A COMPACT DAMPING RING USING RF DEFLECTORS FOR THE INTERNATIONAL LINEAR COLLIDER*

R.W. Helms† and D.L. Rubin, Cornell University, Ithaca, NY 14853, USA

Abstract

Current specifications for the International Linear Collider call for bunch trains hundreds of kilometers in length. We describe a scheme for manipulating a compressed bunch train in the damping ring using RF deflectors and multiple transfer lines. The concept is demonstrated in the design of a 4 km damping ring that circulates 2812 bunches spaced 4 ns apart, and we show that injection and extraction of individual bunches is possible with conventional kickers requiring rise/fall times of only 16 ns. The performance and stability of the 4 km damping ring is evaluated and compared with alternative designs.

DAMPING RING SIZE

The TESLA design establishes baseline parameters for the International Linear Collider (ILC) damping ring, along with a proposed 17 km dog-bone design [1]. The proposed bunch spacing from the source is 337 ns, which leads to a 2820 bunch train nearly 300 km in length. In order to store this train in a damping of reasonable size, the train is wound around the ring several times.

This scheme requires the ability to inject and extract individual bunches from the damping ring. The minimum bunch spacing in the damping ring is then determined by the rise/fall time of the injection/extraction kicker, which the TESLA design assumed to be 20 ns.

An improved kicker would reduce the length of the damping ring by reducing the bunch spacing inside. However, if significant kicker improvements are not realized, the bunch spacing can be manipulated inside the ring so that the bunch spacing requirement of a *slow* kicker is satisfied in the vicinity of the kicker, while the bunch train is compressed further in the remainder of the ring.

DESIGN

To achieve a local increase in the bunch spacing, we propose to use RF deflecting cavities which operate at a different frequency from the accelerating RF, and to utilize the positive and negative crests and both zero-crossings of the deflecting field, to kick adjacent bunches into three separate transfer lines, as shown in Fig. 1. Two of the transfer lines will then have a bunch spacing four times that of the rest of the damping ring, and kickers can be installed in one or both of those lines. This differs from some alternative designs because the kicker is isolated in a separate transfer line, and adjacent bunches do not see the rising and falling kicker field. This proposal, therefore, allows a reduction of approximately a factor of four in the circumference of the damping ring.

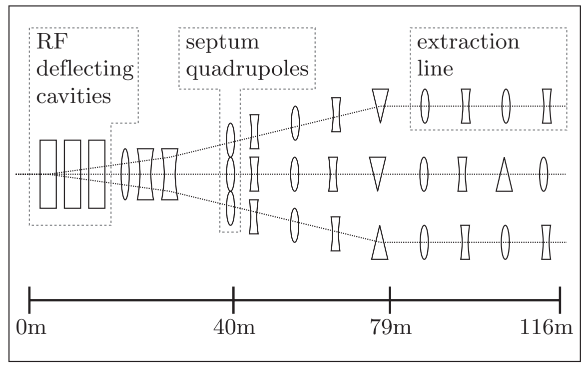

Figure 1: Schematic of the separation scheme, showing the half of the symmetric design. The bends in the center line can be vertical or horizontal.

Lattice

We assume a 2812 bunch train, with bunch spacing in the linac of 352 ns. In the damping ring, the main train is further subdivided into 37 trains of 76 bunches, spaced 4 ns apart, plus a 16 ns gap of at the end of each train. A damped bunch is extracted every 352 ns, from the end of one train and an undamped bunch is injected at the head of another, so that the average current in the ring is constant. This leads to a total damping ring length of 3907 m. Our design uses three 312.5 MHz deflecting cavities on either end of the separation section. Bunches are further deflected by quadrupoles to a separation distance of ± 6.5 cm, where they enter septum quadrupoles and separate transfer lines based on the SLAC B-factory design [2]. The lateral transfer lines reach a final separation of 25 cm, before bending back parallel to the original axis. The need for strong, large-bore quadrupoles to separate the bunches could be obviated by the use of additional deflecting cavities.

The central line in Fig. 1 holds particles from the zero-crossings of the cavity field, and requires some path length adjustment, such as a slight vertical bend, to match the path length of the lateral transfer lines. The remainder of the damping ring lattice uses the arc and wiggler cells from the TESLA dog-bone design [3]. The lattice functions for the lateral transfer line, matched to the large β-functions in the straight section, are shown in Fig. 2, along with the dispersion which is zero at either end.

