DESIGN AND CONTROL OF EMITTANCE GROWTH OF A SHORT BUNCH COMPRESSOR FOR THE INTERNATIONAL LINEAR COLLIDER

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Abstract

We present a short two-stage bunch compressor system that has been selected as an alternative design in Baseline Configuration Design (BCD) for the ILC (International Linear Collider). The designed bunch compressor system has two rf sections and two chicanes in which each chicane consists of four bending magnets. The bunch compressor system has a 680 m long that shows relatively short system length compared to baseline design for the ILC. Beams with bunch length of 6 mm rms can be compressed to 0.15 mm rms in the bunch compressor system. We show the parameters of the bunch compressor and results of beam tracking including coherent and incoherent synchrotron radiations. We performed the lattice tuning such as corrections of orbit distortion, dispersion and skew components to control the emittance growths due to several machine errors in the bunch compressor system. It is shown that the system is error tolerant and the lattice tunings are very effective to suppress the emittance growth.

INTRODUCTION

The damping ring in the ILC BCD was designed to deliver beams of 5 GeV, energy spread of 0.15 % rms, bunch length of 6 mm rms, horizontal emittance of 8.0 μm and vertical emittances of 0.02 μm[1]. The BCD required very short bunch length of 0.15 mm rms in the main linac that may reduce dilution effect of transverse wakefields on the vertical emittance. We investigated a two-stage bunch compressor because a single-stage bunch compressor would produce a beam with large energy spread and big error tolerance.

ILC BCD includes both wiggler-based and chicane-based bunch compressors. In this paper, we present a design for a short two-stage bunch compressor that is based on chicanes. The chicane with four bending magnets does not include quadrupole magnets at dispersion regions.

Bunch compression is achieved by an energy-position correlation in a rf section and by bending sections with energy-dependent path length. Our bunch compressor systems shows a π/2 longitudinal bunch rotations in the longitudinal phase space: The first one is performed by RF systems that correlate the relative momentum of the particles in the bunch. The second one is performed by chicanes that have negative R_{56}. In result, the phase errors generated in the damping ring do not translate into phase errors in the main linac which may generate large energy deviation in the final focus beam. The compressor system can reduce the bunch length of 6 mm rms to 0.15 mm rms. It is shown that final horizontal and vertical emittances in the bunch compressor become 8.6 μm and 0.02 μm, respectively. It is shown that the system has enough error tolerance with the lattice tunings such as the corrections of orbit distortion, the dispersion and the skew component.

DESIGN OF AN ALTERNATIVE TWO-STAGE BUNCH COMPRESSOR

The entire bunch compressor consists of a matching section, a rf section, first chicane, a rf section and second chicane, where each chicane is composed of four bending magnets with length of 6.8 m long each. The two rf sections include L-band RF systems and the optics for the designed bunch compressor is shown in Fig. 1.

The total length of two chicanes is 68.4 m long and the chicane is designed to keep the growth of the horizontal emittance small with respect to the 8 μm emittance. Particle's motions in the bunch compressor are tracked by using of the code ELEGANT[2] to investigate how the beam will behave in the bunch compressor system. Parameters of the bunch compressor are shown in Table I. Figure 2 and 3 show the longitudinal phase spaces at initial beam distribution and after passing the first chicane, respectively. Fig. 4 shows the longitudinal phase space after compression from 6 mm rms to 0.15 mm rms length.

The RF section between the BC1 and BC2 contains normal and skew quadrupoles. The normal quadrupoles are arranged in triples in region of zero dispersion. 4 skew quadrupoles are also set in region of zero dispersion, which allow complete and independent control of the 4 betatron coupling terms. The skew quadrupoles are used to correct coupling introduced by rotation errors in the quadrupoles and bendings in the bunch compressor.

TUNING OF EMITTANCE GROWTHS DUE TO MACHINE ERRORS

For our lattice tuning simulation, alignment error of 300 μm rms and rotation error of 300 μrad rms in all magnets are set. To consider the misalignment of the BPM, each BPM is assumed to have offset error of 300 μm rms. The random errors are given by Gaussian distribution. Correction of the vertical dispersion that is generated by skew components is also performed by 4 skew-quadrupoles. We performed both the dispersion correction and the orbit correction at the same time such that they have a minimum

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value.

