Specifications for the ILC Damping Rings EDR Baseline Lattice

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We outline a parameter specification for the ILC damping rings engineering design phase baseline lattice. This specification has reduced momentum compaction factor and bunch length, compared to the baseline lattice used for the RDR [1].

Main Parameters

Table 1: Main parameters of the baseline lattice for the RDR and proposed for the EDR.

	RDR [1]	Proposed for EDR		
		low rf	nominal	high threshold
Beam energy	5 GeV	5 GeV		
Harmonic number	14516	14042		
RF frequency	650 MHz	650 MHz		
RF voltage[1]	22.1 MV	13.2 MV	21.6 MV	25.8 MV
Number of rf cavities	18	8	16	16
Momentum compaction factor[1]	4×10^{-4}	1.1×10^{-4}	1.8×10^{-4}	2.7×10^{-4}
Natural rms bunch length[1]	9 mm	6.6 mm	6 mm	6.6 mm (2)
Natural energy spread	0.13%	< 0.13%		
Natural emittance	5 µm	< 8 µm		
Transverse damping times	25 ms	< 25 ms		
Betatron acceptance ($A_x + A_y$)	> 0.01 m	> 0.01 m		
Energy acceptance	± 0.5%	± 0.5%		

[1] These parameters should be variable over some range: see Table 2.

[2] Can be reduced to 6 mm with 30.8 MV total rf voltage (18 cavities): see Table 2.

Magnets

The number of different magnet styles should be a minimum. For example, all quadrupoles will ideally have the same length and aperture, with variations in strength provided by changing only the current in the coils.

Layout and Component Spacing

RF Cavities. Each cryostat will contain a single rf cavity. The longitudinal space required for each cryostat is 3.5 m [2]. To allow for driving multiple cavities from a single klystron, the distance between cavities should be $(n\pm\frac{1}{4})\lambda_{rf}$ where n is an integer, and λ_{rf} is the rf wavelength. If located in the same straight as wigglers, the rf cavities should be upstream of the wigglers. There should be sufficient space for installation of 20 cavities. This will allow sufficient voltage (30.8 MV) for 6 mm bunch length with a momentum compaction factor of 2.7×10^{-4}. Operation at the nominal momentum compaction factor of 1.8×10^{-4} and 6 mm bunch length will require a smaller voltage (21.6 MV) which can be provided with 16 cavities.

Wiggler. The drift space between the end of each wiggler and the face of the nearest quadrupole should be 0.75 m. To ease handling of synchrotron radiation, in-line wiggler sections should be less than about 80 m in length (and ideally less than about 50 m). Longer sections in a single straight should have transverse displacements provided by horizontal dog-legs (see Figure 1).

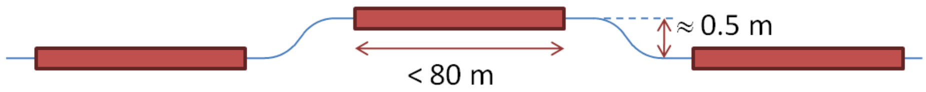

Figure 1: Horizontal dog-legs used to split long sections of wiggler.

Momentum Compaction Factor, Bunch Length and RF Voltage

Presently, the specification for the rms length of bunches extracted from the damping rings is 9 mm. Reducing this to 6 mm would have major benefits for the bunch compressors downstream of the damping rings. A shorter bunch length can be achieved without significant impact on other parameters or design features by increasing the rf voltage in the damping rings; however, this is undesirable, because of the increased cost and additional impedance. The bunch length can be reduced, for fixed rf voltage and frequency, by reducing the momentum compaction factor. Although this will lower certain instability thresholds, recent estimates [3] indicate a substantial margin between the nominal operating parameters (momentum compaction factor 4×10^{-4} and 9 mm rms bunch length) and the thresholds for microwave and other instabilities.

The ring rf voltage V_{rf} is related to the damping rings design parameters by:

$$\left(\frac{eV_{rf}}{E_0}\right)^2 = \left(\frac{U_0}{E_0}\right)^2 + \left(\frac{\sigma_\delta}{\sigma_z}\right)^4 \left(\frac{\alpha_p c C_0}{\omega_{rf}}\right)^2$$

where E_0 is the beam energy, U_0 is the energy loss per turn, α_p is the momentum compaction factor, C_0 is the circumference, ω_{rf} is the rf (angular) frequency, σ_z is the natural bunch length and σ_δ is the natural energy spread. Figure 2 shows the variation in rf voltage with momentum compaction factor for 6 mm and 9 mm bunch length, with all other parameters taking values fixed by the lattice specifications.

