A REDUCED EMITTANCE LATTICE FOR THE NLC POSITRON PRE-DAMPING RING*

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Abstract

The Pre-Damping Ring of the Next Linear Collider has to accept a large positron beam from the positron production target, and reduce the emittance and energy spread to low enough values for injection into the Main Damping Ring. A previous version of the lattice yielded an emittance of the extracted beam that was about 20% too large. In order to get the emittance down to the required value, the quadrupole magnets in the dispersive regions in the ring were moved horizontally; this modifies the damping partition numbers. In addition, the model of the wigglers has been modified to reflect more closely the magnetic field map. The new lattice design meets damping and emittance requirements. The lattice and dynamic aperture studies are presented.

INTRODUCTION

The positron source parameters and the main damping ring specifications for NLC lead to the need for a pre-damping ring that will reduce the emittance from 30,000 mm mrad to below 100 mm mrad for injection into the main damping ring. It is not necessary to produce a flat beam, so the alignment tolerances and coupling correction will be much looser than in the main rings. However, the pre-damping ring will require a relatively large acceptance, which will impact the design of the lattice and its magnetic elements. Table 1 lists some parameters.

The design presented in this note uses a 10-fold symmetric double-bend achromat (DBA) structure. The structure allows separation of the different components, so that the damping wiggler, injection/extraction systems, RF cavities and chicane are all placed in separate straights; this greatly assists lattice design, since the different cells can be optimized independently, and should also ease engineering constraints, for example in locating photon stops to absorb the synchrotron radiation from the dipoles and wiggler. The new design is described in more detail in [1].

The design presented in [2] reduces the emittances to 127 mm-mrad (horizontal) and 70 mm-mrad (vertical). The horizontal emittance is too large by about 20 %. One possibility to decrease this value is to increase the horizontal damping partition number J_x. An increase to about 1.1 was deemed sufficient. This is obtained by positioning the quadrupoles off-center horizontally and therefore using them as additional bending magnets. To obtain a damping partition number of 1.1 in this ring, the circumference must be changed by about 4.2 mm, which corresponds to changing the position of the quadrupole magnets in the arcs by 1.5 mm.

Table 1: Machine parameters.

Energy	1.98 GeV
Circumference	230.93 m
Basic cell type	DBA
Basic cell length	23.09 m
Number of cells	10
Bunches per train	192
Bunch-to-bunch spacing	1.4 ns
Kicker rise/fall time	100 ns
Collider repetition rate	120 Hz
Tunes (hor., vert., synch.)	12.15, 6.19, 0.0098
Natural chromaticities (hor., vert.)	$-26.3, -15.6$
Normalized natural emittance	46 mm mrad
Damping times	3.5, 3.8, 2.0 ms
Energy loss/turn in bends/wigglers/total	284 keV, 519 keV, 803 keV
Assumed coupling	10 %
Assumed inj. edge emittance	30,000 mm mrad
Assumed inj. edge em. incl. jitter	45,000 mm mrad
Extracted emittance (hor., vert.) (rms)	49, 7.9 mm mrad
Momentum compaction	$1.69 \cdot 10^{-3}$
RF voltage	1.72 MV
RF acceptance	1.5 %
RF frequency	714 MHz
Harmonic number	550
Equilibrium energy spread (rms)	0.00089
Equilibrium bunch length (rms)	5.12 mm

The lattice was rematched after moving the magnets. At the same time, the wiggler was changed to give a better representation of the real fields, which, in turn, changed the focusing. To make tune adjustments easier, a pair of quadrupole magnets was added to the wiggler cells.

After the basic lattice was matched, the chromaticity was adjusted and harmonic sextupoles were used to decrease the detuning with amplitude.

LATTICE PARAMETERS

The main parameters of the lattice are given in Tab. 1. The basic double-bend achromat structure of a single cell is shown in Fig. 1. The dispersion is close to zero outside of the achromat. The wiggler generates only small amounts of residual dispersion but provides significant vertical focusing.

Other types of cell with similar structure and lattice functions are constructed for the RF cavities, chicane, injection and extraction systems. The geometry of the lattice is simplified by having the cells the same length, and the spacing of the dipoles the same in each case; thus, the layout is a regular decagon.

