CORNELL ENERGY RECOVERY LINAC LATTICE AND LAYOUT*

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Abstract

The current status of the lattice and layout for the proposed Cornell Energy Recovery Linac lightsource is presented. This design is centered about a new hard X-ray user facility to be located on Cornell's campus, and is adapted to the local topography in order to incorporate the existing CESR tunnel and Wilson Laboratory. Nonlinear charged-particle optics for this new machine have been designed and analyzed. The lattice is populated with various components for the appropriate accelerator physics requirements for orbit, bunch length, and emittance growth control, including a vacuum system compatible with rest-gas-scattering limits, a collimation system for halo from effects like Touschek scattering, and correction coils and BPMs for sub-micron beam stabilization. We also show calculations for an additional bunch compression mode, which compresses 19 pC bunches at a 1.3 GHz repetition rate to 25 fs.

OVERVIEW

Cornell University plans to build an Energy Recovery Linac (ERL) based hard X-ray lightsource, and is in the final preparation of a Project Definition Design Report. Table 1 shows the bunch operation modes for this machine. This paper highlights some of the current progress in designing and simulating the ERL using the *Bmad* software libraries along with the interactive *Tao* simulation tool [1].

LAYOUT

Figure 1 shows the AutoCAD layout for this proposed machine, along with section labels and X-ray beamline locations. Since our last report in Ref. [2], there have been a number of notable changes which were made in a value engineering process under the consultation of an architecture firm, a underground construction advisory board, a company for cryogenic systems and a company providing cost estimate for the beam transport systems:

- The injector and undulators 1–6 and 10–14 are housed in a single new building
- The tunnel enclosing TA and TB has a 40 m radius
- LB shines directly into undulator 1
- Space for a second injector is provided

Additionally, the following sections have been added:

Table 1: Bunch properties for two primary bunch operation modes in the Cornell ERL. The injection energy is 15 MeV, and all SA and NA undulators receive the 5 GeV beam. All modes operate at a 1.3 GHz bunch repetition rate.

	Mode A *Flux*	Mode B *Coherence*	
Bunch Charge	77	19	pC
Average Current	100	25	mA
Injection			
ϵ_x, ϵ_y	31	8	pm
σ_z/c	2	2	ps
σ_δ	2	2	10^{-4}
SA Undulators			
ϵ_x	32	10	pm
ϵ_y	31	8	pm
NA Undulators			
ϵ_x	54	31	pm
ϵ_y	31	8	pm
σ_δ	1.9	1.9	10^{-4}

- A diagnostic beamline DB for merger characterization
- A beam stop BS with defocusing optics
- An extracted beamline EX with a chicane bunch compressor for accelerator physics studies (see Ref.[4])

LATTICE FEATURES

To accommodate the growing complexity of our model, the lattice description has been entirely rewritten to make extensive use of the `multipass` and `superposition` control structures available in *Bmad*. While the former is critical in simulating the energy recovery process, the latter is a convenience which allows various instrumentation to be easily added to and moved around the lattice without disturbing the positioning of other elements. In this manner, vacuum chamber elements such as pump ports and sliding joints exist along with optical elements. A list of common elements along with their counts is shown in Table 2. Additionally, `branch` elements are used to add offshoot sections such as the DB and EX.

With the aid of *Tao*, the optics in this lattice have also been re-optimized for low emittance growth, controlled time of flight terms, custom beam sizes in undulators, energy recovery, bunch compression, and Touschek particle generation and collimation.

* This work has been supported by NSF grants PHY-0131508, DMR-0937466, and a grant from the Empire State Development Corporation.

