Design study on the merger for BXERL-FEL

ZHU Xiong-Wei(朱雄伟)[1)] WANG Shu-Hong(王书鸿) CHEN Sen-Yu(陈森玉)

(Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China)

Abstract In North China, there is a preliminary proposal for ERL-FEL light source (BXERL-FEL) with its aim at "one machine, two purposes" (the XFEL and ERL work simultaneously). One of the key technologies is the merger section. In this paper, we give the physical design of the merger section for BXERL-FEL which merges three kinds of electron beam.

Key words ERL, XFEL, merger

PACS 29.20.Ej, 41.60.Ap, 41.60.Cr

1 Introduction

ERL and XFEL are the competitive candidates for the fourth generation light source. They are complementary to each other, and can not be replaced by each other. The peak brilliance of XFEL is several orders larger than that of the peak brilliance of ERL, their average brilliances are comparable, but ERL can recover the energy at the efficiency of 99.9%, and can support many experiments simultaneously. There are three XFEL facilities under construction: LCLS at SLAC[1], EUXFEL at Europe[2], and the Spring-8 joint project for XFEL in Japan[3]. But ERL is just in the phase of principle proof. There are many ERL test facilities[4] in the world. Recently in North China, there is a preliminary proposal for ERL-FEL light source (BXERL-FEL)[5] with its aim at "one machine, two purposes" (the XFEL and ERL work simultaneously), as shown in Fig. 1. The most challenging task in the accelerator design is to meet the requirements of extremely high peak current (about 4 kA) beam for XFEL while simultaneously transporting and accelerating very high quality and high average current (100 mA) beam to the energy recovery loop.

A generic one-loop ERL has a gun system, a merger, a linac, a loop and, finally, a dump. In all cases, an ERL should preserve the high brightness electron beams generated at the gun through the entire process of acceleration, merging and transportation to the place of the use. Only after the use, the preservation of beam quality becomes less important, unless it affects the energy recovery and lossless transportation to the dump.

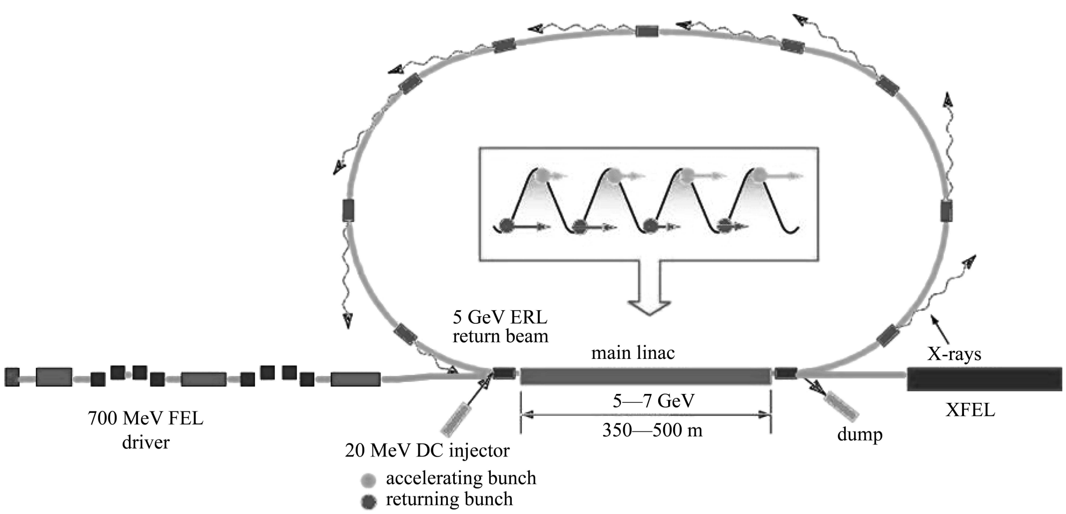

Fig. 1. Schematic layout of the BXERL-FEL.

