3.4 Damping Rings

The NLC damping rings are designed to damp the incoming electron and positron beams to the small emittances needed for collisions. The rings have three purposes: (1) damping the incoming emittances in all three planes, (2) damping incoming transients and providing a stable platform for the downstream portion of the accelerator, and (3) delaying the bunches so that feedforward systems can be used to compensate for charge fluctuations.

To meet these goals, we have designed three damping rings: two identical main damping rings, one for the electrons and one for the positrons, and a pre-damping ring for the positrons. The pre-damping ring is needed because the emittance of the incoming positrons is much larger than that of the electrons. Each damping ring will store multiple trains of bunches at once. At every machine cycle, a single fully damped bunch train is extracted from the ring while a new bunch train is injected. In this manner, each bunch train can be damped for many machine cycles.

The parameters of the two main damping rings are similar to the present generation of synchrotron light sources and the B-Factory colliders that are being constructed in that they must store high-current beams ($\sim$1 A) while attaining small normalized emittances. Table 3.3 compares the NLC ring parameters with those of the SLAC B-Factory Low-Energy Ring (PEP-II LER), the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory, and the Accelerator Test Facility (ATF) damping ring being constructed at KEK in Japan to verify many of the damping ring design concepts. In particular, the stored beam currents are less than half of what the PEP-II LER has been designed to store while the emittance, energy, and size of the rings are similar to those of the ALS and the ATF.

Table 3.3: Comparison of NLC main damping rings with parameters of other rings.

	NLC MDR	PEP-II LER	LBNL ALS	KEK ATF
Energy (GeV)	2	3.1	1.5	1.5
Circumference (m)	220	2200	200	140
Current (A)	1.2	3	0.6	0.6
$\gamma\epsilon_x$ (10^{-6}m-rad)	3	400	10	4
$\gamma\epsilon_y$ (10^{-6}m-rad)	0.03	16	0.2	0.04

Thus, these other rings will be able to test and verify many of the accelerator physics issues that will arise in the NLC damping rings. In particular, strong coupled-bunch instabilities will be studied in the high current B-factories while issues associated with the very small beam emittances, such as intrabeam scattering and ion trapping, will be studied in the ALS and ATF damping rings. In addition, the PEP-II LER and the Advanced Photon Source

(APS) at Argonne National Laboratory will be able to study the photoelectron-positron instability that is thought to arise in positron storage rings.

These similarities with other rings have also simplified the design process and we have been able, and will continue, to benefit from experience at these other accelerators. For example: the damping ring rf system is based on those developed for the SLAC B-Factory and the ATF damping ring, the multibunch feedback systems are based upon the feedback systems which were designed for the SLAC B-Factory and successfully verified on the ALS, and the vacuum system is similar to that used by the ALS. Furthermore, the design uses "C" quadrupole and sextupole magnets similar to those designed at the ALS and the APS at Argonne National Lab, a high-field permanent magnet wiggler very similar to a design developed and installed at Stanford Synchrotron Radiation Laboratory (SSRL), and a double kicker system for extraction similar to one to be tested in the ATF.

The NLC damping ring complex is designed to operate with the parameters listed in Table 3.4. These design parameters exceed the requirements of all presently considered NLC upgrades. The rings produce electron and positron beams with emittances $\gamma\epsilon_x \leq 3 \times 10^{-6}$ m-rad and $\gamma\epsilon_y \leq 3 \times 10^{-8}$ m-rad, at repetition rates as high as 180 Hz. The beams in the damping rings consist of multiple trains of 90 bunches with a maximum single bunch charge of 1.3×10^{10}. (This is 5% higher than the required charge at the IP to allow for beam loss due to collimation.) To provide operational flexibility, we have designed the rings to operate with a peak current roughly 20% higher than the nominal peak current. In addition, the rings have been designed to operate over an energy range of 1.8 to 2.2 GeV with a nominal energy of 1.98 GeV. This will allow the damping rate to be increased if necessary.

Table 3.4: Requirements for NLC damping ring complex.

$\gamma\epsilon_{x\,eq}$ / $\gamma\epsilon_{x\,ext}$ (10^{-6} m-rad)	3.0 / 3.0
$\gamma\epsilon_{y\,eq}$ / $\gamma\epsilon_{y\,ext}$ (10^{-8} m-rad)	2.0 / 3.0
Charge/Bunch	1.57×10^{10}
Bunches/Train	90 bunches/train
Bunch Spacing (ns)	1.4
Repetition Rate (Hz)	180

At present, most of the studies have concentrated on the main damping rings. Although relatively little of the detailed engineering has been performed, we have a good outline of the design and the problems we may encounter. In particular, we have identified and described solutions for the most difficult issues: these are the dynamic aperture, the vertical emittance, the impedance and instabilities, and the stability and jitter in both longitudinal and transverse phase space. As stated, much of the design rests on work being performed for the B-factories presently being constructed and the ATF damping ring.

