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THE OPTIMIZED BUNCH COMPRESSOR FOR THE INTERNATIONAL LINEAR COLLIDER *

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Abstract

The International Linear Collider (ILC) utilizes a two stage Bunch Compressor (BC) that compresses the RMS bunch length from 9 mm to 200 to 300 micrometers before sending the electron beam to the Main Linac. This paper reports on the new design of the optimized BC wiggler. It was reduced in length by more than 30 %. The introduction of nonzero dispersion slope in the BC wigglers enabled them to generate the required compression while having a small SR emittance growth, a tunability range of over a factor of 2 in each wiggler, and less than 3 % RMS energy spread throughout the entire system.

INTRODUCTION

The ILC [1] Ring to Main Linac (RTML) is responsible for transporting and matching the beam from the Damping Ring to the entrance of the Main Linac. One of the main functions the RTML must perform is compression of the long Damping Ring bunch length by a factor of 30~45 to provide the short bunches required by the Main Linac and the IP. In order to achieve the required bunch compression, a two stage system is adopted [2].

BUNCH COMPRESSOR DESCRIPTION

The Bunch Compressor Parameters

The BC must provide compression in two modes: the nominal mode that requires 9mm to 0.3mm compression and the low charge mode that requires a shorter bunch in the IP and therefore the 9mm to 0.2mm compression. Table 1 summarizes the requirements to the main parameters of both the first stage (BC1) and the second stage (BC2) compressor for each of the modes.

The momentum compaction in both BC's stages is produced by the wiggler. Both BC1 and BC2 wigglers consist of 6 identical cells. The schematic of the cell is shown in Figure 1. Every cell is contained in FODO structure with 90^{O} 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 the correction of possible dispersion without introducing betatron coupling or mismatches. Sixteen bends allow tuning R56 while preserving beam's trajectory in quads.

Requirements to BC

Initially the bunch compressor was designed with 239m long wigglers for both stages [3]. Shorter wigglers with same R56 would require more bending and eventually would cause synchrotron radiation (SR) related emittance growth (see Eq. 1).

Table 1: Specifications for the two stages of bunch compressor. Bunch lengths and energy spreads are RMS values, which are somewhat larger than fitted Gaussian widths of the beam distributions.

Parameter	**BC1 value**	**BC2 value**
Nominal configuration		
Initial bunch length	9 mm	1.2 mm
Final Bunch length	1.2 mm	0.3 mm
Initial energy	5 GeV	4.88 GeV
Final energy	4.88 GeV	15 GeV
Initial energy spread	0.15%	2.4%
Final energy spread	2.4%	1.8%
RF voltage	448 MV	11.4 GV
RF phase	-105^{O}	-27.6^{O}
Wiggler R56	-376 mm	-55 mm
Low charge configuration		
Initial bunch length	9 mm	1.5 mm
Final bunch length	1.5 mm	0.22 mm
Initial energy	5 GeV	4.88 GeV
Final energy	4.88 GeV	13.7 GeV
Initial energy spread	0.15%	2.4%
Final energy spread	2.4%	3.1%
RF voltage	451 MV	11.7 GV
RF phase	-105^{O}	-40.9^{O}
Wiggler R56	-353 mm	-47 mm

$$\Delta\varepsilon_N \propto E^6 \cdot I_5 \quad (1)$$

Here ε_N is the normalized emittance, E is beam energy, and $I_5 = \int \frac{\beta\eta'^2 + 2\alpha\eta\eta' + \gamma\eta^2}{\rho^3} ds$ is radiation integral; α, β, γ are the Twiss parameters, ρ is the orbit curvature radius and η is dispersion function [4].

