3.5 Spin Rotators and Bunch Compressors

The purpose of the spin rotators is rotate the polarization vector, which is vertically oriented in the damping rings, into any arbitrary direction so that the beam will be longitudinally polarized at the IP. The rotators are located at the exit of the damping rings and are then followed by the bunch compressors. A spin rotator will be installed on the electron side and space will be left for an installation on the positron side to allow for a future upgrade to polarized positrons or polarized electrons for $\gamma\gamma$ or e^-e^- collisions. The rotators are based on pairs of solenoids separated by a horizontal arc to allow full control over the spin orientation; this is similar in concept to the original SLC spin rotator system. Solenoids were chosen to control the spin because the other alternate, namely a snake, requires a vertical bending chicane which must be unreasonably long to prevent synchrotron radiation from increasing the vertical emittance. Of course, the problem with solenoids is that they couple the beam which, with flat beams, leads to an increase in the projected vertical emittance; this is the reason the original solenoid system is not presently used in the SLC. Our present design uses pairs of solenoids which are optically separated so that the coupling is fully cancelled. There are very tight tolerances on the quadrupole fields between the sextupoles but an extensive skew correction system has been included to ease the tolerances as well as correct any residual coupling from the damping rings.

The NLC bunch compressors must compress the bunches from the damping rings with 4-mm lengths to the 100–150 μm bunch lengths required in the main linacs and final foci. To perform the compressions, a two-stage compressor system has been designed: the first stage follows the damping rings and the second stage operates at a beam energy of 10 GeV at the exit of 8-GeV S-band prelinacs. The compressor system is illustrated schematically in Figure 3.9.

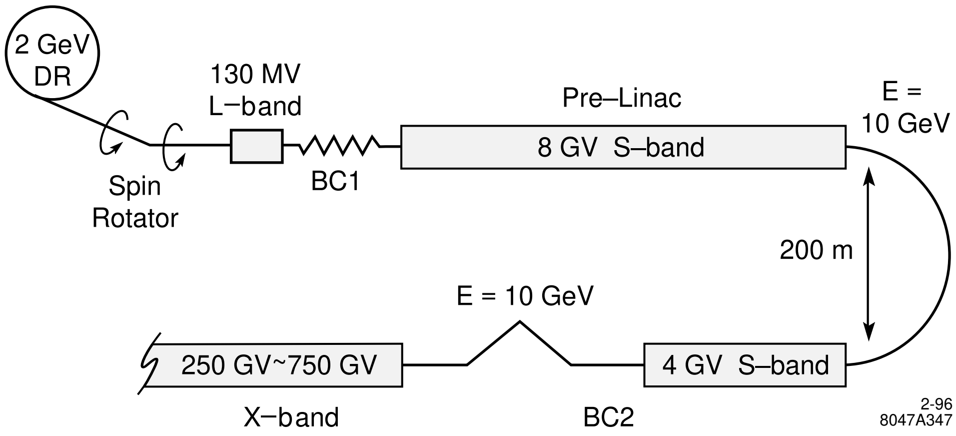

Figure 3.9: Schematic of the NLC bunch compressor system.

The bunch compressor system was designed with three primary goals:

- The compressor system must compress a bunch with length $\sigma_z \approx 4\,\text{mm}$ from the damping rings to the 100–150μm length needed in the main X-band linacs and the final foci. This requires compressing the bunch length, and correspondingly increasing the energy spread, by a factor of 30–40.

- The bunch compressor system should be able to compensate for bunch-to-bunch phase offsets induced by the beam loading in the damping rings; if not corrected, these phase errors would become energy errors at the end of the linacs. This requires that the compressor system rotate the longitudinal phase space by $\pi/2$, translating the phase errors into injection energy errors.

- The bunch compressor system should provide a trombone-like arm, reversing the direction of the beam before injection into the main X-band linacs. This allows extension of the linac lengths to upgrade the beam energy at the IP without significant modification to the injection systems. It also allows for abort systems to dump the beam and feed-forward systems to correct the beam trajectory, phase, and energy before injection into the main linacs.