Received 11 November 2008

1) E-mail: zhuxw@ihep.ac.cn

In the proposal of BXERL-FEL, the merger section should merge three kinds of beam: the FEL beam, the ERL return beam and the ERL injector beam. In this paper, we give the design study of the merger section for BXERL-FEL.

2 Principle of merger

A merger, i.e. a system merging different energy beams, is an intrinsic part of any ERL loop located between the gun and the main linac. Due to the different energy, the trajecories of the high energy and low energy are bent on different angles in the same bend (as shown in Fig. 2, hence leading to the combination of the different energy beams. The main difficulty is the limited space to lay the magnets when merging more beams. The case is more difficult if involving the space charge effect. There are many kinds of merging systems. The main requirement of a merging system is that the beam preserves its emittance going through the merger.

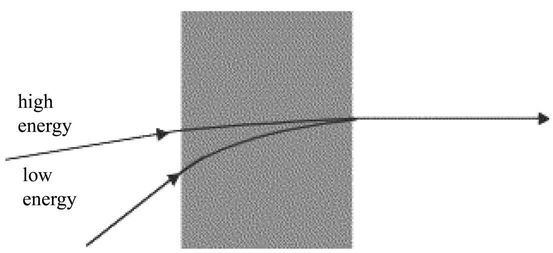

Fig. 2. The principle of the merger.

3 Basic setup of the merger section

The basic setup of the merger is shown in Fig. 3. The merger merges three kinds of electron beam: the 20 MeV electron beam from the DC photocathode injector, the 700 MeV electron beam from the FEL injector driver and the returning 5 GeV ERL beam. According to the energy difference, their bending angles ratio in the merging bend B is 35:1:0.14. The FEL injector driver includes the photoinjector, two bunch compressors and the linac sections. The initial bunch from the photocathode RF gun (the bunch length is 20 ps (FWHM)) is compressed about 100 times to be 100 fs (rms). The 100 fs FEL bunch is dominated by the Coherent Synchrotron Radiation (CSR) effect in the bend, the bending angle in B for FEL bunch is chosen to be 0.4 degree to preserve the beam emittance. So the bending angles for the DC injector beam and the ERL return beam are 14 degrees and 0.056 degree, respectively. The energy of DC injector is set to 20 MeV to make the bending angle small. B1, B2, B3, B construct an acromatic system providing the de-coupling between longitudinal and transverse motions and form a zig-zag path to restrain the space charge effect. The bending angles of B1, B are 0.4 degree, while the bending angles of B2, B3 are 0.6 degree. B4, B5, B are just a chicane and also an acromatic system, their bending angles are 0.056, 0.112, 0.056 degree respectively. B6, B plus three quadrupoles form an acromatic system too, their bending angles are 14 degrees. Due to the small bending angle, the beamlines for FEL driver beam and ERL return beam are very close to each other, and the maximum distance between them is about 7 cm. So we lay the bend alternately at the longitudinal position in order that they don't interfere transversely. We can design a single vacumm box. for these two beams (FEL beam and ERL return beam) and adopt the C type magnet. Because the energy of the FEL beam is lower than that of the ERL return beam, we just consider the B4, B5's effect on the FEL beam which can be negligible.

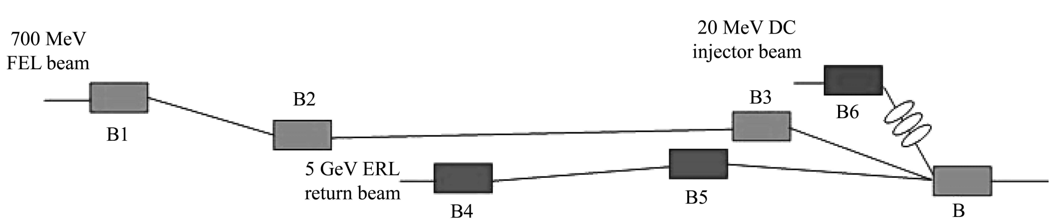

Fig. 3. The schemetic setup of the merger.

