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Progress toward an ERL Extension to CESR *

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Abstract

The status of plans for an Energy-Recovery Linac (ERL) x-ray facility at Cornell University are described. Cornell currently operates the Cornell High Energy Synchrotron Source (CHESS) at the CESR ring. The ERL is planned to be an extension to that ring by a 5-GeV superconducting c.w. linac. The very small electron-beam emittances would produce an x-ray source that is very significantly better than any existing storage-ring light source. The ERL design that is presented has to allow for non-destructive transport of these small emittances. It includes 18 x-ray beamlines for specific areas of research that are currently being defined by an international community. Special attention is given to reuse of many of the existing ring components. Here it is described which subjects are being investigated or will have to be studied at Cornell to prepare for the construction of this new hard x-ray source, references to other contributions to this conference (PAC07) demonstrate this effort. This project illustrates how other existing storage rings could be upgraded as ERL light sources with vastly improved beam qualities and with limited dark time for x-ray users. The here presented list of research topics shows R&D issues for any such upgrade project.

INTRODUCTION

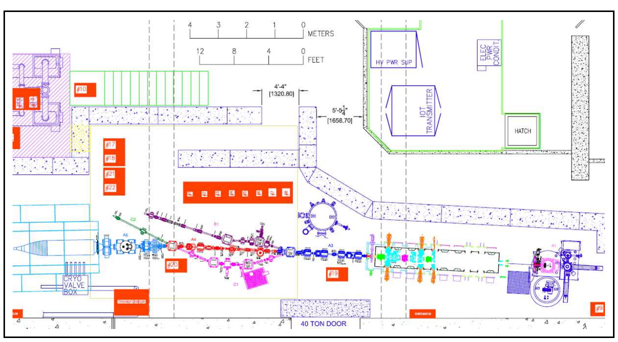

Figure 1: The injector prototype for the Cornell ERL.

The emittances in electron storage rings are determined by the optics of the ring and not by the quality of the injected beam. This is due to the stochastic nature of the emission of synchrotron photons in every bend of the ring, which randomizes the motion of electrons over many turns and makes the equilibrium beam distribution independent of the injected distribution. Linear accelerators do not suffer this emittance dilution and could thus accelerate very small emittances. Beams with emittances that are smaller than those in storage rings could then be used to produce x-ray beams of higher spectral brightness than available from today's storage ring sources.

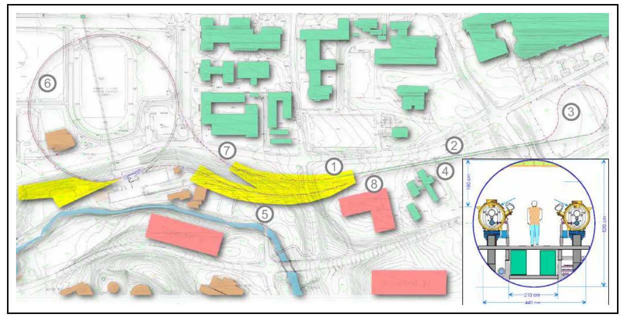

Figure 2: Layout of the planned 5GeV Cornell ERL.

Cornell University has been planning to build a hard x-ray light source based on an ERL for some time [1, 2]. To produce the small emittances needed in the undulators of such a source, a high current, low emittance injector is needed. Cornell university is currently prototyping a DC photo-emission electron source and a 10 MeV injector linac for low emittance beams of high c.w. currents [3, 4, 5, 6]. The layout of this injector is shown in Fig. 1. To the very right, the electron gun is shown, the cryomodule accelerates to the left into a set of diagnostics beamlines. A straight beamline is used for a maximum beam current of 100mA and leads to a 0.5MW beamdump, the top beamline is for smaller currents but is a prototype of the merger beamline that would lead into the main linac of the x-ray ERL. Critical subjects to be tested and optimized will be: suppression of space-charge driven emittance growth, CSR compensation in the merger, cathode materials and lifetime, possibly with a cooled cathode.

