Title

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Abstract

Previous lattice designs for the Next Linear Collider Main Damping Rings [1] have met the specifications for equilibrium emittance, damping rate and dynamic aperture. Concerns about the effects of the damping wiggler on the beam dynamics [2] led to the aim of reducing the total length of the wiggler to a minimum consistent with the required damping rate, so high-field dipoles were used to provide a significant energy loss in the arcs. However, recent work has shown that the wiggler effects may not be as bad as previously feared. Furthermore, other studies have suggested the need for an increased momentum compaction (by roughly a factor of four) to raise the thresholds of various collective effects. We have therefore developed a new lattice design in which we increase the momentum compaction by reducing the field strength in the arc dipoles, compensating the loss in damping rate by increasing the length of the wiggler. The new lattice again meets the specifications for emittance, damping rate and dynamic aperture, while having the benefit of significantly higher thresholds for a number of instabilities.

Disclaimer

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Abstract

Previous lattice designs for the Next Linear Collider Main Damping Rings [1] have met the specifications for equilibrium emittance, damping rate and dynamic aperture. Concerns about the effects of the damping wiggler on the beam dynamics [2] led to the aim of reducing the total length of the wiggler to a minimum consistent with the required damping rate, so high-field dipoles were used to provide a significant energy loss in the arcs. However, recent work has shown that the wiggler effects may not be as bad as previously feared. Furthermore, other studies have suggested the need for an increased momentum compaction (by roughly a factor of four) to raise the thresholds of various collective effects. We have therefore developed a new lattice design in which we increase the momentum compaction by reducing the field strength in the arc dipoles, compensating the loss in damping rate by increasing the length of the wiggler. The new lattice again meets the specifications for emittance, damping rate and dynamic aperture, while having the benefit of significantly higher thresholds for a number of instabilities.

DESIGN OBJECTIVES

Some of the parameters specifying the performance of the Main Damping Rings (MDRs) for the NLC are shown in Table 1. In addition, since the average injected beam power into the ring in operation will be 55 kW, the injection efficiency will have to be close to 100%, and this places demanding requirements on the acceptance.

Table1: NLC Damping Ring Specifications

Bunches per train	192
Bunch-to-bunch spacing	1.4 ns
Kicker rise/fall time	65 ns
Collider repetition rate	120 Hz
Injected horizontal/vertical emittance	150 µm
Extracted horizontal emittance	3 µm
Extracted vertical emittance	0.02 µm
Extracted energy spread	10^{-3}

The circumference of the lattice is constrained by the need to accommodate a number of bunch trains, with sufficient spacing to allow the kickers to turn on and off between the trains. The number of trains stored, and the injected and extracted emittances specify the damping rates. Note that the normalized emittances are given in Table 1. As with the previous design, a circumference of 300 m has been chosen. This provides sufficient room for the necessary number of arc cells to achieve the natural emittance, the damping wiggler, injection and extraction systems and other components. Three bunch trains are stored at any given time.

LATTICE PARAMETERS

Some of the principal lattice parameters for the new design are given in Table 2.

Table 2: Principal Lattice Parameters

Beam energy	1.98 GeV
Circumference	299.792 m
Arc cells	32 TME
Wiggler length	61.6 m
Betatron tunes (x,y)	21.150, 10.347
Natural chromaticity (x,y)	-30.74, -28.76
Natural emittance (normalized)	2.37 µm
Natural energy spread	9.75×10^{-4}
Harmonic number	714
RF voltage	2.0 MV
RF acceptance	1.52 %
Natural bunch length	5.49 mm
Synchrotron tune	0.0118
Momentum compaction	1.39×10^{-3}
Energy loss/turn	970 keV
Damping times (x,y,t)	3.6, 4.1, 2.2 ms

Compared to the previous lattice, the momentum compaction has been increased by more than a factor of four. This was one of the main aims of the design, since this gives an increase of roughly two in the bunch length and reduces the impact of a number of collective effects. The increase in momentum compaction has been achieved by reducing the dipole field by a factor of two. Since this leads to a lower energy loss per turn, and hence longer damping times, it is necessary to increase the length of the wiggler to compensate. In fact, we have somewhat overcompensated by increasing the wiggler from 46 m to nearly 62 m, which reduces the vertical damping time from 5 ms in the previous lattice to 4.1 ms in the present version. This will provide some safety margin against possible effects (such as a mismatch of the injected phase space) tending to reduce the effective damping period.

One concern with the increased length of the wiggler is the effect on the beam dynamics. The dynamic aperture of the lattice is of importance because of the need for a large acceptance, and it is possible that intrinsic nonlinearities in the wiggler field could reduce the dynamic aperture. However, recent detailed studies based on a magnetic design for the NLC damping wiggler suggest that the wiggler length in the present design is acceptable [3].

