NEW CONCEPTS FOR DAMPING RINGS*

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Abstract

The requirements for very low emittance and short damping time in the damping rings of future linear colliders, naturally lead to very small beta functions and dispersion in the ring arcs. This makes it difficult to make chromatic correction while maintaining good dynamics. We have therefore developed a lattice with very simple arcs (designed to give the best product of emittance and damping time), and with separate chromatic correction in a dedicated section. The chromatic correction is achieved using a series of non-interleaved sextupole pairs. The performance of such a solution is comparable to that of current damping ring designs, while there are a number of potential advantages.

1 DAMPING RING REQUIREMENTS

The luminosity of a linear collider is determined by the beam power and spot size at the interaction point. These quantities in turn depend on the damping rate and emittance of the damping rings. To achieve low emittance, the arc cells are tuned with low dispersion and beta functions. However, this makes chromatic correction in the arcs difficult, and some performance must be sacrificed to achieve reasonable dispersion at the sextupoles. Still, strong sextupoles are generally required, which introduce significant nonlinearities in the particle dynamics, limiting the dynamic aperture. Since the mean injected beam power in the damping rings for the Next Linear Collider (NLC) [1] will be 55 kW, any significant particle loss from dynamic aperture restrictions will lead to unacceptable radiation loads on the ring. In addition, storage ring parameters favoring low emittance, such as low energy and small dipole bending angle, tend to lead to long damping times. Present designs for the NLC damping rings [2] are therefore based on lattices in which the energy loss is dominated by strong wigglers. There are some concerns that nonlinearities introduced by the strong wiggler fields may further restrict the dynamic aperture.

Improvements to the existing lattice designs may be achieved by optimizing the arc cells for emittance and damping rate, and placing the chromatic correction in a separate section of the lattice. One possibility we are investigating is to use arc cells based on dipoles bending in alternating directions. In principle, lattices composed of such cells can achieve low emittance and very rapid damping without the need for a wiggler, and can be made very compact. A separate chromatic section allows the possibility of tuning this part of the machine to optimize the nonlinear dynamics. In this paper, we consider an outline design based on these principles, which has a performance approaching that required for the NLC damping rings.

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2 DAMPING RATE AND EMITTANCE

Consider a storage ring with alternating bends, of fields B_0 and rB_0. For a lattice with overall positive bending, we take $-1<r<0$. The vertical damping rate can be written as:

$$\frac{1}{\tau_y}=\frac{\left(1+r^2\right)}{\left(1+r\right)}\frac{C_\gamma}{4\pi}\frac{E^3\omega_0}{\rho_0}$$

where C_γ=8.846×10^{-5} meter/GeV^3, E is the energy, ω_0 is the angular revolution frequency, and ρ_0 is the bending radius in the field B_0. A value of r close to –1 helps to achieve rapid damping.

For a lattice constructed from alternating bends with strong gradients, the natural emittance is a complicated function of the lattice parameters. In principle, a horizontally defocusing gradient in a bending magnet helps reduce the emittance somewhat; however, it is not possible to construct a lattice with stable horizontal and vertical orbits simply from horizontally focusing magnets. Let us therefore assume that the lowest possible emittance in our lattice is not smaller than:

$$\varepsilon_{\min}=C_q\gamma^2\frac{\theta^3}{12\sqrt{15}}$$

where C_q is the quantum fluctuation coefficient, γ the relativistic factor, and θ the maximum bending angle. For $r\rightarrow 0$, this equation indeed gives the theoretical minimum emittance that can be achieved.

The NLC bunch train has 192 bunches with 1.4 ns separation. If we assume a kicker rise/fall time of 65 ns, then the minimum lattice circumference is 100 m. The required damping rate of 1.7 ms is set by the repetition rate of 120 Hz, and the injected and extracted vertical emittances, which indicate a store time of close to 5 damping times. The specified extracted horizontal normalized emittance is 3 µm rad. We can now calculate the dipole field strengths and the number of lattice cells required both in conventional and in alternating-bend lattice designs, for different energies. Note that the energy is restricted to half-integer multiples of 0.44 GeV, to avoid spin-depolarization resonances. For the alternating-bend lattice, we have freedom in choosing the main dipole field; for practical purposes, the maximum field strength is around 1.4 T. The results are shown in Table 1.

