OPTICS LAYOUT FOR THE ERL TEST FACILITY AT PEKING UNIVERSITY*

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Abstract

An ERL test facility will be built at Peking University, which incorporates the compact DC-SRF photo- injector, a superconducting module composed of two 9-cell TESLA-type cavities and a high average power IR FEL oscillator. Physical design of the test facility has been updated according to the expected characteristics of the DC-SRF photo-injector and accelerating module. In this work we will describe the physical issues in detail, especially the latest optics for the facility.

INTRODUCTION

An ERL (Energy Recovery Linac) test facility is under construction at Peking University, with the primary goals to study energy recovery, to demonstrate ERL-based FEL, and to develop the related technologies for ERL, especially those technologies on superconducting photo-injector and superconducting accelerator.

The test facility incorporates the compact DC-SRF photo-injector [1], a superconducting linac composed of two 9-cell TESLA-type cavities and a high average power IR FEL oscillator. The DC-SRF photo-injector, which integrates a DC pierce gun and a 3.5-cell superconducting RF cavity, was designed to produce 6 MeV electron beams with bunch charge of 60 pC, repetition rate of 26 MHz and normalized emittance less than 2 mm-mrad. At present, the DC-SRF photo-injector and 2K cryogenic system have been installed. Preliminary beam loading tests on the injector agree well with dynamics studies and indicate that it is expected to deliver electron beams with bunch charge of 60 pC, repetition rate of 26 MHz and normalized emittance better than 4 mm-mrad.

The single-pass superconducting linac will accelerate the electron beam to full energy of 30 MeV. After bunch compression to 4 ps (FWHM), the electron beam will be used to drive the IR FEL oscillator. The recirculated electron beam, after FEL interaction, is decelerated by the same linac 180 degrees out of the accelerating phase, which leads to energy recovery. Due to cost reason, the ERL test facility is designed to operate in long pulse mode, with a macro pulse length of 2 ms and repetition rate of 10 Hz.

The IR FEL oscillator is designed to lase within 5-10 um. Calculations show that out-coupled macro pulse power of hundreds watts can be achieved. FEL lasing within middle IR to THz regime is also under consideration, which may be realized by reducing the ERL full energy and using wigglers with longer period length. A list of the baseline parameters for the ERL-based IR FEL is shown in Table 1.

Table 1: Baseline Parameters for the ERL-based FEL at Peking University

Electron Beam Parameters	
Energy [MeV]	30
Energy spread, FWHM	0.32%
Bunch charge [pC]	60
Normalized emittance [mm-mrad]	4
Bunch length, FWHM [ps]	4
Micro pulse repetition rate [MHz]	26
Macro pulse length [ms]	2
Macro pulse repetition rate [Hz]	10
Wiggler Parameters	
Period length [cm]	3
Gap [mm]	12 (21)
Kw, rms	1.14 (0.41)
Number of wiggler periods	40
Beta function @ wig centre, horiz. [m]	0.346
Beta function @ wig centre, vert. [m]	0.245 (0.677)
Alpha @ wiggler centre, horiz.	0
Alpha @ wiggler centre, vert.	0
Optical Cavity Parameters	
Cavity length [m]	11.5305
Rayleigh range [m]	0.8
Mirror radius of curvature [m]	5.876
g1.g2	0.93
Extraneous loss	2%
Out-coupling	8% (1%)
FEL Parameters	
Wavelength [um]	10.03 (5.1)
Gain	0.30 (0.10)
Out-coupled peak power [MW]	2.12 (0.97)
Out-coupled macro pulse avg power [W]	220.7 (101.2)
Out-coupled avg power [W]	4.4 (2.0)
Intra-cavity peak power [MW]	26.53 (97.31)
Intra-cavity avg power [W]	55.2 (202.4)

*Work supported by National Basic Research Program of China (2011CB808304).

ISBN 978-3-95450-145-8

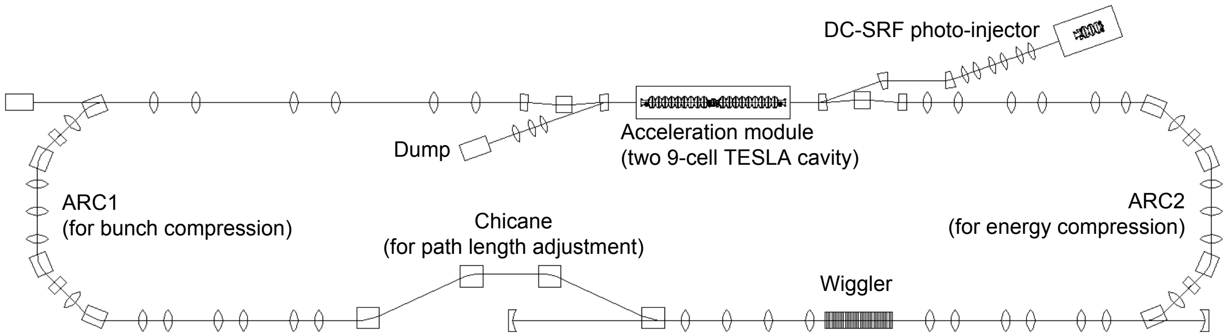

Figure 1: Optics for the ERL test facility at Peking University.

