SLAC-PUB-9240
May 2002

A NEW BUNCH COMPRESSOR CHICANE FOR THE SLAC LINAC TO PRODUCE 30-FSEC, 30-KA, 30-GEV ELECTRON BUNCHES

L. Bentson, P. Emma, P. Krejcik

Contributed to the Eighth European Particle Accelerator Conference,
Paris, France, 6/3/2002—6/7/2002

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

Work supported by Department of Energy contract DE–AC03–76SF00515.

A NEW BUNCH COMPRESSOR CHICANE FOR THE SLAC LINAC TO PRODUCE 30-FSEC, 30-KA, 30-GEV ELECTRON BUNCHES*

L. Bentson, P. Emma†, P. Krejcik, SLAC, Stanford, CA 94309, USA

Abstract

We describe a new bunch compressor chicane for the SLAC linac, which will be used in conjunction with other existing systems, to generate 30-fsec long, 30-GeV electron bunches with up to 30-kA of peak current. The new compressor is a four-dipole chicane located at the 1/3rd point in the linac. It should be installed by October of 2002. The chicane adds a second stage of compression to the linac, where the existing damping ring with its present bunch compressor form the first stage. With this new second-stage compressing from 4 psec to 160 fsec rms, the existing FFTB beamline can easily be adjusted to serve as a third stage and allow final compression down to a minimum of nearly 30-fsec rms. We describe the design considerations of the chicane, which is used to enhance plasma wakefield experiments and also to support the production very high brightness short pulse x-rays.

1 INTRODUCTION

The electron bunch from the SLC damping rings (DR) and existing RTL (ring-to-linac) compressor can be much further compressed in length by adding a 4-dipole chicane in the SLAC linac at sector-10 at 9 GeV (the 1-km point). Particle tracking shows that a 12-μm long rms bunch length can be generated in the FFTB (Final Focus Test Beam) beamline by compressing to 50 μm in this new chicane, and then by further compressing using the existing FFTB bends at 28 GeV [1]. The short electron bunches will be used in plasma wakefield experiments [2] as well as to produce short pulse x-rays from spontaneous radiation generated in an undulator [1]. This note describes the details of the chicane design, including installation issues; diagnostics; vacuum chamber impedance issues; system tuning; and tolerances.

2 CHICANE

2.1 General Layout

The chicane design and location are set by the following goals:

1) should not interfere with PEP-II B-factory operations,
2) can be bypassed for fixed-target operations,
3) should not require removal of more than one klystron's accelerating structure (12 m),
4) should not increase the damping ring horizontal emittance ($\gamma\varepsilon_{x_0} \approx 50$ μm) by more than 10-20%,
5) compression must be linear enough to allow a 50-μm minimum rms bunch length at the end of the chicane.

Point-1 places the chicane down-beam of linac-location 10-4 at 9 GeV, where electrons are extracted to the PEP-II injection bypass line. Point-2 addresses vacuum chamber requirements. Points 3 & 4 dictate bend angle and magnet length requirements. Point-5, in conjunction with the longitudinal pre-chicane linac wakefield, constrains the bunch charge and post-RTL bunch length.

A 4-dipole chicane which accomplishes these goals is being constructed at SLAC for commissioning in Oct. 2002. The chicane is drawn in Figure 1 with symbol definitions and more parameters listed in Table 1. The magnet orientations are yawed by $\theta/2$ to reduce the maximum trajectory excursion from pole centers, loosening field quality tolerances.

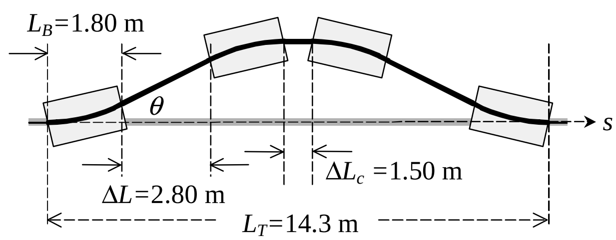

Figure 1: Four-dipole chicane with symbol definitions.

