LATTICE DESIGN FOR ERL OPTIONS AT SLAC*

Y. Nosochkov†, Y. Cai, X. Huang, M.-H. Wang
SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

Abstract

SLAC is investigating long-range options for building a high performance light source machine while reusing the existing linac and PEP-II tunnels. One previously studied option is the PEP-X low emittance storage ring. The alternative option is based on a superconducting Energy Recovery Linac (ERL) and the PEP-X design. The ERL advantages are the low beam emittance, short bunch length and small energy spread leading to better qualities of the X-ray beams. Two ERL configurations differed by the location of the linac have been studied. Details of the lattice design and the results of beam transport simulations with the coherent synchrotron radiation effects are presented.

INTRODUCTION

In a new era of free electron lasers (FEL) such as the Linear Coherent Light Source (LCLS) [1], what may be the future for the traditional light sources based on electron storage rings? One option is the so-called ultimate storage ring [2] which requires the ring technology to be pushed to its limits. The "ultimate" implies reaching the ceiling of brightness at $10^{23}(ph/s/mm^2/mrad^2/0.1\%)$ due to the diffraction limit of one $\AA$ wavelength light spontaneously radiated by electrons in an undulator. Another option is to employ an energy recovery linac (ERL). The same diffraction limit applies to the ERL since it also relies on the spontaneous undulator radiation. However, as a linac based technology, similar to FEL, ERL can provide a much smaller longitudinal emittance than a storage ring and therefore much shorter bunches with narrower energy spread. For this reason, the ERL option may provide us an effective path toward the future of the light sources.

In this paper, we assume that an injector, similar to the one under development at Cornell, is available, and describe two ERL configurations based on reusing the existing SLAC tunnels and the low emittance lattice of the proposed PEP-X ring [3]. We choose the beam injection energy of 150 MeV and perform beam transport simulations with the coherent synchrotron radiation (CSR) for parameter options as in the Cornell study [4] listed in Table 1. The lattice design is optimized for a low emittance growth of $\Delta(\gamma\epsilon) \ll 0.08$ μm-rad to preserve the smallest emittance in Table 1. The transport lines are also made isochronous for maintaining the bunch length and proper return beam deceleration. These designs are also discussed in [5].

* Work supported by the Department of Energy Contract DE-AC02-76SF00515.

† yuri@slac.stanford.edu

Table 1: Parameters for ERL modes with high flux (A), high coherence (B) and short pulse (C).

Mode	A	B	C
Energy, GeV	5	5	5
Bunch charge, pC	77	19	77
Norm. emittance, μm-rad	0.3	0.08	1
RMS bunch length, ps	2	2	0.1
Relative energy spread, %	0.02	0.02	0.1

LONG ERL OPTION

The essential components of an ERL are a superconducting (SC) linac with an injector and dump lines at either end, and a transport line providing undulator straights and a return path back to linac for beam disposal. In the long ERL option, the SC linac is placed in the SLAC existing linac tunnel, and the PEP-II injection tunnel is reused for transporting the beam to the PEP-X ring [3] in the PEP-II tunnel. Horizontal and vertical view of this configuration is shown in Fig. 1. The 150 MeV beam after the gun is accelerated to 5 GeV in the linac, then travels through a long bypass, the isochronous injection line, and 5/6 portion of the PEP-X ring where the undulator straights are located. After that the spent beam is returned back to the linac through the isochronous extraction and loop lines for deceleration to 150 MeV and disposal at the dump.