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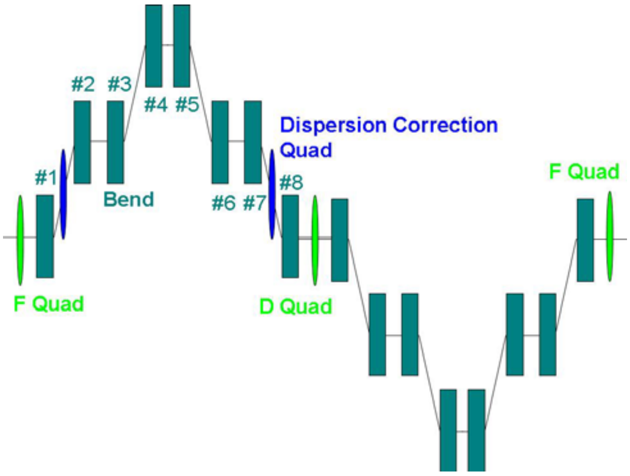

Figure 1: Wiggler's cell schematic

On other hand, wigglers with longer magnets and inter-magnet spacing naturally drive up the costs of both tunnelling and hardware.

We suggest that it is possible to reduce wiggler's length while keeping both the required R56 value and reasonably low bending angles by introducing nonzero dispersion slope (η') at the entrance of each cell. However, designing BC with nonzero η' turns out to be a tricky business. Keeping the wigglers tuneable requires steady beam trajectory in all quadrupoles for changed R56. We also require zero dispersion in FODO quads in order to keep the second order dispersion of the system close to zero, plus we constrain initial and final η' in wiggler's cell to be equal.

OPTIMISATION OF THE BUNCH COMPRESSOR

Optimisation Procedure

To fulfil the above requirements to BC design the following optimisation procedure was suggested.

- We keep η' together with the bending angles of bends #1 and #8 (see Figure 1) constant for different R56. This ensures that the beam is not moved in the quads when wigglers are tuned.
- We zero trajectory displacement Δx over the half of the cell (Eq. 2). By doing so we fix the beam trajectory at wiggler's exit to the reference orbit.

$$\Delta x = \sum_{n=1}^{8} L_{d\,n} \sin(\theta_{out\,n-1}) + \sum_{n=1}^{8} L_b \frac{\cos(\theta_{in\,n}) - \cos(\theta_{out\,n})}{\sin(\theta_{in\,n}) + \sin(\theta_{out\,n})} \qquad (2)$$

Here L_d and L_b are bend-to-bend's drift and bend lengths respectively, $\theta_{in\,n}$ and $\theta_{out\,n}$ are trajectory angles at the entrance and exit of bend number n, and $\theta_{out\,0} \equiv \eta'$ by definition.

- We force η' at the exit of each cell be equal to its entrance value and we keep zero dispersion in FODO quads by requiring $\sum_{1..8}\varphi_n = -2\eta'$ (φ_n is n'th bending angle) and by requiring the mirror symmetry of the first and second halves of the cell.
- Finally, we run the MAD [5] matching routine explicitly constraining R56 to the required value and I_5 to 0 and varying 5 bending angles.

Results

We looped through the procedure described above several times reducing the bends lengths and spacing and trying out different values of η', φ_1 and φ_8 for each length. The ultimate solution allowed us to reduce the total wiggler's length down to 141m for BC1 and 147m for BC2. At the same time the horizontal emittance growth due to the SR is kept below 5.5% for both configurations.

Figure 2 shows beta functions and dispersion for the cell of optimised BC2. Figure 3 shows the beam trajectories for the nominal and low charge configurations in BC2 cell. The respective shift of trajectory in each of the quads is below 10nm. The trajectory returns to the reference orbit at the exit of the wiggler.

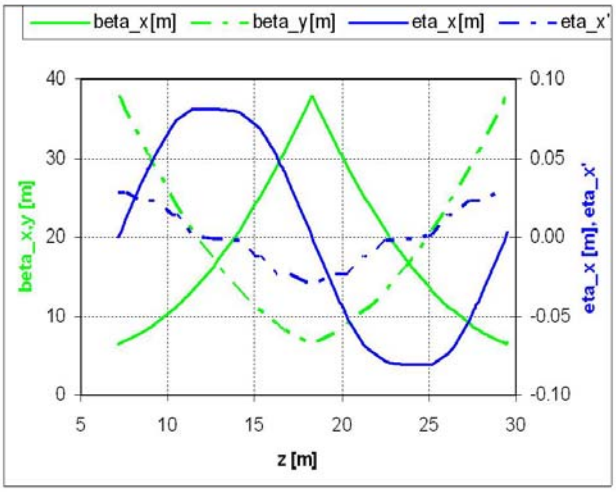

Figure 2: Twiss parameters in BC2 cell.

