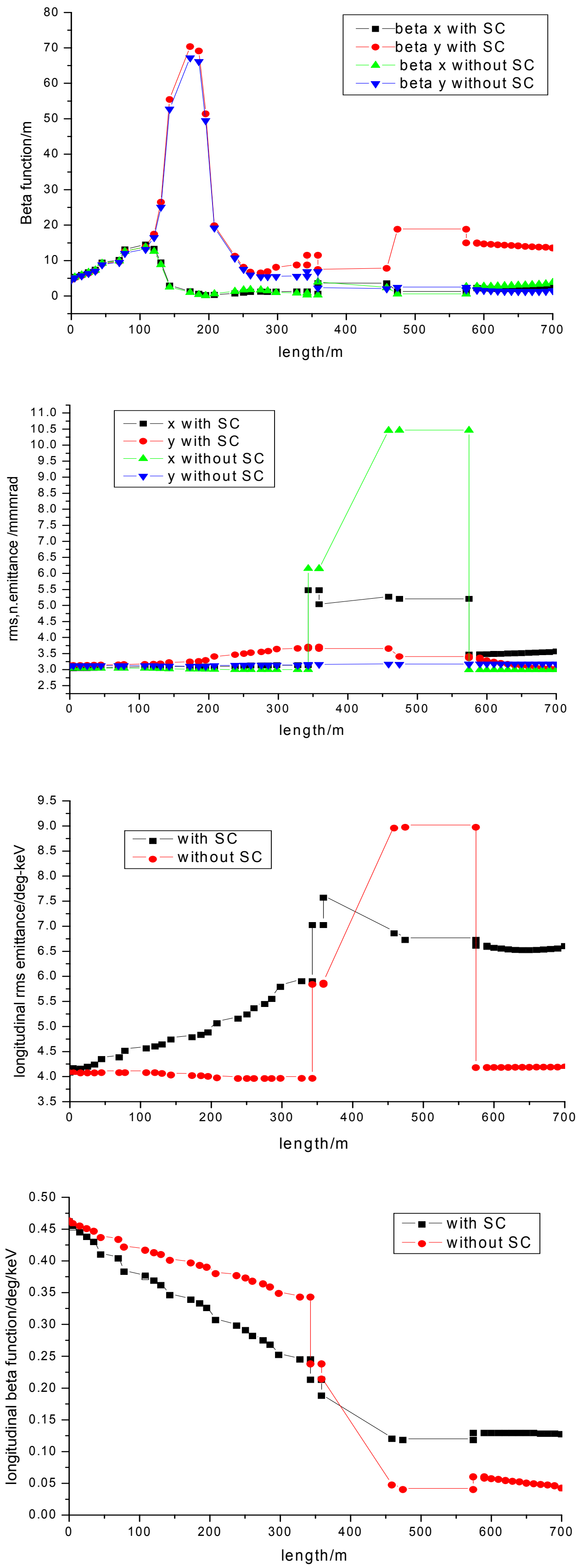

Figure 2: Beta functions and emittance from the injector to the linac

OPTICAL LAYOUT

Injector to linac

Considering the space charge, we have optimized the beam transmission with *parmela* in the injection line. Simulation has been carried out with and without space charge. The result shows that space charge takes little influence on beta function and emittance in x plane. In y plane, the emittance also doesn't change a lot but beta function changes obviously with and without space charge. Figure 2 shows the beta functions from the injector to the linac.

A waist of the transverse beta function has been made at the entrance of the linac but this requirement is not very strict. Simulation shows that the beta function does not change a lot in the exit of the accelerator when the waist is at different positions around the entrance of the linac.

Arc1 to arc2

In the first arc the beta function is symmetric but in the second arc is not. The beta function in x plane makes a waist in the middle of the undulator and keeps small within the undulator for higher radiation power gain. The energy spread is 0.24% (rms) at the entrance of the undulator which fulfills the requirement of lasing. The emittance and energy spread will increase greatly after undulator. We assume that the second arc has an acceptance of 30μm in emittance and 7% full width in energy spread according to the experiences of Jlab and JAERI [7]. The radius of beam envelope is up to 3.5cm in the outer quadrupole of the second arc due to this increase

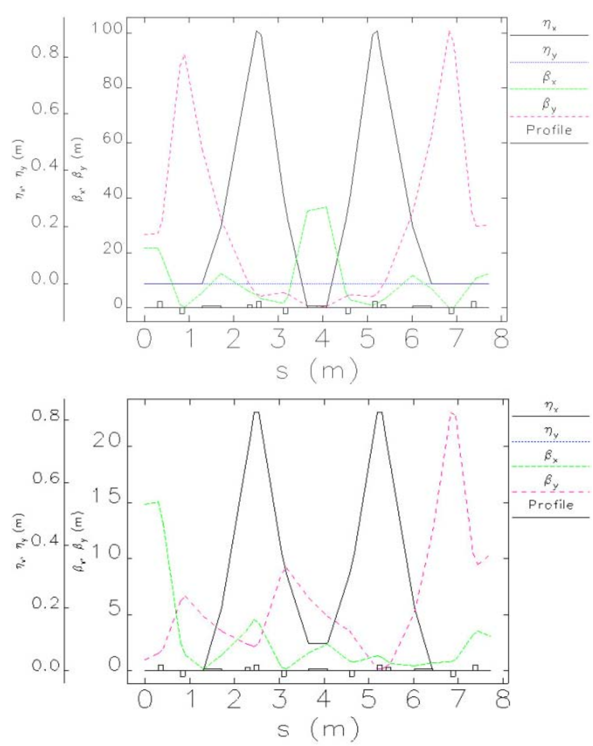

Figure 3: Twiss parameters in the two arcs (Top one is the first arc and bottom one is the second arc)

of emittance and energy spread. The diameter of the aperture of this quadrupole should be ~10cm for completely acceptance of the beam. Figure 3 shows the beta function and the dispersion in the two arcs.

CSR effect is taken into account from the first arc to the second arc in our simulation and it takes little influence on the emittance of the beam.

The second order matrix terms of T_{166} , T_{266} and T_{566} are decreased by using sextupoles in the two arcs. T_{166} and T_{266} are less than 0.02m and T_{566} is less than 1m after optimization.

Arc2 to linac and dump

The beta function of this section is well behaved in our design. The beta function of the beam from the second arc is adjusted by four quadrupoles and goes through the linac. After extraction it goes to the dump and the envelope is controlled well by three quadrupoles.

SUMMARY

The preliminary optical design of the PKU-ERL-FEL is carried out and the beta function of whole loop has been obtained. The result will be checked by further careful simulation with different particle tracking codes before the construction of the beam line of the PKU-ERL-FEL.

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