The horizontal and the vertical orbits are calculated by every BPM and then their orbit distortions due to the machine errors are corrected by using all the horizontal and vertical steering magnets, respectively. The orbit corrections are performed to minimize

$$< z^2 >= \frac{1}{N_{BPM}} \sum_i z_i^2, \tag{1}$$

where z_i denotes the horizontal(x) and vertical(y) orbits in ith BPM and N_{BPM} is the total number of the BPM. Additional horizontal and vertical kick angles $\theta_{x,y}$ are calculated to minimize

$$\sum_i [z_i - \sum_p z_{i,p}(\theta_{x,y})]^2, \tag{2}$$

where $z_{i,p}$ denotes the horizontal and vertical orbits at ith BPM after the kicks $\theta_{x,y}$ by the pth steering magnet. The dispersion functions are corrected by keeping the orbit distortion small and by using all the steering magnets. The dispersion corrections are performed to minimize

$$< \eta_z^2 >= \frac{1}{N_{BPM}} \sum \eta_{z,i}^2, \tag{3}$$

where $\eta_{z,i}$ denotes the horizontal and vertical dispersions at ith BPM. Additional kick angles $\theta_{x,y}$ are calculated to minimize

$$\sum_i [\eta_{z,i} - \sum_p \eta_{z,i,p}(\theta_{x,y})]^2, \tag{4}$$

where $\eta_{z,i,p}$ is the horizontal and vertical dispersions at ith BPM after the kicks $\theta_{x,y}$ by the pth steering magnet.

Fig. 5 shows the growth of the vertical emittance for the different magnitude of quadrupole alignment errors without and with the tuning of the lattice. Fig. 6 shows the optics and orbit distortions due to the machine errors in all magnets. Then horizontal and vertical emittances are increased by factors of 1.48 and 254, respectively. Fig. 7 shows the optics and the orbit distortions after the lattice tunings. The horizontal and vertical emittances are significantly reduced by the tunings, resulting in the increasing in factors of 1.00 and 1.04, respectively. It is shown that it is effective to correct the orbit distortion and the dispersion simultaneously to suppress the emittance growths due to the machine errors. With the tuning of the lattice, it is shown that the beta and dispersion functions can be well recovered with those when the machine errors do not exist, as shown in Fig. 1. Fig. 8 shows the growth of the vertical emittance for the different magnitude of the error of quadrupole rotation without and with the correction of skew components by the 4 skew quadrupoles. Misalignment of the BPM may cause systematic errors in measuring the beam positions. This error was also included as a random offset. In our simulations, it was shown that the offset error of 300 μm does not affect the emittance.

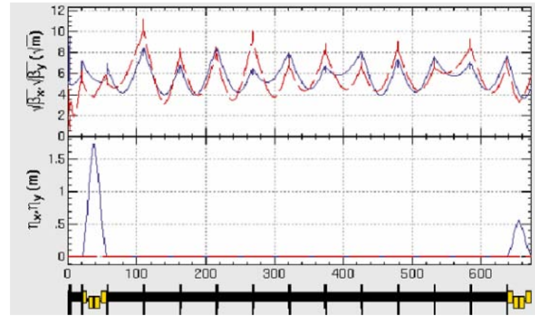

Figure 1: Optics of a short two-stage bunch compressor.

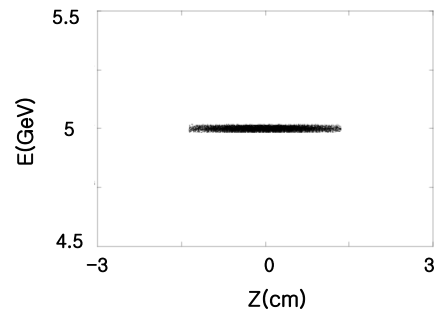

Figure 2: Longitudinal phase space of the initial beam.

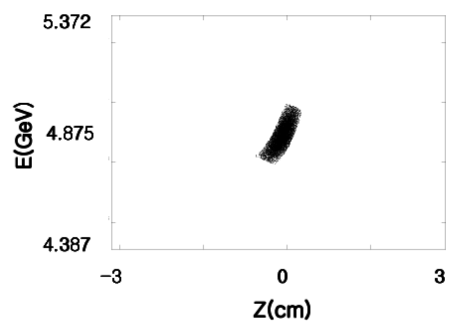

Figure 3: Longitudinal phase space after first chicane.