The two-stage system has a number of advantages over a single stage compressor. In particular, it keeps the rms energy spread less than roughly 2%, it is optically more straightforward, and the bunch lengths are more logically matched to the acceleration rf frequency so that the energy spread due to the longitudinal wakefields can be cancelled locally. The disadvantage of the two-stage design is that it is more complex and lengthy than a single-stage compressor. The first stage rotates the longitudinal phase by $\pi/2$ while the second stage performs a 2π rotation. In this manner, phase errors due to the beam loading in the damping rings and energy errors due to imperfect multibunch energy compensation in the 8-GeV S-band prelinacs do not affect the beam phase at injection into the main linac.

Assuming an rms energy spread of $\sigma_\delta = 1 \times 10^{-3}$, the low energy compressors compress the damping ring beam to a bunch length of 500μm. The final bunch length is roughly independent of the incoming bunch length and the system has been designed to accept an initial bunch length of 5 mm; this is 25% larger than expected from the damping ring. The bunch compressors consist of a 139-MV L-band (1.4-GHz) rf section followed by a long period wiggler which generates the R_{56} needed for the bunch compression.

The high-energy bunch compressors follow the prelinacs. Assuming an rms bunch length of $\sigma_z = 500\mu$m, they compress the beam to a bunch length between 100 and 150μm depending on the NLC parameters. As stated, they are telescopes in longitudinal phase space, rotating the longitudinal phase space by 2π. The bunch compressors consist of a 180° arc which is followed by a 4-GeV S-band (2.8-GHz) rf section and a chicane. Parameters of the high-energy bunch compressors are listed in Table 3.6 for four different NLC parameter sets.

One of the driving philosophies behind the NLC compressor design has been to utilize naturally achromatic magnetic lattices wherever the beam energy spread is large. In particular, the optics is chosen so that quadrupoles are not placed in regions of large dispersion and strong sextupoles are not needed. This choice arises from experience with the SLC bunch

Table 3.6: Parameters for 10-GeV compressor.

	NLC-I a	NLC-I c	NLC-II a	NLC-II c
Energy	10 Gev			
Initial σ_z, σ_ϵ	500μm, 0.25 %			
Final σ_z	100μm	150μm	125μm	150μm
Final σ_ϵ	1.5 %	1.2 %	1.3 %	1.4 %
180° arc R_{56}	0.211	0.147	0.184	0.162
Arc Length	330 m			
V_{rf} (GV)	3.85	3.50	3.73	3.61
f_{rf}	2.8 GHz			
L_{rf}	250 m			
Chicane R_{56}	36 mm			
Chicane Length	100 m			

compressors which are based on second-order achromats where quadrupoles are located in dispersive regions and strong sextupoles are used to cancel the chromatic aberrations. Unfortunately, the SLC design is extremely difficult to operate and tune because of the large nonlinearities and the sensitivity to multipole errors in the quadrupoles; over the years additional nonlinear elements have been added (skew sextupoles and octupoles) to help cancel the residual aberrations but the tuning is still difficult. To further facilitate the tuning in the NLC design, we have explicitly designed orthogonal tuning controls and diagnostics into the system. We feel confident that these considerations will make the system relatively straightforward to operate and tune.

As discussed, the rf acceleration throughout the compressor system (including the 8-GeV prelinac) is performed with relatively low frequency rf. In particular, the first bunch compressors use L-band (1.4 GHz) and the prelinac and second bunch compressor use S-band (2.8-GHz). Although these systems are, in general, longer and more expensive than higher frequency accelerator systems, we feel that their superior acceptances are needed at the lower beam energies. In particular, we have designed the systems so that they have small beam loading and relatively loose alignment tolerances. This is important to provide the reliability and stability that is desired in the bunch compressor system. Of course, such lightly-loaded systems are inefficient and could not be used to accelerate the beams to very high energy.

Finally, although the tolerances on components in the bunch compressor systems are not nearly as tight as in the main linacs or the final foci, we have chosen to adopt the same methods of beam-based alignment and tuning. In particular, to ease the alignment procedures, all of the quadrupoles will be mounted on remote magnet movers and will be powered by individual power supplies. In addition, each quadrupole will contain a BPM with a resolution of 1μm. Similarly, all of the accelerator structures will be instrumented with an rf BPM to measure the induced dipole modes and each girder will be remotely movable; depending on location, the girders will support either one or two structures.