The present damping ring designs have a beam energy of 1.98 GeV; at this energy, a conventional lattice design would require a main dipole field of nearly 4 T. Note that at an energy of 3.3 GeV, the required field reduces to our chosen value of 1.4 T, and the alternating-bend lattice ceases to offer any advantage.

Table 1: Comparison of Conventional and Alternating-Bend Lattice Designs

Energy /GeV	Conventional Lattice		Alternating-Bend Lattice		
	B_0 /T	N_{cell}	B_0 /T	r	N_{cell}
1.98	3.87	34	1.4	-0.534	74
2.42	2.59	42	1.4	-0.381	68
2.86	1.85	50	1.4	-0.211	63
3.30	1.39	57	1.4	0.006	57

3 LATTICE DESIGN

3.1 Parameters

Ideally, we should like a lattice circumference of no more than 100 m for storing a single bunch train, though this is difficult to achieve if more than 70 arc cells are needed. The design we present here is based on an energy of 2.42 GeV, with 80 arc cells, and a circumference of a little under 195 m, which will store two bunch trains. Note that injection and extraction systems, and other necessary components, are not yet included in the lattice design. Some parameters are given in Table 2.

Table 2: Lattice parameters.

Energy	E	2.42 GeV
Circumference	C	194.7 m
Natural Emittance	$\gamma\varepsilon_0$	1.6 µm-rad
Energy Loss/Turn	U_0	1.30 MeV
Damping Times	$\tau_x, \tau_y, \tau_\varepsilon$	1.4, 2.4, 2.0 ms
Betatron Tunes	ν_x, ν_y	39.68, 22.18
Natural Chromaticities	ξ_x, ξ_y	-55.1, -38.4
Synchrotron Tune	ν_s	5.5×10^{-4}
Momentum Compaction	α	2.63×10^{-5}
RF Voltage	V_{RF}	1.35 MV
RF Momentum Acceptance	ε_{RF}	1.5%
Natural Energy Spread	σ_δ	0.12%
Equilibrium Bunch Length	σ_z	1.7 mm

We note that with two bunch trains, and assuming an equilibrium beam emittance ratio of 1%, the required vertical damping time is 3.1 ms, to achieve an extracted vertical emittance of 0.02 µm rad. This lattice therefore has some margin in both the emittance and the damping rate.

3.2 Arc Cell

The lattice functions in a single cell are shown in Figure 1. The magnets are combined function dipoles, with on-axis fields of 1.76 T and –0.960 T, lengths 0.55 m and 0.35 m and gradients –40.8 T/m and 87.3 T/m respectively. Because of the high fields and gradients, these are rather challenging magnet designs. The lattice is rather conservative in terms of emittance and damping time, however, and it is expected that with further optimization, the magnet requirements should be somewhat eased. The overall length of the cell is 1.2 m.

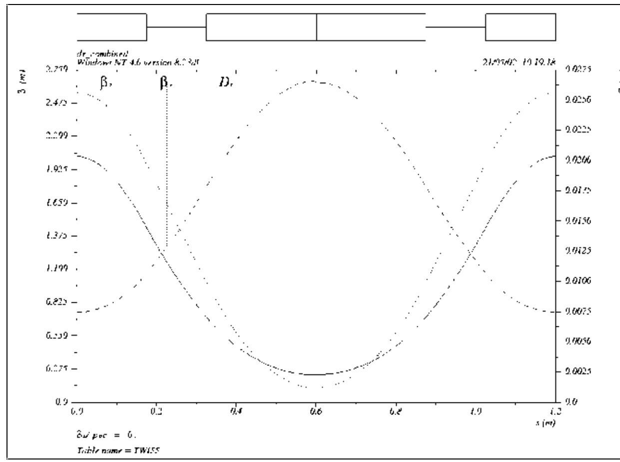

Figure 1: Lattice functions in a single arc cell.