The linac will share the accelerated and decelerated beams where the two beam energies will differ up to a factor of 33.3 at each end of linac. The 371 m linac consists of 16 FODO cells with eight 1 m long cavities per half-cell. The net accelerating gradient is 18.945 MV/m and the RF frequency is 1.3 GHz. The β functions, shown in Fig. 2,

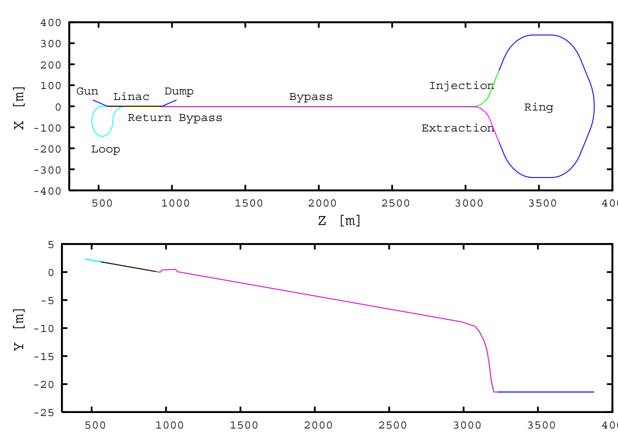

Figure 1: X and Y view of the long ERL configuration.

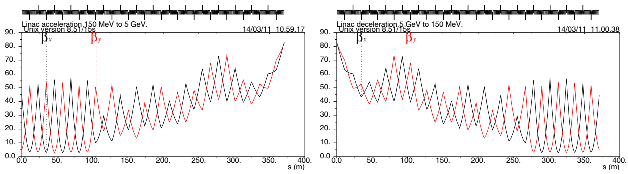

Figure 2: Linac β functions for accelerated (left) and decelerated (right) beams.

are optimized for both beams to avoid high β peaks due to energy difference. They tend to be mirror symmetric for the two beams due to symmetry of the beam energies.

The bypass and injection lines are based on the existing lines in the PEP-II tunnel. The latter has a complicated 3-dimensional geometry with magnet rotations and local coupling. The new lattice is designed to have a very similar geometry, while providing low emittance and isochronous transport. Normalized emittance growth due to incoherent synchrotron radiation (ISR) in the new lattice is reduced from the existing 0.1 μm-rad to 0.007 μm-rad, and the existing $R_{56} = 875$ mm is canceled. The new injection cells in bending regions are similar to the one shown in Fig. 3.

The PEP-X ring is described in detail in [3]. For ERL, the ring damping wigglers and RF cavities are turned off. The ERL extraction line is made almost identical to the injection line providing the same low emittance isochronous properties. The final 263 m turnaround loop consists of 24 isochronous achromatic cells shown in Fig. 3. Due to the optimal cell phase advance, the chromatic W-functions and 2nd order dispersion are canceled in every three loop cells. The ISR emittance growth in the loop is $\Delta(\gamma\epsilon) = 0.05$ μm-rad which should be adequate for the return beam.

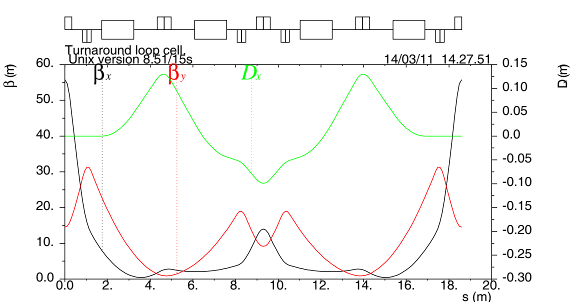

Figure 3: Isochronous and achromatic loop cell.

SHORT ERL OPTION

The second, shorter, ERL configuration has the injector and the SC linac inside the inner area circled by the PEP-X ring as shown in Fig. 4. The same linac design is used here as in the long ERL option for the same beam energy from 150 MeV to 5 GeV. As shown in Fig. 4, the ring injection section, two nearby TME arcs and part of straight sections outside these TME arcs are excluded from the ERL line. The ring modifications include two new 60° bending arcs connecting the linac with the ring. Design of these arcs was optimized for minimal emittance and energy spread growth. The new connecting arc is a factor of 2 shorter

