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DESIGN OF THE ILC RTML EXTRACTION LINES*

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Abstract

The ILC [1] Damping Ring to the Main Linac beamline (RTML) contains three extraction lines (EL). Each EL can be used both for an emergency abort dumping of the beam and tune-up continual train-by-train extraction. Two of the extraction lines are located downstream of the first and second stages of the RTML bunch compressor, and must accept both compressed and uncompressed beam with energy spreads of 2.5% and 0.15%, respectively. In this paper we report on an optics design that allowed minimizing the length of the extraction lines while offsetting the beam dumps from the main line by the distance required for acceptable radiation levels in the service tunnel. The proposed extraction lines can accommodate beams with different energy spreads while at the same time providing the beam size acceptable for the aluminum dump window.

INTRODUCTION

The RTML incorporates three extraction lines, which can be used for either an emergency beam abort or for a train-by-train extraction. The first EL is located downstream of the Damping Ring extraction arc. The other two extraction lines are located downstream of each stage of the two-stage bunch compressor.

The first extraction line (EL1) receives 5GeV beam with an 0.15% energy spread. The extraction line located downstream of the first stage of bunch compressor (ELBC1) receives both compressed and uncompressed beam, and therefore must accept beam with both 5 and 4.88GeV energy, and 0.15% and 2.5% energy spread, respectively. The extraction line located after the second stage of the bunch compressor (ELBC2) receives 15GeV beam with either 0.15 or 1.8% energy spread.

Each of the three extraction lines is equipped with the 220kW aluminum ball dump, which corresponds to the power of the continuously dumped beam with 5GeV energy, i.e., the beam trains must be delivered to the ELBC2 dump at reduced repetition rate.

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 5m center-to-center [2].
- The beam size on the dump window must be at least $\pi\sigma_x\sigma_y$=12mm^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 2.5% (for ELBC1), which implies a dispersion function of less than 0.2m. Additionally, a reasonable limit for the horizontal β-function is about 5km. Since one might want to run beams with an energy spread of 0.15% 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 150nsec.
- The magnets must be physically realizable. Here we limit ourselves to 1T pole-tip fields for the quads, 1.5T fields for the bends, and 0.05T fields in septum magnets [3].
- The extraction line must be made as short as possible.

EXTRACTION SYSTEM

In the EL1 and ELBC1 the abort extraction of the beam is performed by four 2m long fast kickers, which are powered to 35G with a rise time of about 100ns. Routine tune-up beam extraction is performed by a single 1m long pulsed bend located between two central kickers. The bend is excited to 280G to make its bending angle compatible with the cumulative angle provided by four fast kickers.

The ELBC2 extraction system consists of ten 1m long fast abort kickers, and a single 1m long tune-up extraction bend placed in between two central kickers. The abort kickers can be charged to 90G each in 100ns which corresponds to 1MW peak power of the kicker system. The tune-up bend is excited to 900G.

DESIGN OF EXTRACTION LINES

Conceptual Design of Extraction Lines

The strong desire to make the beamline as compact as possible drives the design toward a scenario of "as much bending as possible, as early as possible". On the other hand, horizontal dispersion places limits on dipole strength.

Additionally, dispersion is useless to preserve a beam spot of appropriate size on the dump, and it is harmful for keeping a reasonable beam size throughout the extraction line.

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To decouple the dispersion and beam size issues it is suggested to use Double Bend Achromats (DBA) as bending elements.

The suggested beamline aperture is 4cm. A larger aperture would increase the overall size of the magnets as well as their pole tip field strength. To limit beam size growth we need to balance the desire for stronger bending at the beginning of the extraction line with the need to allocate enough space for focusing quads.

Based on the forgoing considerations, we start with a cell that has periodic solution for the Twiss parameters, and consists of DBA and focusing quads. Then an extraction line is built by stacking as many such cells as needed to generate sufficient separation between the beam dump and the main line.

Design of ELBC1

Since ELBC1 is the most complicated of all three extraction lines we will consider their design using ELBC1 as example.