OPTICS FOR THE ERL TEST FACILITY

Shown in Figure 1 is a schematic layout of the overall optics for the ERL test facility, which is essentially a revision of [2]. The building to host the facility and the layout of the LHe transfer pipes pose stringent constraints to the optics of the ERL test facility. The distance between south straight section and north straight section is 4 m and the return arc is very close to the shielding wall, which leads to very compact arcs. The FEL oscillator is placed opposite the linac for both cost consideration and space limitation. A 4-dipole chicane is used for path length adjustment, while the outward arc (ARC1) is used to compensate R56 for optimized bunch compression of electron beam in FEL operation. The return arc (ARC2), which has a similar optics layout as ARC1, is used for bunch decompression and energy spread compression of electron beam after FEL interaction. Optics design were performed with MAD8 [3]. At full energy of 30 MeV, analytical calculation and ASTRA [4] tracking show that space charge effect can be neglected.

Injection

The injection line, which transports electron beam from the DC-SRF injector into ERL beam line, consists of three doublets and a 3-dipole achromatic dog-leg. The injection angle is chosen to be 20 degrees due to space limitations. The three doublets are used to match electron beam into the linac, which allow variation of injector parameters. Beta functions and dispersion through the injection line are shown in Figure 2.

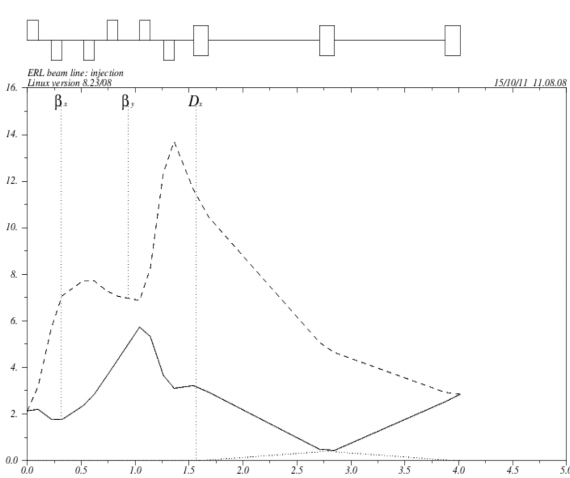

Figure 2: Beta functions and dispersion through the injection line.

Chicane

The 4-dipole chicane is used for path length adjustment. By tuning the bending angles of dipoles between 24.4 and 25.6 degrees, the path length can be changed by 3.74 cm, corresponding to an RF phase change of about 60 degrees. The according R56 of the chicane is between -0.785 and -0.883 m. During the path length adjusting, Twiss parameter does not change much, as shown in Figure 3. Path length adjustment outside this tuning range can be realized by moving the second and third dipoles towards/against each other.

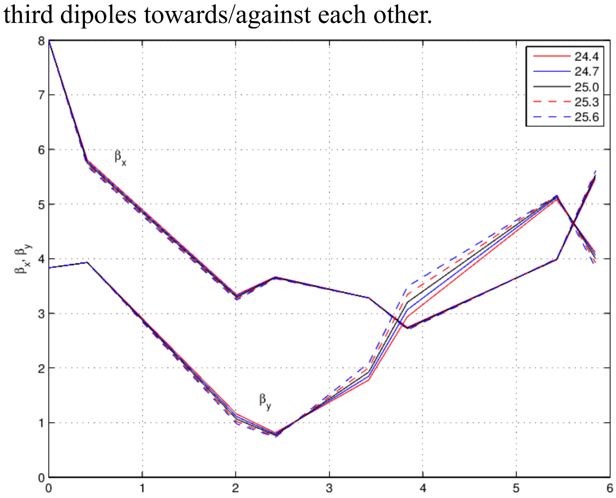

Figure 3: Beta functions through the chicane for different bending angles.