In most aspects, the pre-damping ring has relatively loose requirements. The emittance and damping time requirements are not severe. The required beam stability is not very significant. The two difficult items are attaining the dynamic aperture and the injection/extraction kicker systems. At this time, the design is still in a preliminary stage but we have addressed the difficult items just mentioned.

3.4.1 Main Damping Rings.

The NLC main damping rings are roughly 223 m in circumference and measure 50 m by 80 m. They have a nominal energy of 1.98 GeV and the required damping is achieved using both high field bending magnets and roughly 26 m of damping wiggler. The rings are designed in a racetrack form with two arcs separated by straight sections; the layout is illustrated in Figure 3.7.

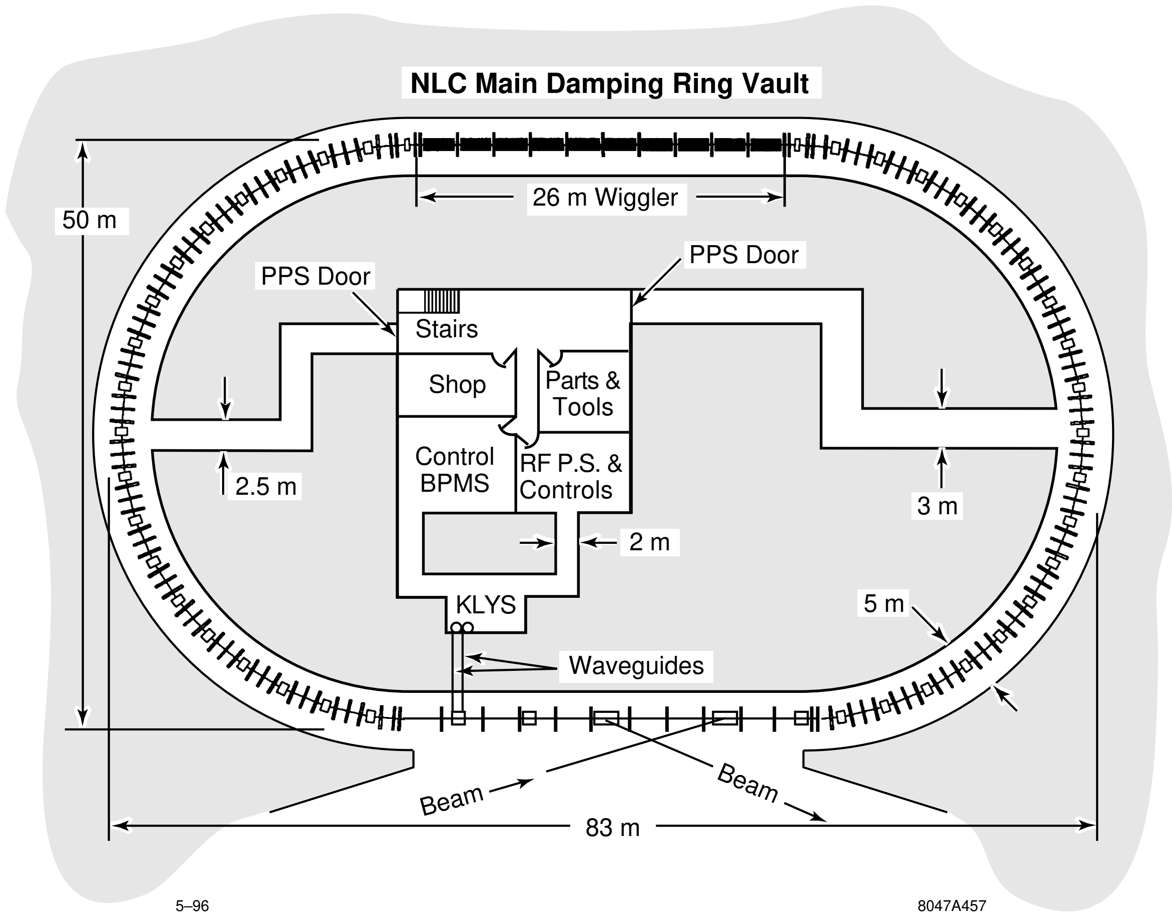

Figure 3.7: Layout of main damping ring.

The main damping rings are designed to damp beams with injected emittances $\gamma\epsilon_{x,y} = 1 \times 10^{-4}$ m-rad to emittances of $\gamma\epsilon_x = 3 \times 10^{-6}$ m-rad and $\gamma\epsilon_y = 3 \times 10^{-8}$ m-rad. The rings will operate at 180 Hz. They provide sufficient damping to decrease the injected emittance by over four orders of magnitude. These parameters are summarized in Table 3.5.