4 Lattice parameters

The length of all the bends is 0.2 m. The parameters of the magnets are summaried in Table 1.

The lattice functions for the FEL beam, the ERL return beam, the DC injector beam are shown in Fig. 4, Fig. 5 and Fig. 6, respectively. The total lengths of them are 62.4 m, 22.6 m and 5 m respectively.

Table 1. The parameters of the magnets.

magnet	length/m	field/T	good field area/mm	gap/mm
B1	0.2	0.061	30	5
B2	0.2	0.102	30	5
B3	0.2	0.102	30	5
B4	0.2	0.061	30	5
B5	0.2	0.122	30	5
B6	0.2	0.061	30	5
B	0.2	0.061	30	5

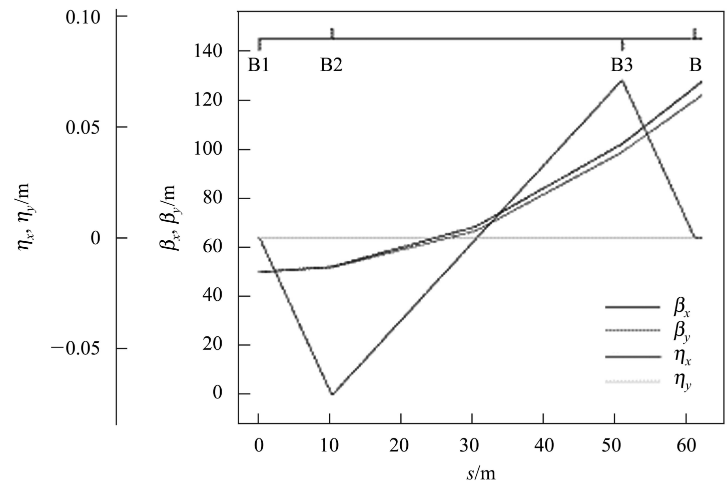

Fig. 4. The FEL merger lattice function.

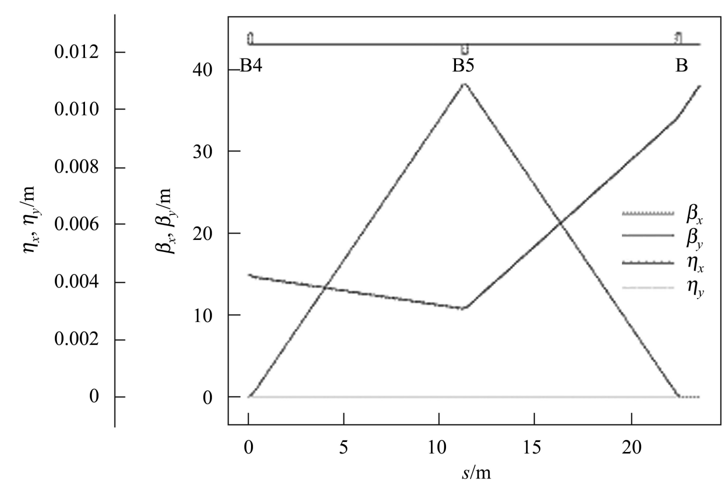

Fig. 5. The ERL return merger lattice function.

5 Tracking simulation result

We have performed the tracking simulation for the merger to calculate the emittance dilution. The code is ELEGANT[6] which includes the 1D CSR effect and space charge effect.

The FEL beam parameters before the merger are the energy of 700 MeV, the bunch length of 100 fs, the normalized emittance of 1 mm mrad, the energy spread of 0.5%, and the charge of 1nC. The normalized emittance dilutes about 0.4 mm mrad in the merger, and the emittance evolution curve is shown in Fig. 7. The slice emittance remains almost unchangeable. For FEL, what we want is the slice emittance.

