FINAL DESIGN OF ILC RTML EXTRACTION LINE FOR SINGLE STAGE BUNCH COMPRESSOR

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Abstract

The use of single stage bunch compressor (BC) in the International Linear Collider (ILC) [1] Damping Ring to the Main Linac beamline (RTML) requires new design for the extraction line (EL). The EL located downstream of the BC will be used for both an emergency abort dumping of the beam and the tune-up continuous train-by-train extraction. It must accept both compressed and uncompressed beam with energy spread of 3.54% and 0.15% respectively. In this paper we report the final design that allowed minimizing the length of such extraction line while offsetting the beam dumps from the main line by 5m distance required for acceptable radiation level in the service tunnel. Proposed extraction line can accommodate beams with different energy spreads at the same time providing the beam size suitable for the aluminum ball dump window.

INTRODUCTION

The redesigned RTML incorporates two 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 second extraction line is located downstream of the single-stage bunch compressor.

The first extraction line (EL1) receives 5GeV beam with 0.15% energy spread. The extraction line located downstream of the bunch compressor (ELBC) receives both compressed and uncompressed beam, and therefore must accept beam with both 5 and 4.37GeV energy, and 0.15% and 3.54% energy spread, respectively.

Each extraction line is equipped with the 220kW aluminum ball dump, which corresponds to the power of the continuously dumped beam with 5GeV 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 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 3.54% (for ELBC), which implies a dispersion function of less than 0.15m. Additionally, a reasonable limit for the horizontal β-function is about 5km. Since one might want to run beams with 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.

Requirements to the ELs in the new RTML are similar to the requirements to the already designed extraction lines [4]. As a matter of fact EL1 is used in the redesigned RTML without any modifications. The ELBC has to accommodate the beam with significantly increased energy spread and therefore must be completely remodelled.

EXTRACTION SYSTEM

In the EL1 and ELBC 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.

DESIGN OF BUNCH COMPRESSOR EXTRACTION LINE

The ELBC is designed in accordance with the concept considered in details in [4].

To decouple the dispersion and beam size issues it is suggested to use Double Bend Achromats (DBA) as EL bending elements. The suggested beamline aperture is 4.7cm. 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 dump and the main line.

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A solution for the ELBC is presented in Fig. 1.

