SPring-8 upgrade plan

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on behalf of
SPring-8 upgrade working group

1. Overview of SPring-8 upgrade plan
2. Ultra-low emittance ring design study
### SPring-8 current parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energy</td>
<td>8 GeV</td>
</tr>
<tr>
<td>Energy spread</td>
<td>0.0011</td>
</tr>
<tr>
<td>Current</td>
<td>100 mA</td>
</tr>
<tr>
<td>Bunch purity</td>
<td>$5 \times 10^{-10}$</td>
</tr>
<tr>
<td>Natural emittance</td>
<td>3.4 nm.rad</td>
</tr>
<tr>
<td>Lattice</td>
<td>Modified double bend</td>
</tr>
</tbody>
</table>

**Graph**

- Long Undulator: $\lambda_u=3.2$ cm, $N=780$
- Standard Undulator: $\lambda_u=3.2$ cm, $N=140$
- Brilliance (photons/s/mm²/mrad²/0.1% BW/100mA)
- Photon Energy [eV]
SPring-8 upgrade working group

- Working group organized in October 2008
- Consists of 50 staffs. 15 from accelerator division
- First symposium for science and accelerator design in June 2009
- First workshop for accelerator design in Dec. 2009
- First talk in Europe (@CERN) in January 2010
- First talk in US today
**Mission**

To renew the existing storage ring in 2019 for substantially improving brilliance and other aspects

**Background**

Performances of third generation light sources are almost saturated.

"**Boundary conditions**"

Inside the existing tunnel, no new building
Dark period ~ 1 year
Do not want to move ID beam lines
X-ray up to 100 keV (as it is now)
Keep stability and filling pattern flexibility (as it is now)
We have discussed varieties of accelerator designs from conservative to ambitious ones;

- Just add damping wigglers + control damping partition?
- Completely new ring in a new building?
- ERL?
- 3 GeV, 6 GeV, 8 GeV, or more?

etc...

Now we basically focus on one design: today's talk
What SPring-8 wants to do (as per now)

1) Ultra-small emittance storage ring, not ERL
   Injection of high quality beam from XFEL C-band linac
   Stability, flexibility of filling patterns, dark period
   Feasibility
2) Electron energy of 6 GeV or less
   Emittance, energy spread, heat load, power consumption
3) As small emittance as reasonably achievable
4) Short bunch options for new sciences
   e.g., pump-and-probe experiments with XFEL
Two ultimate goals

[Phase I] Diffraction limited ring
   Diffraction limited in both vertical and horizontal axes
   Target: 10 keV $\rightarrow \epsilon = 10$ pm.rad

[Phase II] Short bunch options (6D low emittance)
   Short bunch stored in a ring
   Target: 1 ps or less

Background
No significant upgrade, no funding
It would be great if the light source community could define the fourth generation light source based on a ring.
1. Overview of SPring-8 upgrade plan

2. SPring-8 ultra-low emittance ring design
First approach toward diffraction limited ring

Quadruple bends (QB)

\[(\nu_x, \nu_y) = (85.15, 30.35)\]
\[(\xi_{x0}, \xi_{y0}) = (-206, -108)\]

natural emittance = 0.165 [nmrad]

effective emittance = 0.193 [nmrad]

\[\beta_x = 12.3 \text{ [m]}\]
\[\beta_y = 2.7 \text{ [m]}\]
\[D = 0.03 \text{ [m]} \text{ @ straights}\]

* A long straight section (LSS) is temporally connected with a FODO cell.
RING = 4 * (11 * UNIT-CELL + LSS)

4-bend lattice (QB)
Manipulation of nonlinearity

1. Optimization of sextupole strengths (resonance suppression) for on- and off-momentum particles

2. Modified (Gaussian) sextupole magnets

3. Octupole magnets for suppressing amplitude dependent tune shift

4. Non-interleaved/interleaved sextupoles

The lattice design works have mainly been done by Soutome, Shimosaki, Schimizu, and Takao.
1. Optimization of sextupole strengths

