A NEW LATTICE DESIGN FOR THE NLC POSITRON PRE-DAMPING RING*

A. Wolski†, LBNL, Berkeley, CA 94720, USA

Abstract

The positron source for the Next Linear Collider (NLC) will produce a beam larger than the acceptance of the main damping rings, which are optimized for low extracted emittance. A pre-damping ring, with large acceptance, is therefore needed to reduce the emittance of the beam from the source, so it can be accepted by the main damping ring with minimal particle loss. Previous designs, based on a racetrack structure with TME cells in the arcs, have proven difficult to tune for the required dynamic aperture, in part because of the low symmetry. We report here on a new design, with a 10-fold symmetric DBA structure, which meets the principal parameter specifications, and has much greater tuning flexibility.

1 PRE-DAMPING RING REQUIREMENTS

The NLC positron source [1] is specified to produce a beam of normalized edge emittance 30,000 µm-rad. It is not practicable, using a single damping ring, to damp this emittance to meet the specification for injection into the main linac, so a pre-damping ring is used to reduce the emittance to a value at least as small as that of the electron beam from the electron source. Identical main damping rings can then be used for the electron and positron injection systems; designs have already been described for these main damping rings [2]. Parameters driving the design of the pre-damping ring are given in Table 1.

Table 1: Parameters driving pre-damping ring design

Collider repetition rate	f	120 Hz
Bunches per train	N_b	192
Bunch separation	s_b/c	1.4 ns
Kicker rise/fall time		100 ns
Injected x and y edge emittance	$\gamma\varepsilon_{\text{inj}}$	45000 µm
Injected max energy deviation	δ_{max}	± 1.5%
Extracted x and y rms emittance	$\gamma\varepsilon_{\text{ext}}$	<150 µm

Note that the edge emittance is defined as the maximum transverse action of any particle in the beam. The value of 45,000 mm-mrad allows for the 30,000 mm-mrad actual edge emittance, plus 50% transverse jitter. The rms emittance is defined as the mean transverse action of all the particles in the beam. All emittance values are normalized by the energy. The bunches per train, bunch separation and kicker rise/fall time, together with the number of trains stored in the ring determine the circumference of the ring. The aperture is defined by the injected edge emittance and energy distribution; the required damping rate is determined by the injected edge emittance (including jitter: a beam with an injection offset is assumed to filament) and the extracted emittance limit.

Previous lattice designs [3] have used a racetrack structure, with arcs based on theoretical minimum emittance (TME) cells, and long straight sections including the damping wigglers, injection/extraction components, RF cavities and circumference control chicane. The main advantage of the TME cell is that it is a compact structure allowing for very low equilibrium emittance. However, the nonlinear dynamics in a TME lattice tend to be difficult to optimize, and a racetrack structure has limited flexibility. The moderate requirements on the extracted emittance mean that a TME lattice is not absolutely required, and it is possible to meet the specifications using, for example, a double-bend achromat (DBA) structure. We present here a design for the pre-damping ring lattice using a DBA structure, with greater symmetry and flexibility than the TME racetrack.

2 PARAMETERS

The principal lattice parameters are given in Table 2.

Table 2: Principal lattice parameters

Energy	E	1.98 GeV
Circumference	C	230.933 m
Natural emittance	$\gamma\varepsilon_0$	59.7 µm
Betatron tunes	ν_x, ν_y	11.5, 5.39
Chromaticity	ξ_x, ξ_y	-24.8, -13.4
Damping time	τ_y	5.8 ms
Momentum compaction	α	2.00×10^{-3}
Synchrotron tune	ν_s	0.0114
Energy loss per turn	U_0	525 keV
RF voltage	V_{RF}	1.52 MV
Momentum acceptance	ε_{RF}	1.5%
RF frequency	f_{RF}	714 MHz
Equilibrium bunch length	σ_z	5.14 mm
Equilibrium energy spread	σ_δ	0.078%

We assume that the beam is fully coupled, to benefit the horizontal extracted emittance. The circumference allows two bunch trains to be stored, so the store time for each train is 16.7 ms. Under these conditions, and with an effective rms injected emittance of 31,500 µm (approximately 70% of the edge emittance), the extracted emittances are 135 µm in each plane, well within the specified 150 µm upper limit.

