Simulation of the NLC Damping Rings

Viveka Borum

Mathematics Department, Wayne State University, Detroit, MI 48202

Abstract

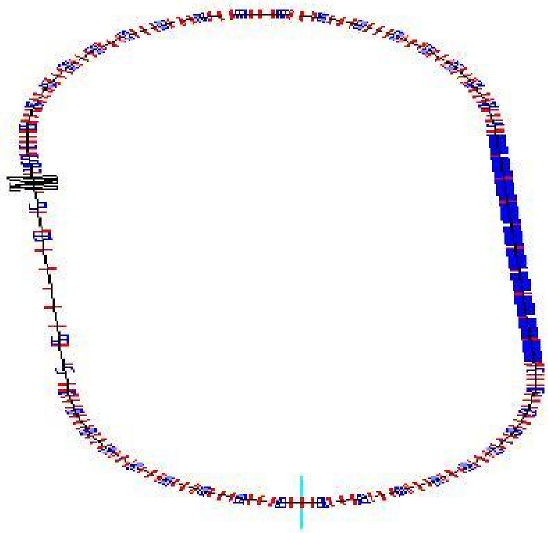
The NLC damping ring complexes provide damping of the electron-positron beams from the sources, producing stable, low-emittance beams which pass on to bunch length compressors and pre-acceleration before entering the main linac. The purpose of the damping rings is to provide low emittance electron and positron bunch trains to the NLC linacs, at a rate of 120 Hz. To obtain the lowest emittance possible, simulations were taken, such as inserting misalignments into quadrupole magnets, in order to see how well the elements need to be alignedto preserve the required emittance.

Introduction

A proposal for the next major high energy physics facility is to build a 500 GeV to 1000 GeV electron-positron linear collider. In order to get a sufficient collision rate between electrons and positrons, the phase space occupied by the bunches must be extremely small. In preparing the electron-positron bunches for the linear collider, there will need to be smaller circular "pre" accelerators which "damp" the bunches, these accelerators are called "damping rings". The NLC main damping rings are designed to accept a beam with normalized emittances both horizontally and vertically of 150 mm-mrad. Therefore, the transverse energy of the beam must be damped to normalized emittances of 3 mm-mrad horizontally and 0.02 mm-mrad vertically.[2] Each ring will store multiple trains of bunches at once, and a single fully damped bunched train is extracted while a new train from the source is injected. Due to the large emittance of positrons that are produced from the target, a pre-positron damping ring is also required, however my project just focused on the elements of the main damping ring.

Design and Layout of the NLC damping rings

The NLC damping ring lattice is a racetrack design consisting of four main components. One component is the wiggler magnet. For the NLC ring, there consists of ten wigglers aligned in a linear arrangement on one side of the damping ring. As the bunches circulate in the damping ring, they lose energy (both transverse and longitudinal) by synchrotron radiation when they pass through the wigglers. However, another component, the RF cavity, which are fed with electric and magnetic fields, re-accelerates the bunches each time they pass through the cavity. For the NLC damping ring, there are three RF cavities which provides longitudinal restoring force, maintaining the bunching structure. The next component are the dipoles(bend magnets). The dipoles are 2 long curving arcs of magnets that are used to transport the separate electron and positron beams from the end of the linac to a single collision point. The last component of the damping ring are the quadrupoles. These magnets which are inserted between dipole magnets, are used to direct charged particle beams towards the target, and to "focus" the beams, just as optical lenses focus light.



Damping Ring Lattice Fig.1

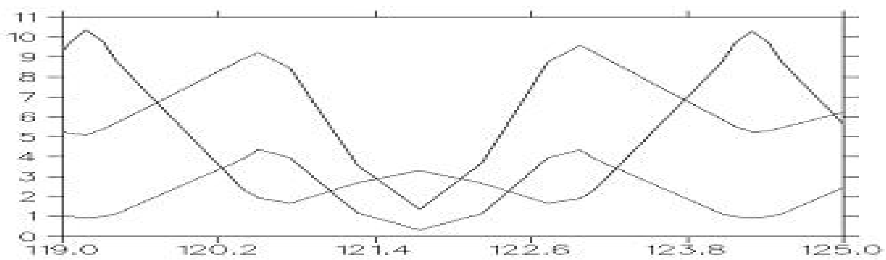
Parameters

TABLE 1. Principal Parameters of the Main Damping Rings

Energy	E	1.98 GeV
Circumference	C	299.792
Number of stored bunch trains		3
Natural emittance	$\gamma\ \varepsilon_0$	2.17 mm-mrad
Tunes	v_x,v_y	27.2616, 11.1357
Natural chromaticity	ξ_x, ξ_y	-37.12, -28.24
Momentum compaction	α	$2.95x10^{-4}$
RF voltage	V_{RF}	1.07 MV
RF acceptance	ε_{RF}	1.5%
Energy spread (rms)	σ_δ	0.091%
Bunch length (rms)	σ_z	3.60 mm
Integrated wiggler field	$\int B_{w^2ds}$	$106.9T^2m$
Energy loss/turn	$U_0 + U_w$	247+530 keV

This table represents the principal parameters for the main damping ring. [1]I would also like to mention a few more such as the maximum current for our damping ring is 0.8 amperes, and the 3 bunch trains consists of 190 bunches per train and a bunch separation of 1.4 nanoseconds.

