DESIGN OF SHORT BUNCH COMPRESSORS FOR THE INTERNATIONAL LINEAR COLLIDER

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Abstract

Design of a damping ring in the ILC (International Linear Collider) imposes bunch length of 6 mm rms and energy spread of 0.15 % rms. This paper investigates bunch compression that provides required compression of beams for the ILC. We present a short two-stage bunch compressor system that has been selected as alternative design in Baseline Configuration Design (BCD) for the ILC. 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 extracted from the damping ring can be compressed to 0.15 mm rms in the designed two-stage bunch compressor system that meets the required compression of beams for the ILC. We show results of beam tracking in the transverse and longitudinal planes including coherent and incoherent synchrotron radiations. These analysis shows that the short two-stage bunch compressor may provide the beam with the required characteristics at the entrance of the main linac.

In addition to the short two-stage bunch compressor, we also present a short single-stage bunch compressor with a 80 m long that may be considered as an option for the bunch length of 300 μm rms in the interaction point.

INTRODUCTION

ILC design demands 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. The damping ring of the ILC was designed to deliver a beam at the energy of 5 GeV, relative energy spread of 0.15 % rms and bunch length of 6 mm rms. Thus, a compression factor of 40 should be achieved in the bunch compressor.

BCD for the ILC includes both wiggler-based and chicane-based two stage bunch compressors. In this paper, we present a design for the short two-stage bunch compressor and a single-stage bunch compressor that are based on chicanes. An important characteristic of the bunch compressor is the ratio of second-order momentum compaction, T_{566}, to linear momentum compaction, R_{56}. For a chicane with four bending magnets, which include no focusing magnets at dispersion regions, path length of a particle is given by a function of the relative energy deviation δ,

$$z(\delta) = R_{56}\delta + T_{566}\delta^2 + \cdots, \qquad (1)$$

and then the ratio of the momentum compaction is

$$T_{566}/R_{56} = -3/2. \qquad (2)$$

For longitudinal coordinates with bunch head at $z < 0$, the R_{56} for a chicane is always negative and the T_{566} is then always positive.

Design of the bunch compressor system for the ILC must satisfy several requirements: (1) The system can make reduce the bunch length to the size of 0.15 mm rms. (2) The system must perform a 90 degree longitudinal phase space rotation so that phase errors generated in the damping ring do not translate into phase errors in the main linac which in result can generate large energy deviations in the final focus test beam. (3) The system must not cause growth of transverse emittances of 8 μm in horizontal and 0.02 μm in vertical. (4) The system should be short and as error tolerant as possible.

Bunch compression in our designs is achieved by introducing an energy-position correlation in a bunch with a rf section and by a bending section with energy dependent path length. The designed bunch compressor systems in this paper show a $\pi/2$ longitudinal bunch rotation that consists of two rotations in the longitudinal phase space. The first one is obtained by RF systems that correlate the relative momentum of the particles in the bunch. The second one is achieved by chicanes that have negative R_{56}.

TWO-STAGE BUNCH COMPRESSOR

Alternative design of the bunch compressor system for the ILC shows a two-stage bunch compressor that is based on the chicanes to compress electron and positron beams, the bunch length of 6 mm rms at 5 GeV energy, to a 0.15 mm rms bunch length. The designed two-stage bunch compressor system 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. The two rf sections include L-band RF components and the designed optics for the 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 horizontal emittance growth small with respect to the 8 μm emittance. Particle's motions in the two-stage bunch compressor system are examined by the code ELEGANT. The parameters of the system are tracked to investigate how the beam will behave in the chicanes and rf sections. Figures 2-4 show the longitudinal phase spaces at initial beam distribution, after passing the first chicane and the second chicane, respectively. Parameters of bending magnets are shown in Table 1.

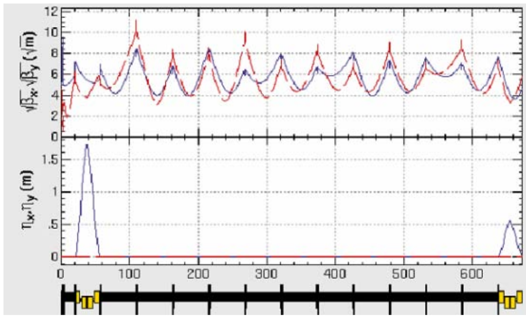

Figure 1: Optics for the short two-stage bunch compressor.

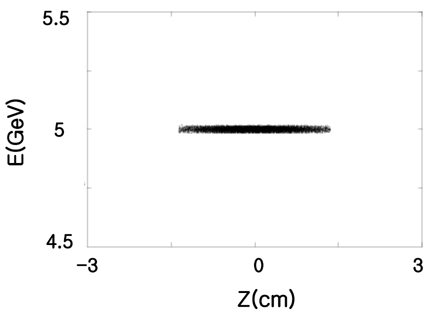

Figure 2: Longitudinal phase space of the initial beam.

The energy-position correlation at the entrance of the first chicane with the length of 34.2 m long is introduced by 12 nine cell cavity that have length of 1 meter each and acceleration gradient of 29 MV/m and rf phase angle of -114 degree in order to provide the necessary 348 MV for bunch compression of factor of 5.4. With the initial 0.15 % rms energy spread the horizontal beam size becomes 2.55 mm at the peak dispersion of 1.7 m. Bunch length, beam energy and energy spread after first chicane are 1.1 mm rms, 4.86 GeV and 1.1 %, respectively.

