A COMPACT-HIGH PERFORMANCE NLC DAMPING RING USING HIGH MAGNETIC FIELD BENDING MAGNETS

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We describe a 1.5GeV damping ring for very low emittance $e^{\pm}$ beams that can be used for the NLC. A key feature of this system is the use of 7T bending magnets to greatly reduce the size and cost of the storage ring as well as the tune and the damping ring while increasing the acceptance. We present only a preliminary study here.

I. INTRODUCTION

There is great interest in the development of the next linear collider, an e^{+} e^{-} collider of 500GeV to 1.5TeV. At least six different designs of this machine exist, all use damping rings to reduce the emittance of the $e^{\pm}$ beams injected into the linear collider. The energy of the damping rings has been chosen to be about 1.5GeV in most cases. In this report we discuss the possibility of using high field superconducting magnets with high quality fields for very compact $e^{\pm}$ damping rings[1,2,3]. We will also discuss a study of a prototype small storage ring and of the superconducting magnets[1]. Such a ring could also be used as part of an asymmetric ϕ factory[4].

II. PREVIOUS STUDIES

In the late 1980's there were several studies of different types of damping rings. In these studies there were cases of very compact damping rings that used superconducting magnets[2,3]. We provide the parameters for the two cases known to us in Table 1 and Table 2.

In the report by R. Palmer there is a formula related to the final emittance that can be reached[2]

$$\varepsilon_{c\eta} \sim \frac{1.2\times 10^{-10}}{\xi}\left(\frac{N}{\sigma_Z\ B^2\gamma^2\ Fm\,\sigma_p}\left\langle\frac{H^{1/2}}{\beta_y^{1/2}}\right\rangle\right)^{1/2} \qquad (1)$$

where N is the number of particles, B is the bending magnetic field, γ, σ_Z, σ_p, β_y all have the normal meaning, H is a lattice function and F_m is related to the fraction of the ring in bending magnets. From this formula we see that increasing the bending magnet field B has the effect of reducing the emittance all other things being equal. Or, one may look at this another way, that increased B could give a smaller damping ring with the same low emittance. The parameter lists in Table 1 seem to bear out this prediction.

Table 1: Palmer (Ref. 2)

	Parameters		E Magnetic Field $B \equiv 4$ Tesla (2)
ε_n	Equilibrium		10^{-8}
N	Electrons/Bunch		4×10^{8}
f	Pulse Frequency	kHz	3
P	Power/Beam		3
E	of Ring	GeV	1.1
R	of Ring	m	50
α_1	Wiggler B/B		0.04
l_W	Length Wiggler	cm	13
l_p	Length of Pole	cm	4.5
η	Chromaticity	m	11×10^{-4}
β_x		m	0.23
β_y		m	0.9
Q_x	Horizontal Tune		210
Q_y	Vertical Tune		50
l_{ext}/l_{quad}			0.6
$\hat{\varepsilon}$	Acceptance	m	1.7×10^{-6}
$\hat{\sigma}_y$	Acceptance	μ	27
$\hat{\varepsilon}_n / \varepsilon_n$			170
σ_p	dp/p in Ring		1×10^{-3}
σ_x	in Ring	mm	4.3
τ	Cooling Time	msec	0.5

III. A VERY COMPACT STORAGE RING WITH HIGH FIELD MAGNETS

We have studied a very compact storage ring with special bending magnets. This study will serve as an illustration of the possibility to develop very low emittance damping rings with a similar structure. In Figure 1 we show a schematic of the compact storage ring.

