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BUNCH COMPRESSION FOR THE TLC. PRELIMINARY DESIGN*

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ABSTRACT

A preliminary design of a TLC bunch compressor as a two-stage device is described. The main parameters of the compressor as well as results of some simulations are presented. They show that the ideal system (no imperfections) does the job of transmitting transverse emittances without distortions (at least up to the second-order terms) producing at the same time the desired bunch length of 50 μm.

1. INTRODUCTION

There are several reasons to choose a short TLC bunch length :

(a) short bunch length is required for controlling the adverse effects caused by the transverse wake field.

(b) the high luminosity of the linear collider is achieved by decreasing the value of the beta-function at the interaction point. Such a decrease is effective only when the value of the beta-function is greater than the effective bunch length.

(c) the cost of the RF power supplies, which is one of the largest cost ingredients of the linear collider, tends to decrease for higher frequencies of the accelerating field; to keep the particle energy spread tolerable for a small wave length one needs a small bunch length.

On the other hand, the adverse effects of the longitudinal wake fields, which become more pronounced when the bunch length decreases, limit the length of the bunch from below.

As a compromise, a bunch length of the order of 70 μm has been chosen for the present design of the TLC.[1] A bunch of this length is not readily obtainable from a damping ring and, hence, a compressor will be needed to transform a long bunch with small momentum spread $\Delta p/p$ into a short bunch with a larger momentum spread.

But there is a limit on how large the resultant momentum spread can be, which is determined by the momentum acceptance of the linac. For the bunch extracted from the TLC damping ring the momentum spread will be typically $\Delta p/p \approx 10^{-3}$ with a bunch length of $l \approx 5$mm. Compression of this bunch length to 50 μm would then require increasing the momentum spread to 10%. That is clearly unacceptable when chromatic aberrations and practical aperture limitations are considered. Therefore, a two-stage compressor with an intermediate acceleration is assumed in the present design. The relevant input parameters of the beam as well as the corresponding desired output parameters for each stage are collected in Table 1.

Table 1.
Compressor input and output parameters.

N	Parameter	1st Stage	2nd Stage
1	Energy (GeV)	1.8	16.2
2	Δl_{in} (mm)	5.0	0.46
3	$\Delta p/p_{in}$ (%)	0.1	0.12
4	Δl_{out} (mm)	0.46	0.037
5	$\Delta p/p_{out}$ (%)	1.1	1.6
6	$\gamma\epsilon_x$ (Mrad)	2.10^{-6}	2.10^{-6}
7	$\gamma\epsilon_y$ (Mrad)	2.10^{-8}	2.10^{-8}
8	$\sqrt{\epsilon_x\beta_x}$ (μm)	54.9	24.4
9	$\sqrt{\epsilon_y\beta_y}$ (μm)	3.11	1.20
10	$\sqrt{\epsilon_x/\beta_x}$ (μrad)	10.35	2.33
11	$\sqrt{\epsilon_y/\beta_y}$ (μrad)	1.83	0.475

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2. THE CONCEPTUAL COMPRESSOR DESIGN

The design of each compressor stage is conceptually similar to the design of the SLC compressor.[1] A bunch extracted from the damping ring first passes through a matching section, where the beta- and eta-functions of the ring are matched to the corresponding periodic functions of the compressor.

The compressor itself consists of two stages. Each stage starts with an acceleration section where a momentum shift $\Delta p/p$ is introduced for each particle dependent upon its longitudinal position Δl within the bunch. The bunch then passes through a transport line where the path length depends upon particle momentum. The linear part of the path length dependance upon momentum is adjusted in such a way as to obtain a minimal bunch length on its exit. As in Ref. 3, the design of the transport line uses the concept of a second-order achromat[3] to prevent the emittance growth due to the second-order aberrations and chromatic effects. There is an intermediate accelerator between the stages 1 and 2 where particles are accelerated from 1.8 GeV to 16.2 GeV. The momentum spread with which the bunch enters the second stage is thus reduced to $\approx 0.1\%$.

The achromat in each stage is built out of four identical cells with 90° betatron phase advance in each plane. That makes the overall first-order transverse transfer matrix of the line equal to unity. Two families of the sextupole magnets compensate the natural first-order chromaticities eliminating at the same time all the second-order chromatic aberrations.[2,3] Cells are chosen to be symmetric, since that makes the phase ellipses of the line admittance on the entrance to the achromat upright and facilitates matching of the phase ellipses of the particle distribution and the amplitude functions.