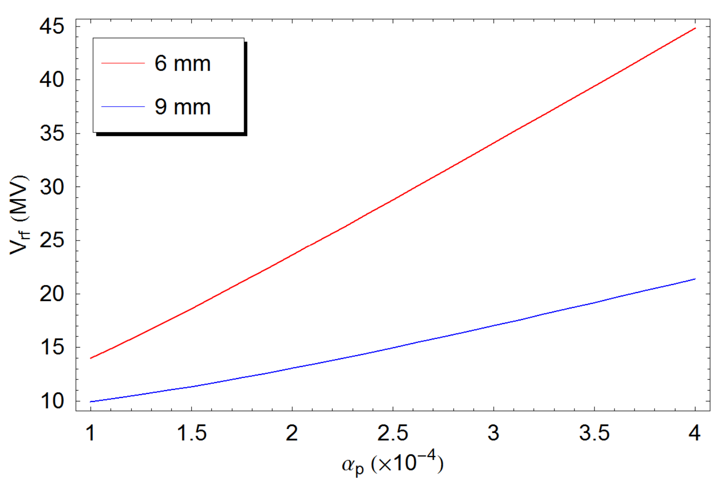

Figure 2: Variation in rf voltage with momentum compaction factor for two fixed bunch lengths in the ILC damping rings.

Reducing the momentum compaction factor reduces the rf acceptance, $\delta_{\max}$:

$$\delta_{max} = \frac{2c}{\omega_{rf}}\frac{\sigma_\delta}{\sigma_z}\sqrt{1-\left(\frac{\pi}{2}-\varphi_s\right)\tan\varphi_s}$$

where φ_s is the synchronous phase, given by:

$$\varphi_s = \pi - \sin^{-1}\left(\frac{U_0}{eV_{rf}}\right)$$

Figure 3 shows the variation in rf acceptance as a function of momentum compaction factor, for 6 mm and 9 mm bunch length, with all other parameters taking values fixed by the lattice specifications. The specified maximum energy deviation of injected positrons is 0.5%. The rms natural energy spread in the damping rings will be approximately 0.13% (dominated by the peak field in the wiggler). Thus, although any rf acceptance over 0.5% is acceptable in principle, an acceptance over 1% is desirable to ensure some margin for the injection, and to allow reasonable beam lifetime for commissioning and tuning.

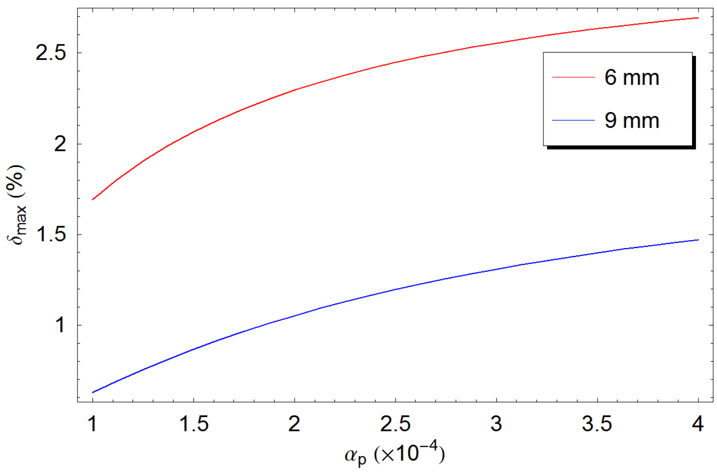

Figure 3: Variation in energy acceptance with momentum compaction factor for two bunch lengths in the ILC damping rings.

Reducing the momentum compaction factor increases the impact of circumference changes on the energy error:

$$\frac{\Delta E}{E_0} = \frac{1}{\alpha_p}\frac{\Delta C}{C_0}$$

With a momentum compaction factor of 2×10^{-4}, an energy error of 1.3×10^{-4} (10% of the natural energy spread) will result from a fractional change in circumference of 2.6×10^{-8}, which corresponds to an absolute change in circumference of 0.17 mm. This indicates the tolerance on the circumference stability. The chicanes must be capable of correcting the circumference over the expected range of circumference variation, which is not directly affected by the momentum compaction factor.

Given the above considerations, we propose to reduce the specified nominal momentum compaction factor to 1.8×10^{-4} while maintaining roughly the same rf voltage. This will reduce the natural rms bunch length from 9 mm to 6 mm. We expect that the microwave threshold will be reduced by roughly a factor of 3, which, according to recent estimates, still provides a good margin. However, since there is still significant uncertainty in the instabilities (including microwave and electron cloud) flexibility in momentum compaction factor and bunch length is strongly desirable both in design and in operation. Some possible scenarios are indicated in Table 2. Note that with the design outlined in the RDR, the rf cavities are naturally provided in groups of four, driven by a single modulator and klystron (constituting an “rf station”). The maximum accelerating voltage per cavity is expected to be around 1.7 MV [2].

