Parameters of Future Rings

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Future Rings

- Greater demands on performance of present and future accelerators
  - Lower emittance
  - Higher current
  - Shorter bunches
  - Top-up mode
  - Bunch trains (gaps)
  - Reduced damping time

- All tend to push limits of beam stability
  - Single-bunch
  - Multi-bunch
Synchrotron Light Sources

- Existing 3rd generation light sources
  - ALS, NSLS, ESRF, ELETTRA, APS, …..

- New light sources
  - DIAMOND, SOLEIL, SSRF, ….

Damping rings for linear colliders

- NLC, TESLA, CLIC
  - Similar to 3rd generation light sources
  - Pushing some parameters
### Comparison of ring parameters

<table>
<thead>
<tr>
<th></th>
<th>ALS</th>
<th>ELETTRA</th>
<th>SRF C</th>
<th>NSLS-ωv</th>
<th>SLS</th>
<th>ATC</th>
<th>SLH</th>
<th>DML-ODN</th>
<th>SSRF</th>
<th>NLC</th>
<th>CLC</th>
<th>TEBA</th>
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<tbody>
<tr>
<td>Energy (GeV)</td>
<td>1.5</td>
<td>2</td>
<td>1.5</td>
<td>0.808</td>
<td>2.4</td>
<td>1.54</td>
<td>2.5</td>
<td>3</td>
<td>3.5</td>
<td>1.98</td>
<td>1.98</td>
<td>5</td>
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<tr>
<td>Momentum compaction</td>
<td>1.00E-03</td>
<td>1.43</td>
<td>1.59</td>
<td>6.78</td>
<td>23.5</td>
<td>0.7</td>
<td>1.93</td>
<td>0.472</td>
<td>8.43</td>
<td>0.71</td>
<td>0.66</td>
<td>0.28</td>
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<td>Energy spread (%)</td>
<td>0.08</td>
<td>0.08</td>
<td>0.075</td>
<td>0.05</td>
<td>0.09</td>
<td>0.072</td>
<td>0.0924</td>
<td>0.0923</td>
<td>0.09</td>
<td>0.078</td>
<td>0.078</td>
<td>0.13</td>
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<tr>
<td>Bunch length (ns)</td>
<td>12</td>
<td>18.7</td>
<td>30</td>
<td>170</td>
<td>13.3</td>
<td>16.7</td>
<td>11.67</td>
<td>16.2</td>
<td>12.7</td>
<td>10</td>
<td>20</td>
<td>10</td>
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<tr>
<td>X/Y damping time (ms)</td>
<td>1.20E-06</td>
<td>2.70E-06</td>
<td>6.28E-06</td>
<td>2.14E-06</td>
<td>2.07E-06</td>
<td>4.30E-06</td>
<td>1.47E-06</td>
<td>8.39E-06</td>
<td>8.15E-06</td>
<td>3.01E-06</td>
<td>1.50E-06</td>
<td>8.00E-06</td>
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<td>Normalized X emittance (m rad)</td>
<td>1.20E-05</td>
<td>2.70E-05</td>
<td>6.28E-05</td>
<td>2.14E-05</td>
<td>2.07E-05</td>
<td>4.30E-05</td>
<td>1.47E-05</td>
<td>8.39E-05</td>
<td>8.15E-05</td>
<td>3.01E-05</td>
<td>1.50E-05</td>
<td>8.00E-05</td>
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<td>Normalized Y emittance (m rad)</td>
<td>1.20E-07</td>
<td>2.20E-07</td>
<td>1.25E-06</td>
<td>4.63E-07</td>
<td>3.01E-06</td>
<td>2.00E-06</td>
<td>5.00E-07</td>
<td>3.00E-07</td>
<td>3.00E-07</td>
<td>5.00E-07</td>
<td>2.00E-07</td>
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<tr>
<td>X / Y damping time (ms)</td>
<td>17</td>
<td>13</td>
<td>4.9/9.4</td>
<td>14</td>
<td>10</td>
<td>6.8/9.1</td>
<td>8.73</td>
<td>7.17/7.14</td>
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<td>8.3</td>
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<td>Longitudinal damping time (ms)</td>
<td>80</td>
<td>5.7</td>
<td>7</td>
<td>5</td>
<td>5.5</td>
<td>4.35</td>
<td>3.56</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
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<tr>
<td>Number of bunches per train</td>
<td>320</td>
<td>388</td>
<td>150</td>
<td>7</td>
<td>10</td>
<td>396</td>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
<td>0.667</td>
<td>20</td>
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<td>Bunch length (ns)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2.8/5.6</td>
<td>2.84</td>
<td>2</td>
<td>2.8</td>
<td>0.667</td>
<td>2.8</td>
<td>0.667</td>
<td>20</td>
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<td>Single bunch current (mA)</td>
<td>400</td>
<td>320</td>
<td>200</td>
<td>1000</td>
<td>400</td>
<td>600</td>
<td>500</td>
<td>300</td>
<td>300</td>
<td>800</td>
<td>820</td>
<td></td>
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<tr>
<td>Bunches per bunch</td>
<td>5.00E+09</td>
<td>1.60E+10</td>
<td>4.20E+09</td>
<td>2.00E+10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Beam pipe radius (cm)</td>
<td>5</td>
<td>10</td>
<td>9</td>
<td>11</td>
<td>1.2</td>
<td>1.25</td>
<td>1</td>
<td>2.3</td>
<td>1.6</td>
<td>2.3</td>
<td>5</td>
<td></td>
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</tbody>
</table>