Table 1: Four-dipole chicane parameters at sector-10.

parameter	symbol	value	unit
electron energy	E	9.0	GeV
linear rms energy spread	σ_δ	1.6	%
initial rms bunch length	σ_z	1.16	mm
x/y norm. rms emittances	$\gamma\varepsilon_x/\gamma\varepsilon_y$	50/5	μm
momentum compaction	R_{56}	−75	mm
bend angle per dipole	$\|\theta\|$	96.2	mrad
bend radius per dipole	$\|\rho\|$	18.3	m
field of dipole magnets	$\|B_0\|$	1.60	T
peak dispersion	η_{pk}	0.444	m

The compression factor is the momentum compaction (R_{56}) and is given approximately by

$$R_{56} \approx -2\theta^2\left(\Delta L + \frac{2}{3}L_B\right), \qquad (1)$$

* Work supported by DOE contract DE-AC03-76SF00515.
† emma@slac.stanford.edu

where the symbols are taken from the figure and $\theta << 1$. At 9 GeV it is also important to consider synchrotron radiation effects. The bend-plane emittance growth from incoherent synchrotron radiation (ISR) is given by

$$\Delta\gamma\varepsilon_x \approx \left(8\times10^{-8}\ \mathrm{m}^2\cdot\mathrm{GeV}^{-6}\right)\cdot E^6\frac{\left|\theta^5\right|}{L_B^2}\left(\Delta L + L_B + \frac{\widehat{\beta}+\breve{\beta}}{3}\right), \quad (2)$$

where $\widehat{\beta}$ and $\breve{\beta}$ are the horizontal maximum and minimum beta functions (55 m and 5 m), respectively, along the chicane. This sets the bend length at $L_B \approx 1.8$ m for an ISR emittance growth of 8%.

Particle tracking (Figure 2) from damping ring exit (1.19 GeV) to FFTB beamline (28.5 GeV), including S-band rf structure longitudinal wakefields, is used to optimize the system design and choose the bunch charge and RTL compressor voltage settings. A bunch charge of 3.5 nC ($N \approx 2.2\times10^{10}$) in the DR and an RTL compressor voltage of 40.8 MV allows maximum compression in both the chicane ($I_{pk} \approx 9$ kA) and the FFTB ($I_{pk} \approx 30$ kA). The choice of charge is important since it scales the wakefield in the 810 meters of linac leading up to the chicane. This wakefield, and an off-crest rf phase of 20.3°, provides a nearly linear energy chirp at chicane entrance (4$^{\text{th}}$ row of Figure 2). The linearity is also improved by choosing the RTL compressor voltage to over-compress the bunch at the linac entrance (3$^{\text{rd}}$ row), forming a more uniform temporal pulse than would be possible with under-compression. After chicane compression (5$^{\text{th}}$ row), the bunch is further chirped by the wakefields of 1872 meters of linac beyond the chicane. This chirp at 28.5 GeV (6$^{\text{th}}$ row) is 1.5% rms and completely determined by the wakefield. This is achieved with an rf phase nearly on crest (4° for PEP-II e^+ compatibility). After the existing FFTB bends, the bunch is compressed to almost 30 kA (7$^{\text{th}}$ row). The bunch has temporal tails, but its core has an rms length of 10.4 μm (gaussian fit), or 35 fsec rms with 2.1×10^{10} electrons (a loss of 5% is typical and is included in the RTL beamline).

2.2 Coherent Synchrotron Radiation

The effects of coherent synchrotron radiation (CSR) in the chicane have been estimated using a 1-D line-charge model to calculate the longitudinal fields and then apply them to the 6-D particle motion. The code is based on references [3] and [4].

The energy loss, spread, and bend-plane emittance growth induced by CSR are shown in Figure 3, plotted along the chicane. A 5-meter drift is added after the chicane to show loss and spread after the final bend. The emittance increase is 4% due to longitudinal CSR effects. The net increase including both ISR and CSR is 10% ($\gamma\varepsilon_x \approx 50$ μm). CSR micro-bunching effects [5] cannot be observed here since the uncorrelated energy spread and horizontal emittance from the DR are too large.

