Sirius Progress
October 2020

- Sirius project overview
- Commissioning results (partial)
- What still needs to be done

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on behalf of the Sirius Team
Brazilian Synchrotron Light Laboratory - LNLS
Sirius is a 4th Generation 3 GeV synchrotron light source with natural emittance of 0.25 nm.rad. It is presently under commissioning at CNPEM/LNLS campus, in Campinas, Brazil.
Brief History of LNLS

1982: Initial discussions on a synchrotron radiation lab in Brazil

1986: LNLS was created

1987, January: LNLS starts hiring technical staff

1987 – 1996: Construction of UVX, a 1.4 GeV, 2nd generation source designed and mostly built from scratch in-house

1997 – 2019: 22 years of operation for users
Sirius Timeline

2008: Preliminary proposal of a new light source submitted to Brazilian Government
Sirius Timeline – 2020

January: Sirius project leader passed away
Sirius Main Parameters

**Storage Ring**

- **e-Beam energy**: 3.0 GeV
- **Circumference**: 518.4 m
- **Lattice**: 20 x S5A
- **Hor. emittance (bare lattice)**: 0.25 nm.rad
- **Hor. emittance (with undulators)**: 0.15 nm.rad
- **Betatron tunes (H/V)**: 49.11 / 14.17
- **Natural chrom. (H/V)**: -119.0 / -81.2
- **Energy spread (rms)**: $0.85 \times 10^{-3}$
- **Energy loss/turn**: 473 keV
- **Damping times (H/V/L) [ms]**: 16.9 / 22.0 / 12.9
- **Beam current (top up)**: 350 mA

**Booster**

- **Circumference**: 496.8 m
- **Emittance**: 3.5 nm.rad @ 3 GeV
- **Lattice**: 50 Bend
- **Cycling freq.**: 2 Hz

**Linac**

- **Energy**: 150 MeV
- **Frequency**: 3 GHz
- **Repetition rate**: 2 Hz

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First experimental results from beamlines

**MANACA – serial micro and nano protein crystallography**

- Protein crystal at the beamline, MXCube interface
- Diffraction pattern recorded with the Pilatus 2M area detector
- Electron density for a protein using Iodine SAD phasing at Manaca – 10/2020
- Fragment density (green) co-crystallized with SARS-COV2 Mpro protease (red) source: Andre Godoy PhD. Manaca 09/2020

**MOGNO – micro and nanotomography**

- 4D tomography
- Imbibition and drainage experiment with 3 mm glass beads sample - 1 tomo/30 seconds
Sirius optics

• 5-fold symmetric optics:
  – 5 high $\beta_x$ and 15 low $\beta_x$ straight sections

• At low $\beta_x$ sections
  – $\beta_x \approx \beta_y \approx 1.5$ m
  – Better matching of electron and photon beam phase-space for undulators $\rightarrow$ brightness optimization
  – Small H and V beam stay clear, allows for undulators with small H and V gaps

• At Permanent Magnet superbend
  – 20 beam sources
  – Beam size: 9.6 x 3.6 $\mu$m$^2$
  – Photon $\varepsilon_c$: 19.2 keV
Initial Commissioning

- **Injection**
  - Off-axis injection in horizontal plane using Non-Linear Kicker (NLK) for beam accumulation @ 2 Hz
  - On-axis injection using Dipole Kicker for beam commissioning
- **Large calibration error in low field EM dipole with respect to high field PM superbend. Initial calibration error of 2.3%**
- **Mismatch in Booster and Storage Ring circumference -> Booster operates off-energy.**
- **Stored beam from on-axis injection was used to perform initial optics measurements and corrections.**
- **After correction, accumulation with NLK was successful.**
- **Overall, the initial commissioning was a smooth process.**
Optics measurement: beta and dispersion functions

- Beta functions measured after LOCO optimization, by individual quadrupole variation method.

Horizontal beta function

Vertical beta function

Dispersion function

Horizontal beta beating = 4.4%

Vertical beta beating = 5.2%
Preliminary emittance measurement

- Preliminary emittance measurement using the undulator beam from MANACA beamline with no focusing optics.

<table>
<thead>
<tr>
<th>Par</th>
<th>Exp. Value</th>
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<tbody>
<tr>
<td>$\beta_x \setminus \beta_y$</td>
<td>17.57 m $\setminus$ 3.99 m</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>0.18%</td>
</tr>
<tr>
<td>K (@7.13 mm)</td>
<td>0.755</td>
</tr>
<tr>
<td>E (-8 eV detune)</td>
<td>9.056 keV</td>
</tr>
</tbody>
</table>

Estimative:
\[
\frac{\Delta\gamma}{\gamma} = 0.11\%
\]

$\epsilon_0 = 400 \text{ pm rad}$

$\Delta\gamma = (0.1, 0.12\%)$

$\epsilon_0 = 400 \text{ pm rad}$

$\Delta\gamma = 0.1\%$

$\epsilon_0 = 400 \text{ pm rad}$

$\Delta\gamma = 0.1\%$

Courtesy Harry Westfhal Jr
Dynamic aperture measurement

- DA in the horizontal plane was measured by kicking the stored beam and following its trajectory turn by turn.