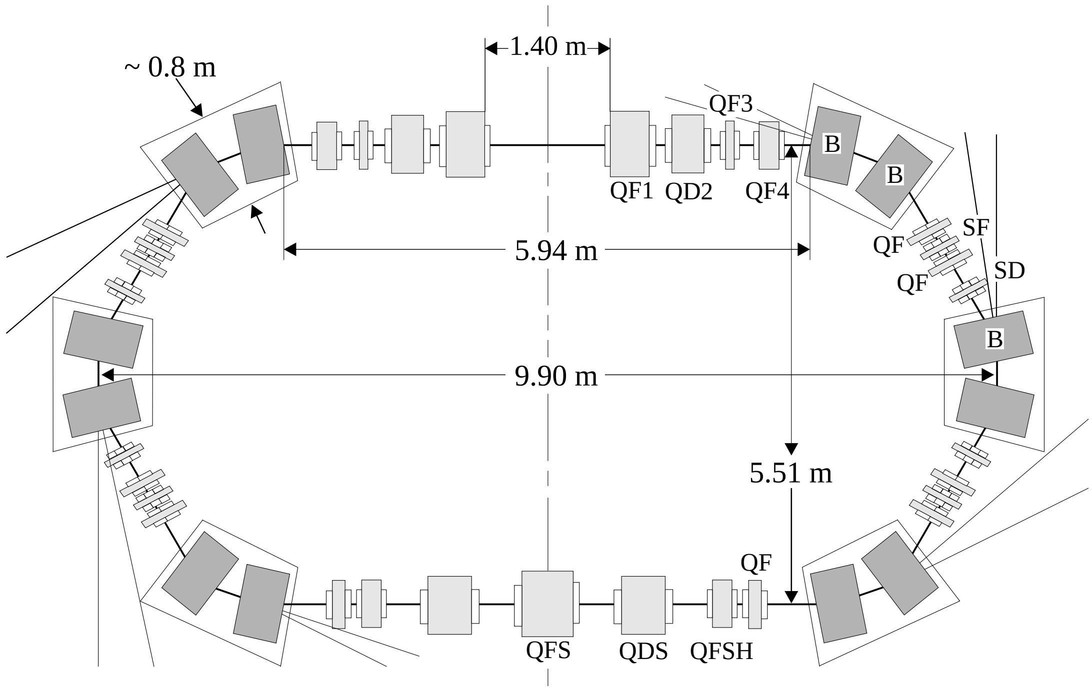

Figure 1: 1.5GeV Superconduction Electron Storage Ring with Conventional Quadrupoles and Sextupoles (Circumference = 26.0m).

