ACHIEVING LARGE DYNAMIC APERTURE IN THE ILC DAMPING RINGS*

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Abstract

The Damping Rings for the International Linear Collider have challenging requirements for the acceptance, because of the high average injected beam power and the large beam produced from the positron source. At the same time, the luminosity goals mean that the natural emittance must be very small, and this makes it particularly difficult to achieve a good dynamic aperture. We describe design approaches and lattice designs that meet the emittance specification and have very promising dynamic aperture.

ILC DAMPING RINGS

Damping rings are needed in the International Linear Collider (ILC) to produce ultra-low emittance and highly stable beams for acceleration in the main linac. The acceptance specifications for the damping rings are set by the positron source, which is expected to produce a beam with normalized emittances of the order 0.01 m in both transverse planes, and with a full-width energy spread up to 2%. To achieve the design luminosity, trains of 2820 bunches with a charge of 2×10^{10} particles will be injected into the rings at a rate of 5 Hz. Optimization of the beam energy in the damping rings (considering damping rate, transverse and longitudinal equilibrium emittances, and collective effects) leads to a value of 5 GeV. The average beam power injected into the damping rings in normal operation will be 226 kW; to avoid radiation loads from injection losses, design of damping ring lattices with significant margin in the acceptance (to allow for linear and nonlinear optics errors) is therefore of great importance.

In this paper, we describe two lattices [1, 2] based on FODO (or modified FODO) arc cells, that have promise for meeting the acceptance requirements. We compare the different strategies used in these lattices to achieve good dynamic aperture. Both lattices meet the specifications for damping rate and equilibrium emittance, and have a "dogbone" layout (Fig. 1) similar to the damping ring described in the TESLA TDR [3]. This allows a large circumference (of the order of 16 km) to accommodate a long bunch train, with reasonable specifications on the rise and fall times of the injection and extraction kickers. Both lattices may easily be modified to smaller circumferences if more ambitious kicker parameters are thought to be feasible.

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The dynamic aperture of the TME lattice presented in the TESLA TDR was roughly five times the injected beam size for on-energy particles. The aim of the design work leading to the lattices presented here was to increase the acceptance margin, and achieve a dynamic aperture of ten times the injected beam size on-energy, and three times the injected beam size for particles with up to 1% energy deviation.

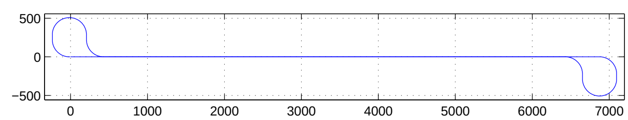

Figure 1: Footprint of a dogbone ILC damping ring, 16 km circumference. Dimensions are in meters.

LATTICE STRUCTURES AND PARAMETERS

The large circumference of the damping rings allows a low natural emittance to be achieved for a relatively high energy by using a large number of arc cells. Each dipole therefore provides a small bending angle, and to achieve a reasonable value for the dispersion (needed both for chromatic correction and for momentum compaction) 5 m long dipoles are used in both lattices described here. However, the lattices differ in the total number of arc cells; in one case, there are 54 cells per arc, and in the other there are 84.

The full lattices are each composed of two arcs, a wiggler section of roughly 450 m (to provide damping times of around 27 ms), and long straight sections with high (200 m) beta functions. Table 1 compares the principal parameters in the two lattices.

Formally, the arc cells in the 54-cell lattice are not FODO cells because there are only two dipoles for each set of four quadrupoles. The dipoles are positioned to minimize the dispersion in the dipoles, and this leads to the most significant difference in the parameters for the two lattices; the momentum compaction factor is more than four times larger in the 84-cell lattice than in the 54-cell lattice. A larger momentum compaction has the advantage that the thresholds for some instabilities are higher, but also has a drawback in that a larger RF voltage is needed to achieve a given bunch length. Note that the RF voltage in the 84-cell lattice is set to give a bunch length 50% larger than in the 54-cell lattice; this again helps with instabilities, but will make the bunch compressors somewhat more difficult.

Table 1: Lattice parameters.

Parameter	54-Cell	84-Cell
Energy	5.0 GeV	5.0 GeV
Circumference	17.0 km	15.9 km
Natural Emittance	0.62 nm	0.68 nm
Tunes (x,y)	83.79, 83.64	75.78, 76.41
Nat. Chromaticity (x,y)	-105, -107	-89, -96
Mom. Compaction	1.14×10^{-4}	4.74×10^{-4}
RF Frequency	500 MHz	650 MHz
RF Voltage	48 MV	66 MV
Bunch Length	6.0 mm	9.0 mm
Energy Spread	1.3×10^{-3}	1.3×10^{-3}
Synchrotron Tune	0.067	0.18

Fig. 2 shows the lattice functions in two arc cells of the 54-cell lattice; Fig. 3 shows the lattice functions in one arc cell of the 84-cell lattice.