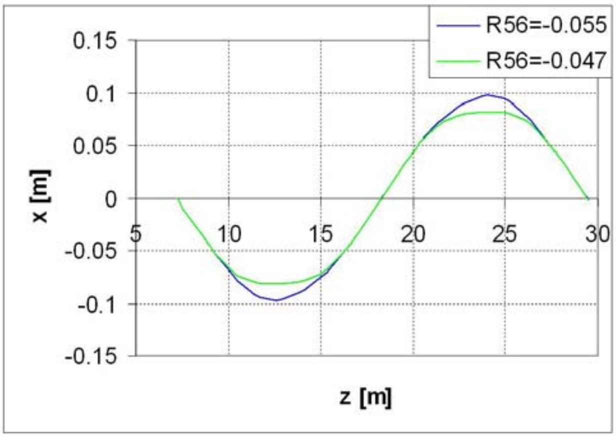

Figure 3: Beam trajectories in BC2 cell for the nominal (blue trace) and low charge (green trace) configurations.

Figure 4 shows the horizontal phase space of compressed beam. One can see that compression down to 0.2mm approaches the limits of linear phase space manipulation.

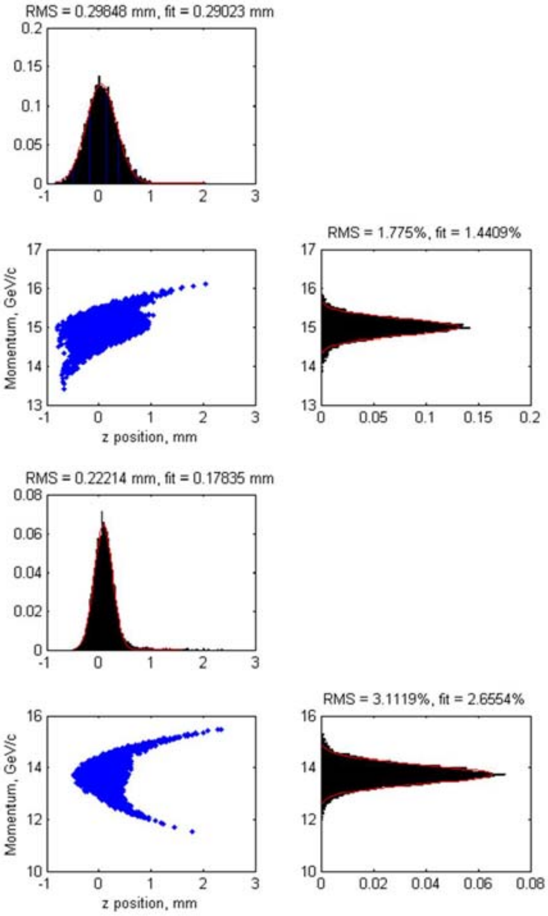

Figure 4: The phase space of the beam compressed to 300um (upper plot) and 200um (lower plot).

ADDITIONAL CONFIGURATIONS

The two bunch compressor configurations presented here set the R_{55} from the damping ring to the main linac to zero, which relaxes the tolerances on synchronous phase variation in the damping ring. The flexibility of the compressor system presented here is sufficient to operate in an alternate set of configurations in which R_{56} is instead set to zero. These configurations would increase the sensitivity to the damping ring synchronous phase variation but would reduce the typical energy spread in the compressor, which would in turn loosen the transverse alignment tolerances in the compressor.

CONCLUSION

In the course of cost optimisation of the Ring to Main Linac Bunch Compressor we managed to reduce its wigglers' lengths by about 38%. To do so we derived and successfully applied the optimisation algorithm based on the introduction of nonzero dispersion derivative in the wigglers.

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