An "NLC-Style" Short Bunch Length Compressor in the SLAC Linac*

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I. Abstract

Experimental tests of a "second bunch length compressor" in a linac is important for the next generation of linear colliders and for other future accelerators. These future accelerators need bunches with lengths of order 0.06 - 0.2 mm. At these lengths, new accelerator dynamics will be encountered. We have studied the possibility of constructing a second compressor with the present SLAC linac and have found a reasonable design[1]. The core of this project is to reconfigure an old beamline (BL-90) at the 1000m location in the linac to: (1) extract a 10 GeV bunch, (2) pass it through a new 96 m long transport line in which length compression is done, and (3) reinject the beam into the main linac in an available drift section. Using the resulting compressed bunch, accelerator physics tests would be performed in the remaining downstream linac with the resulting very high charge density.

The bunch compression in this transport line results from the TRANSPORT element R_{56} as determined from the optics of the transport line. $\Delta z = R_{56}\ \Delta E/E$. For example, if Δz = -0.5 mm, $\Delta E/E$ = 0.5%, R_{56} =-0.1 m, a bunch of 5 x 10^{10} particles would have a final length (σ_z) of about 0.08 mm with a peak current of 9600 A.

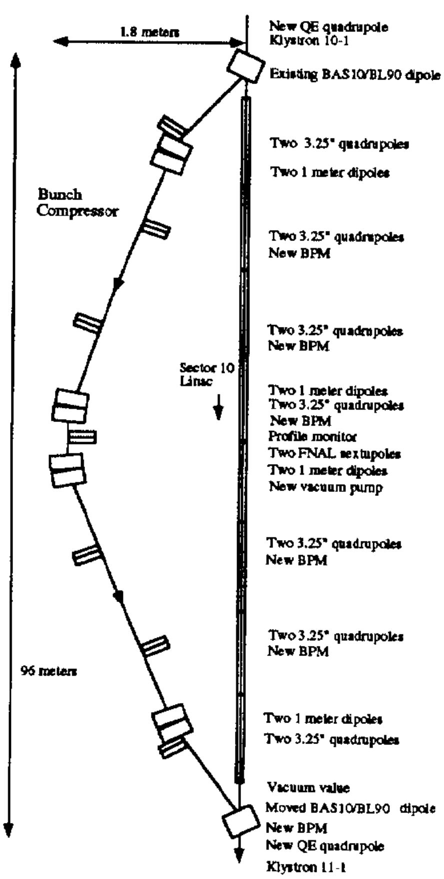

Figure 1 Schematic layout of the short bunch compressor.

II. Decription of the Project

This project would use as much existing SLAC equipment as possible: including the SLC accelerator complex, old SPEAR injection line magnets, spare power supplies and diagnostics. No civil construction is required. The design is aimed at a rapid construction and installation schedule, maintaining flexibility and with no operational impact on other SLAC programs: SLC, FFTB, or B-Factory.

A schematic layout of the bunch compressor is shown in Fig. 1. The basic beam parameters are listed in Table 1. The compressor is to be installed in Sector 10 of the SLAC Linac tunnel. The beam is deflected into the south isle where it travels through a 96 m long lattice of large bore (8 cm) dipole and quadrupole magnets and is then reinjected into the SLAC linac at the drift section at linac Girder 10-9.

Eight large bore dipoles (10D37) and 14 quadrupoles (3 1/4 Q 20) will be used to bend and focus the beam along the transport line. Three pair of correction dipoles are available for steering. Two additional linac style quadrupoles (QE4) will be installed along the main linac to provide for betatron matching. Two sextupoles will be installed at the center of the line to provide for chromatic corrections to reduce horizontal emittance growth.

Table 1 General Parameters of the Bunch Compressor

Parameter	Case #1	Case #2	Case #3
Beam:			
Number of particles (10^{10})	1.0	3.0	5.0
Damping ring:			
Energy (GeV)	1.19	1.19	1.19
Bunch length σ_z (mm)	0.50	0.50	0.50
Energy spread after 1st compression (%)	1.0	1.0	1.0
Linac (Sectors 2-9):			
Peak accel. energy (GeV)	9.0	9.3	11.0
Bunch RF Phase (degrees)	-7.0	13.7	31.0
Second compressor:			
R_{56} (m)	-0.06	-0.06	-0.05
Final energy (GeV)	10.0	10.0	10.2
Final bunch length* σ_z (mm)	0.06	0.083	0.08
Energy spread after 2nd compression (%)	0.60	0.60	0.60

* Determined from FWHM / 2.354.

