ILC Damping Ring
Alternative Lattice Design
(Modified FODO)

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\textbf{18-20 December, 2007}
Most important update after Fermi GDE meeting (October 2007)

Re-matched the dispersion suppressor and the matching sections between dispersion suppressor and wiggler (injection) sections.

Now newest FODO DR lattice can truly be tuned with momentum compaction between $2e^{-4}$ and $6e^{-4}$, by only tuning the quadrupole’s strength, not change any geometry of the ring (dipole strength in the dispersion suppressor do not change).
THE ADVANTAGE OF FODO LATTICE

1. Smaller number quadrupoles and sextupoles used (roughly two thirds), and lower cost.

2. Freely tunable momentum compaction factor in the range between $2 \times 10^{-4}$ and $6 \times 10^{-4}$.

3. Good dynamic aperture.

4. Simpler layout, with only two wiggler sections and cryogenics shaft, no long Transport Line for cryogenics needed.
4 arc sections.

4 straight sections, one for injection, one for extraction, and the other two for RF/wiggler.

Two shafts in all and no TL.

Beam is counter-rotating.
CONSIDERATIONS FOR THE ARC CELL

Scan some arc cell parameters.

- Arc cell number: from 120 to 240.
- Arc cell length: from 20 m to 40 m.
- The short drift length: from 1 m to 3 m.

To get proper dispersion and beta functions at the sextupole location in a cell, suitable maximum beta function (less than 55 m, constrained by vacuum chamber), and freely tunable alpha with different arc cell phase advance.

At last, we select the arc cell length to be 29.4 m, and the arc cell number to be 184.
## COMPARISON WITH OCS8

<table>
<thead>
<tr>
<th></th>
<th>OCS8 (2007.10)</th>
<th>FODO-4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Circumference [ m ]</strong></td>
<td>6476.439</td>
<td>6476.439</td>
</tr>
<tr>
<td><strong>Arc cell</strong></td>
<td>TME</td>
<td>FODO</td>
</tr>
<tr>
<td><strong>Phase advance of arc cell</strong></td>
<td>90/90</td>
<td>60/60~90/90</td>
</tr>
<tr>
<td><strong>Momentum compaction [ 10^{-4} ]</strong></td>
<td>4</td>
<td>2~6</td>
</tr>
<tr>
<td><strong>Quadrupoles in all</strong></td>
<td>682</td>
<td>448</td>
</tr>
<tr>
<td><strong>Dipoles in all</strong></td>
<td>114 × 6 m + 12 × 3 m</td>
<td>368 × 2 m</td>
</tr>
<tr>
<td><strong>Sextupoles in all</strong></td>
<td>480</td>
<td>368</td>
</tr>
<tr>
<td><strong>Number of wiggler straights</strong></td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>
ARC CELL DESIGN

\[ \beta^\pm = \frac{L_p(1 \pm \sin \frac{\mu}{2})}{\sin \mu} \]
\[ D^\pm = \frac{L_p \phi(1 \pm \frac{1}{2} \sin \frac{\mu}{2})}{4 \sin^2 \frac{\mu}{2}} \]

Left: 60/60 cell, corresponding to \(6 \times 10^{-4}\) alpha

Left: 90/90 cell, corresponding to \(2 \times 10^{-4}\) alpha
Select the **90 degree case** as the baseline, the bending angle in the dispersion suppressor is set to be half of the bending angle in the normal arc cell, so that zero dispersion at exit is got naturally for 90 degree case.
Tune the quadrupole’s strength in the dispersion suppressor for the **72 degree case**, to make sure dispersion is free at exit, and dipole strength not changed (Geometry is the same).
Tune the quadrupole’s strength in the dispersion suppressor for the **60 degree case**, to make sure dispersion is free at exit, and dipole strength not changed (Geometry is the same).
INJECTION/EXTRACTION DESIGN (90 DEGREE)

2 septums and 21 stripline kickers (lumped kickers)

Uses two periodic cells, with the total horizontal phase advance matched to be 180 degree
Adjustment of one Chicane: $\pm 2\theta^2 \left( l_c + 0.5l_B \right)$

$10^{-6}$ adjustable

4 Chicane

Emittance $+9.2\%$
$2 \times 10^{-4}$ MOMENTUM COMPACTION

90/90 cell, $2 \times 10^{-4}$ momentum compaction
$4 \times 10^{-4}$ MOMENTUM COMPACTION

72/72 cell, $4 \times 10^{-4}$ momentum compaction
$6 \times 10^{-4}$ MOMENTUM COMPACTION

