MERGER CONSIDERATIONS FOR B*ERL*inPro

B. Kuske, M. Abo-Bakr, A. Matveenko
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany

Abstract

The Helmholtz-Zentrum Berlin für Materialien und Energie (HZB) proposes to construct an ERL test facility [1]. To provide different operational modes for different scientific applications is one of the advantages of these new, linac-driven radiation sources. In contrast to the linear machine layouts of FELs, new challenges arise from incorporating the linac into a circular machine. One of them is the so called merger, a magnetic chicane that threads the low energy, low emittance, but high charge bunch from the gun into the recirculator. The preservation of the ambitious gun parameters and the flexibility to suit all user demands are the dominant design goals. Different design criteria and possible layouts are discussed and a preliminary merger design is proposed.

INTRODUCTION

Energy Recovery Linacs (ERL) are designed to combine the superb bunch properties of modern injectors with the known advantages of storage ring based light sources, such as multiple beamlines and the large diversity in the accessible radiation. ERLs are single (or few) pass devices, that have to utilize an on axis injection, preserving the bunch properties of the injector. Opposite to conventional linacs, the return arc, that transports the bunches back to the linac entry for energy recovery, prohibits a straight forward injection, see Fig. 2. The last arc dipole, necessitates a chicane for the injected beam, or a defecting injection system. In addition, both beams, the injected low energy beam and the returned high energy beam pass through the same magnets, starting from the last merger dipole until the extraction septum after the main linac, imposing strong boundaries on the optics. Although the deflection angle of the common dipole is scaled by the momentum ratio of the two beams, the deflection of the high energy beam will still be a few degrees and has to be anticipated by an appropriate beam offset and angle before. The magnets required to this end increase the merger length and thus the effect of the space charge on the emittance. In order to fullfill all imposed demands, the transformation properties of the merging structure have to be investigated and adequate beam properties have to be defined, taking the effects of space charge and the low injection energy into account. All calculations presented are performed with ASTRA [2], including a 3D-space charge routine for dipoles. If not stated otherwise, the bunch properties were 5000 particles, 10MeV, 77pC, an emittance of $1.0\pi\mu\,rad$, $\sigma_{x,y,z}$=1mm, $\alpha_{x,y}$=0, σ_E=20keV and no correlated energy spread.

GEOMETRICAL LAYOUT

In order to preserve the small emittance from the injector the transformation through the merger has to be achromatic. Three achromatic merger designs are usually concidered: A four dipole C-chicane, a four dipole zigzag chicane (S-chicane) and a dogleg. The achromaticity in a dogleg can only be achieved by the use of quadrupoles, leading to a strong sensitivity towards field and energy errors, as pointed out in [3]. The zigzag merger has been proposed by BNL [4] for optimal compensation of space charge forces. Properly chosen edge focusing distributes the focusing evenly between the x- and y plane. Additionally, a fixed ratio between the length of the outer and the central drift spaces has to be met. The trajectory offset is devided into two smaller parts, due to the crossing of the injection straight by the injected beam, so that the design is rather difficult to incorporate into the machine. The distributed edge focusing gives rise to higher order dispersive terms and leads to emittance growth for large energy spread. The C-chicane with parallel faced dipoles is geometrically simple and cancels dispersion in all orders, but it is not suitable for higher bunch charges. This trade off between charge

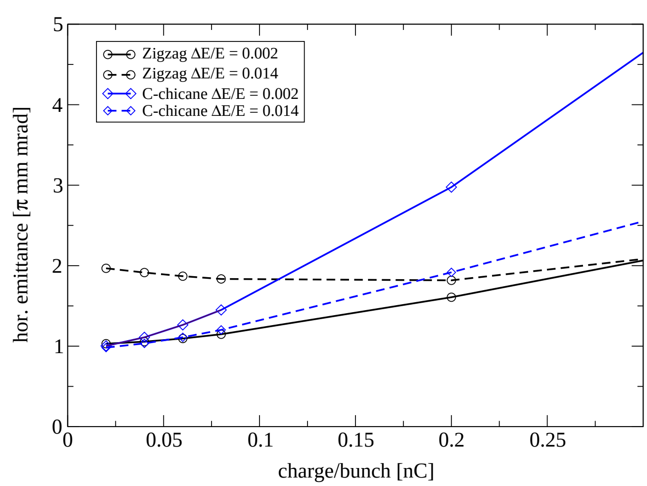

Figure 1: Comparision of a zigzag-chicane (black) and a C-chicane (blue): For bunch charges below 100pC and large energy spread (dashed lines) the C-chicane profits from the lack of higher order dispersion.

and dispersive effects is shown in Fig. 1. The emittance blow up in a typical zigzag chicane with -10°/20°/-20°/10° dipoles (Data: courtesy of D. Kayran, BNL) (black lines) is moderate at higher bunch charges but it increases for small bunch charges, when the energy spread is large (dashed black line). A C-chicane (20° dipoles) (blue lines) pre-

