STATUS OF THE BERLINPRO OPTICS DESIGN *

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Abstract

Following the funding approval late 2010, Helmholtz-Zentrum Berlin officially started the realization of the Berlin Energy Recovery Linac Project B*ERL*inPro in January 2011. The goal of this compact ERL is to develop the accelerator physics and technology required to accelerate a high-current (100 mA) and low emittance (1 mm·mrad normalized) beam, as desired by future large scale facilities based on ERLs, e.g ERL-based synchrotron light sources. Using the flexibility ERLs provides, a short bunch operation mode will also be investigated. A modified optics is presented and different non-linear issues are addressed.

INTRODUCTION

To demonstrate the potential of superconducting ERL's for high current and low emittance operation and to bring ERL technology to maturity, HZB proposed to build B*ERL*inPro [1], a 100 MeV prototype ERL facility. Recently, in order to guarantee the financial viability of the project, the beam energy was decreased to 50 MeV. This implies a shortening of the superconducting accelerator structures to three two-cell cavities in the booster and three 7-cell cavities in linac. Also the cathode laser pulse shaping option has been postponed.

The main adapted parameters of B*ERL*inPro are listed in Table 1. The new machine layout is shown in Fig. 1.

Table 1: Main Parameters of B*ERL*inPro.

beam energy: injection / full	7 / 50 MeV
maximum beam current	100 mA
nominal bunch charge	77 pC
maximum repetition rate	1.3 GHz
bunch length	100fs-6ps
transverse normalized emittance, rms	< 1 mm·mrad

Although of minor priority, a short bunch mode to demonstrate compression down to ~100 fs at a reduced bunch charge is an option.

The primary goal of the project is to demonstrate a low emittance high current operation of an ERL. An emittance compensation scheme is unavoidable to achieve the target transverse emittances. A 2-D emittance compensation scheme developed for B*ERL*inPro is described in detail in these proceedings [2].

Detailed analysis of the mechanisms and suppression techniques of the transversal beam break up (BBU) instability can be found in e.g. [3]. BBU modeling for B*ERL*inPro uses the GBBU code. The modeling shows that 100 mA average current ERL is feasible with good HOM-damped cavities in the main linac. More detailed results can be found in these proceedings [4].

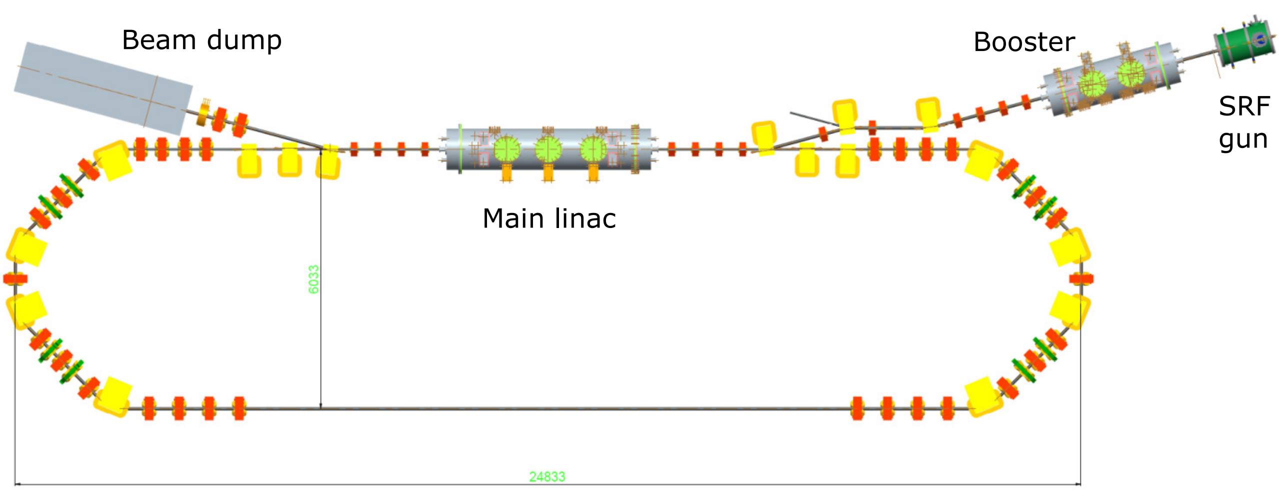

Figure 1: BERLinPro layout.

