BASELINE LATTICE
FOR THE UPGRADE OF SOLEIL

Future Light Source
March 5-9 2018
Shanghai Institute of Applied Physics

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On behalf of the
Accelerators and Engineering Division
Upgrade Lattice Outline

- 2016 proposition 200 – 250 pm.rad
- 2017 baseline 72 pm.rad
- Injection investigation
- Tunnel investigation
- Timeline
SOLEIL Today

2008 : Open to users
2009 : Top-up operation
2018 : 29 beamlines
   (2 under commissioning)

Top-up injection in all modes
Upgrade Lattice Evolution

Actual:

- C = 354 m
- 16 cells of 2 kinds
- 12 m
- 7 m
- 3.8 m
- 4 nm.rad
- 45% of straights

Upgrade 2016:

- 8 m
- 5 m
- 3 m
- 200 -250 pm.rad
- 32% of straights

1/8 of the ring here
2.75 GeV

L. Farvacque et al., A Low-Emittance Lattice for the ESRF, Proceedings of IPAC (2013)
Upgrade Lattice Evolution

To push further the emittance reduction and to maximize the photon flux in the soft X-rays photon energy up to 3 keV:

We increased the number of cells from 16 to 20 without short straight sections giving 20 straights of length of 4.4 m (25% of the circumference). The natural emittance is then reduced down to 72 pm.rad (or 50 pm.rad at full coupling)

The optics also includes low beta function (~ 1 m) at straight center for electron-photon matching

Magnets are stronger:

– Sext < 2000 T/m2
– Quad < 100 T/m
– Dip ~ 0.6 T & 40 T/m

Without Long. Grad. in Bend

Nat. Chro. = -6.7 / -6.3 per cell
= -135 / -125 total
Upgrade lattice baseline

20 cells 72 pm.rad

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference C (m)</td>
<td>354.2</td>
</tr>
<tr>
<td>Energy E (GeV)</td>
<td>2.75</td>
</tr>
<tr>
<td>Working point $\nu_x, \nu_z$</td>
<td>54.3, 18.3</td>
</tr>
<tr>
<td>Nat. Chrom. $\xi_x, \xi_z$</td>
<td>-134, -125</td>
</tr>
<tr>
<td>Mom. Comp. Fact. $\alpha_1$</td>
<td>$1.5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Nat. Emittance $\epsilon_{x0}$ (pm.rad)</td>
<td>72</td>
</tr>
<tr>
<td>Energy spread $\sigma_E / E$</td>
<td>$8.6 \times 10^{-4}$</td>
</tr>
<tr>
<td>Energy loss / turn $U_0$ (keV)</td>
<td>310</td>
</tr>
<tr>
<td>Damp. times $T_{x,z,s}$ (ms)</td>
<td>10, 21, 24</td>
</tr>
</tbody>
</table>

Small extra quadrupole for tuning to be added

Combined dipole & quadrupole with independent variation of few %
Taking at straight center
4 sextupoles and 2 octupoles families are used here

On momentum DA is reduced by ~2 with the RF

4D Tune footprints are kept ±0.1 over 1 turn

Fast drop of the amplitude with energy
Larger tune shift with amplitude when off momentum
Beam pipe diameter of 16 mm
RF Voltage of 1.1 MV
Natural bunch length of 3.7 mm RMS

With 72 in H and 10 in V pm.rad the beam lifetime is about 1.5 h at 500 mA (1.4 nC per bunch)

Up to 3 h at full coupling (50 x 50 pm.rad)
Preliminary IBS effect computed with Elegant code:
Simple Gaussian distribution model

Emittance increase by 30% with natural RMS bunch length (3.7 mm / 0 mA)
Limited to 10% with RF harmonic bunch lengthening (x 5)
Insertion of 3T super-bend in the central magnet of the cell

To increase the photon flux above 10 keV

4 are foreseen, one each 5 cells

Emittance impact is not negligible
The present H-function is not well suited
3 T super-bend

\[ \varepsilon_x = 80 \text{ pm} \cdot \text{rad} \]
\[ \delta_E = 1.15 \times 10^{-3} \]