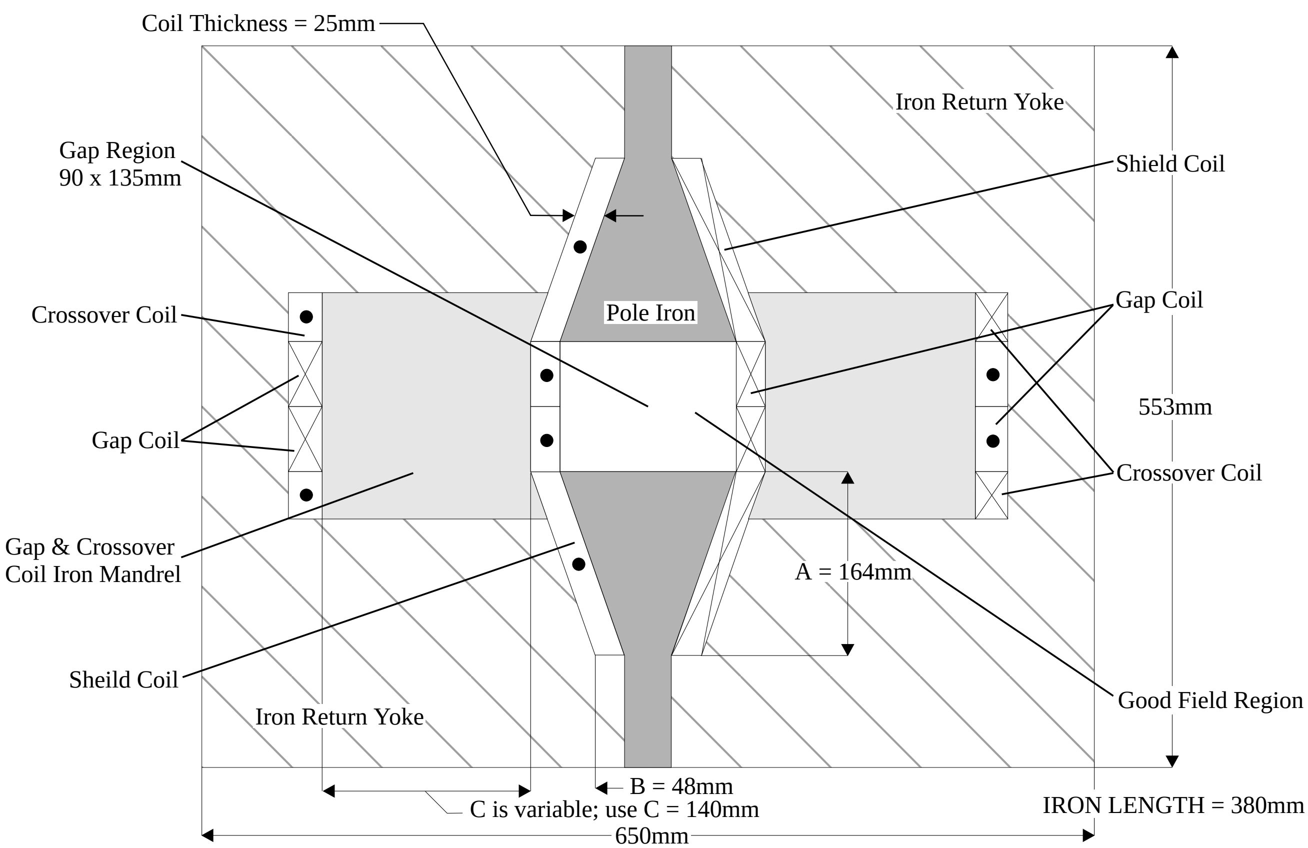

Figure 2: A cross-section view of a 7.2T compact light source dipole. (Quadrupole and sextupole pole face correction coils are not shown.) Each arc consists of three cells with the following cell structure:

The ring has a racetrack shape, shown schematically in Figure 1. It has reflection symmetry about a vertical line through the center of the figure. It consists of two arcs and two straight sections: the straight sections have equal lengths but different beam optics. The magnet layout and orbit functions are shown in Figure 2. The origin is in the center of the insertion-device region. Quadrupoles are represented by rectangles shown above or below the axis, according to whether they are horizontally focusing or defocusing, respectively. Dipoles are shown as rectangles centered on the axis.

QF D B D QF

where QF is half of an F-quadrupole, D is a drift space, and B is a rectangular dipole. The cell closest to the insertion straight section in each arc is missing its first two elements. The cell at the center of each arc contains, in addition, two horizontally focusing sextupoles, SF, which are combined with the QF quadrupoles, and two vertically focusing sextupoles, SD, at the centers of the drift spaces, D.

Table 2: VLEPP (Ref. 3)

Keyword	Units	Achromat
E	GeV	1.54727
Circumference	m	77. (70.)
$\gamma\varepsilon_0$	10^{-6} m-rad	3.
$N_{\text{particles}}$	10^{10}	20.
$\gamma\varepsilon_{\text{INBS}}$	10^{-6} m-rad	6.
τ_x	msec	1.0
τ_y	msec	1.0
U_{RAD}/TURN	kV	760.
RF voltage	MV	0.85
f	GHz	0.5
$\Delta E/E$	10^{-3}	3.0
σ_Z	mm	8. (6)
$\gamma \frac{\partial \nu_x}{\partial \gamma}$		-25.
$\gamma \frac{\partial \nu_y}{\partial \gamma}$		-21
α	10^{-3}	0.6
ν_x		18.35 (25)
ν_y		5.69 (12)
B_0, G_0	T, T/m	1.73; 0.
G_{quads}	T/m	65. (90.)
$\int \text{sext}\ x, y$	T/m	880.; -253
L_{WIGGLER}	m	0.6 x 20
B_{peak}	T	6.
ε_{inj}	10^{-3} m-rad	1.5 10^{-2}

The calculated x and y damping times are 0.4msec, making this suitable for high repetition rate!

IV. THE HIGH FIELD MAGNET STUDY

The key element for a compact storage ring for any use is the high field bending magnet. This magnet must have a high quality magnetic field, with minimal edge effects and higher multipole moments. We believe the magnet discussed here is likely to satisfy these requirements. The parameters of the magnets are given in Tables 3 and 4.

