III. CesrTA Configuration and Optics for Ultra-Low Emittance

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• **Outline**
  
  – **CESR Overview**
    - CESR Layout
    - Injector
    - Wigglers
  
  – Modifications for CesrTA
  
  – Optics for low-emittance operation
e+ / e- colliding beams 1.5-5.5 GeV

Circumference 768 m

45 bunches/beam in trains, electrostatic separation

Currents in CESR to 2x350 mA @ 5.3 GeV >1x150 mA @ 1.9 GeV

120 keV gridded gun

150/300 MeV linac

Full energy synchrotron (60 Hz)

Flexible timing, ~20 bunches/cycle

Filling rates to 100/300 mA/minute
RF Numerology

- RF frequencies critical to CesrTA bunch patterns
  - CESR / Synchrotron / Linac / Gun prebuncher
  - All RF systems phase locked from common source
  - Highest common frequency 71.4 MHz (T=14 ns)

<table>
<thead>
<tr>
<th>System</th>
<th>Frequency</th>
<th>Mult x h.c.f.</th>
<th>Bucket Spacing</th>
<th>Harmonic # in CESR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest common freq.</td>
<td>71.4 MHz</td>
<td>1</td>
<td>14 ns</td>
<td>183</td>
</tr>
<tr>
<td>Injector Prebuncher</td>
<td>214 MHz</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linac</td>
<td>2856 MHz</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synchrotron</td>
<td>714 MHz</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CESR</td>
<td>499.8 MHz</td>
<td>7</td>
<td>2 ns</td>
<td>1281</td>
</tr>
</tbody>
</table>

Multiple CESR buckets on 14 ns pattern can be filled on a single injection cycle. Injector RF chain can be phase shifted between injection cycles to fill any CESR buckets.
Wiggler Magnets

• The OCS6 ILC Damping Ring lattice employs 80 wiggler magnets to achieve its radiation-determined parameters to meet ILC requirements.
  • Effective length: 2.5 m
  • Peak operating field: 1.67 T (max 2.1 T)
  • Magnetic period: 40 cm

• The 12 wiggler magnets in CESR were designed for CESR-c conditions – e+/e- colliding beams 1.5-2.5 GeV beam energy.

• The basic magnetic properties of the CESR-c wigglers closely match the ILC DR design.
Wiggler Magnets

• Several considerations for CESR-c operation determined the principal wiggler properties:
  – Large vertical aperture – 5 cm in warm bore
    • w/ 2.1 T field → super-ferric technology
  – ± 2 cm horizontal “pretzel” orbits
    • wide good-field region – $\Delta B_Y = +0.0, -0.3\%$ over aperture
  – Flexibility in operating field
    • Even # poles to reduce center-end pole difference effects
  – Ring layout constraints
    • ~1.7 m flange-flange
### Wiggler Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Super-ferric</td>
</tr>
<tr>
<td>Peak Field</td>
<td>1.5-2.1 T</td>
</tr>
<tr>
<td>Wiggler Length</td>
<td>1.3 m</td>
</tr>
<tr>
<td>Number of wigglers</td>
<td>12</td>
</tr>
<tr>
<td>Field period</td>
<td>40 cm</td>
</tr>
<tr>
<td>Transv. width of poles</td>
<td>23 cm</td>
</tr>
<tr>
<td>Number of poles</td>
<td>6-20 cm, 2-10 cm, 2-5 cm</td>
</tr>
<tr>
<td>Pole gap</td>
<td>7.6 cm</td>
</tr>
<tr>
<td>Operating Current (2.1 T)</td>
<td>185 A</td>
</tr>
<tr>
<td>Wire operating margin</td>
<td>50%</td>
</tr>
</tbody>
</table>
12 damping wigglers are placed in 6 clusters according to available space in CESR.

- Cryogen distribution
- Optics manipulation
• Rigorous training and measurement program
  • Most trained with 2-3 quenches to 2.3 T – no operational problems with magnets.
  • Hall probe and long flip coil, folded flip coil measurements
Wiggler Field Validation w/Beam

• Beam based measurements confirmed field quality:
  
  – Bunch length ($\sigma_{E}/E_0 = 8.62$ vs. $8.47 \times 10^{-4}$)
  
  – Betatron tunes vs beam position, wiggler field

Vertical and horizontal tune versus vertical beam position at three 8-pole wigglers cluster, VB 58.
(ST, Aug 21 2003)

Vertical and horizontal tune versus horizontal beam position at three 8-pole wigglers cluster, HB 70.
(ST, Aug 21 2003)
• Outline
  – CESR Overview
  – Modifications for CesrTA
    • L0 (CLEO detector)
    • L3 (180° from CLEO)
    • Arc magnets
    • Feedback, diagnostics, survey & alignment
  – Optics for low-emittance operation
Modification Regions
• Conversion for low-emittance operation:
  – Minimize number of wiggler regions to facilitate dispersion control
L0 Modifications

- L0 Layout w/ wigglers, quads, steering (FY08)
  - Remove CLEO VD, DR, RICH, ENDCAP
  - Install elements on rails
  - Cryogenics services from existing SC quad facilities
L3 Modifications