**Existing machines**

**Proposed light sources**

**Proposed damping rings**
Instabilities in rings

♦ Coupled-bunch motion
  ◊ Bunch-to-bunch energy spread
    → Broaden undulator harmonics
    → Energy spread in extracted bunch trains
  ◊ Movement of source point
  ◊ Increase in beamsize
  ◊ Beam loss

> Damp resonances
  ⇒ Cavities, BPM’s, septa, kicker magnets, …

> Feedback systems
  ⇒ Control residual motion
Instabilities in rings

♦ Single-bunch effects
  ◊ Increase in beamsize (transverse and longitudinal)
    → Instabilities
      > Impedance driven, two-beam driven
    → IBS
  ◊ Beam loss
  ◊ “Bursting” phenomena particularly difficult
    → SLC - “sawtooth”, NSLS - coherent radiation bursts
      > Severe consequences downstream of damping rings

◊ Requires very careful vacuum chamber design
  > Reduce short-range wakefields
    ⇒ Understand wakefield / impedance model
    ⇒ Understand instability models
Emittance requirements

♦ Light sources
  ◊ High brightness radiation beams
    → $\gamma_{x} \sim 10 \mu \text{mrad}, \gamma_{y} \sim 100 \text{nmrad}$

♦ Damping rings
  ◊ High luminosity collisions
    → $\gamma_{x} \sim 1 \mu \text{mrad}, \gamma_{y} \sim 10 \text{nmrad}$
  ◊ Extracted beam emittance
    → Evolves from the injected beam emittance, and the natural equilibrium emittance

$$\varepsilon_{\text{extracted}} = \varepsilon_{\text{injected}}e^{-2N_{\tau}t} + \varepsilon_{\text{equilibrium}}(1 - e^{-2N_{\tau}t})$$

♦ Small beams
♦ Small vacuum chambers
♦ Strong short-range wake
♦ High cut-off frequency

♦ Positron beam requires pre-damping ring
  → Large emittance from target
Ring Parameters

- Luminosity determined by repetition rate of bunch trains
- Damping time determined by required rep rate, # trains, store time per train
  \[ \tau \frac{\hat{S}}{f_{\text{rep}}} \frac{1}{N_{\text{train}}} \frac{N_{\tau}}{N} \]
  - Three orders magnitude reduction in vertical emittance
- Need \( E > 2.8 \) GeV with iron magnets
  - Expensive
  - Increase damping rate using wiggler
  \[ \tau = \frac{2.88 \times 10^{12} T_{\text{orbit}}}{B_0 \gamma^2} \]
- Long, narrow gap insertion device
  - Limiting aperture
  - Increases short-range wakefield
Ring Parameters

♦ Energy
  ◇ Adequate damping at minimal cost
  ◇ Preserve spin polarization
    → Spin-tune is half-integer
  ◇ " 2 GeV

E = \left( n + \frac{1}{2} \right) 440 \text{ MeV}

♦ Bunch trains
  ◇ Continuous injection / extraction
  ◇ Requires very stable and fast injection / extraction kickers
    → Sets machine circumference

♦ Intra-beam scattering
♦ Instability thresholds

♦ Transients excite all bunch trains in machine
♦ Phase transient along bunch train
Ring Parameters

♦ Small momentum compaction
  ◇ Sensitivity to orbit changes
    → Increase RF voltage to maintain short bunches
  ◇ Incorporate chicane to control circumference ± few mm
    → Wiggler on / off
    → Other effects
  ♦ Decreases instability thresholds