- The extraction vertex is initiated by 4 septum magnets 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 (DMS), which consists of two bends separated by a quad doublet, which is tuned to zero the dispersion at the exit of the DMS. We choose the DMS bends strength and length to maximize the bending and to limit the dispersion inside the DMS to 0.2m. Then the matching quad doublet is adjusted to zero dispersion at the DMS exit.
- To design the periodic cells we choose such bends that the dispersion inside the DBA is reasonably low. Then the quad located between the bends is adjusted to zero dispersion at the achromat's exit. Next, two fitting quads are adjusted to make the cell periodic.
- Eventually, cells obtained in this manner are stacked together and transverse separation of the dump and the main line is checked.
- Finally, these steps are repeated to minimize the length of each element as well as the lengths of element-to-element drifts.

A solution for the ELBC1 is presented in Fig. 1. It became apparent that only one periodic cell is required in addition to the DMS to separate the dump from the main line by 6 meters. The three additional quads at the end of the dump line are used to blow the beam up so that its size on the dump window satisfies the requirements.

Nonlinear Beam Halo in ELBC1

It was found that for a beam with a high energy spread there is a substantial blowup of beam size at the end of the ELBC1. 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.

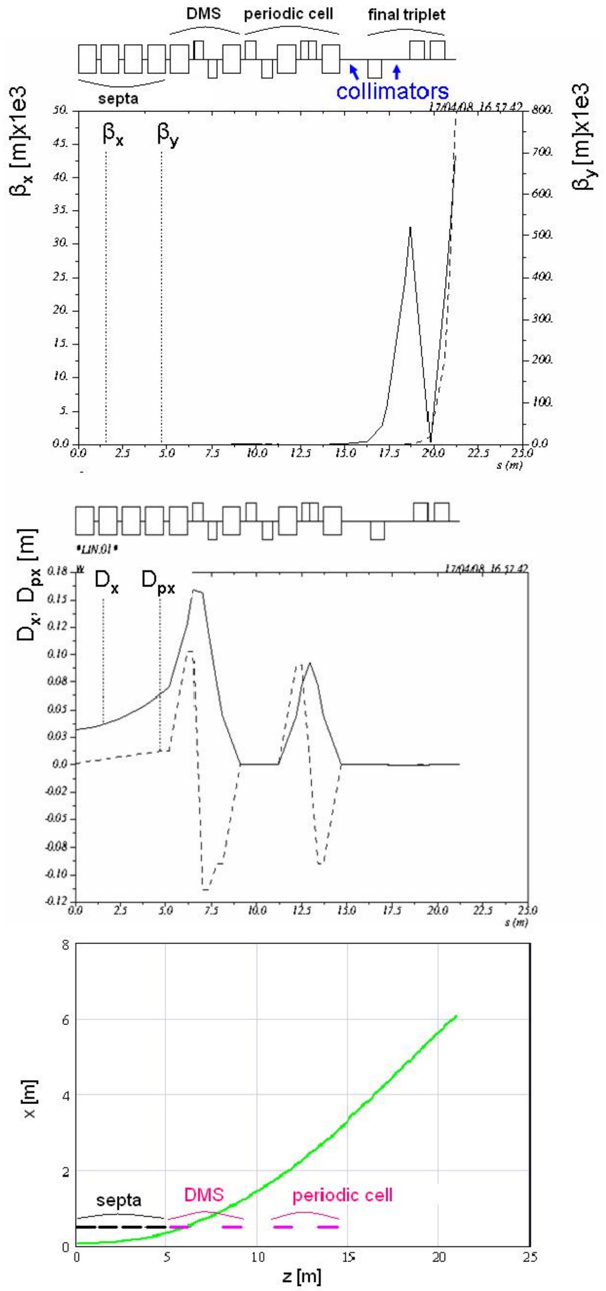

Figure 1: Twiss parameters and dispersion (two upper plots), and beam trajectory (lower plot) in ELBC1.

Fig. 2 shows that while the beam with low energy spread has the designed size, the beam with 2.5% energy spread is much larger.

The main fraction of the beam in off-energy tails is deposited on the final quad triplet. It is suggested to use a system of two collimators to protect the triplet. The first collimator is located ahead of the first quad of the triplet. The second collimator is installed between the first and the second quads of the quad triplet (see Fig. 1). The first collimator has a 15mm aperture in x direction and absorbs 3.9kW of beam power per beam-train. The second collimator has a 38mm x-aperture and absorbs 18.8kW/beam train. Such system completely shadows the quad triplet from direct hits of off-energy beam particles.

