Linear Collider Collaboration Tech Notes

More Options for the NLC Bunch Compressors

January 7, 2000

Paul Emma
Stanford Linear Accelerator Center
Stanford, CA

Abstract:

The present bunch compressor design for the NLC allows control of the final bunch length by way of changes to the horizontal betatron phase advance of the 180ƒ-turnaround arc. This adjustability requirement significantly constrains the design and cost optimization of the system and excludes the possibility of using permanent-magnet quadrupoles in the arc. To relieve this constraint, and to avoid the very strong arc focussing required at the upper limits of the bunch length range, we explore an option of bunch length control using the first compressor stage, with the arc optics fixed.

More Options for the NLC Bunch Compressors

P. Emma
SLAC
October 4, 1999

ABSTRACT

The present bunch compressor design for the NLC allows control of the final bunch length by way of changes to the horizontal betatron phase advance of the 180°-turnaround arc. This adjustability requirement significantly constrains the design and cost optimization of the system and excludes the possibility of using permanent magnet quadrupoles in the arc. To relieve this constraint, and to avoid the very strong arc focussing required at the upper limits of the bunch length range, we explore an option of bunch length control using the first compressor stage, with the arc optics fixed.
+

1 Introduction

The rms bunch length in the main linac of the NLC needs to be adjustable, for the various operating modes, over a range of 90-145 μm (associated with bunch populations of 0.75-1.1×10^{10} ppb, respectively). In previous designs [1] [2], this adjustability is accomplished by changing the horizontal betatron phase advance per cell of the BC2 180°-turnaround arc (μ_x ˜ 90°-135°/cell). Such a scenario requires variable gradient quadrupole magnets in the arc, a lower than optimal phase advance per cell for the 90-μm bunch length, and more FODO-cells in the arc design than minimally necessary. An alternate design of the compressor systems (briefly discussed in reference [2]) would allow the bunch length variation to be accomplished in the first compressor stage (the BC1 wiggler) while leaving the second stage (the arc) fixed. This alternate scenario allows the relatively expensive arc systems to be further cost minimized at a single operating point. In addition, permanent magnet quadrupoles may then be employed in the arc. This option is described in what follows.

2 First Stage Compressor

To provide adjustability of the main linac bunch length, s_{z_3}, using the first compressor stage, its L-band voltage ($V \equiv G_1L_1$) and wiggler momentum compaction ($R_{56} \equiv a_1$) need to both be variable. The value of a_1 can be adjusted simply by scaling the dipole fields in the wiggler while allowing adequate horizontal vacuum chamber in the dipoles. The necessary range, calculated using reference [2], is a_1 = - 0.48 to - 0.75 m. The voltage range required is 140 to 90 MV (s_{z_3} = 90 to 145 μm, respectively). Since a_1 scales with the square-root of the peak wiggler dispersion (*?* ˜ 30 cm at a_1 = - 0.48 m), the vacuum chambers in the wiggler dipoles need to allow additional width, ? *x*, for the horizontal beam translation given by

$$\Delta x \approx h\left(\sqrt{\frac{0.75\,\text{m}}{0.48\,\text{m}}}-1\right) \approx 7.5\,\text{cm}\,. \tag{1}$$

This implies that the width of the vacuum chambers in the wiggler dipoles must be large enough to accommodate ten times the full width beam size (2·10*?*s_{d_1} ˜ 6.0 cm) as well as the maximum beam translation, or approximately 14 cm full width. The dipole field quality also needs to be quite flat (<0.05 %) over this range.

Table 1 lists the BC1 parameters for the 90-μm and the 145-μm main linac bunch length cases. These parameters are computed for a gaussian damping ring beam with a 5-mm rms bunch length and 0.1-% rms energy spread at 1.98 GeV.