3 LATTICE STRUCTURE

The lattice has to incorporate damping wigglers, RF cavities, injection and extraction systems, and circumference control chicanes. One advantage of the DBA structure, is that each of the different systems can be

*Work supported by the US DOE under contract DE-AC03-76SF00098
†awolski@lbl.gov

located in a different straight, with only minor modifications to accommodate the particular requirements of the different components. For example, pairs of quadrupoles may be eliminated from the wiggler sections, since the wiggler itself provides some vertical focusing. The betatron phase advances over the different sections are adjusted to restore the ten-fold symmetry of the lattice, and the resulting structure shows good flexibility in terms of tuning and location of the various systems.

Lattice functions in the wiggler and chicane sections are shown in Figure 1 and Figure 2.

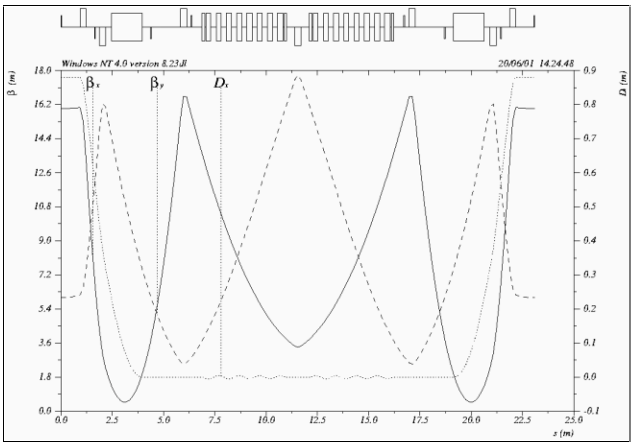

Figure 1: Lattice functions in the wiggler section.

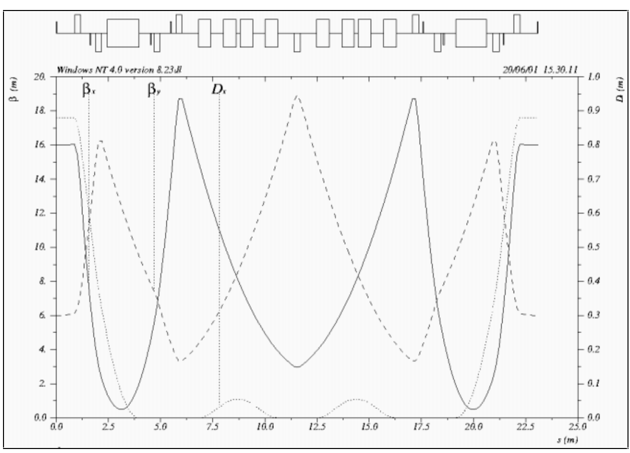

Figure 2: Lattice functions in the chicane section.

The overall lattice structure is shown in Figure 3. There are a total of six wiggler sections, giving a total of twelve damping wigglers, as described below. The injection and extraction straights can be located wherever convenient; with the present transport lines layout, they are diametrically opposite, with the beam circulating clockwise. The RF section is located before the extraction section, so the cavities do not see any "missing" trains.

4 DYNAMIC PROPERTIES

Optimization of the dynamics is important for the ring to meet the acceptance requirements with a large injected beam size, and achieve good injection efficiency. In operation, trains of 192 bunches with a population 8×10^9 particles per bunch will be injected at a rate of 120 Hz. This means that an injection efficiency close to 100% will be needed to avoid an unacceptable radiation load on the ring.

