SINGLE-STAGE BUNCH COMPRESSOR FOR ILC-SB2009

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Abstract

The Project Management Design Team of the International Linear Collider has recently proposed fundamental changes to the published ILC RDR baseline with the goal of presenting a potential alternate design providing a more cost-effective solution. In this framework a new lattice for the Damping Rings has been presented, shortening the exit bunch length from the RDR value of 9 mm down to 6 mm. The shorter bunch length allowed the adoption of a simpler single-stage bunch compressor, instead of the RDR two-stage compressor. The new single-stage compressor has a compression ratio of 20 and still achieves the nominal RDR value of 0.3 mm bunch length at the Interaction Point. The new design has been optimized to generate the required compression while having a small SR emittance growth, and reduced energy spread. The new lattice and its optimization procedure are presented in this paper.

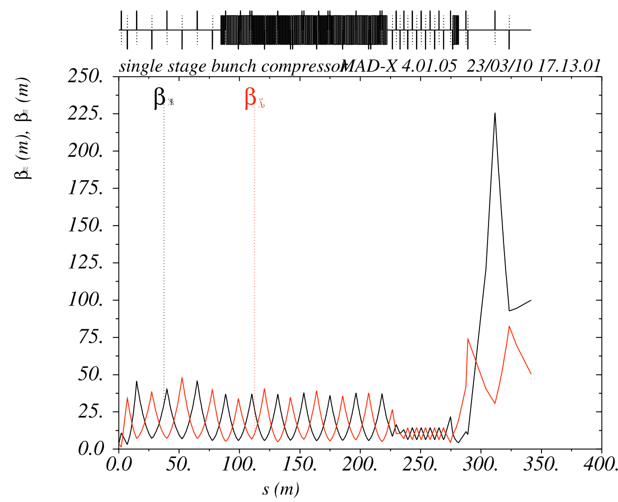

Figure 1: Twiss parameters of the single-stage bunch compressor

INTRODUCTION

The proposed bunch compressor reduces the RMS bunch length from 6 mm to 300 μm in a single stage of compression, with an RF section operating near its zero crossing, followed by a wiggler. The basic parameters of the bunch compressor are listed in Tab. 1. A version of this compressor was previously proposed in [1]; that design has been reviewed, updated and completed: the compressor parameters have been appropriately optimized, the wiggler has been made more flexible and tuned to minimize both optical aberrations and synchrotron-radiation-emission induced emittance growth, the final energy spread also has been kept minimal. A beam diagnostic stand, including bunch length and phase monitors and an emittance measurement station, is located after the wiggler. The bunch compressor is followed by a beam extraction line with a dump. The complete optics is shown in Fig. 1.

Differently from the ILC-RDR design, where the beam exited the two-stage bunch compressor at 15 GeV, in the SB-2009 proposal the beam leaves the single-stage bunch compressor at about 4.4 GeV, and it is directly injected into the main linac. A main linac section compensating for the energy difference must be added to the RDR main linac design.

LATTICE DESCRIPTION

The compressor requires a voltage over 1100 MV of RF cavities at a location where the bunch length is 6 mm. This voltage is achieved by 48 cavities arranged in six ILC-cryomodules type IV, embedded in a three-cells FODO lattice with 90 degrees phase advance per cell. Following the RF system, a short section composed by 4 quadrupoles matches the beam into the wiggler. The RF system introduces the energy-position correlation, the momentum compaction is provided by the wiggler.

The wiggler, that has a R_{56} equal to -170 mm, is based on the Seletzkiy-Tenenbaum prescriptions described in [2] and is embedded in a six-cells FODO structure with 90 degrees phase advance per cell. Two pairs of skew quadrupoles and two pairs of tuning quadrupoles, located $-\mathbf{I}$ apart from each other, are included in the lattice to correct the coupling and to cancel the residual dispersion at the wiggler exit.

The diagnostics includes: four laserwires, located 45 degrees phase advance from each other for emittance measurement; a LOLA cavity for measuring bunch length and phase offset.

Parameters Choice

Starting from an initial energy spread of 0.15% at 5 GeV, and an initial bunch length of 6 mm, a single-stage compressor increases the energy spread in the linear approximation to 3%, in the nominal 300 μm case. In the real case, the energy spread is even slightly larger, as it is necessary to decelerate the beam by running the RF back-phased in order to compensate the impact of the second-order momentum compaction, T_{566}. In a wiggler, it can be calculated that the T_{566} term is as large as -3/2 of the R_{56}. This, coupled with the large energy spread, can significantly contribute to an increase of the final bunch length.