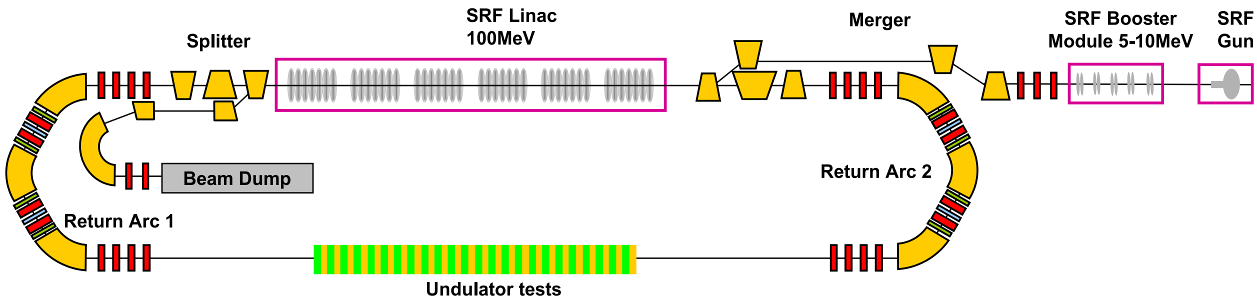

Figure 2: General layout of B*ERL*inPro.

serves the emittance at lower charges also for large energy spread, due to the lack of higher order dispersion. For an envisaged maximal charge of 77pC the C-chicane seems the appropriate choice for B*ERL*inPro. Furthermore, it is beneficial to be able to accomodate larger (correlated) energy spread, i.e. for bunch length adjustment in the merger.

BEAM PROPERTIES

Despite the geometrical layout of the merger also the properties of the entering beam determine the quality of the bunch behind the merger. The energy, bunch length, Twiss functions and the energy correlation have a strong impact on the emittance preservation.

Energy and Bunch Length

Even without taking space charge into account, the bunch length, L, will change during the passage through the merger due to momentum compaction by

$$\Delta L = \Delta p/p \int D(s)/\rho\, ds \qquad (1)$$

with Δp/p, the relative energy spread, D(s) the dispersion function, and ρ the bending radius of the dipoles. This effect, also when space charge is included, is depicted in Fig. 3 for 6MeV bunches. For bunches shorter than 1ps the length is more than doubled, even without space charge. Space charge aggravates the lengthening, especially for high densities, i.e. short bunches or high charge. An optimum can be reaches for 1-2ps long bunches (77pC) that will still be stretched to ≈3ps. The bunch length is an important parameter to control space charge effects and emittance growth. Fig. 4 reflects the decrease in the resulting emittance as a function of increasing bunch length, for the case of 10pC (blue) and 77pC (black) at 10MeV, and for 77pC at 6MeV (green). While the higher charge still can be couterbalanced by an increased bunch length at 10MeV, the combination of 77pC with an energy of 6MeV leads to unrealistically long bunches necessary to preserve the emittance. These conciderations can be used to fix an appropriate injection energy. It should be kept in mind, though, that the bunch length can be further adjusted in the recirculating arc at higher particle energy.

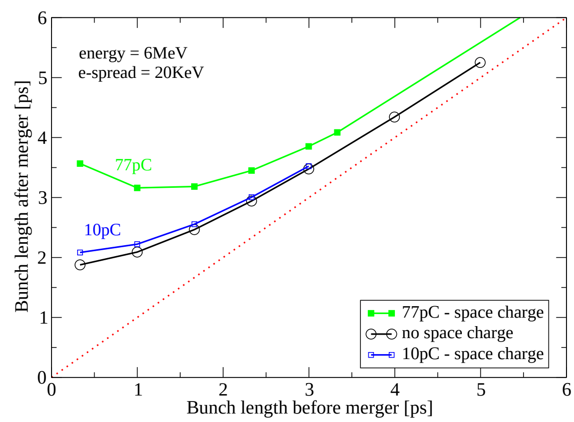

Figure 3: Exit bunch length as a function of the incoming bunch length without space charge (black) and for 10pC (blue) and 77pC (green). A moderate entrance length of 1-2ps yields the shortest exit length for 77pC.

Twiss Parameters

Dipoles with parallel pole faces impose strong vertical focussing on the bunches, which leads to a strong waist in the vertical beam size inside the merger. Chosing a small vertical entrance beam size $\beta_y \approx 10m$ and a strongly diverging beam ($\alpha_y < -10$) relaxes the waist and helps to reduce space charge forces. The horizontal plane is uncritical. The beam slowly diverges and any small value of α_x is acceptable.

Correlated Energy Spread

In combination with the R56 of the merger, an energy correlation imprinted on the bunch in the Booster module down stream can be used to moderately adjust the bunch length. Large negative correlation (higher energy at the tail of the bunch) leads to a reduction, positive correlation to an increase of the bunch length, with the expected moderate emittance decrease.

