DESIGN OF THE ILC RTML EXTRACTION LINES FOR THE RENOVATED TWO-STAGE BUNCH COMPRESSOR

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Abstract

The renovated two-stage bunch compressor (BC) in the International Linear Collider (ILC) Damping Ring to the Main Linac (RTML) beamline requires new design for the extraction lines (ELs). The ELs located downstream of each stage of the BC will be used for both an emergency abort dumping of the beam and the tune-up continuous train-by-train extraction. They must accept both compressed and uncompressed beam with energy spread of 1.4% and 0.1% respectively. In this paper we report the design that allowed minimizing the length of such extraction lines while offsetting the beam dumps from the main line by 5 m distance required for acceptable radiation level in the service tunnel. Proposed extraction lines can accommodate beams with different energy spreads at the same time providing the beam size suitable for the aluminum ball dump window.

INTRODUCTION

It was decided [1-3] to incorporate a two stage bunch compressor [4] into the final design of the ILC [5]. The renovated two-stage BC compresses 6 mm long beam to 0.3 mm. The beam energy and energy spread after the first stage of the BC are 4.8 GeV and 1.4 % respectively. The beam energy after the second stage is 15 GeV and the beam energy spread, while it depends on the ILC operational mode, is 1.26 % at maximum.

The two extraction lines (ELBC1 and ELBC2) considered in this paper are located downstream of respective stages (BC1 and BC2) of the bunch compressor. The ELs can be used for either an emergency beam abort or for a train-by-train extraction. Since these ELs might receive both compressed and uncompressed beam, they must accept beams with both low and high energy spread.

Each extraction line is equipped with the 220 kW aluminum ball dump, which corresponds to the power of the continuously dumped beam with 5 GeV energy.

EXTRACTION LINES REQUIREMENTS

There are multiple requirements to the extraction lines:

- Due to the requirements of acceptable radiation levels in the service tunnel, horizontal offset of the dump from the main beamline must be at least 5 m center-to-center [6].
- The beam size on the dump window must be at least $\pi\sigma_x\sigma_y$=12 mm^2. Such beam size allows the use of an aluminum window on the dump.
- The beamline apertures have to be large enough to accommodate the beam. The RMS energy spread of the beam can be as large as 1.4% (for ELBC1). Additionally, a reasonable limit for the horizontal β-function is about 5 km. Since one might want to run beams with energy spread of 0.04% (for ELBC2 taking 15 GeV uncompressed beam) to the dump the beam size due to dispersion is no help in maintaining the required beam size on the dump window.
- The elements of the straight-ahead beamline and the extraction beamline must have enough transverse clearance.
- One has to arrange for both the train-by-train extraction and emergency abort of the beam, i.e., the emergency abort kicker has to ramp from zero to full strength in less than the minimum bunch spacing of 150 nsec.
- The magnets must be physically realizable. Here we limit ourselves to 1 T pole-tip fields for the quads, 1.5 T fields for the bends, and 0.05 T fields in septum magnets [6].
- The extraction line must be made as short as possible.

Requirements to the ELs in the final RTML are similar to the requirements specified in [6]. As a matter of fact the extraction system of new ELs is copied from 2008 solution.

EXTRACTION SYSTEM

The abort extraction of the beam is performed by four 2 m long fast kickers, which are powered to 35 G with a rise time of about 100 ns. Routine tune-up beam extraction is performed by a single 1 m long pulsed bend located between two central kickers. The bend is excited to 280 G to make its bending angle compatible with the cumulative angle provided by four fast kickers.

EXTRACTION LINES IN LINEAR APPROXIMATION

To satisfy aforementioned requirements, the linear lattices of ELBC1 and ELBC2 are designed in accordance with the concept considered in details in [6].

To decouple the dispersion and beam size issues we use Double Bend Achromats (DBA) as EL bending blocks. The extraction line is built of the cells, which have periodic solution for the Twiss parameters, and consist of DBA and focusing quads. Number of cells is determined by requirement to sufficient separation between the beam

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dump and the main line.

The linear solutions for the ELBC1 and ELBC2 are presented in Fig. 1 and 2 respectively.