When searching for the optimal set of parameters for the bunch compressor, one must also keep into account the nonlinearities due to the back-phased RF system. Therefore, the system must be optimized considering how these nonlinearities combine together. At its simplest, the problem is that the T_{566} of the compressor bending sections $\times R_{65}^2$, where R_{65} is the slope of the RF, can be comparable to the final bunch lengths of interest. This can be compensated to first order by running the beam some distance from the zero-crossing, where there is a nonzero RF curvature (T_{655}) term, and then ultimately balancing the product of $T_{655} \times R_{56}$ with $T_{566} \times R_{65}^2$ so that to lowest order the two terms cancel. It can be shown that for a wiggler or chicane-type compressor (i.e., one which does not bend or offset the beam with respect to its initial trajectory, which is the kind of BC considered for ILC), the compensation described above requires that the RF be decelerating in phase.

A scan of the parameters to find their optimum is visible in Fig. 2. This plot shows the minimum final bunch length achievable by a simplified single-stage bunch compressor as a function of the R_{56}, for different values of T_{566}, when varying voltage and phase of the RF section. This is the result of a semi-analytical calculation, where the RF section implements a realistic tracking through an appropriate accelerating system, whereas the effect of the wiggler is the result of the analytic formula: $z_f = z_i + R_{56}\,\delta_i + T_{566}\,\delta_i^2$, where z_i and δ_i are the initial coordinates of each particle in the longitudinal phase-space. The red-line shows the same thing as it results from a realistic 6d-tracking of a beam, made of single particles, through a realistic wiggler lattice. Not shown in the picture is the final energy spread as a function of the R_{56}. It can be shown that grows from left to right with the R_{56} (smaller R_{56}'s correspond to smaller final energy spreads).

Table 1: Parameters of the Single-Stage Bunch Compressor

Parameter	Value	Unit
Voltage	1106	MV
Phase	-119.2	$^\circ$
R_{56}	-170	mm
final σ_z	300	μm
final σ_δ	3.4	%
Energy loss	532.4	MeV

Wiggler Optimization

The wiggler consists of 6 identical cells that produce the required momentum compaction. The schematic of the cells is the following: every cell is contained in a FODO structure with 90° phase advance per cell. Focusing and defocusing magnets are placed in the zero dispersion regions. Four additional quadrupoles and four skew quads which are nominally set at zero currents can be used for turing of dispersion and removing of betatron coupling mismatches. Sixteen bends per cell allow the tuning of the R_{56}, while preserving beam's trajectory in the quads (see [2]).

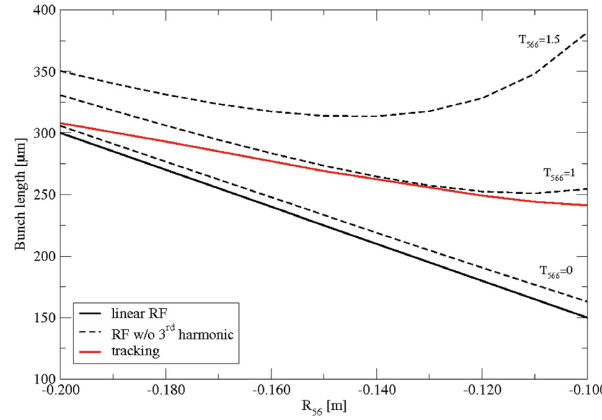

Figure 2: Minimum bunch length achievable by the single-stage bunch compressor as a function of R_{56} and T_{566}

The strengths of the sixteen bends are obtained using an optimization routine that: minimizes the I_5 radiation integral (a term that is proportional to the synrad-induced emittance growth), keeps the beam trajectory straight (to pass by the centers of the focusing/defocusing quads of the FODO structure), sets the R_{56} to the desired value, keeps the first order dispersion minimal.

Following this optimization, any residual first-order dispersion is removed by tuning the four additional quadrupoles that have been previously described.

PERFORMANCE

Emittance Growth

The misalignment of lattice elements and the transverse kicks due to the couplers impact the emittance and induce beam degradation. Misalignment of lattice elements can cause: dispersion, transverse kicks and head-tail intrabunch rotations. All these effects can ultimately lead to emittance blow up. Transverse kicks produced by the couplers present in the accelerating structures, also, can cause transverse kicks that induce emittance degradation[3]. Since the effect of couplers is roughly proportional to the bunch length (see [4]), they are harmful especially in the regions where the bunch is long, such as in the RF section of the bunch compressor.

These detrimental effects on the emittance can be mitigated using beam-based alignment methods. The BBA procedure adopted in this paper proceeds through 5 steps:

1. 1-to-1 correction: correctors steer the beam to pass through the centers of the bpms

2. dispersion free steering: the RF section is run off-phase by $\pm 5^\circ$ in order to generate two test beams, with different energy than the nominal, that are used to reduce the dispersion along the line[5]

3. dispersion bumps: the wiggler's skew quadrupoles are used as dispersion bumps and are tuned to minimize the emittance at the BC exit

4. girder pitch optimization: the cryomodules are tilted longitudinally to cancel transverse intrabunch kicks[6]

Results of the simulations, average of 100 random seeds, are visible in Fig. 3. Final emittance growth is 1.8 nm, without couplers, and 2.3 nm with couplers. Both cases are within the budget.