• L3 changes
  – Remove 2 vertical separators, replace with instrumented beam pipes (FY08)
  – Install upgraded s.r. optics (streak camera) (FY08)
  – Install EC instrumentation in quads and drifts (FY09-10)
Arc Modifications

- 6 wigglers to be removed from arcs – instrument replacement chambers
  - RFA’s in drifts, bends (FY08, 09)
Survey and Alignment

• Quad, sextupole alignment system upgrade
  – LiCAS-II system not funded by STFC
  – Modify alignment fixtures for better resolution (FY08)
  – Install new target system (FY08,09)
  – Purchase and implement laser tracker system (FY09)
    → x2-3 speedup in survey & alignment process
    → improved survey accuracy
– Electron Cloud diagnostics
  • Retarding Field Analyszers in drift and quad chambers
  • Low profile RFA’s in wigglers and bend chambers
– Low emittance diagnostics
  • Upgrade BPM processing electronics – higher resolution, speed
  • High resolution X-ray beam profile monitor – single pass bunch-by-bunch, extendable to 2-D
– Other
  • Upgrade Synchroscan streak camera unit for 4 ns spacing, optics for 2-D recording
  • Extend vacuum instrumentation
    – Partial pressure analyzers, controlled leaks for selected gases, temperature monitoring, gate valves for quick changes, etc.
Feedback Systems

- Present CESR bunch-by-bunch feedback systems in place for bunches in 14 ns buckets.
  - Transverse systems:
    - Standard bpm position pickup
    - Digital processing bunch-by-bunch, variable turns delay
    - Strip line kickers
    - Damping rates ~ 2000 /s
  - Longitudinal system:
    - Standard bpm pickup
    - Digital processing bunch-by-bunch
    - Low Q DAFNE style cavity to drive beam
    - Damping rates ~ 50 /s
• CesrTA Feedback (4 ns bunch spacing)
  – Transverse:
    • Wideband system with direct path across tunnel diameter
CesrTA Longitudinal Feedback

- CesrTA Longitudinal Feedback

  - Upgrade of processing electronics and a slightly modified cavity design and amplifier will permit feedback near present damping rates.
  - Removal of vertical electrostatic separators in L3 is predicted to raise longitudinal instability threshold $x_{4-5}$
• Outline
  – CESR Overview
  – Modifications for CesrTA
  – Optics for low-emittance operation
    • CESR Optics process
    • CesrTA in-progress optics
Optics Design Process

• Every quadrupole & sextupole is independently controllable
• No “standard cell”
• Optics realization:
  – Several optimizer engines available
  – Tracking with non-linearities to find partial derivatives
  – 27 years experience using technique with CESR optics
– Wigglers are modeled using OPERA-3D, producing a 3-D field map.

– The field map is fit to satisfy Maxwell’s equations

– The fit is then integrated symplectically using the Hamiltonian to a user defined order – usually third order

– The wiggler is not varied in the optimization process, however optimizations have been done at discrete wiggler fields - 2.1T, 1.9T, 1.7T
• Fast phase measurements system permits full (including coupled) optics correction in a few minutes.

• Dispersion, chromatic corrections also possible.
• Preliminary optics results

\[ \varepsilon_x = 2.3 \text{ nm} \]
\[ Q_{x,y} = 14.57, 9.62 \]
\[ \tau_{\text{damp } x,y} = 56.4 \text{ ms} \]
\[ \tau_{\text{Touschek}} \approx 12 \text{ m} \]
Dynamic aperture calculations use ACTUAL physical apertures to identify lost particles.

Dashed lines show losses in 20 turns (~physical aperture).

Solid lines show losses in 1000 turns (“dynamic aperture”) 0, 0.5%, 1% dp/p₀

Yellow curve = 3 σ injected beam (εₓ=1000 nm, εᵧ=½ εₓ)

Sextupole, wiggler nonlinearities included
Optics Summary

- Development of optics at 2, 2.5, 5 GeV **in progress**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2.0 GeV</th>
<th>2.5 GeV</th>
<th>5.0 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{Wig}$</td>
<td>1.9 T</td>
<td>2.1 T</td>
<td>1.9 T</td>
</tr>
<tr>
<td>$\varepsilon_x$</td>
<td>2.3 nm</td>
<td>3.4 nm</td>
<td>30.7 nm</td>
</tr>
<tr>
<td>$\tau_{damp(x,y)}$</td>
<td>56.4 ms</td>
<td>35.7 ms</td>
<td>19.1 ms</td>
</tr>
<tr>
<td>$\tau_{i.b.s.}$</td>
<td>$\sim$12 m</td>
<td>$\sim$22 m</td>
<td>—</td>
</tr>
<tr>
<td>$Q_z \at MV_{RF}$</td>
<td>0.054@4.6</td>
<td>0.081@12.5</td>
<td>0.05@9</td>
</tr>
<tr>
<td>$\sigma_z$</td>
<td>9 mm</td>
<td>9 mm</td>
<td>9 mm</td>
</tr>
</tbody>
</table>
• Most topics discussed will be described in more detail in subsequent talks.

• The LEPP staff have extensive experience making effective use of the optics flexibility of the CESR facility.

• This flexibility and the experienced LEPP staff provide an effective and economical conversion path to CesrTA.