Beta and Eta Functions



Lattice function in one arc cell Fig.2

This figure represents the beta and eta function using our own simulation package, bmadz. The significance of the beta function is that it envelopes the particle harmonic oscillation as they circulate around the ring. Each particle will execute a betatron oscillation about a different reference orbit $x_\sigma = \eta(s)\delta$ where $\eta(s)$ is a proportionality function called the dispersion or "eta" function.[3]

Quadrupoles and Misalignments

A main portion of my project dealt with experimenting with quadrupoles. I was first given a damping ring with fewer elements such as: quadrupoles, bend magnets, and a drift. The lattice was unstable at first, and I was able to adjust the strength of the quadrupoles in order to stabilize the lattice. By implementing the bmadz program, I was able to view various twiss parameters. Those parameters basically consisted of the beta and eta functions. By viewing another program in bmadz called stay clear, I was able to view the horizontal and vertical emittances of the damping ring. Once I became familiar with the lattice file and its elements, I was then able to apply misalignments to the lattice. The main reason for placing misalignments into the damping ring is because we know when the real damping ring is placed in the machine that the surveyors will try their best to align the magnets with precision. However, due to ground motion and other factors, we know that some misalignments will occur. Therefore, we needed to evaluate those errors. I first placed misalignments into the lattice with fewer elements, by using emacs editor. I first applied a kicker, which is the simplest approximation of a quadrupole alignment. The parameters of the kicker was .001 radians for a horizontal kick and -0.0008 for the vertical. In this particular lattice file, there were 5 positions to place the kicker. I decided to place them in each one to view their emittances. The next misalignment was placed in the actually NLC damping ring lattice. I placed a misalignment into an individual quadrupole. The quadrupole had an xoffset of 1mm, a yoffset of -2mm and an xpitch of 1mrad. I also made various changes in the offsets and pitch just to view the various emittances. This is one way to simulate how placing errors will effect the emittances, however we know for the real damping ring we need to about random errors. Therefore, Richard Helms a graduate student at Cornell University, created a program calles stay clear 2. This program after given certain offsets and pitch, goes into the damping ring lattice and performs a gaussian distribution of random errors.

Results

Overall, our goal is to lower emittance. However, lowering the vertical emittance is the single most important parameter. The main reason we need the damping rings at all is that we want to produce a beam with a very small vertical emittance. We also realize that dispersion plays a role in producing vertical emittance. This is due to the fact that when the particle is inside the closed orbit,it may slighty disperse from our desired energy, causing it to follow along a different trajectory, this is where we get dispersion which plays a factor in producing the vertical emittance. Most importantly, the following equations, describes the correlation between the vertical emittance and dispersion:
(1)$\Delta y = \eta(\Delta P/Po)$
(2)$\sigma y \approx \sqrt{\beta_{avg}\varepsilon_y}$
(3)$\beta_{avg}\varepsilon_y \approx \eta^2(\Delta P/Po)^2$
(4)$\varepsilon_y \approx \eta^2((\Delta P/Po)^2/\beta_{avg})$

In the above equations, notice that these are approximate equations and not exact because we are scaling and not taking into account damping times. Thus, we can say that Δy is almost equal to σy, and from the latter equations, it's obvious of the correlation between the vertical emittance and dispersion.

Conclusions

My project was a first step in examining all of the parameters that needs to be taken into account in order to lower the emittance. There are other factors that still have to be viewed in order to completely conclude on how to lower the emittance. One major factor is determining exactly how well aligned the magnets need to be in order to maintain the required emittance. Another factor deals with the dynamic aperture. As our particle circulates around the closed orbit, the bend magnets will cause some slight movement of our particle from the design energy. Therefore, finding the dynamic aperture means determining how far away our particle can be from its design energy, before it interacts with something else or is alltogether kicked out of the orbit. Another aspect that needs to be taken into account is examining other twiss parameters such as alpha functions and tunes. There are also issues involving coupling that needs to be taken into account as well.

Acknowledgments

I would like to acknowledge Dave Rubin, Mark Palmer, and Mike Forster, all from Cornell University, for their guidance and patience in helping me throughout this project. I would also like to acknowledge Rich Galik and Gerry Dugan for doing a wonderful job in directing the program this summer. I want to also thank Lora Hine and Monica Wesley for taking care of all the behind the scenes work, in helping to make this an enjoyable summer. Finally, I would like to thank Dr. Bonvicini, Dr. Cinabro and all of the other professors at Wayne State University in preparing me for this program. This work was supported by the National Science Foundation REU grant PHY-0113556 and PHY-0097595 and research grant PHY-9809799.

Footnotes and References

1. Further information about the description of the magnetic lattice for the NLC can be found at http://accelconf.web.cern.ch/AccelConf/p01/PAPERS/FPAH053.PDF
2. Further information about the general description of the Next Linear Collider damping rings can be found at http://accelconf.web.cern.ch/AccelConf/p01/PAPERS/RPPH145.PDF
3. This website also contains insight for the elements and parameters for the NLC Damping Ring http://www-project.slac.stanford.edu/lc/ilc/TechNotes/LCCNotes/PDF/