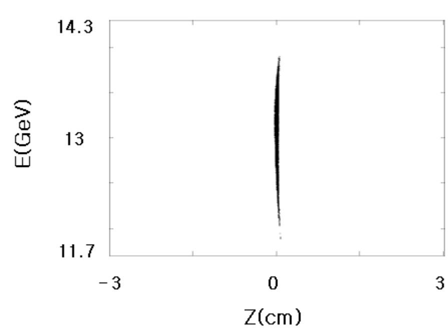

Figure 4: Longitudinal phase space after second chicane.

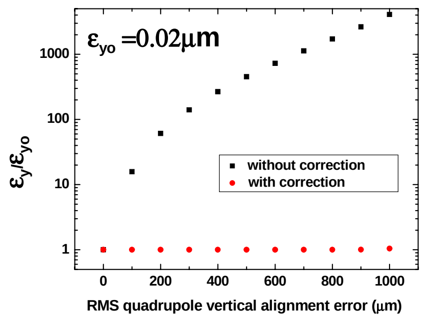

Figure 5: Vertical emittance vs. vertical alignment error in qaudrupoles without and with the tuning of the lattice.

Table 1: Parameters of the bunch compressor.

Parameter	Units	Values
Length	m	680
Initial beam energy	GeV	5
Initial bunch charge	nC	3.2
Initial rms energy spread	%	0.15
Initial rms bunch length	mm	6
Initial rms emittance (H/V)	μm	8 / 0.02
RF voltage in 1st RF section	MV	348
RF gradient in 1st RF section	MV/m	29
RF phase in 1st RF section	degree	-114
Bending angle at chicane 1	degree	10.43
Chicane 1 R_{56}	mm	-474.2
End chicane 1 rms bunch length	mm	1.1
End chicane 1 energy	GeV	4.86
End chicane 1 energy spread	%	1.1
RF voltage in 2nd RF section	MV	11800
RF gradient in 2nd RF section	MV/m	27
RF phase in 2nd RF section	degree	-45
Bending angle at chicane 2	degree	3.43
Chicane 2 R_{56}	mm	-50.8
End rms bunch length	mm	0.15
End energy	GeV	13.26
End rms emittance (H/V)	μm	8.6 / 0.02
End bunch charge	nC	3.2
End rms energy spread	%	2.6

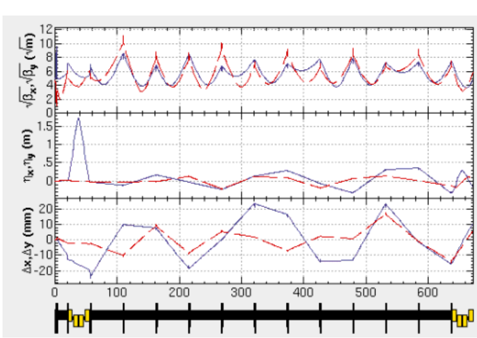

Figure 6: Beta function, dispersion and orbit distortion with the machine errors.

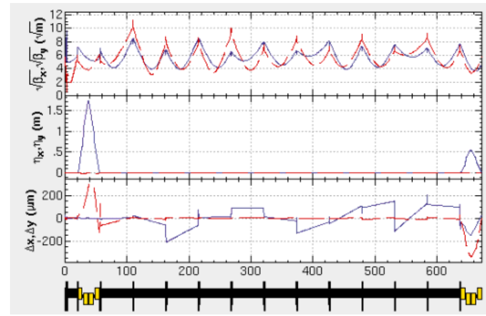

Figure 7: optics and orbit distortion after the tunings of the lattice with the machine errors.

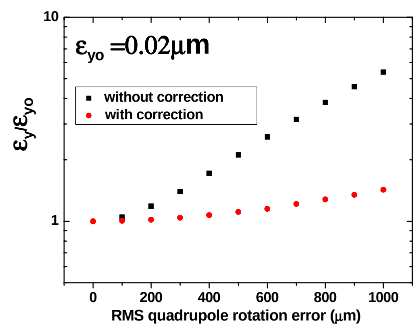

Figure 8: Vertical emittance vs. quadrupole rotation errors without and with the correction of the skew components.

SUMMARY

We presented the design of the alternative bunch compressor which is based on the two chicanes. It is shown that the bunch compressor system satisfies the requirements for the ILC BCD and provides enough error tolerance for conservative machine errors. With the lattice tunings, it is also shown that the optics in the bunch compressor is well recovered and the growth of the emittance is acceptably controlled.

REFERENCES

[1] ILC GDE meeting, Frascati, Italy, 7-10 December (2005).

[2] M. Borland, APS LS-287 (2000).