SOLEIL UPGRADE IDEAS

Amor Nadji

On behalf of Synchrotron SOLEIL team
PLAN

• Key features of the current lattice
• Beamlines (distribution, photon spectrum and brilliance)
• Modes of operation and performances
• Current short term projects
• First thoughts about a major upgrade
  – Strategy
  – Constraints and challenges
  – First ideas
• Summary
### SOLEIL: 3rd Generation Synchrotron Light Source

#### Storage Ring Main Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>2.75</td>
</tr>
<tr>
<td>Circumference (m)/RF frequency (MHz)</td>
<td>354.097 / 352.202</td>
</tr>
<tr>
<td>Betatron Tunes</td>
<td>18.1580 / 10.2280</td>
</tr>
<tr>
<td>Momentum Compaction $\alpha_1 / \alpha_2$</td>
<td>$4.5 \times 10^{-4} / 4.6 \times 10^{-3}$</td>
</tr>
<tr>
<td>Emittance H (nm.rad)</td>
<td>3.9</td>
</tr>
<tr>
<td>Energy spread</td>
<td>$1.016 \times 10^{-3}$</td>
</tr>
<tr>
<td>Coupling, $\varepsilon_V/\varepsilon_H$</td>
<td>1%</td>
</tr>
<tr>
<td>Current Multibunch mode (mA)</td>
<td>500</td>
</tr>
<tr>
<td>Average Pressure (mbar)</td>
<td>$5 \times 10^{-10}$</td>
</tr>
<tr>
<td>Beam Lifetime (h)</td>
<td>12 h</td>
</tr>
</tbody>
</table>

- **Commissioning of the Storage Ring:** June-December 2006
- **First external users:** January 2008.
Circumference: 354 m

4 superperiods

24 straight sections
(21 dedicated to IDs)

4 x 12 m
12 x 7 m
8 x 3.6 m

45% of the circumference available for straight sections

Different $\beta$ functions in straight sections

SDL: Long straight section
SDM: Medium straight section
SDC: Short straight section
SOLEIL lattice since January 2012

Upgrade of one long straight section (SDL)

- 2 canted in-vacuum undulators of 5.5 mm minimum gap
- 2 long beamlines (~180 m).
• 29 beamlines

• 3 beamlines are under commissioning

• Will be open to users on January 2017
5 modes of operation, all in Top-up mode.

<table>
<thead>
<tr>
<th>Mode of operation</th>
<th>Bunch filling patterns</th>
<th>User Operation in 2016</th>
<th>Ultimate performance achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multibunch</td>
<td>Tests RP 2,3%</td>
<td>500 mA</td>
<td>500 mA</td>
</tr>
<tr>
<td></td>
<td>Top-Up Low Alpha 4,8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Top-Up 1 paoquet 5,6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Top-Up 8 paoquets 5,5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid/camshaft mode</td>
<td>Top-Up Hybride + Contrôle RP 50,6%</td>
<td>425 mA + 5 mA</td>
<td>425 mA + 10 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ Slicing on high intensity bunch</td>
<td>Slice length &lt; 200 fs FWHM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 bunches 100 mA</td>
<td>110 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 bunch 16 mA</td>
<td>20 mA</td>
</tr>
<tr>
<td>Low-α: Hybrid mode</td>
<td></td>
<td>4.7 ps RMS for 65 µA</td>
<td>&lt; 3.2 ps RMS for 15 µA</td>
</tr>
</tbody>
</table>
Current short term projects

- Better matching in straight sections hosting high photon energy undulators ($\beta_z \sim 1$m).

- Booster RF upgrade (shorter bunch length).

- Design and construction of a Multipole Injection Kicker (collaboration with MAX IV).

- Local round and ultra low emittance electron beam (collaboration with MAX IV).

- Theoretical and experimental instabilities studies at MAX IV (collaboration with MAX IV).