The layout of the planned 5GeV Cornell ERL is shown in Fig. 2. This design has two 2.5GeV linacs within one tunnel. An injector at (1) is very similar to the one that is currently being prototyped and would send 100mA of 2ps long bunches into the first linac. This accelerates eastward (2) to 2.5GeV, and a return loop (3) leads the beam back to the second linac (4) that accelerates westward to 5GeV. The high energy beam is then used in an arc (5) with 11 x-ray beamlines and is subsequently injected into the CESR tunnel (6) to be used in 2 more beamlines on the west side. From there, it enters a north arc (7) with 5 more x-ray beamlines. Subsequently the beam is injected back into the first linac, decelerates to 2.5GeV, is again turned around in the eastern turn around loop and finally decelerates to 10MeV to be dumped (8).

Once a c.w. linac is available for energy recovery, one could also use it in a not energy-recovered mode to pro-

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duce very short low current beams. In this design, a sub 100fs beam with 2.5GeV would be available for soft x-ray physics and accelerator development.

R&D ISSUES FOR THE CORNELL ERL

An ERL has never been operated at the proposed energy and current of 5GeV and 100mA that are needed for a hard x-ray source. A long list of R&D issues are therefore addressed at Cornell.

Cryomodule, cavity and RF control: Cornell is building the cryomodule [7], cavities [8, 9], couplers [10], and higher-order mode (HOM) absorbers for the injector prototype, many aspects of which are similar to what is needed for the ERL main linac. Furthermore, Cornell is involved in a collaboration with Daresbury, FZD Rossendorf, LBL, and Stanford to make a long-term breakdown test of two 7-cell cavities that are equipped with input couplers and waveguide HOM absorbers of the type needed for the ERL. Cornell furthermore plans to design and construct a complete main-linac cryomodule and test it with RF, and possibly with high-current beam. In a collaboration with JLAB it has already been shown that amplitude and phase stabilization at a loaded Q of 10^8 can be achieved to the required level.

Optics optimization: The optics of the ERL has to satisfy various requirements, including: (a) minimal emittance growth due to incoherent and coherent synchrotron radiation, (b) suitably small beta functions to avoid large sensitivities to error fields, (c) zero dispersion in all undulators, (d) adjustable beam sizes in all undulators, (e) achromatic optics for the 2.5GeV turn around and for the full 5GeV return loop, (e) sextupole correction of second order dispersion, time of flight, and energy aperture.

Orbit and optics correction: Because of the small beamsize in the ERL, the beam position has to be controlled very accurately. Tolerances for power-supply strengths and for the alignment of many components have been specified. The orbit control has to take care that spurious dispersion does not lead to an apparent emittance increase.

X-ray BPMs for 2 beams: Cornell has developed stripline BPMs for the ERL bunch parameters and plans to read them out at 1.3GHz to obtain the difference orbit of the beam in those sections of the ERL where two beams travel 180° apart in RF phase. Shorter striplines could be read out at 2.6GHz to obtain the sum-orbit of the two beams, which then allows to reconstruct each beam's location individually.

Feedback analysis: The vertical beamsize in modern existing storage rings is as small as that of the Cornell ERL. Because stabilization to a fraction of the beamsize is demonstrated in these rings, Cornell is investigating how to apply similar feedback techniques.

Beam-breakup instability (BBU): The current limit due to recirculating BBU instability has been analyzed in detail for monopole, dipole, and quadrupole modes [11]. It has been determined how much it can be increased by a coupled optics and by polarized HOMs; implications for cavity design have been analyzed. And in collaboration with JLAB, experiments have verified that theoretical understanding. BBU due to quadrupole modes can lead to unstable beam-size oscillations and damping of all quadrupole HOMs have been made an important consideration for the cavity design.

Ion removal: The very narrow ERL beams produce a very steep electrostatic potential that can easily trap large ion densities, which would cause detrimental optics errors. Low impedance clearing electrodes were therefore designed that can reduce the ion density to a tolerable level [12]. We find that about 200 electrodes, one at every minimum of the electron beam's potential, are needed to reduce the ion density to about 10^{-4}. This density establishes itself as an equilibrium between ion creation and ion removal and barely eliminates emittance growth during a full ERL turn.