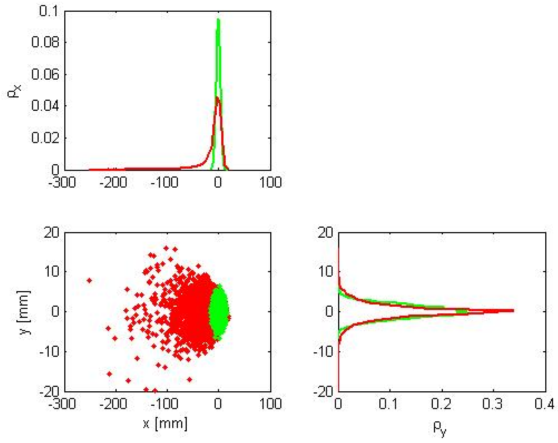

Figure 2: 0.15% (green) and 2.5% (red) energy spread beam on the dump window. In this particular simulation the magnet apertures were ignored.

The result of collimation on the beam size on the dump window is shown in Fig. 3.

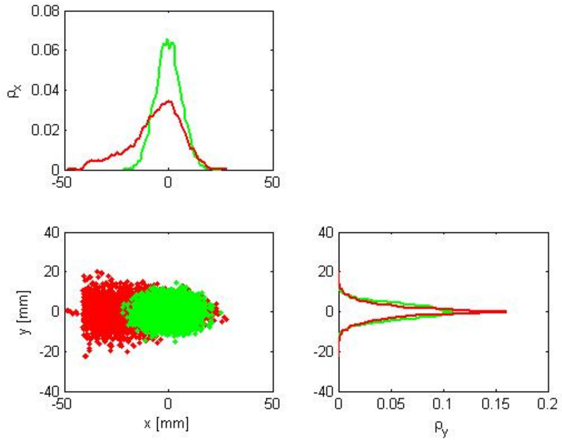

Figure 3: Collimated 2.5% (red) and 0.15% (green) energy spread beam on the dump window.

It is worth noting that the window size of the aluminum ball dump can be customized. It can be made at least as large as 1.5m in diameter [4]. The optimal window size will depend on 'value optimization' between the cost of a collimation system and the transverse size of the dump. Therefore, in this design the collimation system is mainly to shadow quadrupoles rather than to save on dump window size.

In the final design the ELBC1 is 20.7m long. The dump is separated from the main beamline by 6m, center to center. The beam size on the dump window is 24mm^2 for the low energy spread beam; the high energy spread beam does not require the dump window radius to be larger than 5cm.

Design of EL1 and ELBC2

The ELBC2 was designed in accordance to the principles outlined above. The Solution for ELBC2 results in a separation of the beam dump and the main beamline by 5m, center to center. The beam size on the dump window is 45mm^2 for 0.15% energy spread; the high energy spread beam does not require the dump window radius to be larger than 5cm. The overall length of the ELBC2 is 45m.

Since the EL1 always receives 0.15% energy spread beam, the dispersion in this line is not an issue. Therefore, EL1 was designed in straightforward manner. It has FBDB lattice optimized to provide a suitable beam spot on the dump window. In EL1 separation of the dump window from the main beamline is 6m center to center. The beam size on the dump window is 13mm^2. The extraction line is 19m long.

Diagnostics

No precise measurements of beam position in the ELs are required. It is suggested to use button-style BPM pickups, which are an integral part of the quad vacuum chamber , and need about 40mm extra length [5].

BEAM DUMPS

For each of the three 220kW dumps both low and large momentum spread beam is contained within a 5cm radius circle. To allow for equipment positioning tolerances a dump window diameter of 12.5cm was chosen. Calculations show that an aluminum window using a 1mm thick hemispherical design is feasible for a suggested aluminum sphere dump. It has the promise of long term safe operation, even for the 0.15% $\Delta p/p$ optics with beam spot area on the dump window larger than 12mm^2. There are no steady state heat transfer issues to reject the energy deposited by the beam to the cooling water.

CONCLUSION

We described the design of the three ILC RTML extraction lines capable of accepting and transmitting 220kW of beam power. Each EL can be used for both fast intra-train and continual extraction. The second and the third extraction lines are capable of accepting both low and high energy spread beams.

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