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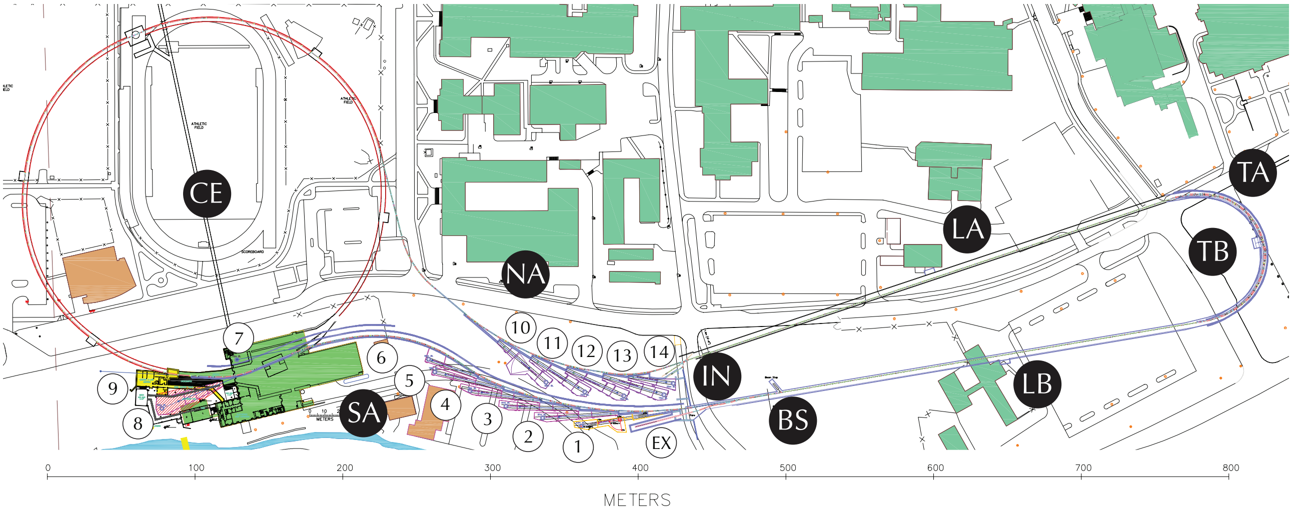

Figure 1: Layout for the proposed Cornell ERL lightsource. The circled numbers indicate X-ray beamlines and their associated undulators. Major sections are labeled with black circles. The machine operates as follows: Electron bunches are procured in the injector (IN) and merged at 15 MeV into Linac A (LA), which accelerates them to 2.7 GeV. They travel along the outer arc of Turnaround A (TA), and are introduced to Linac B, which further accelerates them to 5 GeV. After traveling trough the South Arc (SA), the CESR ring (CE), and the North Arc (NA), they are reintroduced to LA at the decelerating phase. After returning 2.7 GeV to LA, they travel along the inner Turnaround B (TB), and are further decelerated to 10 MeV, after which they are extracted and send to the beam stop (BS).

BUNCH COMPRESSION

Manipulation of the first and second order time-of-flight terms in the CE and NA sections, along with off-crest acceleration, allow bunches to be compressed in undulators 10–14. This scheme works as follows: Bunches with 1 ps durations are accelerated approximately 7° through LA and LB and enter SA at 5 GeV. The time-of-flight terms r_{56} and t_{566} are controlled throughout the CE region, which partially compresses these bunches, and the six-dipole arc just prior to undulator 10 performs the final compression to 25 fs. The achromatic arcs between the subsequent undulators each incorporate a "reverse" bend to make them isochronous and thereby maintain this short bunch length. Following undulator 14, the bunches are decompressed in a similar six-dipole arc to 1 ps, after which their energy is recovered in a second pass through LA and LB.

Table 2: Element Counts

Element Type	Count	Total Length (m)
5 m Undulator	11	55
25 m Undulator	3	75
SRF Cavity	384	310
Dipole Magnet	173	654
Quadrupole Magnet	408	207
Sextupole Magnet	109	28
Pump Port	194	20
Sliding Joint	109	11
Undulator Protector	14	14
Collimator	5	5
Ion Clearing Electrode	232	-
Corrector (X&Y pair)	255	-
BPM	311	-

The effect of Coherent Synchrotron Radiation (CSR) is critical here, and can be the limiting factor in any compression process. Our CSR simulations using *Bmad* for this bunch compression mode, as well as the modes in Table 1, are outlined in Ref. [3], and include all entrance and exit transient effects, as well as the shielding of CSR by the vacuum chamber. The resulting bunch lengths from particle tracking with CSR and shielding, CSR in free space, and no CSR are shown in Fig. 2. There we see that the shielding effect is essential in providing 25 fs bunch durations.

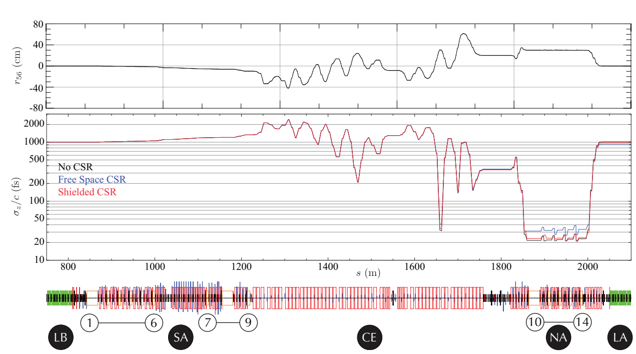

Figure 2: The bunch compression scheme for the Cornell ERL in the high energy user region.