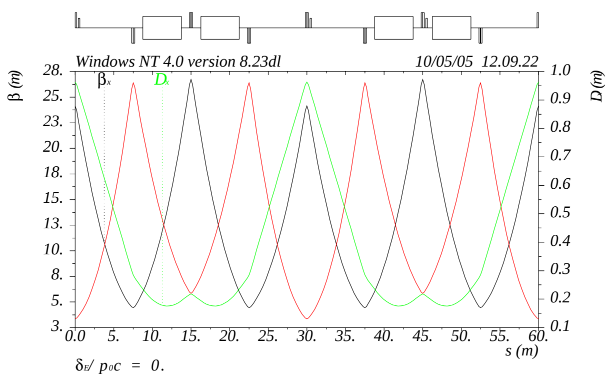

Figure 2: Lattice functions in two arc cells of the 54-cell lattice.

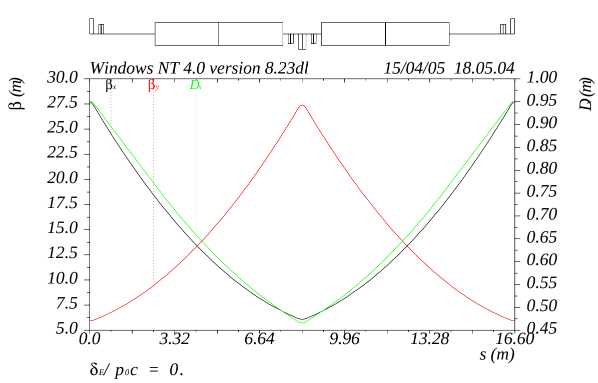

Figure 3: Lattice functions in one arc cell of the 84-cell lattice.

CHROMATIC CORRECTION

The arrangement of sextupoles used for chromatic correction is critical for the dynamic aperture of a lattice. The lattices discussed here take different approaches to the chromatic correction. The 84-cell lattice uses an interleaved scheme, with pairs of sextupoles in each cell located close the positions where the beta functions are at a maximum. The arc cell has been designed to provide good separation of the beta functions at the sextupoles, and large dispersion: these features reduce the strengths of the sextupoles needed for chromatic correction, and hence limit the geometric aberrations arising from the sextupoles. The horizontal and vertical phase advances of the cell were adjusted to find a working point where the geometric effects from the different sextupole families cancel as closely as possible.

In the 54-cell lattice, a non-interleaved sextupole scheme is used: pairs of sextupoles are arranged with π phase advance between the sextupoles in each pair (one pair can be seen adjacent to the quadrupoles at 0 m and 30 m in Fig. 2). For each pair, the chromatic effects combine, while the unwanted geometric effects cancel to all orders (contrast with the interleaved scheme where only the lower-order effects can be cancelled). Using non-interleaved sextupoles, the tune-shifts with amplitude are kept small, and a very large dynamic aperture can be achieved. However, for off-energy particles, the local chromaticity changes the phase advance between the two sextupoles in a pair and the geometric effects no longer exactly cancel; this can limit the dynamic energy acceptance of the lattice. It is possible to optimize the chromatic correction to some extent by using each pair of sextupoles individually.

For both lattices, the sections linking the arcs were tuned to give integer horizontal and vertical phase advance. This essentially restores the high degree of symmetry of the lattice that would otherwise be broken by the straights.

DYNAMIC APERTURE

We use frequency map analysis (FMA) to investigate the dynamics for on-energy and off-energy particles. The results for the 54-cell lattice are shown in Figs. 4 and 5. The color of each point indicates the change in tune (on a logarithmic scale) between the first 256 turns and a subsequent 256 turns. The on-energy dynamic aperture in this lattice is very good, roughly 15 times the injected beam size horizontally, and 10 times the injected beam size vertically. However, the dynamic aperture drops rapidly off-energy.

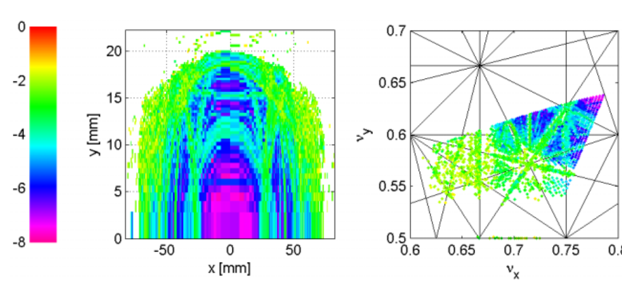

Figure 4: FMA of the 54-cell lattice in x-y co-ordinate space. At the observation point, $\beta_x = 24.1$ m and $\beta_y = 3.36$ m.

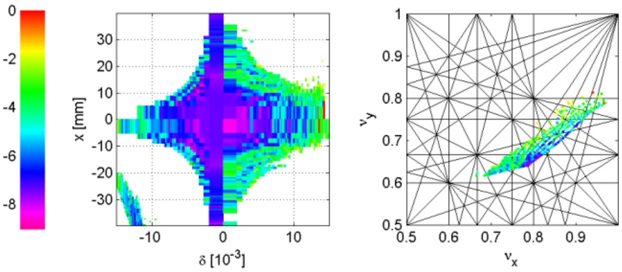

Figure 5: FMA of the 54-cell lattice in δ-x space.