Random truncated Gaussian errors
- Alignment, magnets: 40 µm
- Alignment, girders: 80 µm
- Roll: 0.3 mrad
- Excitation: 0.05 %
- Multipole: $\Delta B / B_{x=12\,\text{mm}} = 1x10^{-4}$
Commissioning with undulators

- 4 undulators for commissioning have been installed in the machine, 1 high beta, 3 low beta straights
- Commissioning undulators: fixed gap, adjustable phase planar undulators (APU)

<table>
<thead>
<tr>
<th>Period</th>
<th>APU22</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length</td>
<td>1.2 m</td>
<td></td>
</tr>
<tr>
<td>Kmax</td>
<td>1.43</td>
<td></td>
</tr>
<tr>
<td>Full gap</td>
<td>8 mm</td>
<td></td>
</tr>
<tr>
<td>Gap for beam</td>
<td>6 mm</td>
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- APU22 undulator commissioning was straightforward. Only APU22 in high beta straight required local quadrupole adjustment. APU22 in low beta straights had no detectable effect on optics.
- For Adjustable Phase Undulators, focusing strength does not depend on phase.
- Final undulators are being developed in-house.
Girder alignment: preliminary measurements

- All magnets have been aligned on the girders in the transverse direction by construction, using precise reference surfaces.
- Since initial alignment (without temperature stabilization), the building has deformed, as expected for a new construction.
- Latest survey shows large transverse and longitudinal girder alignment errors.
Magnet transverse alignment in the girder

- Magnets assembled and aligned on girders “by design” (no adjustable supports).
- Stacked laminations for each pole. Low mechanical tolerances achieved by the Brazilian company WEG.
- BPMs are also aligned on girders by design.
- There is evidence of good intra-girder transverse magnet alignment.

Beam-Based BPM Offset Calibration

Electrical offsets (EO)
- 160 BPMs
- $\sigma_x = 83\ \mu m$
- $\sigma_y = 90\ \mu m$

BBA offsets (includes EO)
- 160 BPMs
- $\sigma_x = 114\ \mu m$
- $\sigma_y = 97\ \mu m$
Tunel temperature and RF frequency

- RF frequency and temperature variation.
- Correlation is not perfect but temperatures are local measurements while RF frequency depends on ring circumference variation, a global effect.
Orbit stability

• Slow Orbit Feedback System (SOFB) is operating @ 10 Hz
• FOFB scheduled for July 2021

Effect of SOFB in orbit stabilization @ low frequency

All BPMs (averaged PSD)

Beam Size: $65 \mu m \times 5 \mu m$

High beta straight section BPM only
Operation current

- Present operation: 40 mA in decay mode, beam stabilized with bunch-by-bunch feedback (BBB)
- Limited by longitudinal instability driven by NC Petra-7 cell RF cavity Higher Order Modes
  - Instability threshold ~ 22 mA
  - Maximum injected current in test run: 90 mA
  - BbB is being optimized/upgraded to be effective up to higher currents
RF System

- Solid state amplifiers @ 500 MHz
  - Developed in collaboration with Soleil, fabricated in China
- LLRF developed by ALBA
- Commissioning with a reduced RF system, with a Normal Conducting Petra 7-cell 500 MHz cavity
- The final system consists of 2 Super Conducting cavities expected to be installed by the end of 2021.

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<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
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<tbody>
<tr>
<td>RF Cavity</td>
<td>1 x NC (Petra-7)</td>
<td>2 x SC CESR</td>
<td>2 x SC CESR</td>
</tr>
<tr>
<td>SS Amplifiers</td>
<td>2 x 60 kW</td>
<td>4 x 60 kW</td>
<td>8 x 60 kW</td>
</tr>
<tr>
<td>Gap voltage</td>
<td>1.8 MV</td>
<td>3 MV</td>
<td>3 MV</td>
</tr>
<tr>
<td>Current</td>
<td>50 mA</td>
<td>300 mA</td>
<td>350 mA</td>
</tr>
<tr>
<td>Installation</td>
<td>2019</td>
<td>End 2021</td>
<td>2023</td>
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Vacuum System (fully in-house NEG-coated chambers)

Storage Ring Static Pressures

Avg $P = 8.10^{-11}$ mbar

Storage Ring Dynamic Pressure

$y = 6E^{-11}e^{0.725}$
Vacuum System (fully in-house NEG-coated chambers)

Storage Ring Static Pressures

Avg P = 8.1 \times 10^{-11} \text{ mbar}

Storage Ring Dynamic Pressure

Target will be reached before expected
Summary and Outlook

• Sirius commissioning has started by the end of 2019 and is progressing slowly, partly due to the pandemic, but steadily.

• There is still a lot of work ahead to reach design parameters.

• Nevertheless, 5 beamlines are already in different commissioning phases and the integration of practically all subsystems, from the storage ring operation to data processing in the beamlines, are being tested.

• We see no show stoppers up to now.

• We defined a prioritized list of subsystem developments aiming at reaching the phase 1 design parameters by the end of 2021.
Thank you!

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