The parameters of ERL returned beam are the energy of 5 GeV, the bunch length of 2 ps, the normalized emittance of 1 mm mrad, the energy spread of 0.2%, and the charge of 77 pC. The normalized emittance dilutes about 0.002 mm mrad, and the emittance evolution curve is shown in Fig. 8.

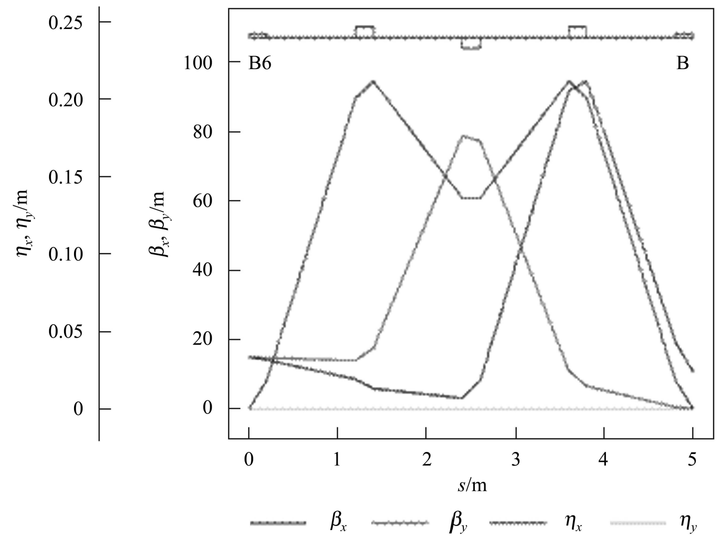

Fig. 6. The DC injector merger lattice function.

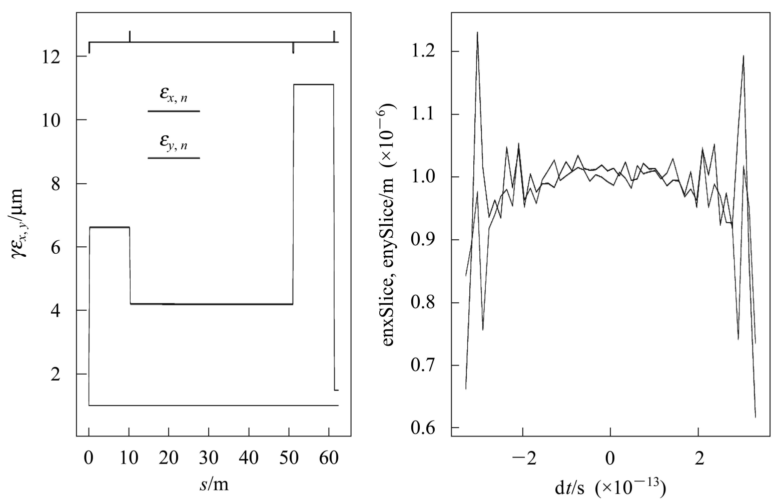

Fig. 7. The emittance evolution of the FEL beam and the slice emittance distribution at the exit.

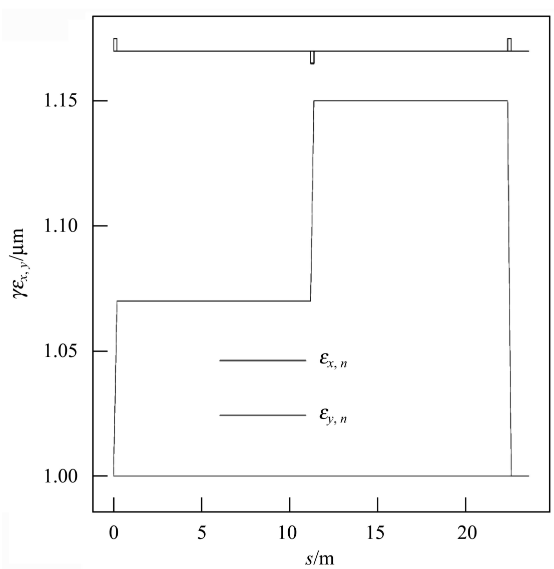

Fig. 8. The emittance evolution of the ERL return beam.