Reverse-bend

Shifted quadrupoles by \( \approx 1.3 \) mm to reduce the H-function and limit the emittance increase (here from 72 to 80 pm.rad)

A. Streun, The anti-bend cell for ultralow emittance storage ring lattices NIMA, 737 (2014)
Add 1.8 T on central bend of other cells to reduce back the emittance ~ 70 pm.rad

Possibility to reduce the emittance down to ~60 pm.rad by pushing further the reverse bend but at the cost of a larger energy spread and a lower momentum compaction ...
Electron-Photon Matching

Diffraction limited photon beam emittance is 65 pm.rad at an energy of 3 keV

\[ \beta_{\text{matched}} = \frac{L}{\pi} \approx 1.27 \text{ m} \] for a undulator of 4 m

With 50 pm.rad and \( \beta = 1 \text{ m} \) the beam size is 7 µm and 7 µrad RMS in divergence in both planes at source.
The brilliance increase reach two orders of magnitude in the region of interest:

Between 1 to 3 keV, exceeding a value of $10^{22}$ photons/s/mm$^2$/mrad$^2$/0.1%bw

It can exceed $10^{20}$ photons/s/mm$^2$/mrad$^2$/0.1%bw at 40 keV,
Transverse Coherence Fraction Comparison

The photon beam should be fully coherent up to almost 200 eV, exceeding 40 % at 1 KeV And reaching 14 % at 3 KeV
Undulator Spectral Purity Comparison

![Graph showing flux density vs. photon energy for different undulator source types.]
Try Vertical Injection With Non Linear Kicker (NLK)

Off axes to accumulate

Keep the lattice symmetry

Take advantage of the large vertical beta function

Take advantage of the natural small vertical emittance of the booster

But : vertical betatron oscillation versus low gap ID …

Take advantage of the phase to use two small NLK
Try Vertical Injection With Non Linear Kicker

Tracking with emittance (9 rms):

- With present 130 nm.rad from the booster
  First cell large orbit and strong sextupoles enlarge the particle vertical excursions and reach the 5 mm ID gap

- With only 30 nm.rad, vertical excursions are reduced

We envisage to upgrade the booster too:

=> Doubling the number of cells gives 30 nm.rad
=> Reuse ring quad and sext?

The booster emittance of 130 nm.rad became rather large as compared to low emittance acceptance lattices...
Longitudinal Injection on Chromatic Orbit With a NLK and an Extra RF Pulse

Beam injected on a chromatic orbit by mean of an NLK located in the dispersion bump at an energy offset of +6%.

200 turns

NLK accommodation still under investigation ...

### Table

<table>
<thead>
<tr>
<th></th>
<th>Main RF (MV)</th>
<th>Harm. 3 (MV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>+ injection</td>
<td>+1.4</td>
<td>+0.47</td>
</tr>
</tbody>
</table>

Tracking with a booster emittance of 30 nm.rad gives 100% efficiency on a perfect baseline lattice.

**Derived from:**
Fitting the Tunnel and Beamline Positions

The 20 cell symmetry gives a "round" geometry that doesn't perfectly fit the present tunnel with long and short straight sections. Modulating the deviation per cells (initially 18°):

- 17°
- 17°
- 18.4°
- 19.2°
- 18.4°
- 17°

Keeping sextupole and octupole strengths, the beam dynamics is ~unchanged. Emittance increase is marginal.

But enlarge the number of dipole magnet types (± 7 % in dipolar field)

Nevertheless, 8 ratchet walls will have to be also slightly changed to have:

- The 20 straight line sources (17 identified for experiments)
- The 4 3T bend sources available

\[
\begin{align*}
\beta_x &= 1.0 \, \text{m} \\
\beta_z &= 1.0 \, \text{m}
\end{align*}
\]
Quadrupole Strength Errors

Simple error quad strength by 1‰ rms, 500 trials

Large beta beat of few percents

DA drops from 1.5 to ~1.2 mm
Lower Emittance With On Axes Injection

As a possible candidate ...

