RENOVATED 2-STAGE BUNCH COMPRESSOR FOR THE INTERNATIONAL LINEAR COLLIDER

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Abstract

The International Linear Collider (ILC) utilizes a Bunch Compressor (BC) in the Damping Ring to Main Linac Transfer Line (RTML) that compresses the RMS bunch length from 6 mm to 300 micrometers before sending the beam to the Main Linac. It was decided to utilize a two stage BC for the design baseline, since it provides an additional option for the ILC to work with 150 micrometers long bunches and reduces the energy spread at the RTML exit under normal operational conditions. In this paper we report the new design of the optimized two-stage bunch compressor.

INTRODUCTION

The ILC [1] 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 ~20 to provide the short bunches required by the Main Linac and the IP.

CHOICE OF THE PROPER BUNCH COMPRESSOR

The BC must work in the nominal operational mode that requires 6 mm to 0.3 mm compression. In addition to that it is considered beneficial to have the ability to compress the beam from 6 mm to 0.15 mm. This option is important for the future upgrades of the ILC.

In the process of designing the RTML two realistic options were considered.

Since initially it was required to compress a 9 mm beams it was suggested to utilize a two stage bunch compressor [2] with tuneable R56 that allowed for beam compression from 9 mm to both 0.3 mm and 0.2 mm. The momentum compaction in both BC's stages (BC1 and BC2) of such compressor is produced by the wiggler.

Both BC1 and BC2 wigglers consist of 6 identical cells. The schematic of the cell and respective Twiss parameters are shown in Figures 1 and 2. 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.

The length of each wiggler was minimized while keeping both the required R56 value and reasonably low bending angles (and thus limiting the horizontal emittance growth due to the synchrotron radiation) by introducing nonzero dispersion slope (η') at the entrance of each cell. At the same time we kept the wigglers tuneable, that is, we made the beam trajectory in all quadrupoles steady for changed R56 values.

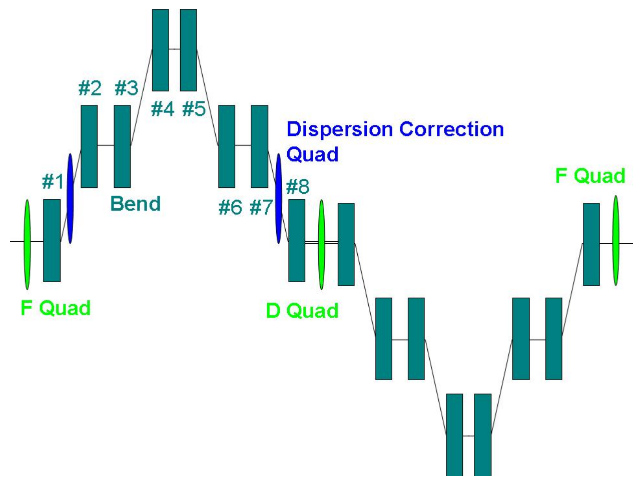

Figure 1: Wiggler cell schematic.

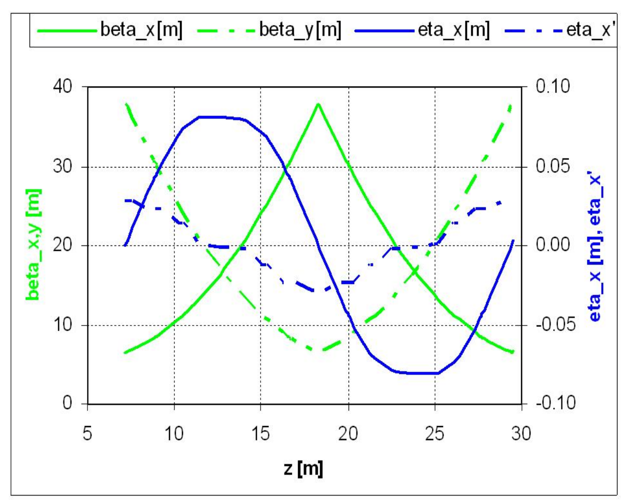

Figure 2: Horizontal and vertical beta functions (green) and dispersion and dispersion slope (blue) in the wiggler cell.

As one can see from Figure 2, the dispersion in FODO quads is zero in order to keep the second order dispersion of the system close to zero. The mirror symmetry of the first and second halves of the cell (see Figure 1) together with the requirement to the sum of 8 bending angles in each half of the cell to be equal to $-2\eta'$ forces η' at the exit of each cell to be equal to its entrance value.

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This solution allowed us to reduce the overall length of the bunch compressor significantly [2] as compared to the BC with more conventional wigglers [3]. The optimized wigglers lengths are 141m for BC1 and 147m for BC2.

Switching the ILC to the operational mode requiring compression of the 6 mm long beam led to the design of a single stage bunch compressor [4]. This compressor consists of the RF system introducing the energy-position correlation and the described above wiggler re-optimized for new conditions. Elimination of the second stage of the bunch compressor results in the substantial reduction in the beamline length (314 meters) and removal of some hardware.

Apparently the advantage of a single stage bunch compressor is its price. On the other hand the two stage bunch compressor suggests more flexibility and smaller energy spread throughout the RTML. Moreover, the final beam length of 0.3 mm is at the limit of what is achievable with a single stage BC. Therefore the option of the future ILC upgrade to 0.15 mm is unfeasible with the single stage bunch compressor. These considerations resulted in a decision to utilize the two-stage BC for the ILC RTML [5, 6].

OPTIMISATION OF THE 2-STAGE BUNCH COMPRESSOR

In the latest ILC design in the 5 Hz operational mode both the electron and the positron beams have 0.11% energy spread at the entrance of the bunch compressor. In the 10 Hz operational mode the electron beam has 0.12% energy spread upstream of the BC and the positron beam has 0.137% energy spread at the BC entrance.