Table 1. Summary of 1st compressor parameters for the 90-μm and the 145-μm main linac bunch length.

parameter	symbol	90 μm	145 μm	unit
Single bunch population	N	0.75	1.10	10^{10}
Bunch length after 1st-compressor (rms)	s_{z_1}	500	760	μm
Energy spread after 1st-compressor (rms)	s_{d_1}	1.04	0.67	%
Voltage of L-band section (gradient × length)	G_1L_1	139	89	MV
RF phase* of L-band section	f_1	- 101.8	- 97.7	deg
Energy after 1st-compressor stage	E_1	1.95	1.96	GeV
Momentum compaction of wiggler	a_1	- 0.48	- 0.75	m
Peak dispersion in wiggler dipoles	?	30	38	cm
Energy spread after pre-linac (rms)	s_{d_2}	0.26	0.17	%

* Accelerating crest at 0°, but 'zero-crossing' at - 90° where bunch-head energy < tail energy

3 Pre-Linac

The S-band pre-linac follows the wiggler and accelerates the beam to 8 GeV where it enters the arc. For the 145-μm case, the bunch length in the pre-linac must be increased to 760 μm. The longer bunch tightens the S-band rf structure transverse alignment tolerances by a factor of ~2. But the reduced energy spread above will also loosen quadrupole alignment tolerances at the low-energy end, which, according to reference [1], dominates the emittance dilution for a 500-μm bunch length. In addition, the study in reference [2] has reduced the pre-linac length by 25% which already slightly loosens the structure alignment tolerances with respect to reference [1]. Therefore, the longer bunch in the pre-linac needs to be studied, but does not seem to present a major problem.

The smaller energy spread after the wiggler, in the 145-μm case, also produces a smaller energy spread in the arc (from 0.26 % to 0.17 % rms). This, by itself, loosens arc quadrupole alignment tolerances by 35% and reduces electron depolarization in the arc from 1.1 % to 0.5 %.

4 Second-Stage Compressor

The changes for BC2, using bunch length control in BC1, are summed up in Table 2. Since the emittance growth due to incoherent synchrotron radiation is minimized at higher phase advance (~135°/cell), the arc is reduced in length, number of components, and cost, by a design which moves in this direction. In fact, the emittance growth is a weak function beyond 108°/cell [3]. A compromise at 108°, rather than an unnecessary 135°, eases quadrupole alignment tolerances in the arc. The right side of Table 2 is therefore computed for 108°/cell.

With this new scenario the number of FODO-cells in the arc is reduced from 53 to 44, the arc length is slightly reduced, and quadrupole magnets are shorter. In addition, it is now possible to use permanent magnets for the quadrupoles as well as the bends.

Finally, a phase advance per cell in the arc of 132.7° [2] is no longer necessary for the 145-μm bunch length case, where this very strong focusing produces unnecessarily tight quadrupole alignment tolerances over the arc. A phase advance per cell of 108° reduces the alignment tolerances by ~25%. For the 145-μm bunch length, the reduced arc energy spread, in conjunction with the weaker quadrupoles, loosens the alignment tolerances by a factor of two. The chicane design is not changed by the new option, but its strength no longer needs to be adjustable.

Table 2. Summary of 2^{nd} compressor parameters for a 90-μm main linac bunch length in the case where the BC2-arc phase advance is *adjustable*, and the case where the BC2-arc is *fixed* at 108°/cell. A 4-% relative horizontal emittance growth across the arc is allowed due to incoherent synchrotron radiation.

parameter	symbol	*adjustable*	*fixed*	unit
Momentum compaction of arc	a_2	0.24	0.24	m
Number of arc cells	N_c	53	44	—
Length of arc (including ?-suppressors)	L_a	165	155	m
Hor. phase advance per cell in arc	μ_x	90	108	deg/cell
Length of bend magnets	L_{Ba}	0.8	1.0	m
Dipole field of bend magnets	B_B	9.7	9.3	kG
Quadrupole magnet length	L_Q	26	20	cm
Quadrupole magnet pole-tip radius	r_Q	6	6	mm
Max. pole-tip field of quadrupoles	$\|B_Q\|$	8.1	7.7	kG

5 System Stability

The sensitivity of the compressor system to variations in the extracted phase from the damping rings is a major concern. Much of the attention in the design has been focused on the sensitivity of the interaction point (IP) energy with respect to phase jitter at damping ring extraction [1] [2]. A sensitivity of <0.1% IP relative energy change per 21°-S-band DR phase change has been achieved. Detailed simulations using this new option, where the BC2 arc is fixed and the BC1 is adjustable, have been run which demonstrate this same low sensitivity, and better, are still attainable. The longitudinal wakefields (L-band, S-band and X-band), rf curvature and 2^{nd} and 3^{rd} order momentum compaction are all included in the runs. Fig. 1 shows the results.