- Test with users at lower coupling ($\sim 0.2 \%$, $\varepsilon_z \sim 8$ pm.rad).
New optics with lower vertical beta in medium and short straight sections

**Actual**

\[ \beta_z \]

SDC 2.7 m  
SDM 2.3 m  
SDL13 2.3 m  

\[ \beta_x \]

SDL13 8 m  
High divergence

**New**

\[ \beta_z \]

SDC 1.0 m  
SDM 1.3 m  
SDL13 1.3 m  

\[ \beta_x \]

SDL13 12 m  
low divergence  
in horizontal  
asked by users
Local round and low emittance beam

A. Chao and P. Raimondi (SLAC-PUB-14808)

\[ \left( \mathcal{E}_x \right)_{\text{apparent}} \sim \sqrt{\left( \mathcal{E}_x \cdot \mathcal{E}_z \right)_{\text{ring}}} \]

Long straight section SDL09 (12 m)

• Skew quadrupole length : \( L = 0.14 / 0.39 / 0.20 \) m
• Skew quadrupoles gradient < 40 T/m
• 1 quadrupole of the ring reach gradient > 20 T/m

Optics with 4.2 m available for the solenoid

RMS Beam Size and Divergence at source point (Coupling = 0.01)

<table>
<thead>
<tr>
<th></th>
<th>WITH Solenoid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 T ; 60 T</td>
</tr>
<tr>
<td>Horizontal emittance (pm.rad)</td>
<td>400</td>
</tr>
<tr>
<td>Vertical emittance (pm.rad)</td>
<td>400</td>
</tr>
<tr>
<td>H-size (µm)</td>
<td>60.3 ; 24.6</td>
</tr>
<tr>
<td>H-divergence (µrad)</td>
<td>6.6 ; 16.2</td>
</tr>
<tr>
<td>V-size (µm)</td>
<td>60.3 ; 24.6</td>
</tr>
<tr>
<td>V-divergence (µrad)</td>
<td>6.6 ; 16.2</td>
</tr>
</tbody>
</table>
Local round and low emittance beam: Application to the bio-crystallography beamline PX2 (SOLEIL)

Sideview scheme

U20
9th harm. @ 12.7 keV

Diaphragm
1.6 x 1.6 mm²

Prim. Slits
open

Channelcut
Si111 @ 12.7 keV

KB mirrors
Slopes = 0.5 μrad RMS
Rough. = 2 Å RMS

Image plane

Source

Diaphragm: SRW, Wave Propagation*

Sample: SPOTX**

\[ \Sigma_{x,z} = 204.92 \times 14.23 \, \mu m^2 \] (H x V)
Flux = \( 2.14 \times 10^{14} \) ph/s/0.1% BW

\[ \Sigma_{x,z} = 25.60 \times 26.40 \, \mu m^2 \] (H x V)
Flux = \( 1.84 \times 10^{14} \) ph/s/0.1% BW

\[ \Sigma_{x,z} = 1.45 \times 0.68 \, mm^2 \] (H x V)
Flux = \( 1.43 \times 10^{14} \) ph/s/0.1% BW

\[ \Sigma_{x,z} = 0.67 \times 0.81 \, mm^2 \] (H x V)
Flux = \( 1.56 \times 10^{14} \) ph/s/0.1% BW

\[ \Sigma_{x,z} = 14.8 \times 3.8 \, \mu m^2 \] (H x V)
Flux = \( 1.51 \times 10^{13} \) ph/s

\[ \Sigma_{x,z} = 2.8 \times 4.5 \, \mu m^2 \] (H x V)
Flux = \( 1.67 \times 10^{13} \) ph/s

* José-Miguel Luque-Raigon (post-doc in Accelerator Physics group at SOLEIL)
Local round and low emittance beam:
Application to the bio-crystallography beamline PX2 (SOLEIL)

**Sample : SPOTX**

Flux Density \(\text{ph/s/mm}^2\) = 2.7 \(10^{17}\)

Flux density at the sample is increased by a factor of 5

Flux Density \(\text{ph/s/mm}^2\) = 1.3 \(10^{18}\)

FWHM Sizes = 14.8 \(\times\) 3.8 \(\mu\text{m}^2\) (H \(\times\) V)
Flux = 1.51 \(\cdot\) \(10^{13}\) ph/s

FWHM Sizes = 2.8 \(\times\) 4.5 \(\mu\text{m}^2\) (H \(\times\) V)
Flux = 1.67 \(\cdot\) \(10^{13}\) ph/s

Towards a test with users at lower coupling (~ 0.2% $\varepsilon_z \sim 8$ pm.rad).