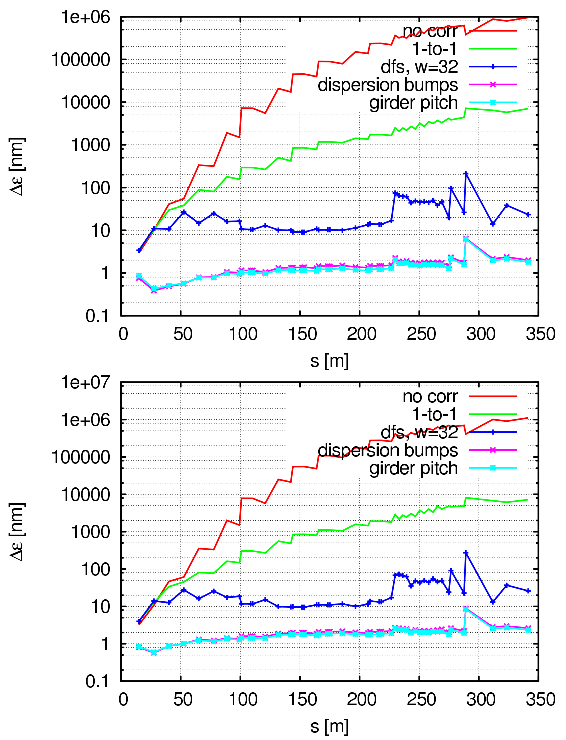

Figure 3: Emittance growth along the bunch compressor during beam-based alignment, in presence of static misalignments. In the upper plot the effects of the couplers' wakes.

CONCLUSIONS

A single-stage bunch compressor for ILC, compressing the bunches from 6 mm bunch length to 0.3 mm, is presented. Its design includes diagnostics and extraction line. The performances of the compressor are adequate and beam dynamics simulations do not show special threats with respect to the RDR two-stage compressor. The advantages of a single-stage bunch compressor are: its shorter length, it requires only a single beam diagnostics station and one extraction line with dump. It carries some drawbacks, though,: it is less flexible; the final energy spread is large, in excess of 3% RMS; it is necessary to compensate the T_{566} by running the RF backphased rather than at the zero-crossing, which reduces the beam energy in the linac and increases the RMS energy spread at linac injection;

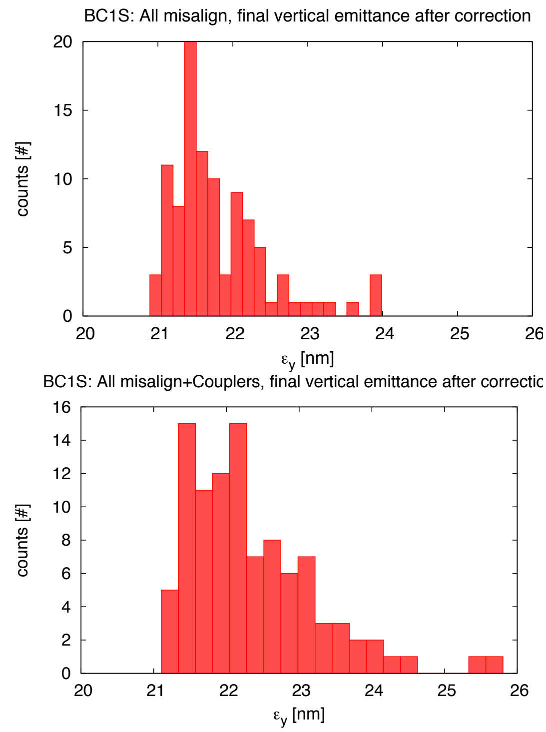

Figure 4: Histogram of emittance growth for 100 seeds after beam-based alignment. Top graph shows the result neglecting the couplers effect

even with T_{566} compensation, the remaining nonlinearities in the compression process require that the bunch be slightly overcompressed, resulting in a larger RMS energy spread. Larger compression ratios are hardly achievable with this design, since they would imply even larger final energy spreads and more RF cavities at the long-bunch location. Larger compression ratios could be achieved adding 3^{rd} harmonic cavities and sextupole magnets to correct for the optical aberrations.

REFERENCES

[1] P. Tenenbaum et al., "Multi-stage Bunch Compressors for the International Linear Collider", Proceedings of PAC 2005, Knoxville, Tennessee

[2] S. Seletskiy, P. Tenenbaum, "The Optimized Bunch Compressor for the International Linear Collider", Proceedings of PAC 2007, Albuquerque, New Mexico

[3] A. Saini et al., "Study of Coupler's Effects in ILC Like Lattice", this conference

[4] V. P. Yakovlev et al., "Final Results on RF Kick and Wake Caused by the RF Couplers", this conference

[5] T. O. Raubenheimer, D. Ruth, "A Dispersion-free Trajectory Correction Technique for Linear Colliders", SLAC-PUB-5222, October 1990

[6] A. Latina et al., "Emittance Dilution Caused by the Couplers in the Main Linac and in the Bunch Compressors of ILC", Proceedings of PAC 2009, Vancouver, Canada