The corresponding plots for the 84-cell lattice are shown in Figs. 6 and 7. The on-energy dynamic aperture is again good: 20 times the injected beam size horizontally, and more than 20 times the injected beam size vertically. There is again a rapid drop in dynamic aperture for off-energy particles, but is still several times the injected beam size at 1% energy deviation.

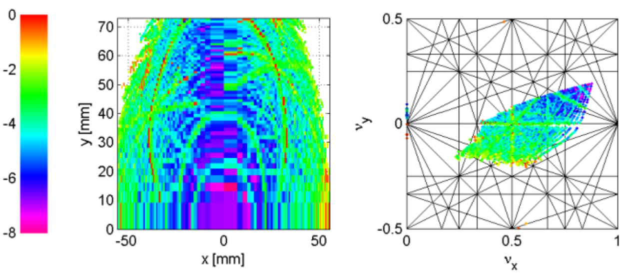

Figure 6: FMA of the 84-cell lattice in x-y co-ordinate space. At the observation point, $\beta_x = 7.50$ m and $\beta_y = 13.0$ m.

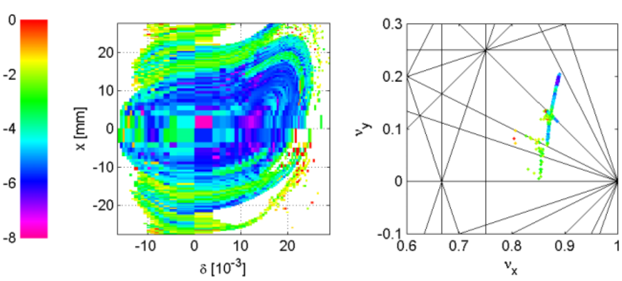

Figure 7: FMA of the 84-cell lattice in δ-x space.

TRACKING WITH RF

The frequency map plots shown in the previous section were computed with the RF cavities turned off in the lattice models. To better understand the real dynamic acceptance of the lattice, we tracked a distribution of particles produced from a model of the positron source [4] through lattices with the RF turned on. The transverse emittances of the distribution were a little less than the specified value of 0.01 m, and the full-width energy spread was around 2%. The particles were tracked through 500 turns of the lattices, which corresponds to one damping time (synchrotron radiation effects were not included). The distributions in phase space before and after tracking through the 84-cell lattice are shown in Fig. 8. Large physical apertures were used throughout the lattice, so that any losses would be the result of dynamical effects. In this case, only one particle was lost out of the distribution of nearly 2000 particles; the lost particle had the largest energy deviation (1.23%) of any particle in the beam, and also had large horizontal and vertical betatron amplitudes.

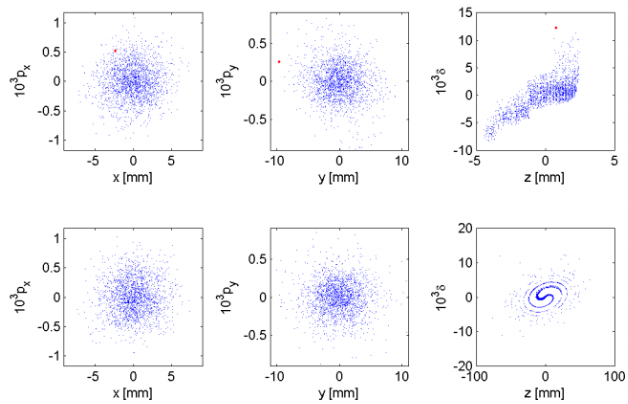

Figure 8: Phase space distributions of a sample positron bunch before (above) and after (below) tracking through the 84-cell lattice. The single particle lost in the tracking is marked in red in the upper plots.

In tracking the same distribution through the 54-cell lattice, five particles were lost, all at large betatron amplitudes and energy deviations. The behavior of the two lattices is consistent with the FMA studies discussed above.

COMMENTS AND CONCLUSIONS

Lattices based on FODO arc cells are possibilities for the ILC damping rings. We have produced two lattice designs based on FODO arcs, using different strategies for achieving the necessary dynamic acceptance. Both lattices achieve good dynamic aperture, though with little margin in the acceptance for off-energy particles; it should be possible to collimate the beam at low energy to achieve the necessary injection efficiency. The designs presented here can be further developed, for example, by optimizing the momentum compaction to give a balance between the required RF voltage and instability thresholds.

REFERENCES

[1] A. Wolski, "Lattices with Large Dynamic Aperture for ILC Damping Rings," LBNL-57045 (February 2005).

[2] Y. Cai, "Dynamic Aperture in Damping Rings with Realistic Wigglers," SLAC-PUB-11084 (April 2005).

[3] "TESLA Technical Design Report," DESY 2001-011 (March 2001).

[4] Y. Batygin, private communication.

0-7803-8859-3/05/$20.00