- Global feedback by means of a modulated vertical dispersion wave: **Done**
- Local ID (high frequency) coupling feedforward, to cancel ID contribution to the coupling: **in progress**
- Re-alignment of the storage ring: **in progress**
- Local ID focusing feedforward, to cancel ID contribution to the beta beating: to be foreseen in order to make reliably the online measurement of emittance and energy dispersion at pinholes.
- Optimization of Transverse Feedback parameters versus current at minimum coupling.
First thoughts about a major upgrade:

- Strategy
- Constraints and challenges
- First ideas
Development of Scientific case

**Scientific Sections**

| Surfaces-Interfaces-Nanosystems | Atomic and molecular Physics | Biology and Health | Physical Chemistry of soft condensed matter | Physical Chemistry of hard condensed matter |

**Strategy**

- **Presentations**: Representatives of different communities: "Future challenges in your domain".
- **Refined scientific case per subject domain**.
- **Provisional cost and time scale estimates** => **Upgrade Plan version 1 (November 2016 for the SAC and December 2016 for the council)**

- **User community representatives**

- **Started October 2015, first draft available from 1 section**.

- **Starting March 2016**

- **Consultation**

- **Started early 2015**
The Final requirements should derive from future science goals.

Target date: 2025

First directions:

- Higher brilliance and coherence fraction.
- Short « intense » pulses.
Constraints and Challenges

• Constraints
  – Get more than a factor 10 lower H-emittance (< 400 pm.rad).
  – Keep circumference, tunnel & hall.
  – Keep beamlines source points.
  – Serves very broad photon energy range: from IR to 30 keV on undulators and to 80 keV on wigglers.
  – Re-use injector: Linac & booster.
  – Radiation shielding.

• Main challenges:
  – Small circumference (354 m).
  – Presence of short straight sections.
  – Versatile communities.
First Ideas
Use MBA structure to reduce the horizontal emittance

\[(M_1, M_2)\]

- \(M_1\): Number of dipoles in SDL-SDM cell type
- \(M_2\): Number of dipoles in SDM-SDC-SDM cell type.

\[
(E_{x}^{\text{Combined MBA}})_{\text{min}} = \frac{1}{8\sqrt{15}} \frac{C_q \gamma^2}{J_x} \theta_0^3 \left\{ \frac{1}{2 + (M_1 - 2)^{3/3}} + \frac{1}{2 + (M_2 - 2)^{3/3}} \right\}
\]
Lengths of the magnet sections are quite limited in the current SOLEIL configuration:

12.5 m (SDL-SDM) and 5.73 m (for each side of SDM-SDC-SDM)

Preliminary results (presented at IPAC2015) indicate that:
- Horizontal emittance in the 100 ~ 200 pm.rad range appears reachable.
- However, the required focusing strengths and chromaticities “blow up” as expected.
Solution with increased magnet sections, lower dipole fields (0.8 T) and integrating anti-bends in focusing quadrupoles.

⇒ SDL = 9 m instead of 12 m; SDM= 5 m instead of 7 m and SDC= 2.8 m instead of 3.8 m.
Lattice based on 7BA (à la ESRF) and 6BA (à la Diamond)

\[ \varepsilon_x = 250 \text{ pm}.\text{rad} \quad \xi_{x0} = -84 \quad \xi_{z0} = -77 \]
Lattice based on 7BA (à la ESRF) and 6BA (à la Diamond)

- Optics: Transformation phase shift and sextupoles optimisation
- Straight sections: SDL = 8 m, SDM = 5 m and SDC = 2.8 m
- Gmax = 80 T/m and SLmax = 160 T/m (integrated)
- Off momentum aperture not good yet
Nominal operation:

\[ \varepsilon_x \sim 200 \text{ pm.rad} \]
\[ \varepsilon_z \sim 8 \text{ pm.rad} \]
\[ I = 500 \text{ mA} \]
\[ \sigma_I > 45 \text{ ps (RMS)} \]

Short bunch operation**:

\[ \varepsilon_x \sim 600 \text{ pm.rad} \]
\[ \varepsilon_z \sim 50 \text{ pm.rad} \]
\[ I = 100 \text{ mA} \]
\[ \sigma_I \sim 1 \text{ ps (RMS)} \]

*: obtained with a harmonic cavity tuned to lengthen the bunch (\( > x \ 3 \)).