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† helms@lepp.cornell.edu

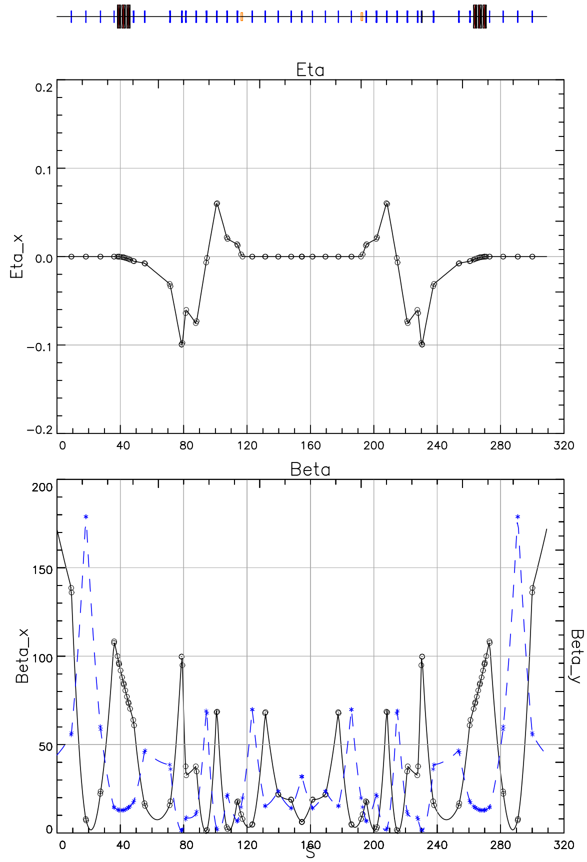

Figure 2: Dispersion and β functions for the lateral transfer line. The dispersion is zero at either end.

RF Deflecting Cavities

We have based our RF deflecting cavities on the specifications for the superconducting "crab cavities" designed for the KEK B-factory [4]. In our simulations, the cavity is represented as a rectangular cavity resonator with a sinusoidal time dependence. Tracking is done by integration through the complete EM field. Aperture effects are not present, but for particles nearly on-axis, this representation gives reasonable spatial, temporal, and energy dependence.

Each cavity provides a 1.3 MeV transverse kick to the 5 GeV beam. We have assumed that the damping ring's main (longitudinal) RF system will operate at 500 MHz, with bunch separation in the damping ring of 4 ns. The bunch spacing in the extraction line is therefore 16 ns, which is the requirement of the kicker (alternative choices are possible if this kicker is not achievable). The deflecting (transverse) RF frequency $f_\perp$ must be chosen to deflect adjacent bunches in the proper direction, and is related to the bunch frequency f_{bunch} by

$$f_\perp = \frac{1}{2}\left(n + \frac{1}{2}\right) f_{\mathrm{bunch}}. \qquad (1)$$

The following table shows several frequencies compatible with our 250 MHz bunch frequency:

n	$f_\perp$ (MHz)
1	187.5
2	312.5
3	437.5
4	562.5

The KEK crab cavities operate at 500 MHz, which falls between the $n = 3$ and $n = 4$ options. However, we have chosen $f_\perp = 312.5$ MHz which is shown in Fig. 3. A lower cavity frequency reduces the differential deflection of the head and tail of bunches encountering these time varying fields. Figure 4 shows individual particles with different longitudinal displacements tracked through a single cavity. The effects are worse for higher frequencies, and particularly severe for particles at the zero-crossing of the deflecting field.

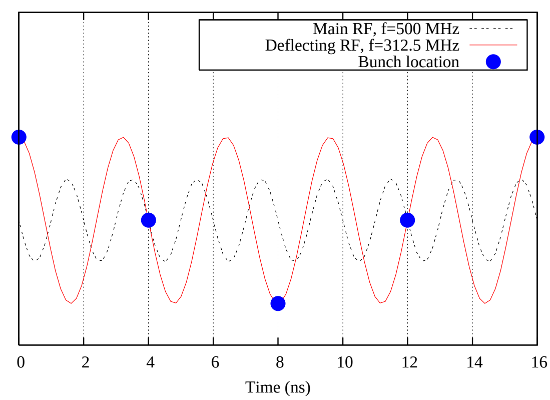

Figure 3: Relationship between 500 MHz accelerating RF (dashed), 312.5 MHz transverse RF (red), and 4 ns bunch spacing.

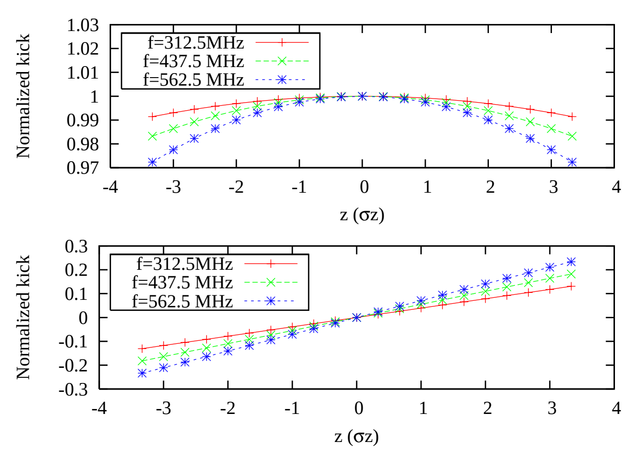

Figure 4: Normalized deflection of particles as a function of z position, shown for three possible RF frequencies.

PERFORMANCE

This smaller ring achieves comparable emittance performance to the 17 km design, using fewer wigglers and weaker accelerating RF. A comparison of relevant parameters is shown in Table 1.