Arcs

The outward arc (ARC1) and return arc (ARC2) have similar optics layout; each consists of four 45-degree rectangular dipoles, three sets of quadrupoles for R56 adjustment and two sextupoles for T566 adjustment. When adjusting the path length of electron beam with the chicane, R56 of the outward arc is tuned accordingly for optimized bunch compression. With this arc design,

ISBN 978-3-95450-145-8

quadrupole strength does not change much during the R56 tuning when path length is adjusted by about 6 cm (corresponding to an RF phase change of about 90 degrees), which diminishes the effects exerted on transverse phase space by the longitudinal phase space tuning. To compensate R56 from the chicane for optimized bunch compression of electron beam in FEL operation, R56 of the outward arc will be tuned between 0.25 and 0.37 m. The optics is accordingly optimized so that beta functions do not change much at the arc exit for different R56s, as shown in Figure 4. R56 of the return arc is 0.525 m, which makes the entire transport approximately isochronous.

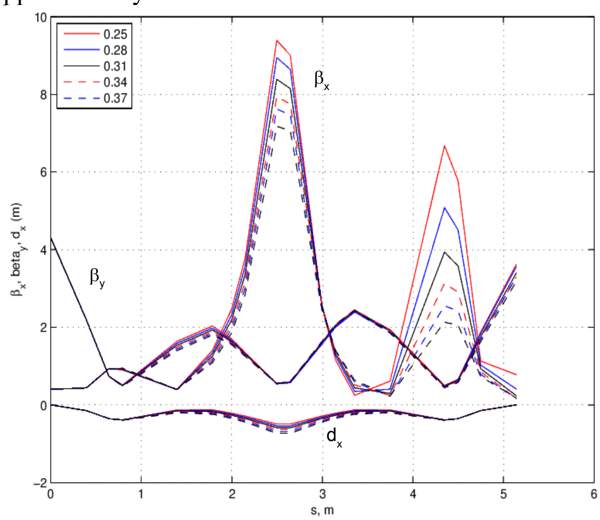

Figure 4: Beta functions and dispersion through the outward arc (ARC1) for different R56s.

Matching Optics

The transfer line from the linac to the outward arc composes a symmetric extraction chicane and a straight section of about 7.5 m long, on which are located three doublets for electron beam matching into the outward arc. The extraction chicane consists of three dipoles; on both ends are sector bends, while in between is a rectangular bend.

The transfer line from the outward arc to the 4-dipole chicane consists of three doublets for electron beam matching into the chicane and beam envelop controlling. The transfer line from the chicane to the wiggler consists of four quadrupoles, which are used to optimize the transverse phase space of electron beam for FEL operation.

The transfer line from the wiggler exit to the return arc consists of three doublets, which are used to match the electron beam after FEL interaction into the return arc and control the beam envelop.

The transfer line from the return arc to the linac is very similar to that from the linac to the outward arc. It comprises three doublets for electron beam matching into the linac and a symmetric 3-dipole chicane with sector bend at both ends and rectangular bend in between.

The overall beta functions and dispersion for the test facility are shown in Figure 5.

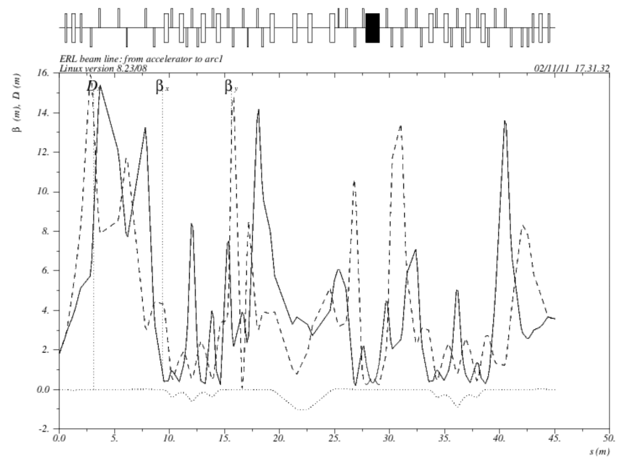

Figure 5: Beta functions and dispersion for the ERL test facility. Bending angle of the chicane dipoles is 25 degrees; R56 of ARC1 is 0.308 m, R56 of ARC2 is 0.525 m, R56 of the chicane is -0.833 m.

SUMMARY

The optics design for the ERL test facility at Peking University has been updated according to the expected characteristics of DC-SRF photo-injector and accelerating module. The constraints to optics from the building to host the ERL test facility and the layout of LHe transfer pipes have been taken into account in the design.

As a test facility, the optics design gives as much flexibility for ERL and ERL-based FEL experiments as possible.

Study on beam dynamics is on-going. Further optimization of operation parameters for DC-SRF injector will be performed to improve the characteristics of the electron beam, especially to lower the transverse and longitudinal emittance.

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ISBN 978-3-95450-145-8