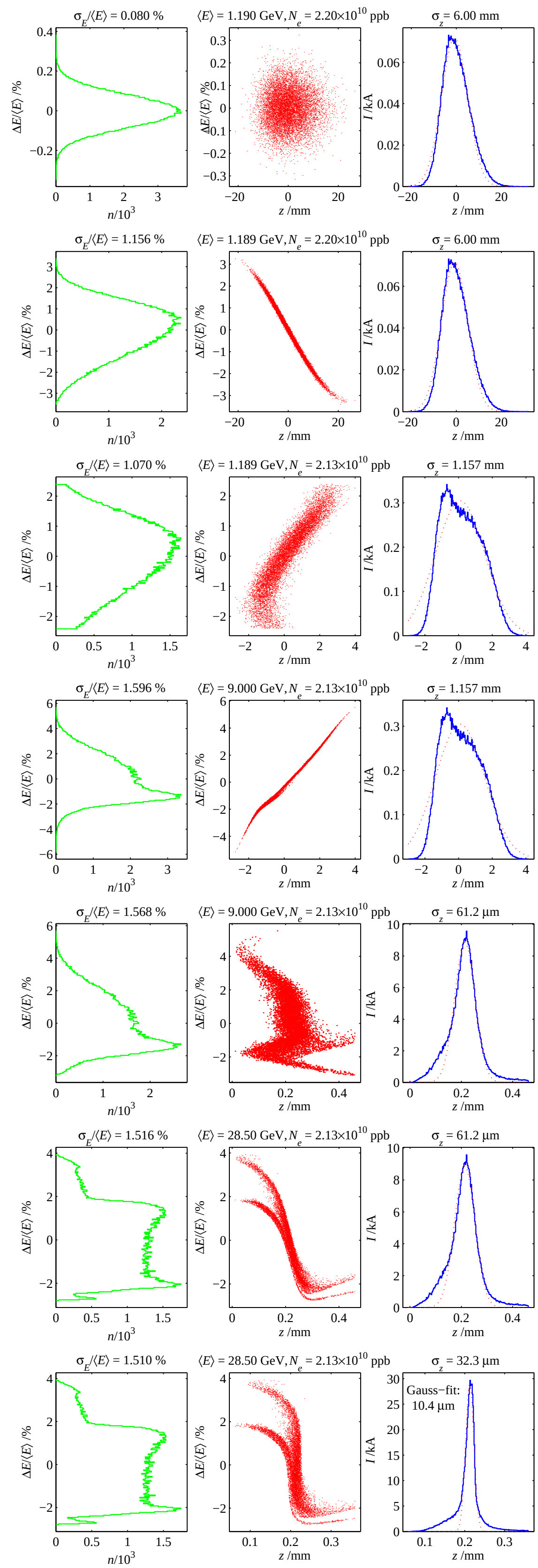

Figure 2: Longitudinal phase space progression through linac (*row*-1: DR exit, *row*-2: after RTL rf, *row*-3: after RTL bends, *row*-4: at chicane entrance, *row*-5: after chicane, *row*-6: at linac end, *row*-7: after FFTB bends).

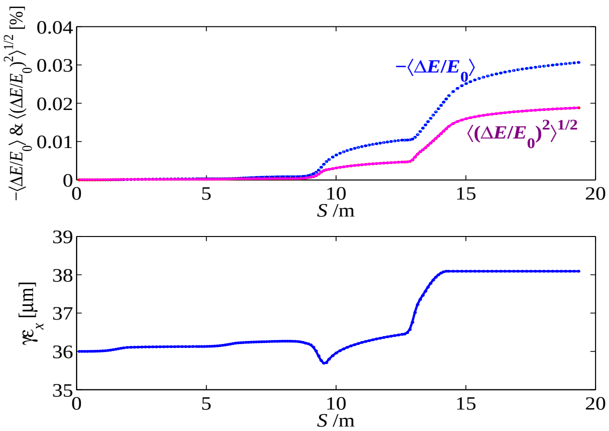

Figure 3: CSR-induced relative energy spread (top/magenta), loss (top/blue), and horizontal emittance growth (bottom/blue).

2.3 Chicane Design and Tolerances

The large horizontal beam size in the chicane (up to 7 mm rms) and the small transverse emittances from the damping rings require very good dipole field quality across especially the inner two bend magnets (B2 & B3). The field component tolerances, to control the emittance growth to <2%, are listed in Table 2 with $|b_i/b_0|$ as the $2(i+1)$-pole tolerance at $x = r_0$ (e.g., $i = 2$ is sextupole).