Table 3.5: Parameters for main damping rings and the pre-damping ring.

	MDR	PDR
Circumference (m)	223	171
Energy (GeV)	1.8–2.2, 1.98 nominal	
Max. Current (A)	1.2	
Max. Rep. Rate (Hz)	180	
Bunch Trains $\times$ Bunches per train	4×90	3×90
Train/Bunch Separation (ns)	60/1.4	64/1.4
ν_x, ν_y, ν_s	23.81, 8.62, 0.004	10.18, 8.18, 0.018
$\gamma\epsilon_{x\,eq}$ (m-rad)	2.56	7.7
$\gamma\epsilon_x$, $\gamma\epsilon_y$ (with intra-beam scatt.)	3.1×10^{-6}, 1.5×10^{-8}	4.5×10^{-5} (coupled)
σ_ϵ, σ_z	0.09%, 4.0 mm	0.1%, 7.5 mm
$\xi_{x\,,\mathrm{uncorr}}$, $\xi_{y\,,\mathrm{uncorr}}$	-41.8, -22.4	-13.9, -10.0
τ_x, τ_y, τ_z (ms)	4.06, 4.62, 2.50	4.44, 6.15, 2.73
U_{SR} (kV/turn)	644	371
J_x	1.14	1.39
α_p	0.00047	0.0051
RF Voltage, Frequency	1 MV, 714 MHz	2 MV, 714 MHz
Lattice	40 TME Cells	30 FOBO Cells

The main damping ring lattice is based on detuned Theoretical Minimum Emittance (TME) cells which were chosen because of eased requirements on the combined-function bending magnets. The chromaticity is corrected with three families of sextupoles and the dynamic aperture is more than sufficient. The damping is performed using both high-field bending magnets and ten 2.5-m sections of damping wiggler.

The rings operate with four trains of 90 bunches. The bunch trains are injected onto and extracted from the closed orbit using pulsed kickers and DC septa. To avoid coupled-bunch instabilities the rf cavities are based on those of the PEP-II B-Factory and a transverse bunch-by-bunch feedback system is used. As stated, the rings are designed to operate with maximum bunch charges of 1.57×10^{10} particles; this is roughly 20% more than the maximum needed at the IP. In addition, the electron source has been designed to provide additional charge to allow for at least 10% losses during injection into the electron damping ring. Similarly, the positron source has been designed to produce at least 20% additional charge to provide for losses during injection into the pre-damping ring.

Finally, because the rings must generate extremely small beam emittances, there are tight jitter and alignment tolerances. Extensive effort has been made to include cancellations and tuning procedures in the design that will ease the tolerances to reasonable levels. In particular, all of the quadrupoles and all of the sextupoles will have independent power supplies and remote magnet movers. This will facilitate beam-based alignment as well as matching of the lattice functions.

3.4.2 Positron Pre-Damping Ring

The design of the pre-damping ring for positrons is similar to the SLC damping rings, except the lengths are scaled by a factor of five. The ring has a racetrack form with dispersion-free straight sections for injection and extraction. The ring is roughly 60 meters by 40 meters and is illustrated schematically in Figure 3.8.

In the design, the injection and extraction regions are in the straight sections on opposite sides of the ring. To reduce the requirements on these components, the systems are designed to occupy most of these regions. To minimize rf transients during injection and extraction, a new bunch train will be injected one half turn after a train is extracted. Furthermore, the rf cavities are placed downstream of the injection kicker and upstream of the extraction kicker so that the injection/extraction process will not interrupt the beam current seen by the rf cavities.

The positron pre-damping ring is designed to damp the large emittance positron beam from the positron source to an emittance of roughly $\gamma\epsilon_{x,y} = 1 \times 10^{-4}$ m-rad; these parameters are summarized in Table 3.5. At this point, the positrons are injected into the positron main damping ring where they are damped to the desired final emittances. The pre-damping ring allows us to decouple the large aperture requirements for the incoming positron beams from the final emittance requirements of the linear collider.

The pre-damping ring does not need to produce flat beams. Thus, to maximize the damping of the transverse phase space, the ring has horizontal damping partition number $J_x \approx 1.4$, and operates on the coupling difference resonance. This increases the damping in both the horizontal and vertical planes. Furthermore, like the main damping ring, the ring damps multiple trains of bunches at once, the number of which is determined by the ring circumference.