The energy-position correlation at the entrance of the second chicane is introduced by 440 nine cell cavity that have length of 1 meter each and acceleration gradient of 27 MV/m and rf phase angle of -45 degree in order to provide the necessary 11800 MV for bunch compression of factor of 7.3. With the 1.1 % rms energy spread the horizontal beam size becomes 6.6 mm at the peak dispersion of 0.6 m in the second chicane. Obtained final bunch length is 0.15 mm rms, and final beam energy and energy spread are 13 GeV and 2.6 %, respectively. Parameters of the two-stage bunch compressor are shown in Table 2.

SINGLE STAGE BUNCH COMPRESSOR

The parameters of the designed single-stage bunch compressor are listed in Table 3. The designed optics for the bunch compressor is shown in Fig. 5. Obtained final bunch

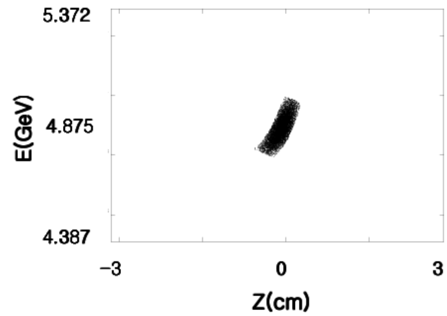

Figure 3: Longitudinal phase space after the first chicane in the two-stage bunch compressor.

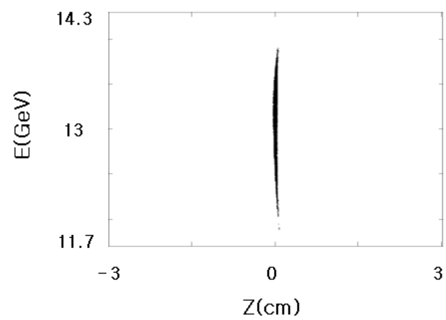

Figure 4: Longitudinal phase space after the second chicane in the two-stage bunch compressor in the two-stage bunch compressor.

length is 0.3 mm rms and the deceleration in the system is just 0.5 GeV. The relative energy spread at the entrance of the main linac is 3.5 %. The value is larger than the second-stage bunch compressor and this is an inevitable result of using a single-stage bunch compressor. Fig. 6 shows beam distribution in the longitudinal phase space at the exit of the bunch compressor. From the comparison of the Fig. 4 and Fig. 6, the two-stage bunch compressor shows an advantage of shaping the beam distribution by pulling the Gaussian tails in toward the core.

The energy-position correlation at the entrance of the first chicane is introduced by 33 nine cell cavity that have length of 1 meter and acceleration gradient of 34 MV/m and rf phase angle of -118 degree for bunch compression of factor of 20. With the initial 0.15 % rms energy spread the horizontal beam size becomes 1.42 mm at the peak dispersion of 0.95 m. Parameters of the single-stage bunch compressor are shown in Table 3.

CONCLUSION

We presented designs of the short two-stage and one-stage bunch compressors that are based on the two chicanes, which provide the bunch lengths as short as 150 μm

Table 1: Bending magnets in chicanes of the two-stage bunch compressor.

	At chicane 1	At chicane 2
Number	4	4
Bending angle	10.43 deg.	3.43 deg.
Length of a bend	6.8m	6.8 m
Length between B1 and B2	0.4 m	0.4 m
Length between B2 and B3	2 m	2 m

Table 2: Parameters of the two-stage 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
Inital rms bunch length	mm	6
Initial rms emittance (H/V)	μm	8 / 0.02
RF voltage in 1st RF section	MV	348
RF phase in 1st RF section	degree	-114
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 phase in 2nd RF section	degree	-45
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

Table 3: Parameters of the single-stage bunch compressor.

Parameter	Units	Values
Legnth	m	80
Initial beam energy	GeV	5
Initial bunch charge	nC	3.2
Initial rms energy spread	%	0.15
Inital rms bunch length	mm	6
Initial emittance (H/V)	μm	8 / 0.02
RF phase	degree	-118
Chicane R_{56}	mm	-190
Bending angle	deg.	6
Length of a bend	m	4.16
End rms bunch length	mm	0.3
End energy	GeV	4.5
End bunch charge	nC	3.2
End emittance (H/V)	μm	8.3 / 0.02
End energy spread	%	3.5

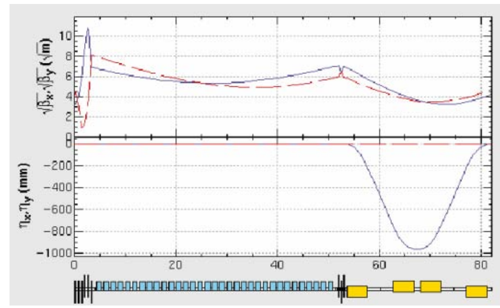

Figure 5: Optics for short singe-stage bunch compressor.

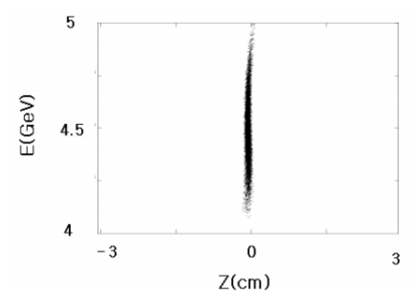

Figure 6: Longitudinal phase space after the chicane in the single-stage bunch compressor.

and 300 μm, respectively. The single-stage bunch compressor shows relatively large energy spread at the entrance of the main linac that may affect the performance of the ILC. The designed two-stage bunch compressor is a reasonable option which satisfies the requirements for the ILC and it needs a short system length.

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