V. SCALING TO A DAMPING RING

Another approach to the emittance of the damping ring gives

$$\varepsilon_{qn} \propto \frac{1}{Q^3} \qquad (2)$$

where Q is the tune of the machine, Again it is an oversimplification but we may assume that the tune of a compact storage ring can grow as the circumference of the machine

$$Q \propto C \qquad (1)$$

In this case we can study the scaling from our compact ring to the cases illustrated in Table 1 and Table 2. Figure 3 shows this type of scaling.

Table 3: 1.5 GeV Synchrotron Dipole Parameters

Basic Dipole Parameters	
Number of Bending Units	6.0
Number of Dipoles per Bending Unit	2.0
Dipole Bend Angle (degrees)	30.0
X Ray Fan Angle (degrees)	20.0
Integrated Magnetic Induction* (Tm)	2.62
Peak Design Central Induction (T)	7.2
Magnet Iron Length (mm)	376.0
15 sigma Beam Height (mm)	~ 70.0
15 sigma Beam Width (mm)	~ 51.0
Magnet Gap (mm)	90.0
Magnet Pole Width (mm)	135.0
Overall Iron Width (mm)	650.0
Overall Iron Height (mm)	553.0
Slope Coil Height (mm)	164.0
Coil Thickness (mm)	25.0
Cold Mass per 30 degree Dipole (kg)	1070.0
Overall Bending Unit Mass (kg)	2540.0
Estimated Dipole Magnet System Cost (M$)	4.6

* at the peak machine energy of 1.5GeV

Table 4: Parameters for Magnets in a 1.5GeV Compact Synchrotron

Magnet Design	Magnetic Induction or Gradient (T, Tm^{-1}, or Tm^{-2})	Magnetic Length (m)	Pole Aperture Radius (mm)
Superconducting Dipoles			
B	6.894	0.38	67.5 x 45
Conventional Quadrupoles			
QF	22.67	0.125	45.0
QF1	17.65	0.380	60.0
QD2	-24.06	0.340	45.0
QF3	8.43	0.100	45.0
QF4	31.86	0.280	35.0
QFSH	21.83	0.200	45.0
QDS	-21.83	0.400	45.0
QFS	21.83	0.400	45.0
Conventional Sextupoles			
SF	410.2	0.1	45.0
SD	-549.6	0.1	45.0

* The dipole aperture is not a radius.
X and Y half dimensions are given.

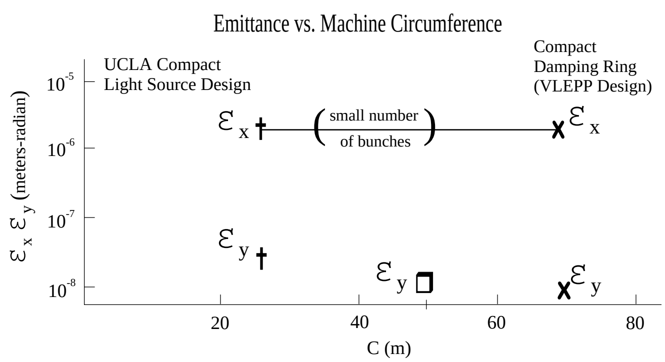

Figure 3: Emittance vs. machine circumference.

In Table 5 we show the general parameters of the storage ring. The vertical emittance is predicted to be ~ 2 x 10^{-8}m, which is in the range of the emittance needed for the NLC. We are now undertaking a study of the effects of increasing the tune of the machine and of the use of multi bunches with trains of bunches.

Table 5 : Parameters for the Compact Synchrotron

Electron Energy (GeV)	1.5
γ	3914
Circumference (m)	26
Tune ν_x	3.17
Tune ν_y	2.57
Horizontal Emittance*, (m-rad)	2.34 x 10^{-6}
Vertical Emittance*, (m-rad)	2.34 x 10^{-8}
Horizontal, β_{max} (m)	3.09
Vertical, β_{max} (m)	6.66
RF Voltage (kV)	2500
FR Frequency (MHz)	499
Momentum Compaction	0.0985
Bunch Length, σ_l (cm)	3

* unnormalized

VI. REFERENCES

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