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Five 3-inch diameter position monitors will be built to provide for steering and energy analysis in the compressor. A profile monitor (screen type) will be located in the center of the transport line to provide for energy spread monitoring and control. Existing RF controls in Sectors 2-9 will be used to create the beam energy and energy spread needed for the compressor. Existing wire scanners in Sector 11 (50 m downstream) will be used for emittance and betatron phase space monitoring of the reinjected beam. The existing wire and screen profile monitors at the end of the linac will be used to measure the energy spread of the beam. When coupled with the RF phase controls from Sectors 11-30, these monitors will determine the bunch length[2] to about 30-50μm. The existing collimators in Sectors 18, 29, and 30 will be used to measure collimator steering. The geometry of this beam line was chosen so that no RF changes are needed.

III. Beam Line Optics

The optics of the transport line provides for proper compression, matched betatron functions, corrected dispersion, and second order corrections with sextupoles. The transport line is symmetrical about the mid-point. The transverse extent of the line was adjusted to provide clearance in the south isle of the tunnel for the widths of the magnets and for access. The quadrupoles in the compressor are relatively strong producing the desired "reversed dispersion function" at the center where all the compression is done. The resulting dispersion is shown in Fig. 2. The quadrupole pair at the center of the line is adjusted to remove any residual dispersion at the end of the compressor. The betatron matching is done by the two new linac quadrupoles and others in the linac. The β- functions are shown in Fig. 2.

Bunch length reduction can be adjusted by changing the

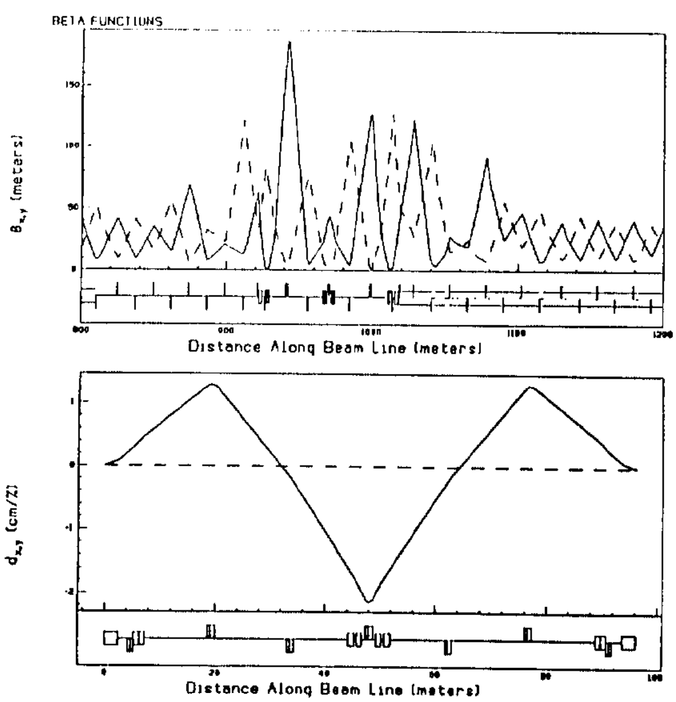

Figure 2 β-functions and dispersion along the compressor.

energy spread of the bunch or by a change of the lattice phase advance per cell of the quadrupoles between the end and center bends. R_{56} values from -0.15 m to 0. m can be handled.

IV. Bunch Compression

The bunches are extracted from the damping ring and compressed to 0.5 mm in the Ring-To-Linac transport line. They are then accelerated to 10 GeV with the appropriate RF phase to introduce the required head-tail energy spread for the second compression. The sign of R_{56} was chosen to allow the present BNS phases and resulting energy spreads to remain nearly intact, thus preserving our existing emittance control procedures. An explicit example of bunch compression is shown in Fig. 3 for a bunch charges of 5 x 10^{10} electrons per bunch. Other beam parameters for this and other cases are listed in Table 1. The bunch lengths quoted here are for the core of the beam which contains about 80-90% of the particles and have the long tails excluded. For the case of 5 x 10^{10} the resulting peak current is about 9600 A.