Ion-gap production: An alternative method of avoiding the accumulation of ions within the electron beam would be the production of regular gaps in the beam. The effect of gaps has been studied, and the technical feasibility of their creation by kickers or by a gaps in the gun-laser beam is being investigated.

Ion instabilities: Even the strongly reduced density of ions that is left after the installation of clearing electrodes can drive the fast ion instability. It has been found that the clearing speed from electrodes is not fast enough to suppress this instability. Landau damping and the mixing of ions which travel at different velocities to the clearing electrodes might fill that role.

Energy spread budget: During deceleration, the uncorrelated energy spread of the beam increases by the ratio of high to low energy, i.e. 500. The tolerance to an increase in energy spread in the high energy section of the ERL is therefore very small. Longitudinal wake fields are therefor being considered very carefully, including roughness wakes, resistive wall wakes, and short and long range wakes of all common vacuum components, including the narrow chambers of undulators.

CSR shielding: For very short bunches in an ERL, CSR can have detrimental effect on the emittance at various places: (a) at the merger where the 10MeV beam from the injector is sent into the main linac, (b) at every bend in the turnaround at 2.5GeV and in the 5GeV return loop. This limits the current per bunch and the minimal bunchlength that can be reached. If the effect from CSR could be reduced by shielding fields in a narrow vacuum chamber, shorter, more intense bunches could be provided. The CSR shielding effect is therefore being investigated.

Coupler kicks: Perturbations from the rotational symmetry of cavities leads to time dependent transverse electric fields. These can produce a significant emittance growth. It was found that a cancellation occurs when the coupler location alternates from being in front of the cavity to being behind the cavity. A symmetrization of the fields in the coupler region by a stub opposite the coupler was designed to further reduce the coupler kick. [13].

Distribution of pumps and pressure: The synchrotron radiation load on the walls of the vacuum chamber, together with the out-gassing rate and the placement of vacuum pumps determines the pressure profile along the ERL. This pressure profile has been computed to determine ion creation rates and gas scattering rates.

Gas scattering and IBS scattering: Because the energy uncorrelated relative energy spread increases by 500 during deceleration, it was investigated in how far the energy spread from gas scattering and IBS leads to beamloss. It became clear that a detailed design of collimation sections is essential.

Halo creation: Beam halo can be created by scattering and reflection of light from the gun's laser, by scattering of the photo-electron before emission, by field emission, by dark current in cavities, and by particle motion in nonlinear charge and other E&M fields. Collimator sections have to be designed that limit the damage from loosing halo particles.

Loss rates, radiation background, and collimator design: In storage rings, the lifetime is a very sensitive indicator of slow beam loss. In the ERL, one needs to guard against small but continuous beamloss, which can easily accumulate to very relevant radiation background and component damage. A detailed design of collimation sections is needed that limits the x-ray radiation load.

Machine protection: A very sensitive and reliable beam loss measurement and beam abort strategy has to be developed for machine and environmental protection.

Many accelerator physics issues still have to be investigated: The longitudinal space charge instability has to be taken into account for a relatively long section of the linac. The optics for the two beams withing the linac relies heavily on RF focusing of low medium energy beams. A validation of the accuracy of models for that focusing is needed. The power load on the vacuum chamber of the ERL is up to 1.2kW/m and a detailed design of the vacuum components to accommodate this load is needed, considering the strong sensitivity of the ERL beam to longitudinal wake fields. Diagnostics for high energy, non-destructive measurements of the 3D beam distribution are needed, as well as measurements of spectral brightness for which an ERL is optimized.

Many R&D items are related to the development of x-ray beamlines: Relevant items are fast, and precise x-ray BPMs, feedback on x-ray beams and x-ray stabilization, undulator design and construction (cryogenically cooled, superconducting, permanent magnet, short period, in-vacuum, tolerances, etc.) X-ray experiments that take full advantage of the improved beams have to be designed, and related technology has to be developed, e.g. high rep rate pump lasers, new x-ray detector technology, microbeam refractive lenses, transmission Laue lenses, zone plates, KB mirrors, high power density multilayers, and ultra high data rate handling. X-ray beam-line components have to be developed for ERL parameters, e.g. high heat-load crotch, high power-density windows, high coherence optics, windowless and optics free beam lines.

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