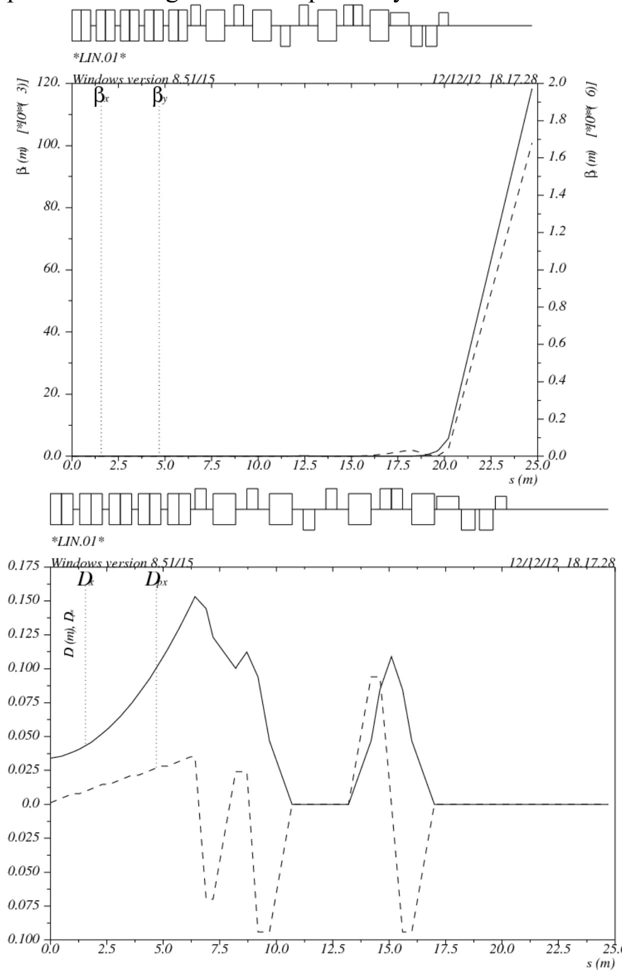

Figure 1: Twiss parameters and dispersion in ELBC1.

The extraction is initiated by a set of septum magnets (5 for ELBC1 and 6 for ELBC2) deflecting the beam from the main beamline by distance large enough to accommodate regular bends and quads. The septa are followed by a dispersion matching section consisting of two bends and two quads, which are tuned to zero the dispersion at the exit of the section.

The periodic cells (one for ELBC1 and two for ELBC2) following the dispersion matching section separate the dump from the main line by required distance. The quads at the end of the dump line are used to blow up the beam size on the dump window to the specified requirements. The resulting lengths of ELBC1 and ELBC2 are 24.7 m and 45.8 m respectively.

BEAM DUMP

The 220 kW aluminum ball dump [6] will be used for each of the lines. A nominal dump window diameter is 12.5 cm.

Calculations show that an aluminum window using a 1 mm thick hemispherical design is feasible for a suggested aluminum sphere dump. It has the promise of long term safe operation, with beam spot area on the dump window larger than 12 mm^2. There are no steady state heat transfer issues to reject the energy deposited by the beam to the cooling water.

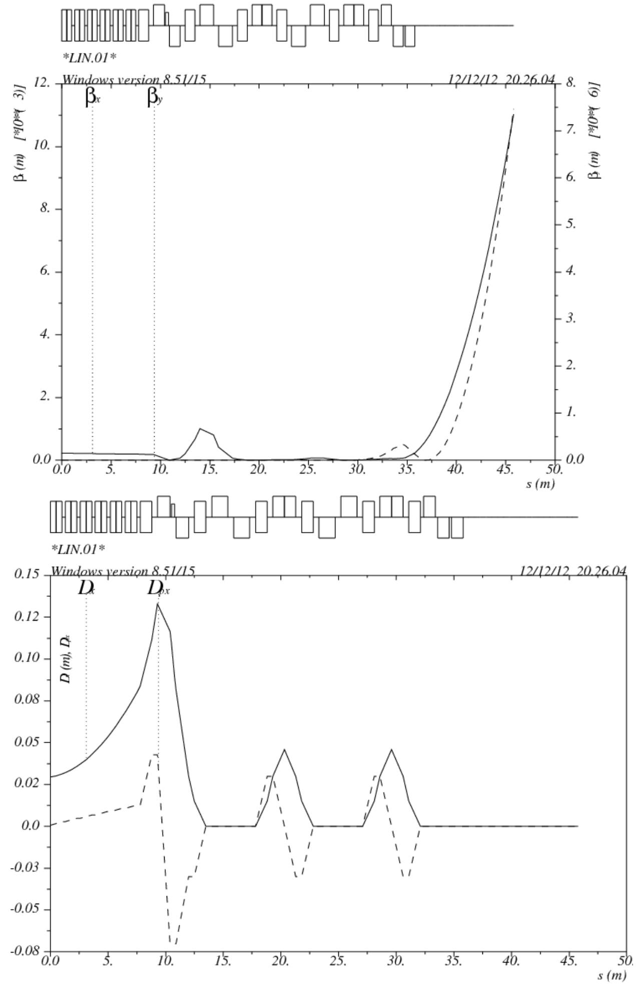

Figure 2: Twiss parameters and dispersion in ELBC2.