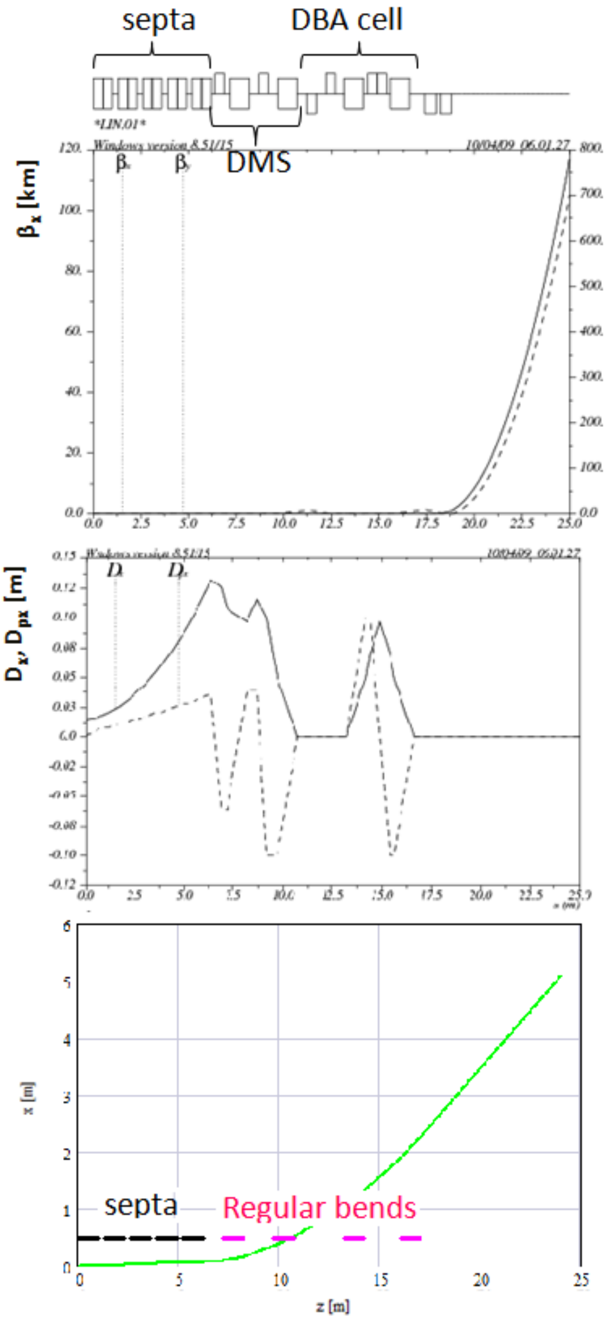

Figure 1: Twiss parameters and dispersion (two upper plots), and beam trajectory (lower plot) in ELBC.

The extraction vertex is initiated by 5 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 and two quads, which are tuned to zero the dispersion at the exit of the DMS.

It became apparent that only one periodic cell is required in addition to the DMS to separate the dump from the main line by 5.1 meters, which results in 24m long EL. The quad doublet at the end of the dump line is used to blow the beam up so that its size on the dump window satisfies the requirements.

BEAM DUMP

It is suggested to use for ELBC the 220kW aluminum ball dump discussed in [4]. A nominal dump window diameter is 12.5cm. The window size can be customized. It can be made at least as large as 1m in diameter [5].

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.

NONLINEAR EFFECTS

For a beam with a high energy spread there is a substantial blow-up of beam size at the end of the ELBC. 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. A large fraction of the beam in off-energy tails is deposited on the final quad doublet. Figure 2 shows the effect of nonlinearity on horizontal beam size throughout extraction line.

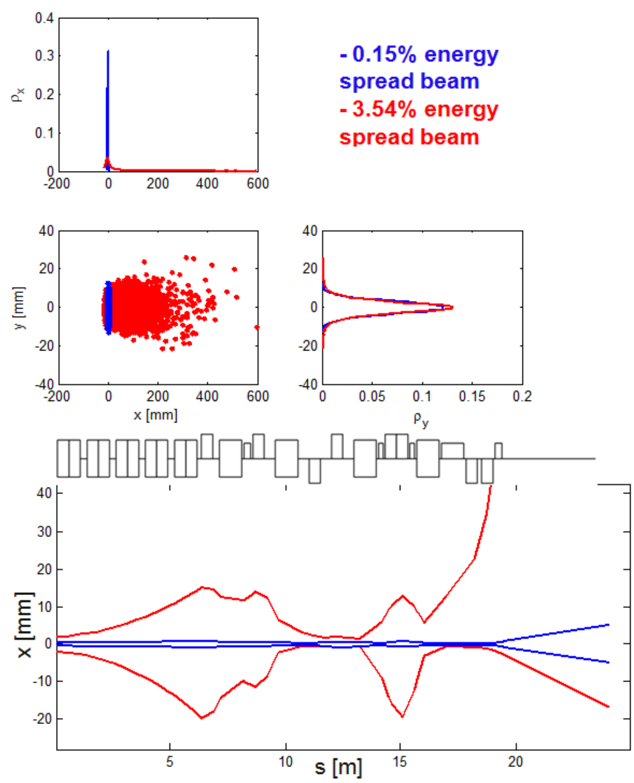

Figure 2: Beam sizes on the dump window for 3.54% (red) and 0.15% (blue) energy spread beams (upper plot). The horizontal beam size evolution through the extraction line for 3.54% (red) and 0.15% (blue) energy spread beams (lower plot).

As Fig.2 shows, 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.