Optimization of sextupoles (resonance suppression) for on- and off-momentum particles

Y. Shimosaki,
2nd Workshop on Nonlinear Beam Dynamics in Storage Rings (2009)

Dynamic aperture (DA)

QB (ring) $\delta = 0\%$

(10um RMS Error for SX assumed)
Momentum Acceptance

QB (ring) $\delta = +1\%$

QB (ring) $\delta = +2\%$

QB (ring) $\delta = +3\%$

QB (ring) $\delta = -1\%$

QB (ring) $\delta = -2\%$

QB (ring) $\delta = -3\%$
2. Modified (Gaussian) sextupole

Sextupole field is damped at large betatron oscillation.

Tune shift vs betatron amplitude

Dynamic aperture

2. Modified (Gaussian) sextupoles

Modified field with 'damping coefficient' $K$

$$B_y = S \exp[K(x^2 - y^2)] \times [(x^2 - y^2)\cos(2Kxy) - 2xy\sin(2Kxy)]$$

There seems to be some effects on DA.

*Note: The simplest way of using the same Gaussian factor to all SXs did not work.*

How can we optimize the modified field distribution?
3. Octupole magnets

Amplitude-dependent tune shifts and resonances by octupoles are controlled with 8 family octupoles.
4. Non-interleaved or interleaved sextupole


Non-interleaved

Interleaved

Nonlinear kick by the first SX is compensated by the second.

Now we are working on it especially for our new lattice.

Manipulation of nonlinearity

1. Optimization of sextupole strengths (resonance suppression) for on- and off-momentum particles

2. Modified (Gaussian) sextupole magnets

3. Octupole magnets for suppressing amplitude dependent tune shift

4. Non-interleaved/interleaved sextupoles
We halt the calculation with QB here and try a new lattice with more bends.

<table>
<thead>
<tr>
<th>N</th>
<th>4 (QB)</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>ε_{mod} [nm]</td>
<td>0.165*1</td>
<td>0.084</td>
<td>0.049</td>
<td>0.031</td>
<td>0.021</td>
<td>0.014</td>
</tr>
<tr>
<td>ε_{achr} [nm]</td>
<td>~0.300*2</td>
<td>~0.154</td>
<td>~0.089</td>
<td>~0.056</td>
<td>~0.038</td>
<td>~0.026</td>
</tr>
</tbody>
</table>

*1 Natural emittance with a modified QB
*2 ROUGH estimation for achromats

w/o IBS (see next page)

2. Damping wiggler(s) $\times 1/2$

3. Damping partition control $\times 1/2$

Total: $150 \text{ [pm.rad]} \times \frac{1}{2} \times \frac{1}{2} \approx 40 \text{ [pm.rad]}$

$20 \text{ pm x 20 pm with full coupling}$

Touchek lifetime gets higher(?)
Intrabeam scattering (IBS) Effect

QB lattice: $\varepsilon_y = 10$ pm.rad, $V_{rf}/U_0 = 2.4$ (7MV@6GeV)

Not negligible at low energies

K. Soutome

New lattice design with 6 bends has just begun...
New lattice design with 6 bends

Matching Section Design Issues:
- dispersion suppression
- configuration of Q, SX and OCT
- optimization of beta functions
- length of straights

Need matching

K. Soutome
Preliminary study: 6-bend cell structure

Unit Structure by "D.Einfeld and M.Plesko, NIMA335(1993)402" (modified for SPring-8 case)

Unit Length: 3.78m

K. Soutome
Interleaved sextupoles in 6 bend lattice

\[ \Delta \nu_x = 0.453 \ldots close \text{ to } 0.5(\pi), \Delta \nu_y = 0.096 \]

Sextupoles Configuration (tentative)

K. Soutome
Interleaved sextupoles in 6 bend lattice

Simulation result on 6 bend lattice will be presented at IPAC2010 by Soutome et al.