RF cell There is more than sufficient space for four RF cavities. It is assumed at present that the cavities will be the same design as used in the main damping rings [3, 4], being HOM-damped structures based on the PEP-II design. Studies of instabilities driven by modes in the cavities have

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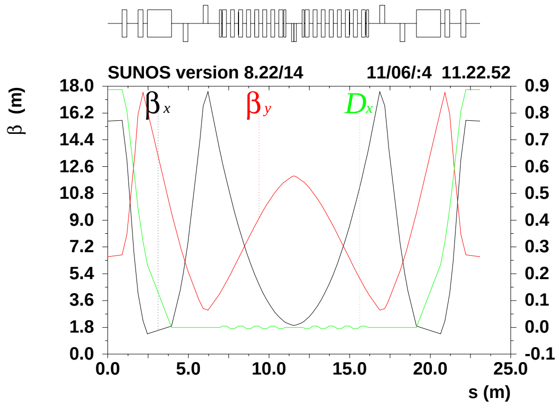

Figure 1: Lattice functions in one wiggler cell.

yet to be carried out, though it is expected that any unstable modes will be readily suppressed by a feedback system.

Chicanes The present design uses two separate chicanes, each being identical in design to that used in the main damping ring and allowing adjustment of the circumference of ±2 mm each.

Injection/Extraction Systems We have assumed the same design for the injection/extraction kickers and septa as given in the NLC ZDR [5]; The central defocusing quadrupole provides additional bending for the injected/extracted beam. The circumference of the lattice allows for a kicker rise/fall time of 119 ns. The technical constraints so far look reasonable.

Overall Structure The sequence of cells can be chosen for practical convenience; there are no fundamental lattice issues. The only constraint is that the RF cell has to be located somewhere from the injection to the extraction straight (following the direction of the beam), where the cavities will not be subject to any transient beam loading resulting from the injection/extraction cycle.

DYNAMICS AND ACCEPTANCE

Chromatic Properties

To allow correction of the chromaticity with moderate sextupole strengths, the achromat is designed to provide large horizontal dispersion and good separation of the horizontal and vertical beta functions between the dipoles. Constraining the beta functions to low values throughout the lattice helps keep the natural chromaticity of the lattice low. Harmonic sextupole magnets, placed in regions of zero dispersion, can be used to correct nonlinear betatron parameters.

The working point in tune space is shown in Fig. 2. The tune variation with energy deviation looks sufficiently small to allow reasonable dynamic momentum acceptance. We have not yet carried out a completely rigorous analysis of the harmonic sextupole tuning, and further optimization may be possible. We are not overly concerned about the proximity to coupling resonances: low betatron coupling is not a performance requirement for the pre-damping ring, since the specification on extracted emittances places equal upper limits in the two transverse planes.

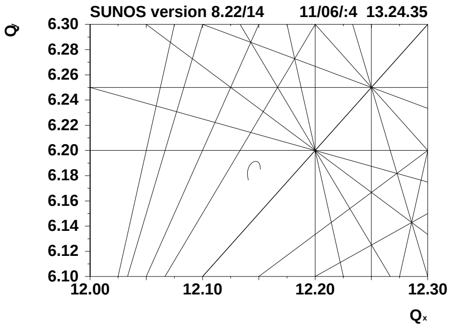

Figure 2: Working point in tune space. The nominal working point is (12.145, 6.191): the curved line shows variation in tunes up to ±2 % momentum deviation. Resonance lines up to fifth order are shown.

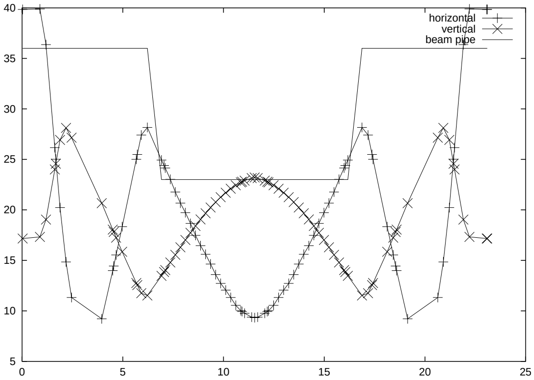

Figure 3: Required acceptance in the wiggler cell.

Acceptance

The specified acceptance of the ring is for an edge emittance of 45,000 mm mrad (30,000 mm mrad plus 50 % allowance for mismatch and jitter) and half-width energy spread of 1.5 % (1.0 % energy spread plus 50 % allowance for jitter). Figure 3 shows the required acceptance for the wiggler and RF cell. In the horizontal plane the aperture is slightly too small in the arcs. As this is at a place with high dispersion, only particles with large amplitude and large energy offset would get scraped. Nevertheless we are thinking about increasing the aperture there by a couple of mm. In the vertical plane the aperture is very tight between the wiggler and the adjacent quadrupole. The aperture will need to be opened up immediately following the wiggler and not closer to the quadrupole as depicted here.

The equilibrium bunch length is 5.2 mm with an energy spread of 0.089 % (see Tab. 1). Thus, we expect that soon after injection the bunch length is likely to filament to around 87 mm. With an RF wavelength of 420 mm, and rapid longitudinal damping, this is not anticipated to be a problem.