NONLINEAR EFFECTS

For a beam with a high energy spread there is a substantial blow-up of beam size at the end of the ELs. In Y direction the growth of the beam halo is due to chromatic aberrations, while in X direction it is because of both chromatic aberrations and nonlinear dispersion.

While the beam with small energy spread is contained within the envelope of reasonable size, the high energy spread beam explodes in horizontal size making the optical solution for the EL obtained in linear approximation unfeasible.

In the previous designs of the 2-stage BC extraction lines a number of solutions that mitigate the nonlinear halo were considered, including collimators, superconducting quads of large aperture and large diameter dump window. On the other hand, for the single stage BC there was found an extraction line solution [7] that uses relatively weak sextupoles for containing the nonlinear halo and doesn't require any additional beam collimation.

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Following the recipe adapted from single stage BC EL solution, we found that for ELBC1 the two sextupoles can contain the nonlinear hallo of the high energy spread beam. Such beam can be accommodated by the dump window of nominal 12.5 cm diameter, and there is no need in additional collimation. As Fig, 3 demonstrates, both high energy and low energy beam sizes are within the limits allowing for transporting through the EL and for utilization of nominal size dump window.

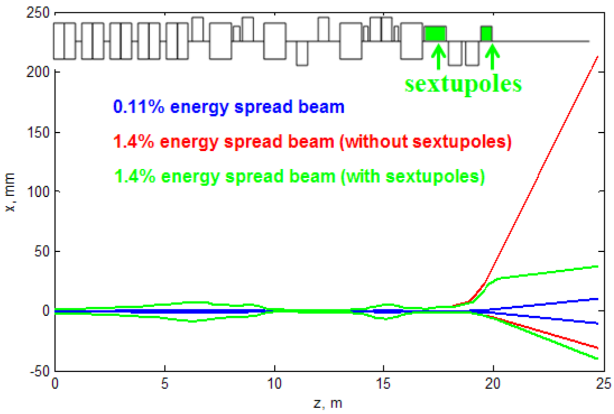

Figure 3: The horizontal beam size evolution through the extraction line for 1.4% (red – without sextupoles, green with sextupoles) and 0.11% (blue) energy spread beams.

In case of ELBC2 we found that the high energy spread beam can be contained with the help of only one sextupole strategically placed at the location of highest dispersion. Figure 4 shows that sizes of both low- and high-energy spread beams allow utilizing aluminum ball beam dump with a dump window of 12.5 cm diameter.

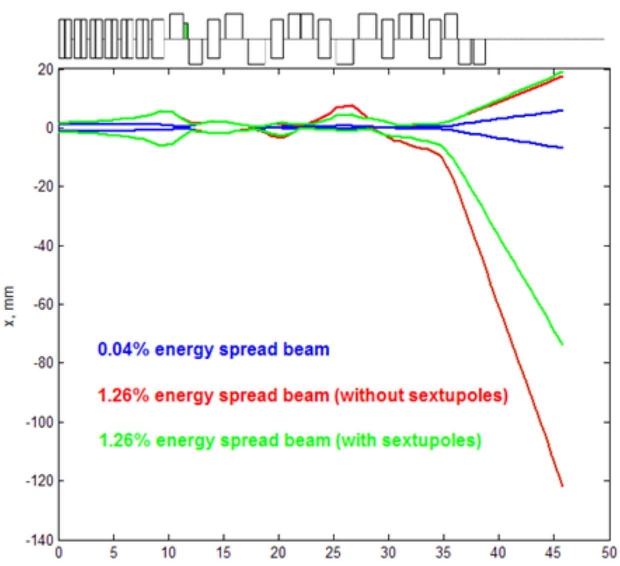

Figure 4: The horizontal beam size evolution through the extraction line for 1.26% (red – without sextupoles, green with sextupoles) and 0.04% (blue) energy spread beams.

CONCLUSION

We described the final design of the ILC RTML extraction lines located downstream of each stage of the renovated two-stage bunch compressor. The extraction lines are only 24.7 m and 45.8 m long. They are capable of accepting and transmitting 220 kW of beam power. The ELs can be used for both fast intra-train and continual extraction, and are capable of accepting both low- and high-energy spread beams.

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