The tunes and chromaticities of a single cell are 0.341 and –0.467 in the horizontal plane, and 0.139 and –0.247 in the vertical plane. 80 such cells are required in the full lattice.

3.3 Chromatic Correction

Lattice functions in one chromatic correction section are shown in Figure 2. The dispersion is controlled by weak bends, and the correction is achieved by 8 pairs of sextupoles, each pair forming a –I transformer. In principle, this cancels the geometric aberrations; however, the non-zero lengths of the sextupoles means that some nonlinear terms remain, leading to a finite dynamic aperture. Also, the phase advance between the sextupoles varies for off-momentum particles, so it is not clear whether a good dynamic momentum acceptance will be achieved. The largest sextupole gradient is 5035 T/m^2.

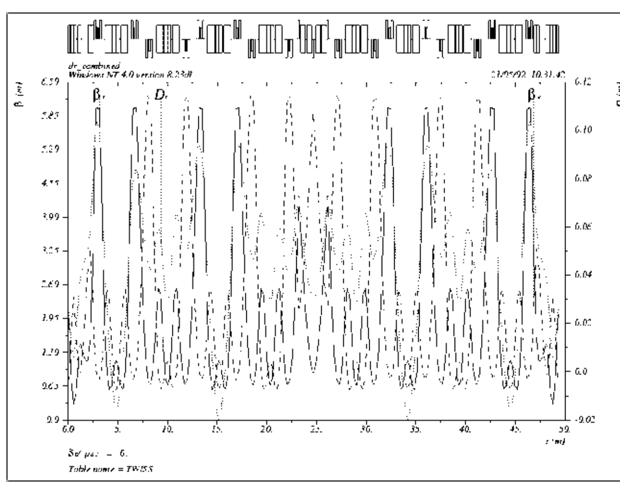

Figure 2: Lattice functions in the chromatic correction section.

With the sextupole scheme used, the higher order chromaticities are small. This can be seen in Figure 3, which shows the variation in the tunes with momentum deviations up to ±2%. Allowed resonances in a two-fold symmetric lattice up to fourth order are also shown. The good chromatic properties of the lattice suggest that it should achieve a reasonable dynamic momentum acceptance.

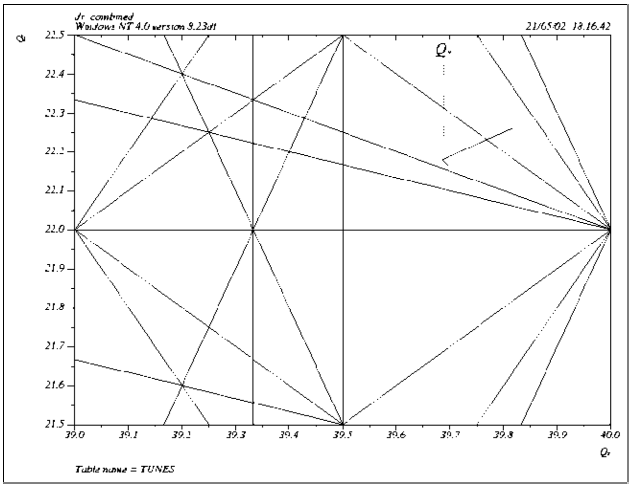

Figure 3: Variation in tunes with momentum deviations up to ±2%.

3.4 Dynamic Aperture

There is no absolute requirement on the dynamic aperture, though it is thought that a dynamic aperture roughly 15 times larger than the injected beam size will be needed. This allows some margin to catch particles in the tails of the distribution; it allows for reduction from higher-order multipoles and other errors; and it minimizes nonlinear distortion of the phase space seen by the core of the beam. The latter effect is important, since a mismatch of the phase space may lead to filamentation of the injected beam, and an increase in the emittance during the first part of the damping cycle.