Figures 1 and 2 present the horizontal and the vertical amplitude functions for each stage, respectively. Figures 3 and 4 give the horizontal dispersion functions and the bunch length along both achromats. Tables 2 and 3 contain the list of magnetic elements and the parameters of each of them in the TRANSPORT[4] notation. Two-dimensional TURTLE[5] scatter plots of a thousand randomly chosen particles in the $(\Delta l, \Delta p/p)$ plane at the exit of the each stage are presented in Figs. 5 and 6.

Table 4 contains the main parameters of both compressor stages.

3. EMITTANCE CHANGE DUE TO RADIATION AND NON-LINEAR EFFECTS

Of special concern is the emittance increase due to the quantum character of the radiation in a magnetic field. The design should provide that such a growth is small compared to the transverse emittance of the bunch. The effect is evaluated by Sands.[7] The absolute and relative emittance increases due to this effect are to be found in Table 4.

The simulation results, in particular Figs. 5 and 6, show that the ideal designed system (without imperfections) does the job of transmitting transverse emittances without distortions (at least up to the second-order terms) producing at the same time the desired bunch length of 50 μm.

In the last row of Table 4 the main non-linear term of the accelerating field is evaluated and is seen not to

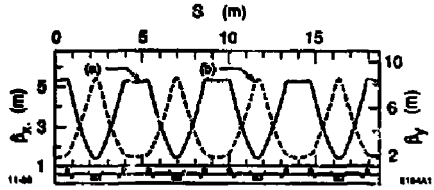

Fig. 1. Horizontal (a) and vertical (b) β-functions for the first compressor stage.

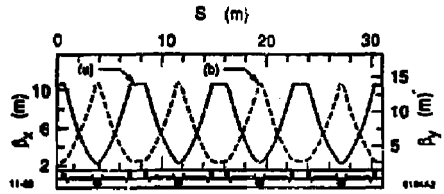

Fig. 2. Horizontal (a) and vertical (b) β-functions for the second compressor stage.

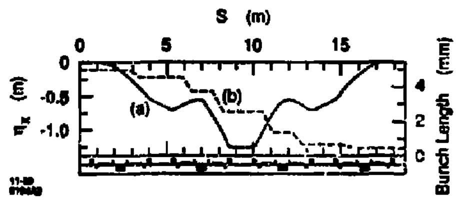

Fig. 3. Horizontal dispersion function (a) and the bunch length (b) along the first compressor stage.

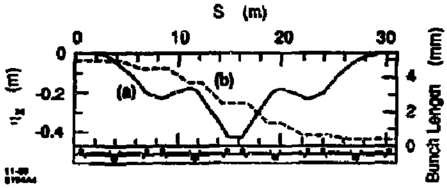

Fig. 4. Horizontal dispersion function (a) and the bunch length (b) along the second compressor stage.

Table 2. Lattice of Stage 1.

Element	Label	Length (m)	Field (kG)	Pole Radius (mm)
9.		4.		;
3.0	"BGND"	0.61351;		
5.00	"Q1A"	0.19070	1.24505	10.0000;
3.0		0.12000;		
18.00	"SEXA"	0.10000	-0.03078	10.0000;
3.0		0.12000;		
4.000	"BH1"	0.60000	-12.58428	0.0;
3.0		0.12000;		
18.00	"SEXB"	0.10000	0.043344	10.0000;
3.0		0.12000;		
5.00	"Q1B"	0.25000	-0.89500	10.0000;
3.0	"SYM"	0.00000;		
5.00	"Q1B"	0.25000	-0.89500	10.0000;
3.0		0.12000;		
18.00	"SEXB"	0.10000	0.043344	10.0000;
3.0		0.12000;		
4.000	"BH1"	0.60000	-12.58428	0.0;
3.0		0.12000;		
18.00	"SEXA"	0.10000	-0.03078	10.0000;
3.0		0.12000;		
5.00	"Q1A"	0.19070	1.24505	10.0000;
3.0	"BGND"	0.61351;		
9.		0.		;

Table 3. Lattice of Stage 2.