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LATTICE DESIGN

The overall layout of the electron MDR, with associated injection and extraction lines, is shown in Figure 1. The positron and electron MDRs are identical, but the positron complex includes a pre-damping ring to accept the large emittance beam from the positron source, and reduce its dimensions so that it can be accepted cleanly by the MDR. The four arcs in the MDR are composed of detuned Theoretical Minimum Emittance (TME) cells. The detuning from the strict minimum emittance conditions is necessary to optimize the dynamic stability with the given space constraints. Two long straights, each containing approximately 30 m of wiggler are located opposite each other. The remaining two straights contain all other systems.

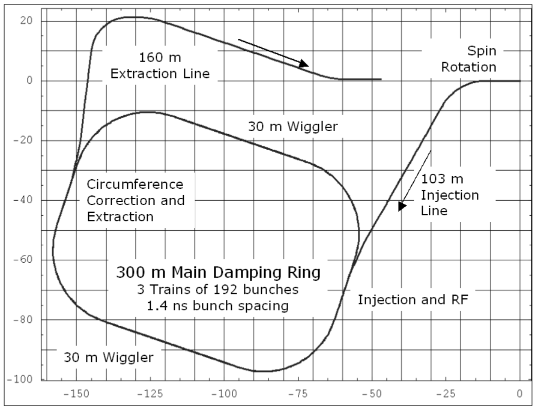

Figure 1: Overall Layout of the Electron MDR

The lattice functions in one TME cell are shown in Figure 2.

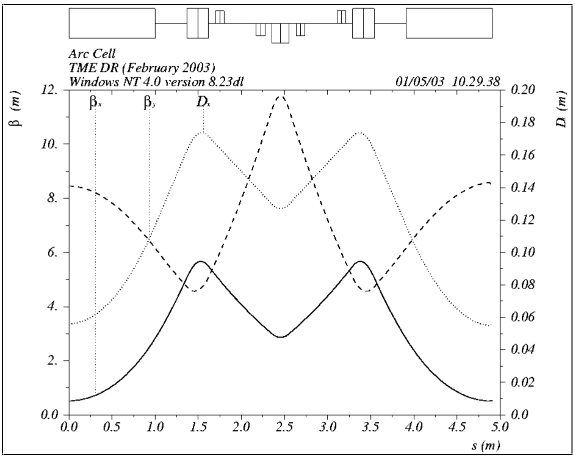

Figure 2: Lattice Functions in One Arc Cell

The arc dipoles have a main field of 0.6 T, and a vertically focusing gradient of 2.0 T/m. The horizontally focusing quadrupoles in the cell are offset with respect to the nominal straight path between the dipoles, to provide some bending of their own. This helps to allow more independent control of the dispersion and horizontal beta function, to reduce the natural emittance of the lattice while allowing flexibility for optimizing the nonlinear dynamics. The quadrupoles have a pole-tip radius of 24 mm, and the beam is offset horizontally from the quadrupole center by 2.6 mm.

The lattice functions in the injection straight are shown in Figure 3.

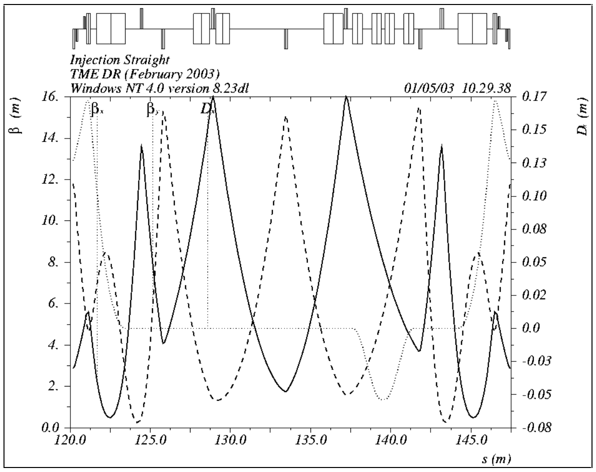

Figure 3: Lattice Functions in the Injection Straight

The injection septum is in two parts with a quadrupole sandwiched in between. Following the injection kicker is a four-magnet chicane, which provides control of the circumference over a range ±2 mm (since the RF frequency is locked to other parts of the collider, small changes in beam energy must be effected by direct variation in the circumference). The extraction straight is similar to the injection, except that five RF cavities are located immediately before the extraction kicker. The cavities allow variation of the RF voltage up to 2.5 MV, so the bunch length may be reduced (and RF acceptance increased) if allowed by collective effects. The location of the RF cavities ensures that trains can be extracted and injected into the ring without inducing any transient effects from changes in the beam loading in the cavities.