♦ Bunch length
  ◇ Short
    → Maintain peak current below instability thresholds
    → Avoid excessive intra-beam scattering
      > Harmonic cavities
        ⇒ Light sources
        ⇒ CLIC
  ♦ Short bunch - lower instability thresholds
NLC

♦ Consists of:
  ◇ e+ source and polarized e- source to produce high-current bunch trains
  ◇ damping rings for small emittances
  ◇ bunch compressors for short bunches
  ◇ X-band linacs to attain high gradient acceleration for high energy
  ◇ collimation section to remove large amplitude particles
  ◇ final focus for small spots
  ◇ two IPs for alternate experiments
NLC Damping Rings Complex

- Reduce emittance of low-energy $e^+ e^-$
- Stable platform for injection into linacs
  - Similar to 3rd generation light sources

<table>
<thead>
<tr>
<th></th>
<th>Pre-damping ring</th>
<th>Main damping rings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>1.9 – 2.1</td>
<td>1.9 – 2.1</td>
</tr>
<tr>
<td>Circumference (cm)</td>
<td>214</td>
<td>297</td>
</tr>
<tr>
<td>Bunch spacing (mm)</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Fill pattern</td>
<td>2 trains / 95 bunches</td>
<td>2 trains / 95 bunches</td>
</tr>
<tr>
<td>Damping time (ms)</td>
<td>&lt; 5.21</td>
<td>&lt; 5.21</td>
</tr>
<tr>
<td>$N_{max}$/bunch</td>
<td>$1.9 \times 10^{10}$</td>
<td>$1.6 \times 10^{10}$</td>
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<tr>
<td>Current (mA)</td>
<td>800</td>
<td>750</td>
</tr>
<tr>
<td>Injected emittance X/Y (m-rad)</td>
<td>&lt; $9 \times 10^{-2}$</td>
<td>&lt; $150 \times 10^{-6}$ (rms)</td>
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<tr>
<td>Extracted emittance X/Y (m-rad)</td>
<td>&lt; $1 \times 10^{-4}$</td>
<td>&lt; $3 \times 10^{-6} / 0.03 \times 10^{-6}$</td>
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<tr>
<td>RF Voltage (MV)</td>
<td>2</td>
<td>1.5</td>
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<tr>
<td>Momentum compaction</td>
<td>0.0051</td>
<td>0.0066</td>
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<tr>
<td>Energy spread (%)</td>
<td>0.09</td>
<td>0.09</td>
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<tr>
<td>Bunch length (mm)</td>
<td>8.4</td>
<td>3.8</td>
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<td>Wiggler field (T)</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Synchrotron radiation power per section (kW)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Vacuum pressure (Torr)</td>
<td>$1 \times 10^{-9}$</td>
<td>$1 \times 10^{-9}$</td>
</tr>
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<td>Maximum repetition rate (Hz)</td>
<td>120</td>
<td>120</td>
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</table>
Damping Rings RF Systems

- Main damping rings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Energy</td>
<td>1.98 GeV</td>
</tr>
<tr>
<td>Circumference</td>
<td>297 m</td>
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<tr>
<td>RF Frequency</td>
<td>714 MHz</td>
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<tr>
<td>Harmonic Number</td>
<td>708</td>
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<tr>
<td>Bunch Spacing</td>
<td>2.8 ns</td>
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<td>Beam Current</td>
<td>0.75 A</td>
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<tr>
<td>$\sigma_z$</td>
<td>0.09 %</td>
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<tr>
<td>$\alpha$</td>
<td>4 mm</td>
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<tr>
<td>$\alpha'$</td>
<td>0.00066</td>
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<tr>
<td>$U_{str.}$</td>
<td>750 k eV/turn</td>
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<tr>
<td>$U_{HOM's}$</td>
<td>5.6 k eV/turn</td>
</tr>
<tr>
<td>$U_{parasitic}$</td>
<td>36 k eV/turn</td>
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<tr>
<td>$\nu_{RF}$</td>
<td>1.5 MV</td>
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<tr>
<td>Number of Cavitys</td>
<td>3</td>
</tr>
<tr>
<td>Number of Klystrons</td>
<td>1</td>
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<tr>
<td>Cavity Wall Dissipation</td>
<td>42 kW cavity</td>
</tr>
<tr>
<td>Klystron Power</td>
<td>1 MW</td>
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<tr>
<td>Shunt Impedance</td>
<td>3.0 M\Omega cavity</td>
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<td>$U_{do a d e f i l}$</td>
<td>25500</td>
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<tr>
<td>Coupling Factor</td>
<td>5.8</td>
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<tr>
<td>$\phi_{synchro} $</td>
<td>32°</td>
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<tr>
<td>Optimum Detuning at Full Current</td>
<td>106 k Hz</td>
</tr>
<tr>
<td>Synchrotron Frequency</td>
<td>6.9 k Hz</td>
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<td>Loaded Q</td>
<td>3777</td>
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<tr>
<td>Energy acceptance</td>
<td>± 1.8%</td>
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</table>
HOM Damping