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RECIRCULATOR OPTICS

A recirculator is used to transport the accelerated beam back to the linac where it is decelerated to recover the beam energy. The primary goal for its layout is beam transport without significant losses while conserving the excellent quality of the beam. As the generation of short (100 fs-range) pulses is intended as an additional feature for B*ERL*inPro, the recirculator will be designed to have also compressor capabilities. The main requirements to the magnet lattice are:

- large transverse (moderate β-function) and longitudinal acceptance (low dispersion) to minimize the loss rate,
- varying R_{56} to allow for bunch compression / decompression or long bunch operation (-0.4m < R_{56} < 0.4m in each arc),
- suitable total betatron phase advance per turn to maximize BBU limited current threshold,
- variable β-functions in the arcs to optimize CSR power and induced emittance growth for short pulses,
- matching to the beam conditions out of the injector/merger and inside the linac respectively, and into the dump line.

In Fig. 2 the Twiss parameters of the first recirculator arc of a magnet lattice, currently under investigation, are exemplarily shown. To decrease the maximum dispersion and thus increasing the recirculator's energy acceptance we changed from 3x60 to 4x45 degree bends per arc. The relatively large beta functions outside the arc arise from matching to the BBU optimized values out of the linac.

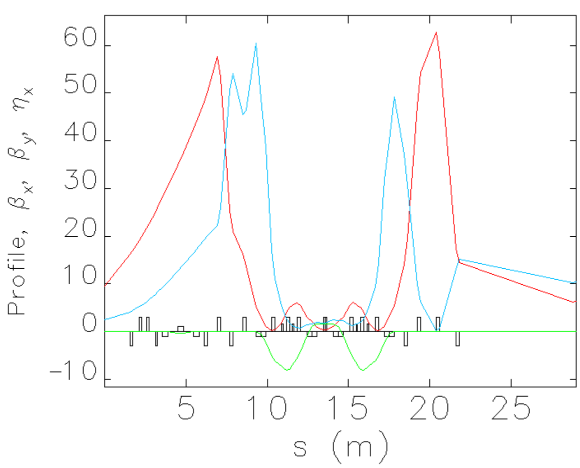

Figure 2: β-functions (x=red, y=blue; [m]) and dispersion*10 (green, [m]) of the first recirculator arc, tuned to R_{56} = 0 m.

CSR EFFECTS AND WAKE FIELDS

Coherent synchrotron radiation (CSR) is the effect that limits the minimum bunch length. Even with 2 ps long bunches and 100 mA average current, CSR power exceeds that normally encountered in storage rings. Moreover, CSR from the last dipole is in danger of being deposited in the linac cryomodule and requires special attention.

The total coherently radiated energy in a bending magnet with a radius R and an angle φ can be estimated as (see e.g. [11])

$$\Delta E \sim Q^2 \frac{R^{1/3}\varphi}{l_0^{4/3}}, \qquad (1)$$

where Q is the bunch charge, l_0 is the bunch length, which is assumed to be constant inside the magnet. The numerical coefficient depends on the particle distribution along the bunch. Only stationary CSR wake was taken into account. This simple estimation is accurate enough for the low emittance mode of B*ERL*inPro.

Since CSR covers the (sub)mm-wavelength region, it's reflectivity from the metal vacuum chamber is high and radiation is transported easily. The necessity of collimators in front of the cryomodules is being discussed.

CSRTrack [10] was used to accurately model the 3D problem for both low emittance and short pulse modes. The particle distribution after the linac is imported from ASTRA [12]. At 100 mA, 5 kW of CSR power is expected in the low-emittance mode and emittance growth is of the order of 60% in the horizontal plane. In the short pulse mode at the full current CSR power is about 25 kW and an order of magnitude emittance growth is possible. In the latter case CSR limits the minimal bunch length to about 140 fs at 77 pC bunch charge.

High CSR power is one of the reasons the average current in the short pulse mode will be limited. We plan to absorb the power at CSR collimators and to cool the vacuum chambers.

Resistive wakes are another source of energy loss heating vacuum chambers of the accelerator. For the low emittance mode the long wave range approach [7,8] can be applied with the scaling law for the energy loss

$$\Delta E \approx \frac{2.5\cdot Q\cdot L}{a\cdot l_0^{3/2}\sigma^{1/2}}\left[\frac{V\cdot m^2}{\Omega^{1/2}}\right], \qquad (2)$$

where L and a are the length and radius of the (circular) vacuum chamber, l_0 – the bunch length [m], σ – the static conductivity [$\Omega^{-1}\cdot m^{-1}$], Q – bunch charge [nC]. The numerical coefficient is taken for a Gaussian longitudinal distribution in the bunch. In the low emittance mode we expect an average power loss of 350 W (aluminium vacuum chambers).