Table 2: Field quality tolerances for chicane dipole magnets evaluated at a radius r_0 = 10 cm.

parameter	**symbol**	**B1/4**	**B2/3**	**unit**
dipole field error	$\lvert\Delta b_0/b_0\rvert$	0.1	0.1	%
quadrupole error	$\lvert b_1/b_0\rvert$	0.3	0.02	%
sextupole error	$\lvert b_2/b_0\rvert$	10	0.2	%
octupole error	$\lvert b_3/b_0\rvert$	20	1.0	%
decapole error	$\lvert b_4/b_0\rvert$	40	2.0	%

Similar to CSR effects, other longitudinal wakefields in the chicane can generate energy spread and therefore emittance growth. Two such wakes are the resistive-wall [6] and the surface roughness wakes [7], both if which become more pronounced with shorter bunches.

The final bend vacuum chamber, where the bunch is shortest, is only 2-cm in height ($\equiv 2a$) and thus, the resistive-wall wakefield requires some consideration here. The emittance growth induced by the RW wake is

$$\frac{\Delta\varepsilon_x}{\varepsilon_{x0}} \approx 0.024\left[\frac{e^2cN(\Delta L+L_B/2)}{\pi^2 aE}\right]^2 \frac{Z_0}{\sigma}\frac{1}{\sigma_z^3}\theta^2\frac{\beta_x}{\varepsilon_{x0}} << 1\,, \quad (3)$$

where $Z_0 \approx 377\ \Omega$, σ is conductivity ($5.9\times10^7\ \Omega^{-1}\cdot\mathrm{m}^{-1}$ for copper, $0.14\times10^7\ \Omega^{-1}\cdot\mathrm{m}^{-1}$ for stainless), β_x is the beta function in the center of 4th bend, and the other parameters are listed in Table 1. A stainless steel chamber will generate a 2% emittance growth, so to be safe, copper plating is added to the B4 chamber. Similarly, the surface finish of the B4 chamber must be <3 μm assuming >100 μm bump length in the beam direction.

2.4 Diagnostics and Tuning

A profile monitor and stripline beam position monitor (BPM) are included at the chicane center to monitor the energy spread and pulse-to-pulse energy jitter. The BPM will provide 50-μm position resolution and ±15 mm linear dynamic range. The profile monitor is an insertable phosphorescent intercepting screen to measure the nominal 7-mm rms beam size.

The bunch length after the chicane (50 μm) will be measured using a 2.44-m long S-band transverse deflecting rf structure which has been installed at the end of the SLAC linac for this purpose [8]. This system has already been tested with a 500-μm bunch length.

Two small correction quadrupole magnets, with nominal zero gradient, are included in the chicane to allow empirical tuning of dispersion. A set of four wire scanners are located just after the chicane, where they were used in the past for SLC emittance measurements. These wire scanners can be used to measure the 'projected' emittance for CSR studies and also to set the correction quadrupoles if, due to dipole field or alignment errors, the dispersion function is not perfectly closed.

Finally, the chicane also allows a clear measurement of the longitudinal wakefield for a 50-μm bunch length in the SLAC S-band accelerating structures. This is an important measurement for the Linac Coherent Light Source (LCLS) [9].

4 REFERENCES

[1] M. Cornacchia et al., "A Subpicosecond Photon Pulse Facility for SLAC", SLAC-PUB-8950, LCLS-TN-01-7, Aug 2001. 28pp.

[2] P. Muggli et al, "E-157: A Plasma Wake Field Acceleration Experiment**"**, in *LINAC-2000*, 2000.

[3] E. L. Saldin, et al., "On the Coherent Radiation of an Electron Bunch Moving in an Arc of a Circle", *TESLA-FEL 96-14*, Nov. 1996.

[4] G. Stupakov, P. Emma, "CSR Wake for a Short Magnet in Ultrarelativistic Limit", *EPAC-2002*, Paris, France, June 3-7, 2002.

[5] S. Heifets, et al., "CSR Instability in a Bunch Compressor", SLAC-PUB-9165, March 2002.

[6] K.L.F. Bane, M. Sands, "The Short-Range Resistive Wall Wakefields," Micro Bunches Workshop, Upton, New York, September 28-30, 1995.

[7] G. Stupakov, "Surface Roughness Impedance", Physics of, and Science with, the X-ray Free Electron Laser, Arcidosso, Italy, Sep. 2000.

[8] R. Akre, L. Bentson, P. Emma, P. Krejcik, "Bunch Length Measurements Using a Transverse RF Deflecting Structure in the SLAC Linac", *EPAC-2002*, Paris, France, June 3-7, 2002.

[9] "LCLS CDR", SLAC-R-593, April 2002.