♦ Longitudinal modes

Cavity with 30° spherical mid section (714m):
30° nosecone, 3 dumbell wgs @ 30°, offset pep-type coupler
(714 MHz, 100m wake, 3 cm sigma)

\[ \Delta \omega = j \frac{f_{rf}}{E_e} \alpha p \frac{f_0}{f_s} Z_{\text{eff}} \text{long.} \]

→ Damp higher-order modes

> Transverse feedback system required

⇒ HOM’s, two-beam instabilities, and resistive wall

♦ Transverse modes

Cavity with spherical mid section (714m):
3 dumbell waveguides at 30°,
dipole modes, offset pep-type coupler
(714 MHz, 100m wake, 3 cm sigma, x=3cm)

\[ \Delta \omega = - j \frac{f_0}{2E_e} \beta_{x,y} Z_{\text{eff}} \text{trans.} \]
Gap Transient Effects

♦ Bunch-to-bunch synchronous phase variation
  ◇ Leads to energy variation after bunch compression
  ◇ 4° / 30 ps

♦ Compensation techniques
  ◇ Adaptive-inverse feedforward with broadband klystron (?f " 10 MHz)
  ◇ Harmonic cavities
  ◇ Ring off-frequency (•f " 40 kHz)
  ◇ High-stored-energy cavities

\[ \Delta \phi = \frac{2k_I_o T_{gap}}{V_{cavity} \sin \phi_{synch}} \]
NLC Impedance Model

♦ Longitudinal wake
  ◊ Major vacuum chamber components
    → RF cavities
    → Resistive wall
    > Small vacuum chamber
    → BPM’s
    > High-frequency resonances
    → Ante-chamber slots
    → Bellows shields
    → Injection and extraction magnets

♦ Similar impedance model for transverse wake
  ⇒ Cho Ng talk
ZDR - Longitudinal single-bunch

- Potential well distortion
- Microwave instabilities
  - $Z/n \approx 0.025$
  - Strong threshold estimate
    \[ I_p = \frac{2\pi |\eta| \left( \frac{E}{c} \right) (\beta \sigma_p)^2}{\left| \frac{Z}{n} \right|_{\text{eff}}} \]
    → Threshold $\approx 2 \times$ operating current
  - Simulations
    → Threshold $\approx 4 \times$ operating current

\[ \lambda z (\text{mm}^{-1}) \]

\[ V_{\text{ind}} (\text{kV}) \]

\[ N \left( 10^{10} \right) \]
ZDR - Transverse single-bunch

- Transverse mode coupling instability (TMCI)
  - Simulations

\[ I_b = \frac{4 \left( \frac{E}{e} \right) \nu_s}{\langle \text{Im}(Z_\perp) \beta_\perp \rangle R} \frac{4\sqrt{\pi}}{3} \sigma_1 \]

→Threshold " 10 x operating current
ZDR - Fast ion instability

- Interaction between intense electron beam and ions gives rise to fast transverse instability
- Growth time <" 1 ms
- Experimental evidence from ALS and PLS

- Maintain average pressure < 1 nTorr
- Bunch-by-bunch feedback system
- Additional gaps in bunch trains
ZDR - Electron cloud instability

- Intense positron beam produces cloud of photoelectrons and secondary electrons
- Experimental evidence at BEPC
- Desorbs gas from surfaces
- Interaction between positron beam and electron cloud gives rise to fast transverse instability

- Low secondary emission coatings
- Bunch-by-bunch feedback system
- Solenoidal magnetic fields
ZDR - Lifetime and IBS

- Gas-scattering lifetime several hours
- Touschek lifetime few minutes
  - Increase bunch volume for commissioning studies
- Intra beam scattering (IBS)
  - Significant at lower energies
  - Higher energy preferable
    - Reduced growth from IBS
    - Reduced damping time
Conclusions

♦ Damping rings and synchrotron light sources face similar problems with collective effects
  ◇ Intense beams
  ◇ Small vacuum chambers

→ How good is the impedance model?
→ How good are the impedance calculations and measurements?
→ How good are the instability models and analyses?

⇒ Subjects of this workshop