CHROMATIC PROPERTIES AND DYNAMIC APERTURE

The linear lattice has been designed to keep the natural chromaticities as small as possible, and to provide locations for the chromatic sextupoles with large dispersion and good separation of the beta functions. This allows the strengths of the sextupoles needed to correct the chromaticity to be kept low, so that it is possible to obtain a reasonable dynamic aperture. There remains some significant higher order chromaticity: the variation in tune with momentum deviations up to ±1.5% are shown in Figure 4. Resonance lines up to fifth order are also shown.

The dynamic aperture of the lattice for on-momentum particles is shown in Figure 5. The half-ellipse in the plot shows fifteen times the injected beam size at the observation point. No errors are included, except for a systematic octupole component of integrated normalized strength $k_3l = 100\ \mathrm{m}^{-3}$ per period. A more detailed study of the effect of the wiggler on the beam dynamics is reported elsewhere in these proceedings [3].

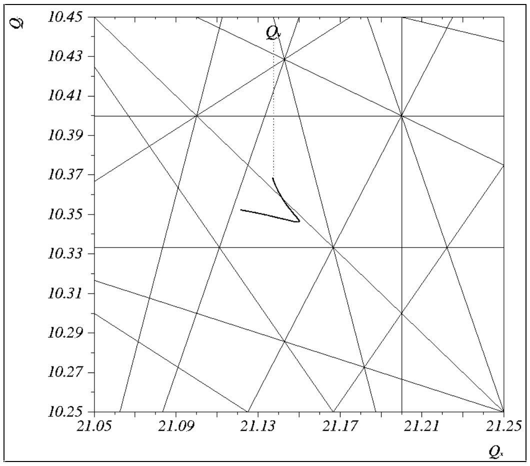

Figure 4: Tune Variation with ±1.5% Energy Deviation

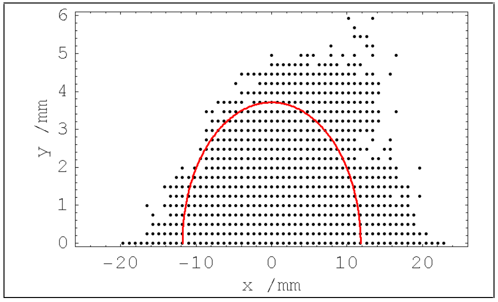

Figure 5: Dynamic Aperture for On-Momentum Particles

For particles with momentum deviations of ±1%, the dynamic aperture falls somewhat below the target of fifteen times the injected beam size. The dynamic aperture of the lattice is probably sufficient, although further optimization is desirable. Studies of the effects of systematic and random field errors and magnet misalignments are planned.

ALIGNMENT SENSITIVITIES

The luminosity of the collider depends critically on the vertical emittance from the damping rings, and the specifications are demanding. The 2001 design was very sensitive to misalignments, mainly because the vertical tune was too close to an integer value. This has been corrected in the present design. The sensitivities may be quantified by giving the rms sextupole misalignment, or quadrupole roll, that would, without any other errors, generate the specified vertical emittance [4]. These values are given in Table 3, with values for the Advanced Light Source (ALS) at LBNL for comparison.

Table 3: Misalignments Generating 0.02 μm Vertical Emittance

	NLC MDR	ALS
Sextupole Alignment [μm]	53	30
Quadrupole Roll [μrad]	511	200

Note that a vertical emittance of 0.02 μm has recently been achieved in the ALS [5]. We therefore have some confidence that the specified vertical emittance for the NLC MDRs is achievable.

INSTABILITY THRESHOLDS

To estimate the effect of the larger momentum compaction, we consider the microwave threshold estimated by the Boussard criterion, and the threshold for a microwave-type instability driven by the radiation impedance (CSR instability) [6,7,8]. These effects are of concern because of the increase in the longitudinal emittance and, more importantly, because of the transients introduced if these instabilities appear in a bursting mode as has been frequently observed. For the nominal bunch charge of 0.75×10^{10}, the microwave impedance (*Z/n*) threshold has increased from 100 mΩ to 630 mΩ. The thresholds for the CSR instability as a function of radiation wavelength are shown in Figure 6. The vacuum chamber will cut off wavelengths above values around 3 mm (which is less than the bunch length). The increased momentum compaction has significantly raised the microwave and CSR instability thresholds, as expected.

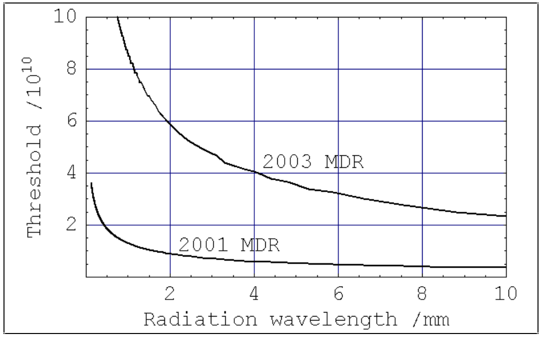

Figure 6: CSR Instability Thresholds

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