A number of possibilities were considered [6] for mitigating the nonlinear halo, including utilizing collimators, sextupoles or some combination of those with superconducting quads of large aperture together with large diameter dump window. Collimators present simple but inelegant solution complicating the overall EL design. Since the main source of high-energy halo is nonlinear dispersion, it is logical to place a sextupole at the very beginning of the EL. Such solution requires only two sextupoles, but the one located at the exit of last septum shall be a very compact magnet, probably of an exotic shape. It is also preferable not to use superconducting magnets in the dump line. Additionally, the larger is the dump window the more expensive the extraction line is.

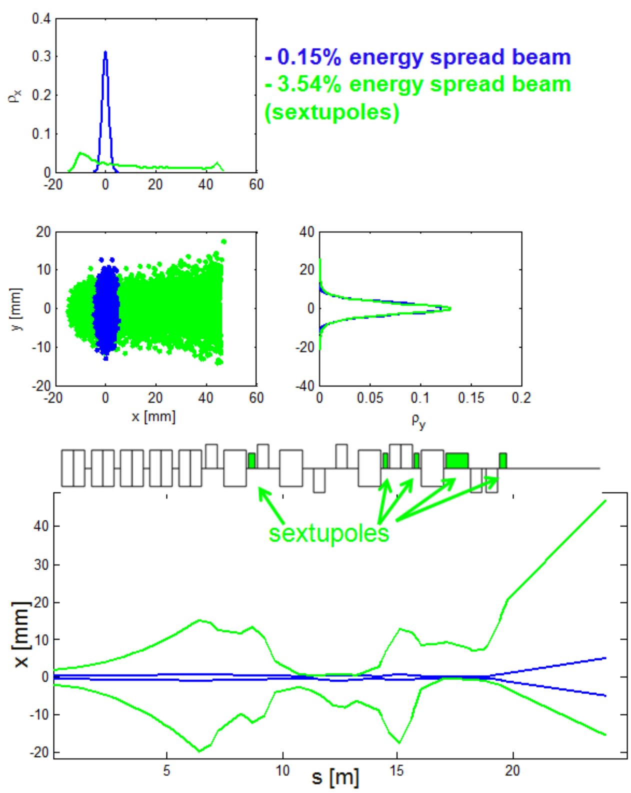

Figure 3: Beam sizes on the dump window for corrected 3.54% (green) and 0.15% (blue) energy spread beams (upper plot). The horizontal beam size evolution through the extraction line for corrected 3.54% (green) and 0.15% (blue) energy spread beams (lower plot). The sextupoles in the lattice are shown with green colour.

As a result of these considerations we found the solution with relatively weak sextupoles distributed throughout the extraction line. The high energy spread beam in this scenario can be accommodated by the dump window of nominal 12.5cm diameter, and there is no need in additional collimation or usage of superconducting magnets. Figure 3 demonstrates the found solution. As one can see, 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. Beam size on the dump window is 17mm^2 in low energy spread case and less then 70mmx40mm in high energy spread case.

The specifications for the final design of considered extraction line are given in Table 1.

Table 1: Specifications for the final design of ILC RTML extraction line.

Class of magnets	Number of magnets	Length, m	Pole tip field (max), kG
Abort kicker	4	2	0.035
Tune-up bend	1	1	0.28
Septum bend	5	1	0.5
Bend	4	1	15
Quadrupole	1(figure-8)	0.5	10
	8	0.5	
	1	1	
Sextupole	1	0.3	5
	2	0.2	10
	1	1	10
	1	0.3	10

CONCLUSION

We described the final design of the ILC RTML extraction line located downstream of the new single-stage bunch compressor. The extraction line is only 24m long and is capable of accepting and transmitting 220kW of beam power. The EL can be used for both fast intra-train and continual extraction, and is capable of accepting both 0.15% and 3.54% energy spread beams at 5MeV and 4.37MeV respectively.

REFERENCES

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