Element	Label	Length (m)	Field (kG)	Pole Radius (mm)
9.		4.		;
3.0	"BGND"	0.60000;		
5.00	"Q1A"	0.30000	3.95726	10.0000;
3.0		0.12000;		
8.00	"SEXA"	0.10000	-0.36189	10.0000;
3.0		0.12000;		
4.000	"BH1"	2.00000	-6.41640	0.0 ;
3.0	"DRVA"	0.12000;		
18.00	"SEXB"	0.10000	0.58043	10.0000;
3.0		0.12000;		
5.00	"Q1B"	0.30000	-3.71447	10.0000;
3.0	"SYM"	0.00000;		
5.00	"Q1B"	0.30000	-3.71447	10.0000;
3.0		0.12000;		
18.00	"SEXB"	0.10000	0.58043	10.0000;
3.0	"DRVA"	0.12000;		
4.000	"BH1"	2.00000	-6.41640	0.0;
.0		0.12000;		
18.00	"SEXA"	0.10000	-0.36189	10.0000;
3.0		0.12000;		
5.00	"Q1A"	0.30000	3.95726	10.0000;
3.0	"BGND"	0.60000;		
9.		0.		;

produce any significant changes in the momentum spread for both compressor stages. The same is true for the nonlinearity due to second-order terms in the transformation matrix (T_{556} terms in TRANSPORT notation). Since the bunch length is about 10 times longer in the compressor RF section than in the linac, the wake fields are about 10 times stronger. However, since the section is short this would lead to only a small effect. In addition, since the correlation induced by the RF yields lower momentum of particles at the tail of the bunch, the bunch is stabilized by BNS damping[8] throughout part of the structure.

To conclude it is important to note that these two designs are simply examples and are not unique, e.g., the final compressor might be included in a 180° bend in order to keep the site shorter. Several examples of 180° arcs

Table 4. Main compressor parameters.

N	Parameter	1st Stage	2nd Stage
1	Length (m)	18.67	31.04
2	Bend Angle/magnet (°)	7.205	1.361
3	Number of Magnets	8	8
4	Radius of curvature (m)	4.771	84.218
5	Total Angle Bend (°)	57.64	10.89
6	Correlation $(\Delta p/p)/l$ (%/mm)	0.21517	3.4012
7	RF (GHz)	3.0	17.0
8	λ (cm)	10.0	1.76
9	$\theta = 2\pi l/\lambda$	0.314	0.164
10	V_o (MV)	57.3	1058.5
11	$\langle H/\rho \rangle$	$2.5 \cdot 10^{-2}$	$1.6 \cdot 10^{-5}$
12	$\Delta\epsilon$(Mrad)	$2.03 \cdot 10^{-12}$	$4.45 \cdot 10^{-12}$
13	$\Delta\epsilon/\epsilon$ (%)	0.36	7.8
14	$\Delta(\Delta p/p) = \theta^2/6$	0.016	0.0045

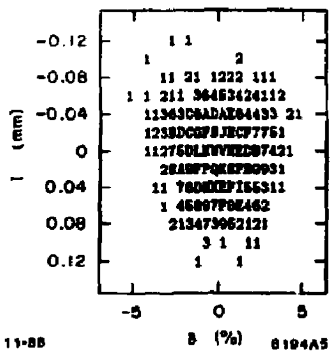

Fig. 5. Scatter plot in the horizontal phase space $(\Delta\ell, \Delta p/p)$ of 1,000 rays at the exit of the first compressor stage. Rms half widths are $(\Delta p/p)_{rms}$ = .088%, $(\Delta\ell)_{rms} = 0.487$ mm.

which accomplish this have been calculated with favorable results.[9]

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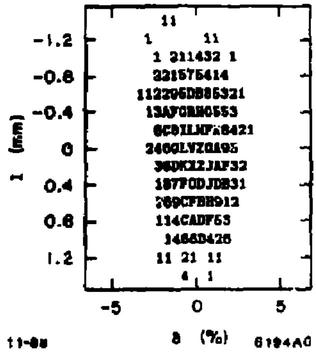

Fig. 6. Scatter plot in the longitudinal phase space $(\Delta\ell, \Delta p/p)$ of 1,000 rays at the exit of the second compressor stage. Rms half widths are $(\Delta p/p)_{rms}$ = 1.591%, $(\Delta\ell)_{rms} = 0.037$ mm.

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