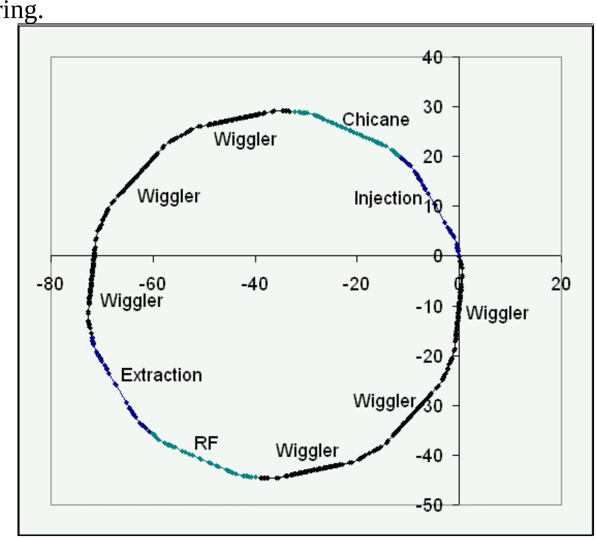

Figure 3: Pre-damping ring structure. Horizontal and vertical scales are in metres.

Tuning the dynamics in the present structure is easier than in the racetrack design, since the DBA has obvious locations for auxiliary sextupoles. The present design includes four families of harmonic sextupoles. The working point of the lattice in tune space is shown in Figure 4. Proximity to coupling resonances is not a problem, since the plan is for the beam to be fully coupled. The tune shifts for ±2% momentum deviation do not look severe, and indicate acceptable dynamic momentum acceptance. The dynamic aperture is shown in Figure 5. This is determined by tracking 500 turns through the lattice, with the observation point at the center of the achromat.

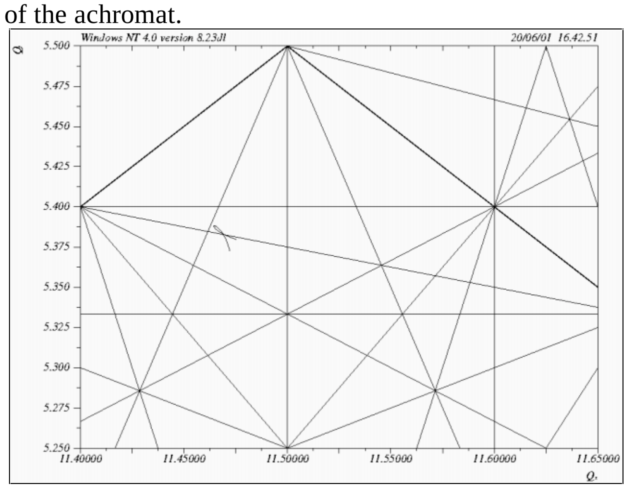

Figure 4: Working point of the lattice in tune space.

5 SYSTEMS AND COMPONENTS

5.1 Magnets

The dipole field is 1.383 T, with no gradient. The largest quadrupole gradient is 2.1 T/m, and the largest sextupole gradient is 74 T/m^2. These fields are compatible with a pole tip radius of 40 mm, which will allow an internal beam pipe radius of 36 mm. With the peak edge beam size at injection 31 mm, the physical aperture should be sufficient.

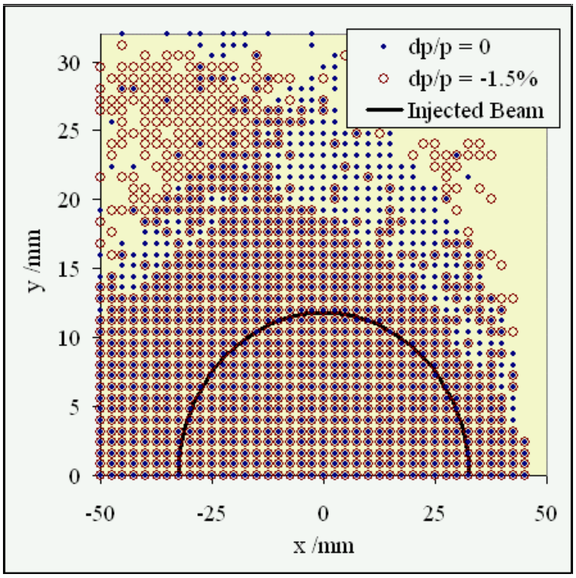

Figure 5: Dynamic aperture for on-momentum particles, and particles with –1.5% momentum deviation.