In the short pulse mode the resistive wake limits together with the CSR wake the bunch length. The approximation (2) is not valid for the parameters of the bunch in the short pulse mode, since the size of mirror charges in the vacuum chamber ($\sim a/\gamma = 0.2mm$) is longer than the bunch. In this case we take $l_0 = a/\gamma$ for estimation. Up to 2.5 kW power will be deposited to the walls at the full (100 mA) current. It should be

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mentioned, that roughness of the vacuum chamber further increases this value.

ION ACCUMULATION

The main effect of the accumulated ions (e.g. [5,6,9]) is an additional focusing in the recirculator. In order to keep the shift in the betatron phase advance due to ion cloud reasonable, the neutralisation factor should be kept below 10^{-2}. Positions for clearing electrodes will be chosen in the points with max electron beam potential. Fig. 3 shows $\ln(\sigma_x + \sigma_y)$, which is proportional to the on-axis electron beam potential, for the optics, shown in Fig. 2.

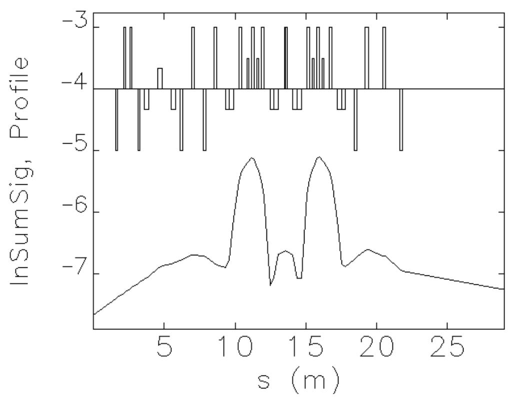

Figure 3: $\ln(\sigma_x + \sigma_y)$ (proportional to the on-axis electron beam potential) in the B*ERL*inPro arc.

HALO AND COLLIMATION

Analysis of the possible sources of the halo particles shows, that at usual storage ring vacuum levels (10^{-8}-10^{-9} Torr) the Touscheck effect and the gas scattering are not important for single-pass machines like B*ERL*inPro. We expect the main source of beam losses to be connected to "beam tails" arising from the electron gun.

A halo collimation system should be installed in the injector and merger sections to cut off the halo particles at low energy. The acceptance of the recirculator ring must be much larger, than the acceptance of the collimating system.

Initial modelling of the halo dynamics was performed with the ASTRA particle tracking code. In Fig. 4 some illustrations are shown with a postulated initial distribution of the halo particles starting from the cathode and the particle distribution after the merger section. The particles lost on 4 collimators with 40 mm diameter installed after the gun, booster, in the merger section and before the main linac are shown in green.

The exact numerical evaluation of the particle losses is not possible since the source and distribution of the halo particles are not known in advance.

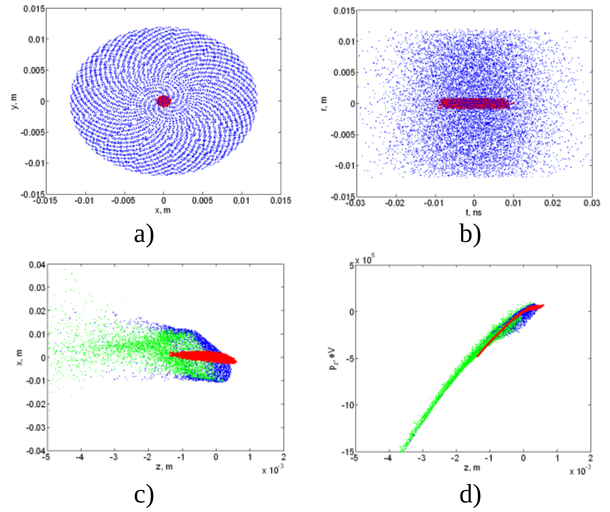

Figure 4: Particle distribution from ASTRA. Red – active beam particles, blue – passive halo particles, green – particles lost in collimators. Initial distribution on the cathode in a) – *x-y* plane, b) – *x-t* plane. Particle distribution after the merger section in c) – *x-z* plane, d) – p_z-*z* plane.

CONCLUSION

The energy recovery linac project BERLinPro has been funded in 2010 and many aspects of the layout of the machine have been addressed since. The linear optics has been adapted to the changes due to the energy reduction to 50MeV and the arc layout has been modified for larger energy acceptance. Work on non-linear effects like CSR, ion trapping, halo and BBU are in progress and mayor challenges have been identified. The publication of a CDR with a more detailed description of the technical realization of the project is planned towards the end of 2011.

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