Figure 4 shows the dynamic aperture for on-momentum particles, and Figure 5 the dynamic aperture for particles with –1.5% momentum deviation. In each case, particles were tracked 500 turns through the lattice.

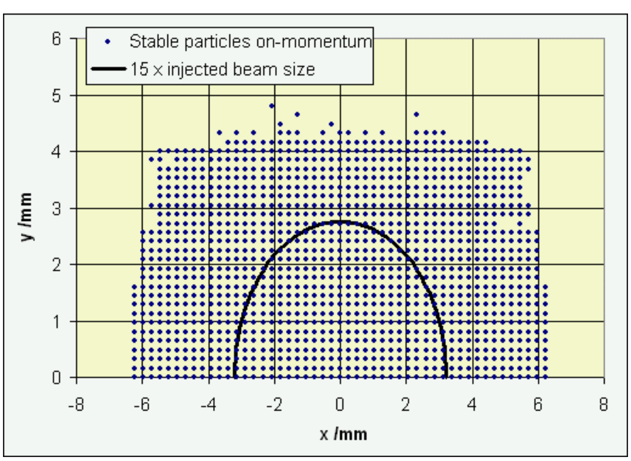

Figure 4: Dynamic aperture for on-momentum particles.

The observation point has beta functions 1.44 m horizontally, and 1.07 m vertically. The aperture for particles with positive momentum deviation increases slightly above that for on-momentum particles.

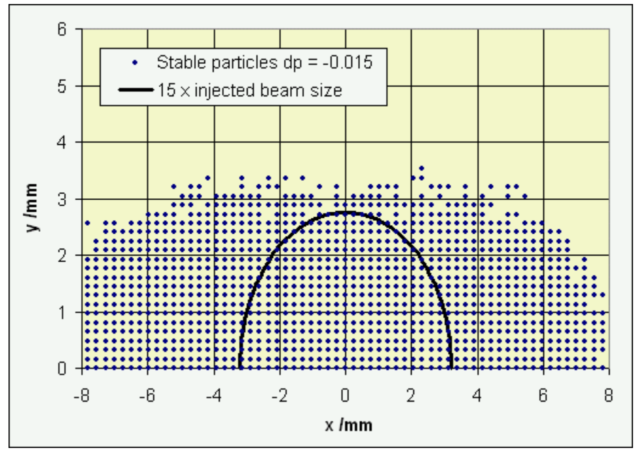

Figure 5: Dynamic aperture for particles with –1.5% momentum deviation.

The dynamic aperture for this lattice is somewhat in excess of 15 times the beam size up to significant momentum deviation, and is significantly better than existing lattice designs.

4 DISCUSSION

The lattice we have described was intended to demonstrate the feasibility of a structure having chromatic correction separate from the arcs. Using an alternating bend scheme for the arc cells, we have been able to achieve an emittance and damping times well within the NLC specifications, at an energy close to that of the existing damping ring design. The circumference is somewhat larger than we should like; ideally, the damping ring would store a single bunch train, but it appears difficult to achieve the low emittance in a lattice having half the present circumference.

The sextupole scheme we have used in the chromatic correction section is effective in canceling geometric aberrations; the remaining nonlinear terms arise from the non-zero lengths of the sextupoles. Although the dynamic aperture is already rather better than that in the existing damping ring designs, it is possible that with careful tuning, it may be improved. The dynamic momentum acceptance in particular shows a clear improvement over existing designs.

There still appears some work to do before such a lattice as the one presented here, can be considered a practical proposition. For example, we should like to reduce the magnetic field strengths, and include necessary systems and components, e.g. for injection and extraction.

REFERENCES

[1] The NLC Collaboration, “2001 report on the Next Linear Collider”, SLAC-R-571, June 2001.

[2] A. Wolski and J. Corlett, “The Next Linear Collider Damping Ring Lattices”, proceedings PAC 2001.