5.2 Wiggler

There are twelve wigglers in total, arranged in pairs in six sections of the lattice. Detailed wiggler designs have not yet been produced, but the specified parameters are given in Table 3.

Table 3: Wiggler parameters

Wiggler peak field	B_w	1.4 T
Wiggler period	λ_w	1.0 m
Wiggler total length		49.5 m
Integrated field	$\int B^2\,ds$	48.5 T^2m
Wiggler Energy loss per turn	U_w	241 keV

Note that the wigglers provide nearly half the total radiation loss. This is a modest fraction compared to main damping ring designs for NLC (70%) or TESLA (90%). With these parameters, it is expected that a half-aperture of greater than 25 mm can be achieved in the wiggler section, which allows sufficient aperture for the peak edge beam size of 20 mm in these sections.

5.3 Injection and Extraction Systems

No work has been done on the components in the injection and extraction systems since the publication of the NLC ZDR [2], and we have therefore assumed the same parameters as were specified at that time. The kickers and septa are each 2 m long, with the kickers providing a deflection of 8 mrad (injection) and 6.6 mrad (extraction), and the septa a deflection of 150 mrad. The central horizontally defocusing quadrupole provides additional bending for the injected/extracted beam. The circumference of the lattice allows for a kicker rise/fall time of just under 120 ns. The apertures of the kickers and septa are sufficient, and the geometry of the injection and extraction regions do not present any difficulties.

5.4 RF Cavities

The RF voltage requires four normal conducting cavities, which will are expected to be of the same design as that used in the main damping rings, i.e. HOM-damped structures based on the successful PEP-II cavities. Studies of coupled-bunch instabilities suggest that all the longitudinal modes are below the damping threshold, while unstable modes in the transverse plane are driven by the resistive wall impedance, and will be easily dealt with by a feedback system.

5.5 Circumference Control Chicane

The RF power in the damping rings will be phase-locked to other systems in the NLC, and so it will not be possible to make small adjustments to the beam energy by varying the RF frequency. For this reason, the NLC damping ring designs include chicanes for making adjustments to the energy through small changes in the circumference. In the present pre-damping ring design, we include two separate chicanes, each consisting of four dipoles, on either side of the central dipole in one of the straight sections. The total circumference adjustment range is ±4mm, which corresponds to an energy variation of a little less than 1%.

6 FUTURE WORK

The DBA lattice presented here has so far proven more flexible in design than the racetrack TME structures previously considered. Initial optimization of the dynamics has led to an acceptable dynamic aperture and energy acceptance, though further optimization could increase the available margin. Field quality tolerances need to be specified, and the effects of a nonlinear wiggler field, which could be significant, have to be investigated. Detailed designs of injection and extraction systems have also yet to be produced. Coupled bunch instabilities should easily be dealt with by a feedback system, but other collective effects, such as electron cloud, have yet to be studied in detail. Nonetheless, it is expected that, because of the relatively large beam size, collective limitations will not be severe.

7 REFERENCES

[1] Y.K. Batygin, V. Bharadwaj, D.C. Schultz, J.C. Sheppard, "Design Studies of Positron Collection for the NLC," PAC'01, June 2001.

[2] A. Wolski and J.N. Corlett, "The Next Linear Collider Damping Ring Lattices," PAC'01, June 2001.

[3] The NLC Design Group, "Zeroth-Order Design Report for the Next Linear Collider," SLAC-474, May 1996.