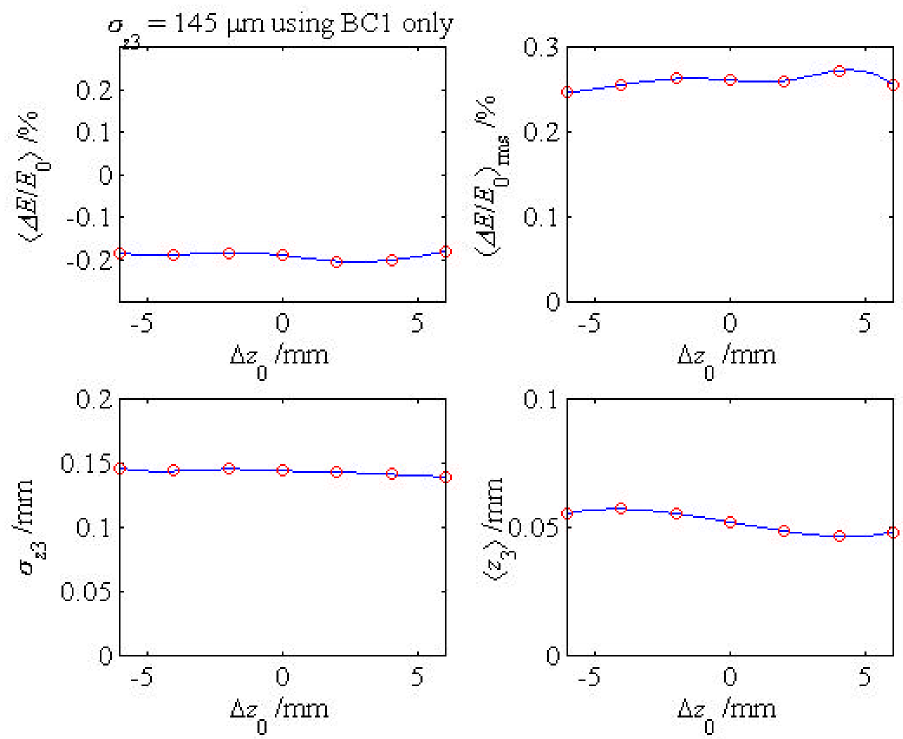

Fig. 1. At the interaction point, the variation of mean energy (top-left), rms energy spread (top-right), rms bunch length (bottom-left), and mean longitudinal bunch position with respect to IP location (bottom-right), versus initial 'phase' error, ? z_0, at damping ring extraction (±6 mm ˜ ±21° S-band).

6 Conclusions

The variable bunch length in the NLC main linac can be accomplished by adjusting the second-stage of compression (the arc) or by adjusting the first-stage of compression (the wiggler). The second option has advantages over the first in that arc is then fixed and its design can be further cost optimized. In addition, the very strong focusing in the arc for the 145-μm bunch length is no longer required, which significantly eases emittance dilution effects. The arc may then be composed of permanent magnets for a reduced cost. The negative impact for the adjustable-BC1 is the tighter alignment tolerances of the pre-linac rf structures due to the longer bunch there. This does not appear to be an outstanding issue in the context of the other performance improvements discussed here.

7 References

[1] *Zeroth-order Design Report for the Next Linear Collider*, SLAC-REP-474, May 1996.

[2] P. Emma, *Cost and Performance Optimization of the NLC Bunch Compressor Systems*, LCC-0021, Aug. 1999.

[3] R.H. Helm, H. Wiedemann, *Emittance Dilution in a FODO-Cell Lattice*, PEP-303, May 1979.