Table 2: Natural rms bunch length in the damping rings over a range of values for the momentum compaction factor and rf voltage.

<table>
<tr><td colspan="3" align="right">Momentum compaction factor:</td><td>1.1×10^{-4}</td><td>1.8×10^{-4}</td><td>2.2×10^{-4}</td><td>2.7×10^{-4}</td></tr>
<tr><td>Number of rf cavities</td><td>Voltage per cavity (MV)</td><td>Total voltage (MV)</td><td colspan="4">Natural rms bunch length (mm)</td></tr>
<tr><td>8</td><td>1.28</td><td>10.2</td><td>9.0</td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>1.55</td><td>12.4</td><td>7.0</td><td>9.0</td><td></td><td></td></tr>
<tr><td>8</td><td>1.65</td><td rowspan="2">13.2</td><td rowspan="2">6.6</td><td rowspan="2">8.5</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>12</td><td>1.10</td></tr>
<tr><td>12</td><td>1.23</td><td>14.8</td><td>6.0</td><td>7.7</td><td>8.5</td><td></td></tr>
<tr><td>12</td><td>1.54</td><td rowspan="2">18.5</td><td rowspan="2">5.2</td><td rowspan="2">6.6</td><td rowspan="2">7.3</td><td rowspan="2">8.1</td></tr>
<tr><td>16</td><td>1.16</td></tr>
<tr><td>16</td><td>1.35</td><td>21.6</td><td></td><td>6.0</td><td>6.6</td><td>7.3</td></tr>
<tr><td>16</td><td>1.61</td><td rowspan="2">25.8</td><td rowspan="2"></td><td rowspan="2">5.4</td><td rowspan="2">6.0</td><td rowspan="2">6.6</td></tr>
<tr><td>18</td><td>1.43</td></tr>
<tr><td>18</td><td>1.71</td><td rowspan="2">30.8</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">5.4</td><td rowspan="2">6.0</td></tr>
<tr><td>20</td><td>1.54</td></tr>
</table>

With a low momentum compaction factor of 1.1×10^{-4}, a bunch length of 6.6 mm could be achieved with just two rf stations (eight cavities). Three rf stations would allow a bunch length of 6.0 mm to be achieved. If instabilities allow, this low momentum compaction factor could provide a possible “start-up” option (with two rf stations), or a fall-back solution in the case of regular operations requiring more rf stations, if one rf station fails.

A nominal momentum compaction factor of 1.8×10^{-4} would allow a 6 mm bunch length to be achieved with four rf stations (16 cavities; compared with the 18 cavities in the RDR design), and operation with 6.6 mm bunch length with three rf stations. As mentioned above, this momentum compaction factor and a 6 mm bunch length would be expected to reduce the instability thresholds by a factor of roughly 3, compared with the RDR design.

In the later stages of the engineering design phase, or during commissioning and operation, instabilities may be found to be more difficult than presently expected. In that case, operation at a higher momentum compaction factor and bunch length may be desirable. With a momentum compaction factor of 2.7×10^{-4}, a bunch length 6.6 mm can be achieved with four rf stations. These parameters should increase the instability thresholds by more than 50% compared to a “nominal” parameter set with momentum compaction factor 1.8×10^{-4} and 6 mm rms bunch length.

For the EDR baseline lattice, it seems reasonable to specify momentum compaction factor variable in the range 1.1×10^{-4} to 2.7×10^{-4}, with 1.8×10^{-4} the expected “nominal” value; extracted rms bunch lengths up to 6.6 mm should be allowed, with 6.0 mm the expected “nominal” value. Space should be available for installation of up to five rf stations (providing 20 cavities) in each ring, although only three rf stations may be installed initially.

References

[1] The ILC Reference Design Report, ILC-REPORT-2007-001 (August 2007). http://ilcdoc.linearcollider.org/record/6321/files/

[2] R. Boni, RF System Specification Sheets (2006). https://wiki.lepp.cornell.edu/ilc/bin/view/Public/DampingRings/RfAllCompSpecSheets

[3] G. Stupakov, “Status and future plans for instability studies for the ILC damping rings,” presented at ILCDR07-KEK (December 2007). https://wiki.lepp.cornell.edu/ilc/pub/Public/DampingRings/KEKWorkshopTalks/Stupakov.pdf