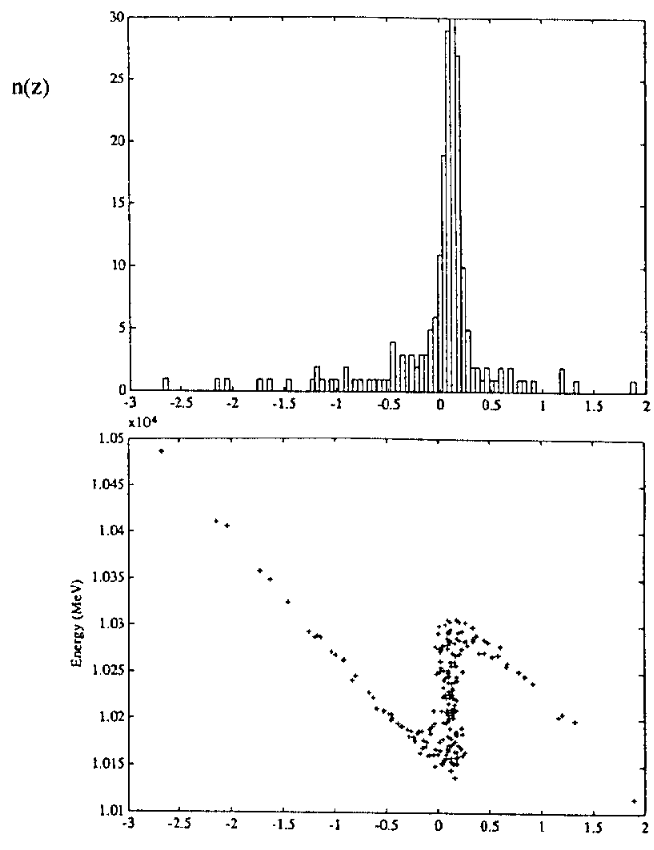

Figure 3 Bunch compression example for N = 5 x 10^{10} e^- and σ_z = 0.08 mm. The energy versus longitudinal position (z) correlation after compression is shown in the lower plot. The longitudinal density distribution is shown in the upper plot.

This compressor can also be configured to study the effectiveness of a "transformer" style compressor. In this case the R_{56} is raised to over-compress the bunch followed by a RF phase change of downstream klystrons to remove the remaining energy spread. A combination of increasing the magnet strengths and reducing the beam energy will accommodate this study.

Several studies of tolerances required of the input beam parameters and the accelerator and compressor conditions have been done. For 5 x 10^{10}/bunch, the changes in the resulting bunch length from variation of the input bunch charge indicate that the bunch charge should be kept constant to 10%. Also, for 5 x 10^{10}/bunch, the changes in the resulting bunch length with the transport line R_{56} values suggest that the "compressor strength" should be held to about 5-10%. Finally, studies of the effects on compression from changes of the phase of the linac RF shows that the linac RF phase should be set to about 1 degree.

With the quadrupole lattice and the sextupole corrections properly set for this compressor, the transverse emittance growth should be kept below 10% or $\Delta\gamma\varepsilon_x < 0.3 \times 10^{-5}$ r-m, invariant. The vertical emittance, in principle, should be unaffected. However, due to small quadrupole roll errors, coupling of horizontal dispersion into the vertical must be controlled with a few weak skew quadrupoles.

IV. Potential Accelerator Investigations

Wakefields in the short bunch length regime: Theoretical calculations[3] for the longitudinal wakefields of a short bunch in a series of accelerating cavities are strongly dependent on the ratio of the bunch length to the iris radius of the cavities and on the number of cells over which the wakefields are integrated. Using the bunch lengths produced with this compressor and accelerating the bunches to 40 GeV, longitudinal wakefields can be measured in a regime where the uncertainties are on the order of 25 to 50%. The expected energy spread at the end of the accelerator versus the linac RF phase is shown in Fig. 4 for the nominal SLAC longitudinal wake and for a value twice as large. Given our ability to measure the energy spread to about 0.1%, we can measure the longitudinal wakes to about 5 - 10%.