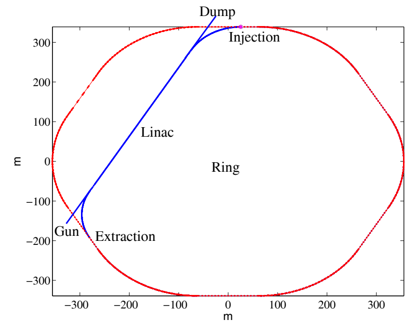

Figure 4: Layout for the short ERL configuration.

than the nominal 60° TME arc. Using the TME arc as a starting point, the dipole length and drift space in the new arc were reduced by half. This also reduced the bend radius by half. As a result, the emittance growth due to ISR in this short arc is about the same as in the nominal TME arc. The expected normalized emittance growth due to ISR for the complete ERL line is very small $\sim$1 nm-rad.

TRACKING SIMULATIONS

Parameters for three ERL operational modes considered in the tracking study are listed in Table 1. The A, B and C modes are targeted for high flux, high coherence and short-pulse, respectively. In the Elegant [6] tracking model, each dipole is represented by 20 kicks, and the number of bins for line density calculation is 600. CSR effects in drifts that follow dipoles are also modeled, with an evaluation step size of 5 cm. The number of macro-particles is 400,000. Tracking study was carried out for both ERL options, however, below we only present results for the long ERL option since the other option shows similar behavior. Results for mode B are not shown because it has much smaller CSR effect than mode A.

The initial distribution at 5 GeV is obtained by tracking a corresponding Gaussian beam through the linac. The longitudinal distributions at the end of the linac are shown in Fig. 5. The beam then goes through the injection transport line, the ring, the extraction line, the turnaround loop and finally comes back to the start of the linac. The energy losses in the injection line and the ring are shown in Fig. 6. The ratio of CSR to ISR energy loss is 10% for mode A and 500% for mode C.

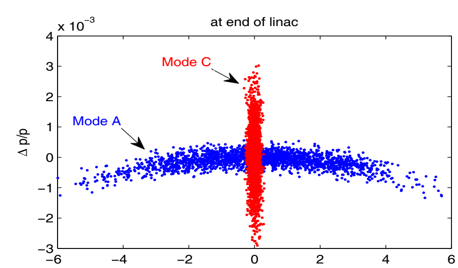

Figure 5: Longitudinal spread at end of the linac for modes A and C.

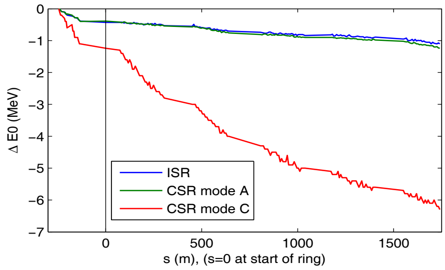

Figure 6: ISR and CSR energy loss in modes A and C.

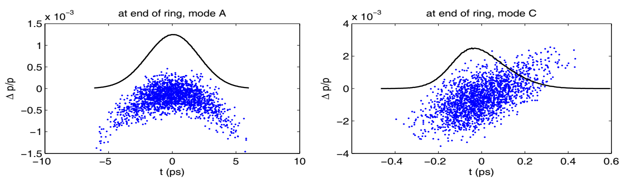

Figure 7: Longitudinal distributions for modes A and C at exit of the PEP-X ring. The line density is in arbitrary unit.

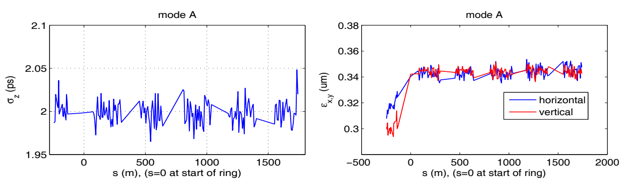

Figure 8: Bunch length and emittance for mode A.