The magnets and vacuum system are being designed to provide sufficient aperture to accept a 2-GeV beam with an edge emittance of $\gamma\epsilon_{x,y} = 0.09$ m-rad and momentum spread of $|\delta p/p| \leq 1.5\%$ plus 2-mm clearance for misalignments and mis-steering. Given the nominal injected edge emittance of $\gamma\epsilon_{x,y} = 0.06$ m-rad, this provides a substantial margin for injection and internal mismatches. In addition, the injector specifications assume that roughly 20% of the delivered charge is lost at injection into the pre-damping ring. The pre-damping ring

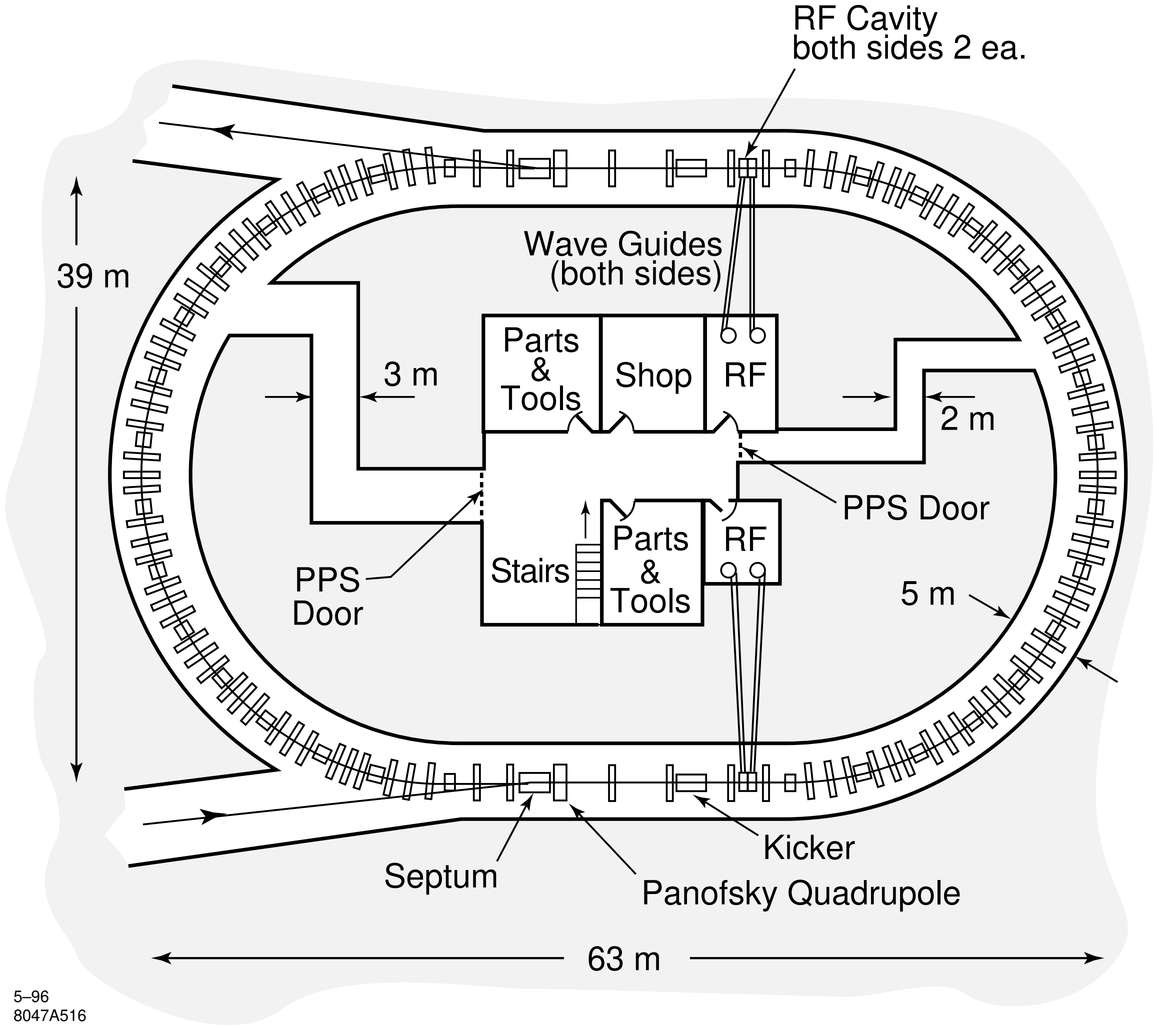

Figure 3.8: Layout of the positron pre-damping ring.

is designed to operate with a maximum bunch charge that is roughly 20% greater than the maximum required at the IP.

Like the main damping rings, all of the quadrupoles and all of the sextupoles will have independent power supplies and remote magnet movers. This will facilitate beam-based alignment as well as matching of the lattice functions which is especially important in the pre-damping ring because of the limited aperture.