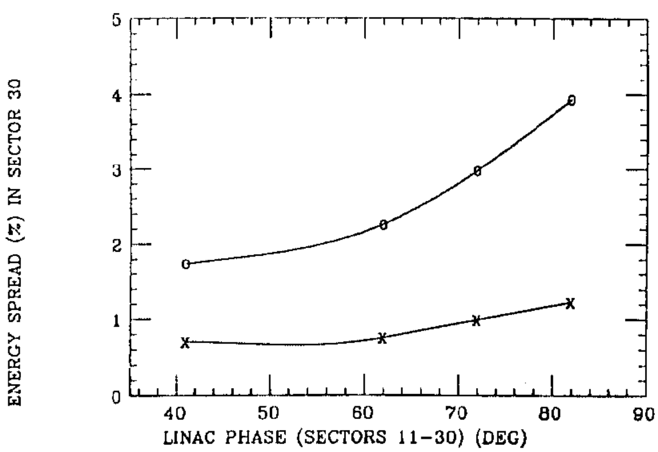

Figure 4 Energy spread at the end of the linac versus linac phase downstream of the compressor. The bunch charge is 3 x 10^{10} compressed to σ_z = 0.083 mm in Sector 10. The (x) points used the nominal longitudinal wakefields in the Sectors 11-30. The (o) points used twice the nominal wakefields. The final beam energies are 25-35 GeV.

Tolerances for the Next Linear Collider: The second bunch compressor for the NLC must preserve both the horizontal and vertical emittances of the incoming bunches[4]. The compressor described here has been designed to test many of the required tolerances including alignment, RF phasing, magnet strengths, coupling, second order optics, as well as energy and energy spread control of multiple bunches.

Instrumentation for Short Bunch Lengths: The required bunch lengths in the new generation of accelerators are on the order of 0.05 to 0.2 mm. There are no proven methods of measuring bunch lengths below about 1.0 mm, except for RF-energy spread manipulation techniques which require a long linac[2] (50 μm resolution) such as the SLAC linac. There are several proposed non-invasive methods using coherent synchrotron radiation, normal synchrotron radiation, or high frequency cavities. With this new compressor and the SLAC linac, these new monitors can be tested and calibrated against the known RF-energy spread measurement technique.

Collimator deflections: Collimators are used to remove unwanted halo from the bunches in a linear collider. However, if the bunch passes through the collimator off-axis, then transverse forces from image currents deflect the core of the bunch increasing the beam emittance[5]. The next linear collider with its small emittances is particularly sensitive to these deflections. As a result, very complicated collimation sections have been designed[6]. It is important that these transverse effects be experimentally verified. The expected deflection for the charge density of a compressed beam (3 x 10^{10} at 0.08 mm) is about 10 μrad which is 5 times the natural angular size. This deflection can be measured to ~10%.

Short bunch lengths for the FFTB: With this compressor bunch lengths below 0.08 mm can be provided to the FFTB[7]. Bunch intensities of about 1 x 10^{10} at full energy and 2 x 10^{10} at a reduced energy (~40 GeV) are possible. This reduced length would allow the entire bunch to be simultaneously focused in the FFTB with a design β_y^* of 100 μm.

V. References

1. J. Seeman, et al, "Beam Parameters of a Possible Emittance-Dynamics Test Area for NLC Studies at the SLC," XV Int. Conf. on High Energy Accelerators, Hamburg, Germany, p. 821 (1992).
2. L. Merminga, et al., " Bunch Length Measurements in the Linac," SLC Experimental Report #116, Stanford (1990).
3. S. A. Heifets and S. A. Kheifets, "High Frequency Limit of the Longitudinal Impedance of an Array of Cavities," SLAC-PUB-4625, Stanford (1988).
4. S. Kheifets, et al., "Bunch Compression for the TLC," *Particle Accelerators*, Vol. 30, p. 1037 (1990).
5. K. Bane and P. Morton, "Deflections by the Image Current and Charges of a Beam Scrapper," 1986 Linear Accelerator Conf., SLAC-Report-303, p. 490, (1986).
6. N. Merminga, et al., "Optimizing a Nonlinear Collimation System for Future Linear Colliders," SLAC-PUB-5507, Stanford (1991).
7. "Final Focus Test Beam Project Design Report," SLAC-Report-376, Stanford, (1991).