60/60 cell, $6 \times 10^{-4}$ momentum compaction
## TOTAL PARAMETERS OF THREE CRITICAL MODES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\alpha_p = 2 \times 10^{-4}$</th>
<th>$\alpha_p = 4 \times 10^{-4}$</th>
<th>$\alpha_p = 6 \times 10^{-4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference [ m ]</td>
<td>6476.439</td>
<td>6476.439</td>
<td>6476.439</td>
</tr>
<tr>
<td>Harmonic number</td>
<td>14042</td>
<td>14042</td>
<td>14042</td>
</tr>
<tr>
<td>Energy [ GeV ]</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Arc cell</td>
<td>FODO</td>
<td>FODO</td>
<td>FODO</td>
</tr>
<tr>
<td>Tune</td>
<td>58.29 / 57.25</td>
<td>46.28 / 47.24</td>
<td>40.29 / 41.25</td>
</tr>
<tr>
<td>Natural chromaticity</td>
<td>-74 / -73</td>
<td>-54 / -55</td>
<td>-48 / -49</td>
</tr>
<tr>
<td>Momentum compaction [ 10^{-4} ]</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Transverse damping time [ ms ]</td>
<td>25 / 25</td>
<td>25 / 25</td>
<td>25 / 25</td>
</tr>
<tr>
<td>Norm. Natural emittance [ mm-mrad ]</td>
<td>3.36</td>
<td>4.2</td>
<td>5.4</td>
</tr>
<tr>
<td>RF voltage [ MV ]</td>
<td>15</td>
<td>22</td>
<td>31</td>
</tr>
<tr>
<td>Synchrotron tune</td>
<td>0.038</td>
<td>0.061</td>
<td>0.091</td>
</tr>
<tr>
<td>Synchrotron phase [°]</td>
<td>145</td>
<td>157</td>
<td>164</td>
</tr>
<tr>
<td>RF frequency [ MHz ]</td>
<td>650</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>RF acceptance [ % ]</td>
<td>1.21</td>
<td>1.48</td>
<td>1.65</td>
</tr>
<tr>
<td>Natural bunch length [ mm ]</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Natural energy spread [ 10^{-3} ]</td>
<td>1.28</td>
<td>1.28</td>
<td>1.28</td>
</tr>
</tbody>
</table>

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DYNAMIC APERTURE $6 \times 10^{-4}$ ALPHA CASE

The blue line is three times injected positron bunch size. Tracking for 1000 turns, no errors, using MAD.
FMA $6 \times 10^{-4}$ ALPHA CASE

ILC DR FODO4 lattice, calculated frequency map (NAFF),

- $x$ position [mm] (injection straight)
- $y$ position [mm]

- Frequency range: $-10$ to $-3$
The blue line is three times injected positron bunch size. Tracking for 1000 turns, no errors, using MAD.
FMA $4 \times 10^{-4}$ ALPHA CASE

![Graph showing ILC DR FODO4 lattice, calculated frequency map (NAFF).](image)

- x position [mm] (injection straight)
- y position [mm]

- Frequency values range from $-10$ to $-3$.
Left: no errors; Right: **with high order magnets errors**. The blue line is **three times injected positron** bunch size.
FMA is used to optimize the lattice and the DA. The optimized result for $2 \times 10^{-4}$ momentum compaction mode
WITH HARMONIC SEXTUPOLES

$2 \times 10^{-4}$ momentum compaction mode, with 3 group harmonic sextupoles

Left: no errors; Right: with high order magnets errors
$4 \times 10^{-4}$ momentum compaction mode, on momentum particles, without errors; Left: OCS8, Right: FODO-4b

The blue line is three times injected positron bunch size.
### Touschek lifetime:

\[
\frac{1}{\tau} = \frac{r_e^2 c N_0}{8\pi \gamma^2 \delta_{\text{max}}^3 \sigma_x \sigma_y \sigma_z} D(\varepsilon)
\]

**4 × 10^{-4}** momentum compaction mode. Energy acceptance 1.48%, bunch population 2 × 10^{10}, Touschek lifetime is 160 minutes

<table>
<thead>
<tr>
<th>Element</th>
<th>Length [m]</th>
<th>Field or Gradient</th>
<th>Aperture [m]</th>
<th>Pole-tip field [T]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipole</td>
<td>2</td>
<td>0.2246 T</td>
<td>0.06</td>
<td>0.2246</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>0.3</td>
<td>10 T/m</td>
<td>0.06</td>
<td>0.3</td>
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<tr>
<td>Sextupole</td>
<td>0.25</td>
<td>17.67 T/m²</td>
<td>0.06</td>
<td>0.00796</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENT

Thanks to A. Xiao and L. Emery et al. in ANL who designed the RF/wiggler sections.

Many thanks to Prof. M. Zisman for his kind suggestions and help. Also thanks Prof. Cai of SLAC for his help.
Thanks for your attention.