Parameter	TESLA	Multi-line
length	17 km	4 km
horizontal extracted emittance (ϵ_x)	.8 nm	.74 nm
damping time (τ_d)	28 ms	23 ms
equilibrium bunch length (σ_z)	6 mm	6 mm

Table 1: Comparison of emittance with TDR specifications

The use of alternative transfer lines is somewhat unorthodox. For simulations involving multi-turn tracking, our method has been to create two rings, each containing a different transfer line. Ultimately, this will be extended to four rings, two of which contain the lateral transfer lines, and two of which contain the two different phases of the central transfer line. For now, the two existing rings are concatenated and tracked as a single ring, with appropriate adjustments made for tunes, etc. Multi-turn tracking in this fashion, with the inclusion of localized radiation at each element, confirms that the emittance is uncompromised by the multiline scheme.

Dynamic Aperture

The dynamic aperture of this ring is shown in Fig. 5. This is smaller than we would desire, especially since the introduction of wiggler nonlinearities are likely to compromise it further. However, we have yet to optimize cell length and sextupole distribution.

The deflecting cavities in this design are subject to fluctuations in their amplitude and phase. These fluctuations will cause undesirable deflection of the bunches and reduce the dynamic aperture. In evaluating the performance, we assume fractional field errors of $\pm 10^{-3}$ and phase errors of $\pm 0.1°$ [5]. Figure 5 shows the impact on the dynamic aperture when these, or more putative fluctuations are taken into account. Random errors are added to each cavity independently, and recalculated after each turn. Although the ring in this analysis is not well tuned for a large dynamic aperture, it is evident that field strength and phase fluctuations have a minimal effect.

Space Charge Tune Spread

One of the principle advantages of a smaller damping ring is the reduction of space charge effects without the potential need for local coupling bumps. Figure 6 shows the reduction in the space charge tune spread in our ring, relative to that of the 17 km design. Tracking was done with BMAD, with space charge forces calculated based on the equilibrium beam size and corresponding kicks added at each element. For both lattices, skew quadrupole components have been added to sextupole elements to produce ϵ_y/ϵ_x=.01.

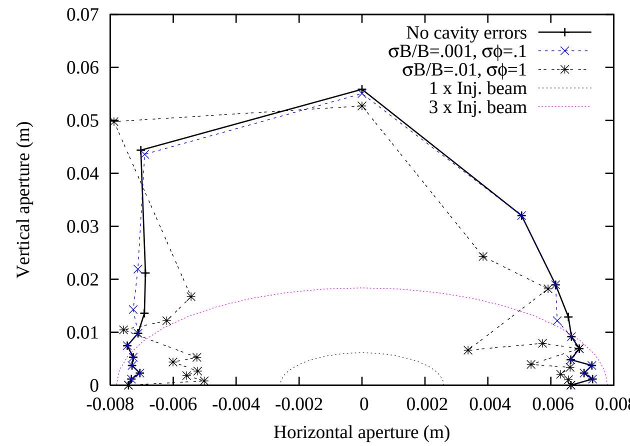

Figure 5: Dynamic aperture for on-energy particle showing impact of cavity amplitude and phase fluctuations.

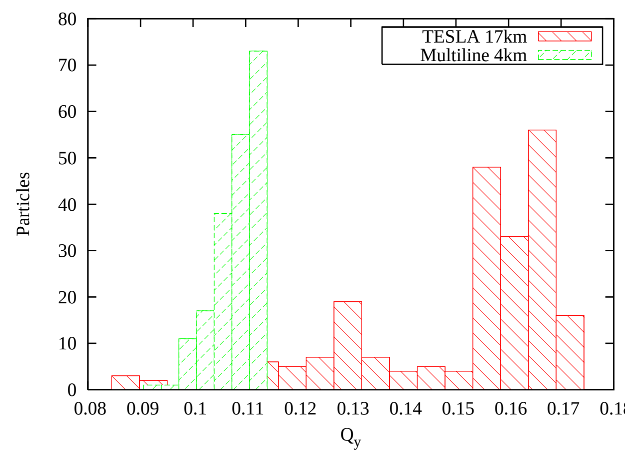

Figure 6: Vertical tune spread in TESLA 17 km ring and multi-line 4km ring, with ϵ_y/ϵ_x = .01.

CONCLUSION

We have promising results that the use of RF deflecting cavities can reduce the ILC damping ring circumference by a factor of four. We have implemented the apparatus for tracking through these cavities, and tracking through rings with multiple transfer lines. With a completed lattice and improvements in the dynamic aperture, we believe that this design will be a feasible alternative or compliment to improvements in kicker technology.

REFERENCES

[1] *TESLA Technical Design Report*

[2] An Asymmetric B Factory Based on PEP - Conceptual Design Report, SLAC-0372

[3] *http://www.desy.de/ wdecking/dog/dog6.4.1.lat*

[4] K. Akai and Y. Morita, KEK Report No. 2003-123, 2003

[5] S. Belomestnikh, private communication