9 BA variation giving a natural emittance of 32 pm.rad
Also 20 cells for one turn

On momentum DA is limited but has a rather large off momentum DA
Intensive MOGA optimization
On axis injection / off momentum
Temporal Structure and Short Bunches

Temporal structure

- As today: Hybrid/Camshaft mode, 1 bunch, 8 bunches
- Possibility of Pseudo Single Bunch


Short pulse option

Use of two harmonic cavities of different frequencies «à la BESSY VSR» to shape the longitudinal phase space producing short and long bunches

<table>
<thead>
<tr>
<th>SOLEIL</th>
<th>$f_{RF}$ (GHz)</th>
<th>$V_{RF}$ (MV)</th>
<th>$V'_{RF}$ (MV, GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal RF SC cavity</td>
<td>0.352</td>
<td>1</td>
<td>$2\pi 0.35$</td>
</tr>
<tr>
<td>First harmonic SC cavity</td>
<td>1.760</td>
<td>10</td>
<td>$2\pi 17.6$</td>
</tr>
<tr>
<td>£th harmonic SC cavity</td>
<td>1.936</td>
<td>9.1</td>
<td>$2\pi 17.6$</td>
</tr>
<tr>
<td>Even fixed points</td>
<td></td>
<td></td>
<td>$2\pi 35$</td>
</tr>
<tr>
<td>Gain</td>
<td></td>
<td></td>
<td>$35/0.35 = 100$</td>
</tr>
<tr>
<td>Theoretical bunch length reduction</td>
<td></td>
<td></td>
<td>$\sqrt{100} = 10$</td>
</tr>
</tbody>
</table>


Jankowiak et al., The Bessy VSR Project For Short X-Ray Pulse Production, Proceeding of IPAC 2016

From 24 to 2.4 ps FWHM (at 0 mA)
## Timeline

<table>
<thead>
<tr>
<th>Date</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 2016</td>
<td>Council meeting, presentation of the first proposal for an upgrade.</td>
</tr>
<tr>
<td>2017 - 2019</td>
<td>Discussions regarding the definition of the project (beamlines and storage ring); definition of objectives. Baseline Lattice defined.</td>
</tr>
<tr>
<td>2018 - 2019</td>
<td>Continuation of discussions and prototyping to assess feasibility of key options.</td>
</tr>
<tr>
<td>2019</td>
<td><strong>Decision to launch a Conceptual Design Report (CDR).</strong></td>
</tr>
<tr>
<td>2019-2020</td>
<td>CDR based on preliminary studies and prototyping.</td>
</tr>
<tr>
<td>2020</td>
<td><strong>Decision to launch a Technical Design Report (TDR).</strong></td>
</tr>
<tr>
<td>2022</td>
<td><strong>Decision to start the project.</strong></td>
</tr>
<tr>
<td>2022-2025</td>
<td>Reconstruction of storage ring and beamlines.</td>
</tr>
<tr>
<td>2026</td>
<td>Restart of user operation.</td>
</tr>
</tbody>
</table>
Conclusion

The present SOLEIL upgrade lattice baseline achieve a low natural emittance of 72 pm.rad or 50 x 50 pm.rad at full coupling.

Including a third harmonic cavity should guarantee a correct beam lifetime as well as a limited emittance increase from IBS.

Low beta function at straight level for a good electron-photon matching up enabling a very high brilliance in the 1 to 3 keV region (SOLEIL scientific case target).

Injection is still under investigation while keeping the high lattice symmetry enabling a more comfortable beam dynamics acceptance.

Additional changes (under investigation) :
- Beamlines redistribution
- Injector upgrade with much lower emittance from the booster (130 down to ~30 nm.rad)
- Super-Conducting to warm main RF system (no space anymore and lower voltage needed)
- 8 ratchet walls to be slightly modified

Ongoing task :
- Extensive errors analysis
- Magnet design and pulsed elements feasibility just started
Thank you for your attention
For a undulator of 4 m, the matched beta function is:

\[ \beta \approx \frac{L_{\text{und}}}{\pi} = 1.27 \text{ m} \]
Increase the number of FODO-cell by 2 by splitting the long dipole

**Actual optics**

Natural emittance: 140 nm.rad
110 nm.rad at minimum

**Possible upgrade:**

Splitting the long 32 dipoles with 32 additional quadrupoles

Natural emittance is 30 nm.rad

Keep RF and injection/extraction section as there are.