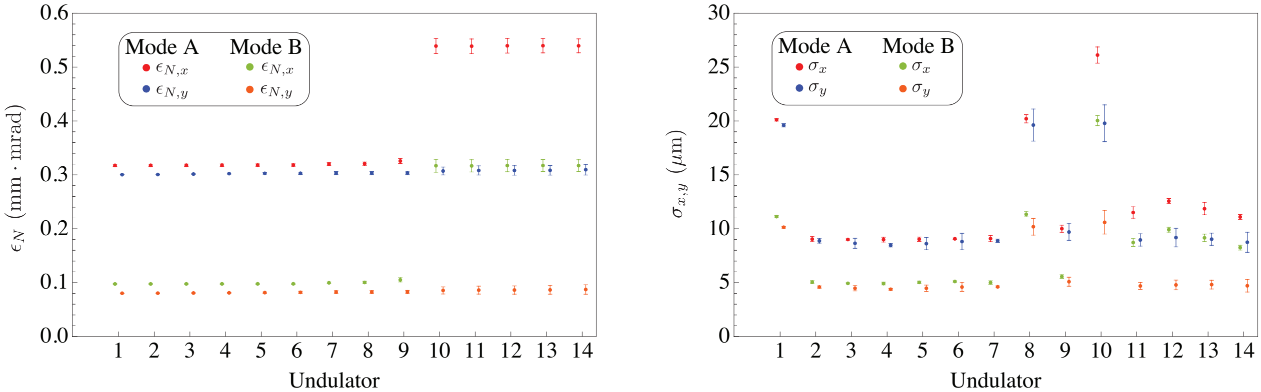

Figure 3: Averages and standard deviation error bars from 1000 independent misalignment simulations with automatic SVD orbit correction. These simulations use the following standard deviations for errors: 0.1 mm offsets for quadrupoles and cavities, 0.1 mrad cavity pitch angles, 0.1° cavity phases, 0.3 μm BPM noise, and 10^{-4} relative errors in cavity gradients, dipole chains, and quadrupole fields, Incoherent radiation losses and fluctuations are also included. The orbit itself is contained within the BPM noise.

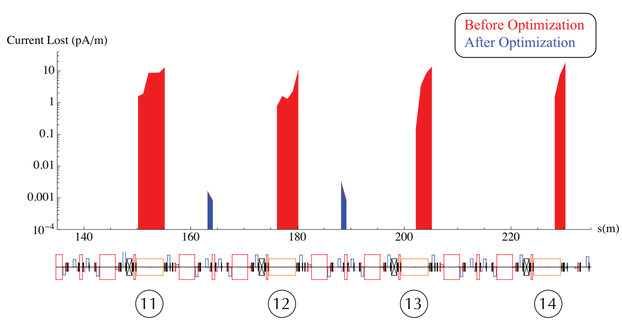

Figure 4: Touschek scattering optics optimization.

ORBIT CORRECTION

To more closely simulate a real machine, our model incorporates various misalignments and field errors for all elements. Unfortunately, may small errors can add up and cause the beam to be lost in the vacuum chamber wall, so we have implemented in *Tao* a first-turn orbit correction scheme based on Singular Value Decomposition (SVD). This works as follows: A response matrix for BPM readings due to corrector strengths is formed from the ideal design lattice. The lattice is then given various errors, and the beam is typically lost. Using only BPMs and correctors that see the beam, the appropriate pseudoinverse is built from the stored response matrix, and is then applied to these readings. This process is iterated until the beam survives the entire lattice, and a few final applications of the full pseudoinverse simultaneously minimizes weighted BPM readings and corrector strengths.

Figure 3 shows statistics for emittances and transverse bunch sizes at all undulators from 1000 independent applications of this algorithm. So far this has only been done for modes A and B, because the bunch compression mode requires a computationally intensive CSR calculation.

TOUSCHEK SCATTERING

Ideal collimator locations for Touschek scattered particles were explored in Ref. [5], but unfortunately the set of locations available to place such devices is limited. Collimators are now placed at strategic locations, but occasionally the optics need to be optimized to shift losses to these collimators. An example of this is shown in Fig. 4. We have also found that minimizing the heuristic function

$$\mathcal{G} \propto \frac{\mathcal{H}_x}{\sqrt{\sigma_x \sigma_y}}$$

tends to suppress the severity of Touschek particle orbit deviations.

OUTLOOK

A full stability analysis that incorporates the automatic SVD orbit correction algorithm is in progress, and should produce a list of acceptable error tolerances for the machine. We hope to soon incorporate space charge calculations and X-ray optics in our simulations in order to perform realistic start-to-end simulations.

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