Dynamic Aperture

To assist with injection efficiency, the dynamic aperture of the lattice is improved through the use of harmonic sextupoles.

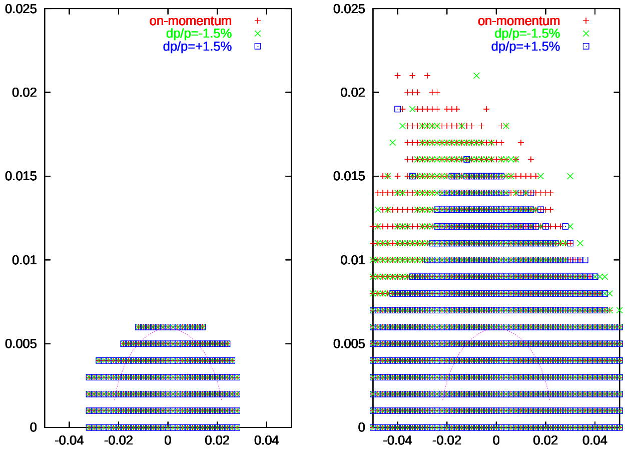

Figure 4: Dynamic apertures for particles with zero and $\pm 1.5\,\%$ momentum deviation with (left) and without (right) apertures.

The dynamic apertures, for particles with zero and $\pm 1.5\,\%$ momentum deviation, are shown in Fig. 4. The dynamic aperture is calculated by tracking 200 turns. The tracking is done with physical apertures to model the size of the beam pipe. Without the physical apertures the dynamic aperture is much larger (see Fig. 4). The required acceptance, also shown in Fig. 4, is calculated using an edge acceptance of 45,000 mm mrad. The dynamic aperture appears to be beyond the required limit. We have not so far included multipole field errors in the magnets. It is to be expected that with more work, optimizing the the locations and strengths of the harmonic sextupoles, the dynamic aperture may be improved.

We also had a short look at frequency maps. They were calculated assuming reasonable errors. The frequency map was calculated without any corrections and with the tunes being corrected back to the nominal values. The one with the uncorrected tune shows no strong resonances within the required aperture. The one with the corrected tune looks slightly worse but so far no effort has been made to optimize the tunes beyond avoiding resonances of order three or less.

WIGGLER

A magnetic design and field map for the hybrid technology damping wiggler has been produced [6]. For analysis of the dynamics, we have followed the same approach as in [7]. The results of symplectic tracking through a single period of the wiggler are shown in Fig. 5. Because of the detailed nature of the field fit, the tracking is too slow to be practical for dynamic aperture calculations, and we have therefore approximated the dynamics using thin octupole and dodecapole components in the wiggler: the dynamics of this model are the lines shown in Fig. 5, which match very closely the points obtained by tracking. We note that this is not a completely rigorous model of the wiggler dynamics, since the nonlinear effects of the wiggler field cannot in general be reproduced using thin multipoles. A more careful analysis is planned [8], but for the present purposes the multipole model appears to work well enough to give the dynamic aperture calculations some credibility.

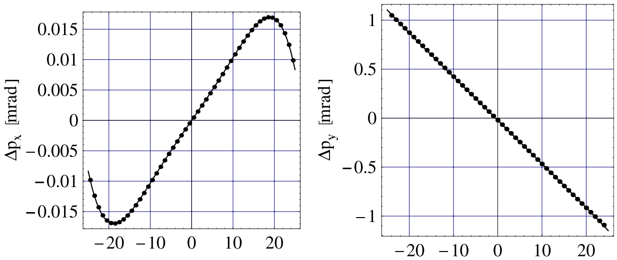

Figure 5: Results of symplectic tracking through a single wiggler period.

The integrated square of the field from the field map ($1.907\,\mathrm{T}^2\mathrm{m}$) is much larger than that found using the usual lattice model with pole lengths that are a quarter of the wiggler period ($0.98\,\mathrm{T}^2\mathrm{m}$). We find that by raising the peak field in the lattice model from 1.4 T to 1.956 T, and including a small focusing ($k_1 l = -0.008\,\mathrm{m}^{-1}$ per period), we produce the horizontal and vertical focusing and the integrated field found from the field map. Using the correct integrated field is also important for finding the correct energy loss per turn, and this, in turn, has an important impact on the damping times and the natural emittance.

SUMMARY

Changing the damping partition numbers in the previous lattice reduced the extracted emittance to an acceptable value. The inclusion of an improved wiggler model also helped in reducing the emittance. The dynamics in the lattice look reasonable.

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