TECHNICAL REALISATION

The shorter the merger, the smaller the impact space charge can have. The length of a C-chicane is dominated

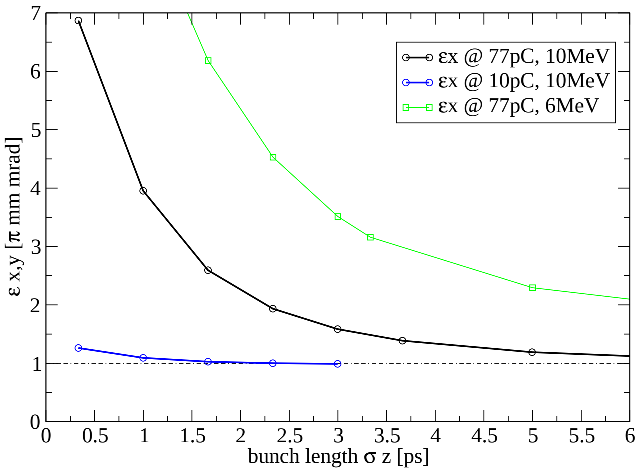

Figure 4: Emittance preservation depends strongly on the bunch length, the energy and the charge. At 10MeV emittance blow up at higher charge can be compensated by moderate bunch length increase.

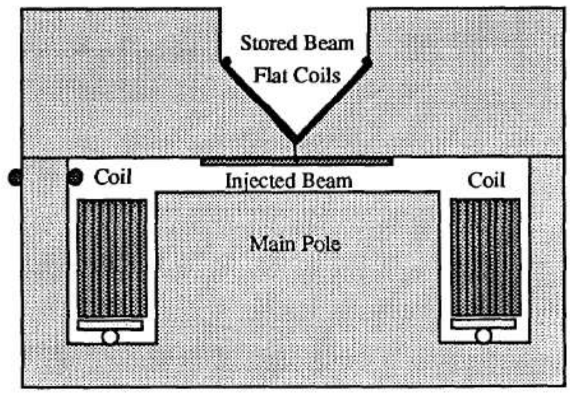

Figure 5: Example of a Lambertson septum magnet (cross section), used for injection into the Duke storage ring, [5]. The leakage field in the V-notch is 10^{-3} (10^{-4} with compensation) of the field in the injection gap.

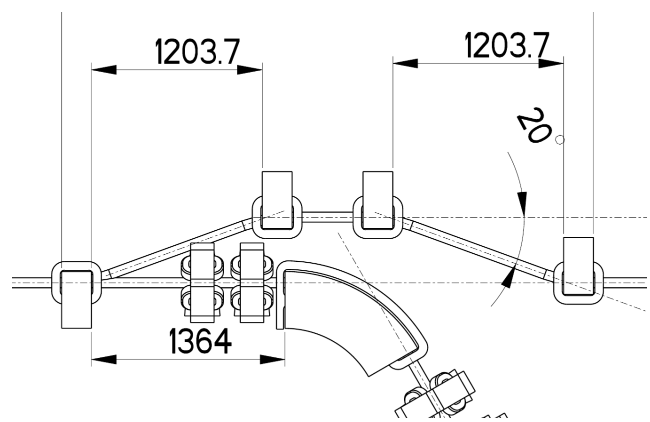

Figure 6: Shortest merger layout. The Lambertson septum makes the high energy chicane obsolete.

by the necessity to pass the optical elements and the chicane of the high energy return beam, Fig. 2. One option to shorten the structure and use lower deflection angles is to use a common yoke for both beams not only for the last, but also at the 3rd merger dipole. An even shorter solution is to use a Lambertson septum as a forth merger dipole, see Fig. 5 and [5]. The idea is to guide the high energy beam through a field free region in the yoke of the dipole, making the high energy chicane obsolete. The Lambertson magnet would lead the injected beam parallel to the high energy beam, so that one or both beams would enter the linac off axis by a few mm. For this case, the potential of higher order mode exitation has to be studied carefully. An alternative would be to guide the injected beam in a small angle to the on axis high energy beam and to use a weak steerer at the crossing point for the remaining angle correction. A possible layout of the merger is shown in Fig. 6. With a deflection angle of 20° and space for two quadrupoles for the manipulation of the 100MeV beam, the Lambertson magnet could be placed roughly 1.4m after the last arc dipole. Allowing 0.5m for diagnostics between the inner dipoles, the complete merger length would not exceed 3.8m.

SUMMARY

The merger for B*ERL*inPro will consist of a C-chicane with four parallel faced dipoles. This choice is based on a comparision between different merger types in the parameter range envisaged for this ERL test facility. The injection energy and further bunch parameters beneficial for the emittance preservation could be identified and goal values for the merger entrance could be defined. A technical solution leading to a merger with minimal length is sought by employing a Lambertson septum as a 4th merger dipole, making an additional chicane for the high energy beam obsolete. The $1.0\pi\,\mu \cdot rad$ emittance expected from the booster will be preserved in the merger. Unforseen emittance blow up can be compensated by increasing the bunch length, which has then to be compensated in the recirculator at high energy.

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