\[ \Delta \nu_x = 0.453 \ldots \text{close to } 0.5(\pi), \Delta \nu_y = 0.096 \]

K. Soutome
Short bunch options: couples of candidates

- Injection of femtosecond e-beams from C-band linac to SR
  Pro: Possibility of bunch compression via CSR
  Challenges: CSR effect, Wakefield, IBS,

- Longitudinal strong focusing in a storage ring
  Pro: Longitudinally varying bunch length along a ring
  Challenges: Technologies for focusing devices,
  CSR effect, difficulty in making long bunches

[Diagram of XFEL linac, Booster, Storage ring, Linac]
Closing remarks

An ensemble of XFEL and new SPring-8 would be a great opportunity to execute new sciences. We find it important to see how far we can reach with a storage ring.

Two ultimate goals

(Phase I) Diffraction limit
(Phase II) Short bunch

Obviously manipulation of nonlinearity is inevitable.
We are working on it.

Further breakthrough may be needed such as a round beam scheme, and/or a new injection scheme that helps reduce required DA.

Hopefully the new lattice design will be finished by Fall 2010.
Round beam scheme may yield diffraction limit locally

Transformation between canonical and physical momentum in solenoid is

\[ P_x = p_x + eA_x = p_x - (eB_z/2)y \]
\[ P_y = p_y + eA_y = p_y + (eB_z/2)x \]

This is essential for manipulating emittance defined by \((x, p_x, y, p_y)\).

...K. Oide

Example Design of Matching Section
(for DB Lattice) by H. Tanaka

**Figure 1:** General scheme of the insertion.

\[ \beta = \frac{2[B \rho]}{B_z} \]
\[ \sigma_x = \sigma_y = \sqrt{\frac{\beta \varepsilon_x}{2}} \]
\[ \sigma_{x'} = \sigma_{y'} = \sqrt{\frac{2 \varepsilon_y}{\beta}} \]
\[ \sigma_x \sigma_{x'} = \sigma_y \sigma_{y'} = \sqrt{\varepsilon_x \varepsilon_y} \]

**e.g.** \[ B_z = 1.5T, E = 6GeV, \varepsilon_x = 0.2 nmrad, \varepsilon_y = \varepsilon_x \times 0.003 \Rightarrow \sqrt{\varepsilon_x \varepsilon_y} = 11 pmrad \]
Other issues

- RF frequency, superconducting, harmonics,

- Injection schemes
  pulsed multipole magnets
  synchrotron injection

- Round beam scheme via solenoids
Short bunch options

- Short bunch injection from XFEL C-band linac

- Longitudinal strong focusing

Longitudinal betatron function

\[ \beta_L(s) = \frac{1}{\sin \mu_c} \left[ R_{56}(L) - U \cdot R_{56}(s_1) R_{56}(s_2) \right] \]

\[ = \frac{1}{\sin \mu_c} \left[ \alpha_c \cdot L - U \cdot R_{56}(s_1) R_{56}(s_2) \right] \]

Strong focusing

\[ U = \frac{e}{E_0} \frac{dV}{dz} \approx \frac{eV_{rf}}{E} \frac{2\pi}{\lambda_{rf}} \]: acceleration gradient

### Theoretically minimum emittance for 6 bends

<table>
<thead>
<tr>
<th>$E$ [GeV]</th>
<th>$\sigma_\delta$ [%]</th>
<th>$\varepsilon$ [pmrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0.121</td>
<td>72</td>
</tr>
<tr>
<td>7</td>
<td>0.106</td>
<td>55</td>
</tr>
<tr>
<td>6</td>
<td>0.091</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>0.076</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>0.061</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>0.046</td>
<td>10</td>
</tr>
</tbody>
</table>

$J_x = 1.27$, $J_y = 1.00$, $J_s = 1.73$

**Note:** Emittances in this table represent the minimum values that can be achieved with the porposed 6B cell. These will be increased when achromat condition is imposed on the straights.