At exit of the ring, the longitudinal distributions are shown in Fig. 7. It is noted that the distribution for mode A is almost identical to its initial distribution. Yet the distribution for mode C is stretched along the z-direction because of the large energy spread and non-zero phase slippage factor. The evolution of emittance and bunch length are shown in Fig. 8 and 9. The emittance is increased for both horizontal and vertical planes in the 3-dimensional injection

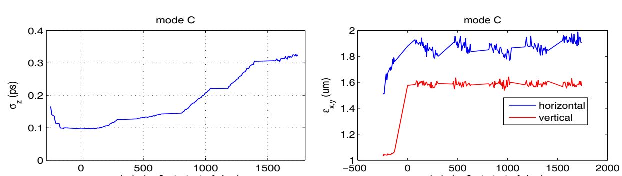

Figure 9: Bunch length and emittance for mode C.

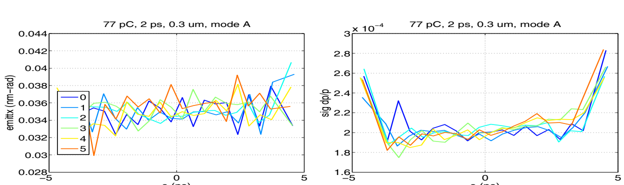

Figure 10: Slice emittance and energy spread for mode A. Points 0 and 5 are at ring entrance and exit.

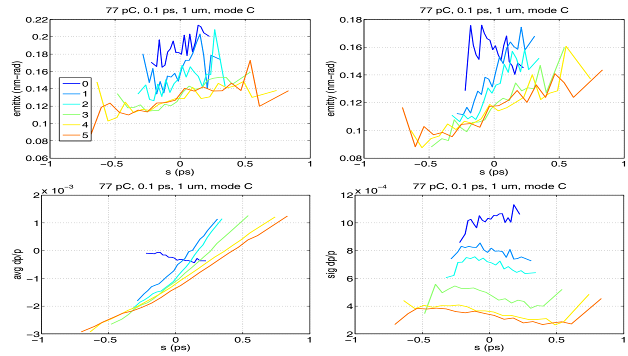

Figure 11: Slice X and Y emittance, average and rms energy spread for mode C.

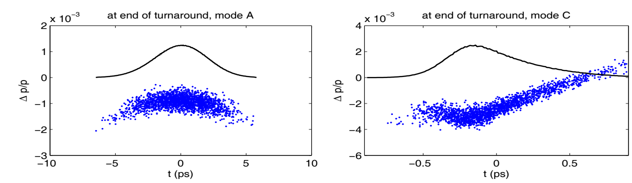

Figure 12: Longitudinal spread for modes A and C at the end of the turnaround loop. Line density is in arbitrary unit.

transport line.

We also calculated slice emittance at center of ring long straight sections as shown in Fig. 10 and 11. There is no emittance or energy spread growth in the ring for mode A. But there are significant changes for mode C due to the beam longitudinal motion. At end of the turnaround loop the longitudinal spread is shown in Fig. 12. The total energy loss in the loop is 2.5 MeV for mode A and 4.0 MeV for mode C, compared to ISR energy loss of 2.4 MeV.

SUMMARY

Aside from the injector, the geometry and lattice for the two ERL configurations, including superconducting linac and fitting to the SLAC tunnels, have been developed. Tracking simulations performed for the operating modes in Table 1 show that the emittance can be preserved for the modes A and B. For the short bunch mode C, the growth of emittance is significant due to the CSR effect. A reduction of its bunch charge or further optimization may be necessary.

REFERENCES

[1] P. Emma et al., http://www.nature.com/nphoton/journal/vaop/ncurrent/abs/nphoton.2010.176.html.
[2] M. Bei et al., Nucl.Instrum.Meth. A622, 518-535 (2010).
[3] K. Bane et al., SLAC-PUB-13999 (2010).
[4] D. H. Bilderback et al., Synchrotron Radiation News, V.23, No.6 (2010).
[5] R. Hettel et al., "Status of the PEP-X Light Source Design Study," this Conference.
[6] M. Borland, APS Report No. LS-287 (2000).