The parameters of the DC injector beam are the energy of 20 MeV, the bunch length of 2 ps, the normalized emittnace of 1 mm mrad, the energy spread of 0.2%, and the charge of 77 pC. The normalized emittance dilutes about 0.01 mm mrad. The emittance evolution curve is shown in Fig. 9.

In our layout, the FEL driver finishes the full two cascading compressing before the bunch enters the merger. Due to the CSR effect, the bending angle of the 100 fs FEL bunch is at the level of about 0.5 degree to make the merger design difficult. Another idea is that the FEL driver finishes only one compressing before the bunch enters the merger. The other bunch compressor is placed in the main linac of ERL. This idea makes the merger design easier (the bunch is relatively long), but the beam dynamics in the main linac is more complex. Our choice doesn't have much effect on the main linac beam dynamics of ERL.

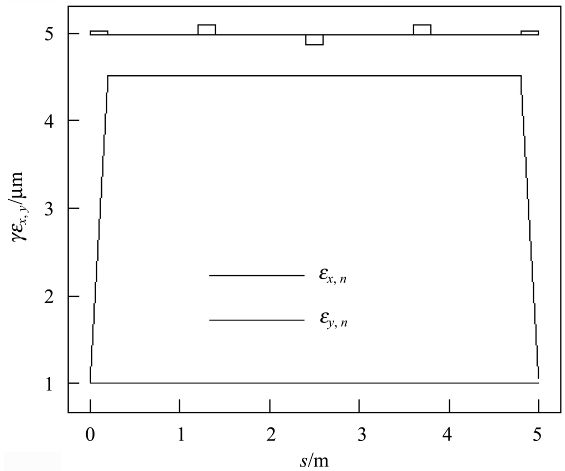

Fig. 9. The emittance evolution of the DC injector beam.

6 Discussions and conclusions

There are two types of candidates for the 4th generation light source. One is the X-ray free electron laser (XFEL)[1] based on an advanced electron linac. The peak brilliance of XFEL is unprecedented (about 10 orders larger over 3rd light source), and the optics pulse length is at the level of 100 fs which makes the ultrafast process research possible. The other one is the Energy Recovery Linac (ERL) based on an advanced electron linac and one recovery loop for a partially transverse coherent electron beam. The most important advantages of the ERL are that it can use the power source economically and provides more than 30 photo beam lines simultaneously for the users and the optical pulse length of ERL is at the level of ps. XFEL and ERL are complementary to each other and can't be replaced by each other.

In our proposal, we use the common SC linac for the XFEL and ERL simultaneously. One of the key parts of our proposal is the merger section. Because the energy spread compensation section after the last bunch compressor is very long, it is better for the FEL beam to finish the compressing before it enters the main linac so that the length of the common section is maximum. The bending angle for 100 fs FEL beam is at the level of 0.5 degree which makes the space crowded for the layout of the merger bends,.We have calculated the bend geometry position carefully. The result shows that the bends and the vacuum box don't interfere, they can coexist. Finally, we also simulate the effect of one beamline related bends on the other beam, the interaction effect can be omitted. So our merger scheme is one of the merger solutions for our proposal.

References

1 Linac Coherent Light Source (LCLS) Design Report, SLAC-R-59. 2002
2 TESLA Technical Design Report. 2001
3 SCSS XFEL Conceptual Design Report. 2005
4 Merminga L. Energy Recovery Linacs. PAC. 2007
5 CHEN Sen-Yu et al. A Proposal for BXERL-FEL. 2008
6 Borland M. Advanced Photon Source LS-287. 2000