We tuned the bunch compressor parameters for these three cases so that at the BC exit the beam is 0.3 mm long and the R56 for both stages is reasonably small. The resulting BC specifications are presented in Table 1. The example of the longitudinal phase space of the compressed beam is show in Figure 3.

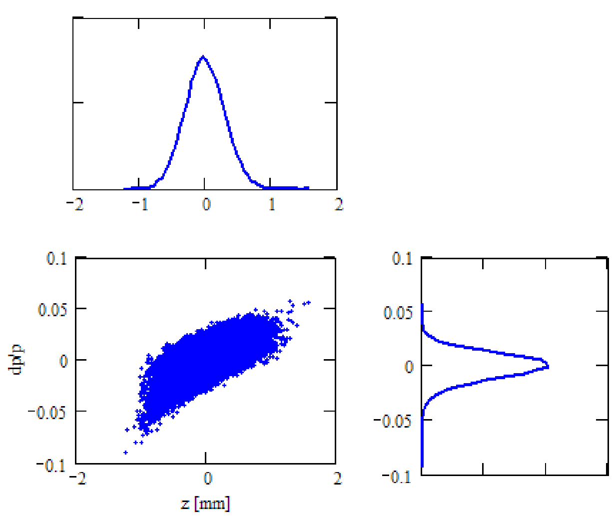

Figure 3: Longitudinal phase space of the compressed beam (positron beam, 10Hz operational mode).

Table 1: Specifications for the two stages of the BC. The final BC2 energy spread is given for the energy that the beam has at RTML to Main Linac treaty point (15GeV)

Parameter	**BC1 value**	**BC2 value**
5 Hz mode configuration for both electrons and positrons		
Initial bunch length, rms	6 mm	0.9 mm
Final Bunch length, rms	0.9 mm	0.3 mm
Initial energy	5 GeV	4.8 GeV
Final energy	4.8 GeV	14.9 GeV
Initial energy spread, rms	0.11 %	1.42 %
Final energy spread, rms	1.42 %	1.12 %
RF voltage	465 MV	11 GV
RF phase	-115^{O}	-24^{O}
Wiggler R56	-372 mm	-55 mm
10 Hz mode configuration for electrons		
Initial bunch length, rms	6 mm	0.9 mm
Final Bunch length, rms	0.9 mm	0.3 mm
Initial energy	5 GeV	4.8 GeV
Final energy	4.8 GeV	14.8 GeV
Initial energy spread, rms	0.12 %	1.42 %
Final energy spread, rms	1.42 %	1.17 %
RF voltage	465 MV	11 GV
RF phase	-115^{O}	-25.3^{O}
Wiggler R56	-372 mm	-55 mm
10 Hz mode configuration for positrons		
Initial bunch length, rms	6 mm	0.9 mm
Final Bunch length, rms	0.9 mm	0.3 mm
Initial energy	5 GeV	4.8 GeV
Final energy	4.8 GeV	14.6 GeV
Initial energy spread, rms	0.137 %	1.42 %
Final energy spread, rms	1.42 %	1.24 %
RF voltage	465 MV	11 GV
RF phase	-115^{O}	-27.2^{O}
Wiggler R56	-372 mm	-55 mm

As one can see this solution easily provides compressed beams for all three scenarios and keeps energy spread throughout the RTML below 1.5%. The presented two stage bunch compressor can also be tuned to compress the beam down to 0.15 mm. For instance, for the case of the positrons in 10 Hz operational mode the BC1 parameters stay unchanged to keep the energy spread at BC1 low and BC2 R56 is -40 mm, RF2 phase and voltage are -48.4^{O} and 12.3 GV respectively. The resulting beam is 0.15 mm long and has 1.9% energy spread at 15GeV. The beam energy out of the bunch compressor is 13GeV. Figure 4 shows the longitudinal phase space of the respective beam.

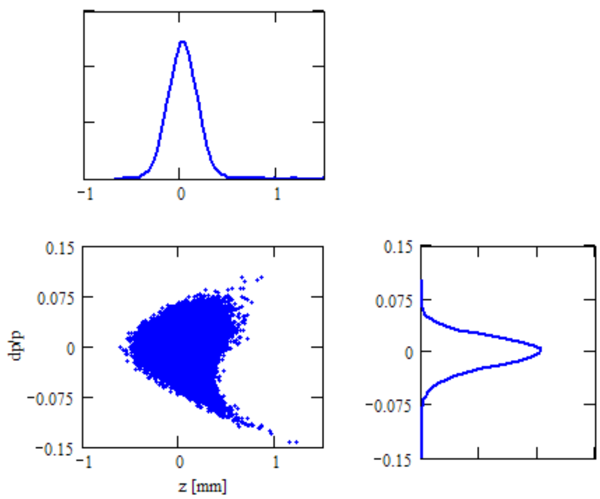

Figure 4: Longitudinal phase space of the beam compressed to 0.15 mm (positron beam, 10Hz operational mode).

CONCLUSION

We reviewed the two possible options for the ILC RTML bunch compressor.

While a single stage bunch compressor has a shorter length and therefore is less pricy, the two-stage bunch compressor gives a lower energy spread throughout the RTML and is feasible for compression of the 6 mm beam down to 0.15 mm.

Since this option is important for possible ILC upgrades the 2-stage BC was chosen for the final ILC design. We tuned the 2-stage BC parameters for three operational cases of the beam initial energy spread to provide 0.3 mm compressed beam. In addition, we demonstrated the compression of the beam with the largest of three operational energy spreads to 0.15 mm.

ACKNOWLEDGEMENTS

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