**: nominal RF frequency (352 MHz) + additional cavities (either like VSR project or using Crab cavities).
Electron Beam size comparison

SOLEIL today

\[ \sigma_x = 335 \, \mu m \]
\[ \sigma_z = 10 \, \mu m \]

SOLEIL tomorrow

\[ \sigma_x = 20 \, \mu m \]
\[ \sigma_z = 2 \, \mu m \]

Calculation performed in a short straight section with \( \epsilon_x = 250 \, \text{pm.rad} \)
Simultaneous short and long bunches

- Shaping the longitudinal phase space by high gradient SC systems.
- BESSY VSR project: use of two harmonic cavities with two different frequencies.
- Substantial challenges: high gradient “HOM free” SC cavities, stability requirements, lifetime, ...

<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>2.5</td>
<td>(2\pi \times 0.88)</td>
</tr>
<tr>
<td>First harmonic SC cavity (n=5)</td>
<td>1.760</td>
<td>25</td>
<td>(2\pi \times 44)</td>
</tr>
<tr>
<td>Second harmonic SC cavity (n=5+1/2)</td>
<td>1.936</td>
<td>22.7</td>
<td>(2\pi \times 44)</td>
</tr>
<tr>
<td>Even fixed points</td>
<td></td>
<td></td>
<td>(2\pi \times 88)</td>
</tr>
<tr>
<td>Gain</td>
<td></td>
<td></td>
<td>(\frac{88}{0.88} = 100)</td>
</tr>
<tr>
<td>Bunch length reduction</td>
<td></td>
<td></td>
<td>(\sqrt{100} = 10)</td>
</tr>
</tbody>
</table>

\[ \sigma_{L} \propto \sqrt{\frac{\alpha}{V'}} \sigma_{E} \]

\[ V' = \frac{dV}{dt} = 2\pi f_{RF} V_{RF} \]

Nominal bunch length \(\approx 15\) ps RMS
Short bunch of 15/10 \(\approx 1.5\) ps RMS

G. Wüstefeld et al.  
Proceedings of IPAC2011, San Sebastian, Spain
Simultaneous short and long bunches

- 352 MHz
- 1.76 GHz
- 1.936 GHz
- SOMME

present cavity + SC cavities 1 + 2
Longer bunches

- 352 MHz
- 1.76 GHz
- Sum

V [MV]

t [ns]
Short bunch using a time dependent radio frequency orbit deflection

\[ f_1 = h f_{RF} \]
\[ f_2 = \frac{hm \pm 1}{m} f_{RF} \]

\[ \delta y'(\hat{z}) = \frac{eU_1}{E_b} \sin(2\pi f_1 \sigma_\tau \hat{z}) - \frac{eU_2}{E_b} \sin(2\pi f_2 \sigma_\tau \hat{z}) \]


Numerical application to SOLEIL

\[ \sigma_{x-ray} \approx \sigma_T \frac{\sqrt{\sigma_y^2 + \sigma_{\theta}^2}}{y'(1)} \approx \frac{E_b}{eU_1} \frac{\sqrt{2\varepsilon_y L_u + \frac{\lambda_x}{\pi L_u}}}{2\pi f_1} |\sin(\pi \nu)| \]

Parameters used:

- \( E = 2.75 \text{ GeV} \)
- \( V = 4 \text{ MV} \)
- \( h = 8 \) (\( f_{RF0} = 352 \text{ MHz} \) and \( f_1 = 2.8 \text{ GHz} \))
- \( \varepsilon_y = 50 \text{ pm.rad} \)
- \( L_u = 2 \text{ m} \)

<table>
<thead>
<tr>
<th>Photon energy</th>
<th>700 eV</th>
<th>12 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch length (RMS)</td>
<td>0.7 ps</td>
<td>0.3 ps</td>
</tr>
</tbody>
</table>
SUMMARY

- 26 beamlines are open to the users, 3 are under commissioning, to be opened by January 2017.

- 5 modes of operation (all in Top-up) + FemtoSlicing operation (since 14/03/2016).

- Good availability of the beam (98.9% in 2015) and good MTBF (105 h in 2015).

- Short term projects towards improvement of the storage ring operation.

- First thoughts for a major upgrade of the facility to satisfy science goals.
  - Horizontal emittance ~200 pm.rad → MBA
  - Short “intense” pulses ~1 ps → High gradient SC RF systems or deflecting RF kicks.