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# SOLEIL UPGRADE PROJECT AND FORESEEN BEAM INSTRUMENTATION

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## *Abstract*

SOLEIL Synchrotron has an upgrade plan to replace its storage ring by a new one based on multi-bend (7/4BA) achromat lattice. The Conceptual Design Report (CDR) has been published recently and the Technical Design Report (TDR) phase should be finished for the end of 2023.

For the beam instrumentation, most of the equipment will have to be replaced, to overcome cases of electronics obsolescence and to fulfil the new tight requirements. Among them, the most challenging ones are the micron resolution transverse beam size measurement, the beam position monitoring and the stability feedbacks. The present machine will be used to validate some prototypes and it is planned to upgrade part of the diagnostics ahead of the dark period to speed-up the commissioning of the new storage ring.

This paper presents the diagnostics systems that are foreseen for the SOLEIL upgrade project.

## SOLEIL UPGRADE

SOLEIL Synchrotron is a third-generation light source in operation since 2006. The 2.75 GeV storage ring based on a Double-Bend achromat (DBA) lattice provides a broad spectrum of photon ranging from the far infra-red to hard X-rays to 29 beamlines.

SOLEIL is working on an upgrade project plan based on Multi-Bend Achromat (MBA) lattice. The Conceptual Design Report (CDR) has been published [1] and the Technical Design Report (TDR) phase has started recently. The CDR reference lattice is based on 20 non-standard alternating 7BA and 4BA Higher-Order Achromat (HOA) cells reaching a horizontal natural emittance of about 80 pm.rad at the energy of 2.75 GeV and equal horizontal and vertical β-functions of between 1.5 to 1.0 m at the center of all Insertion Device (ID) straight sections [2]. Figure 1 compares the arrangement of the magnets in the 7BA cell of this new lattice and the one in the Double Bend Achromat (DBA) cell of the existing machine.

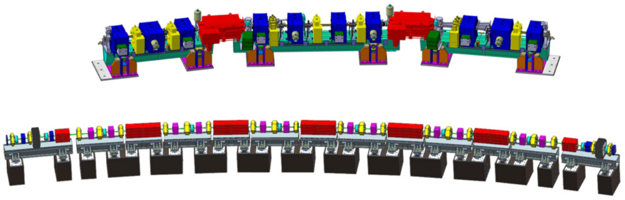

Figure 1: Engineering layout of the 7BA cell type of the new MBA-ARC (bottom) and the SOLEIL DBA-ARC cell (top).

The new machine implementation should minimize the impact on the ID source point position and reuse the existing tunnels and their radiation shielding walls [3].

The achieved natural horizontal emittance is about 50 times smaller than that of the existing SR (Fig. 2) and the effective emittance calculated in the straight section source points would be about 100 times smaller than the average value in those of the current SR.

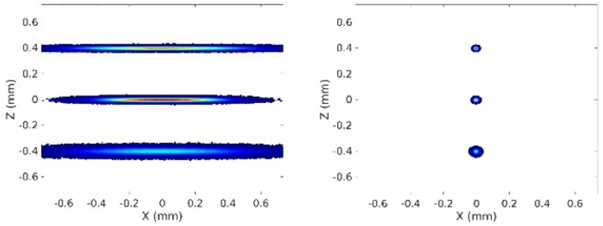

Figure 2: Comparison of the transverse beam profiles of the present SOLEIL (left) for the three straight sections with 1% coupling and SOLEIL Upgrade CDR reference lattice (right) with 50 pm.rad emittance in each plane.

With appropriate low gap IDs, this emittance reduction will improve the brilliance and coherent flux by more than two order of magnitudes [2].

## FORESEEN BEAM INSTRUMENTATION

Most of the SOLEIL present diagnostics systems will have to be renewed to fit the new technical specifications of the upgrade (Table 1), but also to overcome obsolescence of the electronics.

Table 1: Current and Future Beam and Machine Parameters

| | **SOLEIL** | **SOLEIL-Upgrade** |
|---|---|---|
| H. Emit. [pm.rad] | 4000 | 80 |
| V. Emit. [pm.rad] | 20.3 | 80 |
| H. Beam Size (min value at source point) [µm rms] | 180 | 7.4 |
| V. Beam Size (min value at source point) [µm rms] | 8 | 2.8 |
| BPM Aperture [mm] | 84x25 | 16 |
| Pos. and Angle Stability (wrt size and divergence) | 10% | 2-3% |
| Orbit Feedback Efficiency | 200 Hz | 1 kHz |

Horizontal beam size reduction, compacity of the equipment and overall stability are the main new challenges to be overcome.

### *Transverse Beam Size*

The electron beam transverse emittance is expected to be close to 50 pm.rad in both planes (with IDs) in the full coupling mode and could be reduced to 1 pm.rad in the vertical plane for coupling correction (machine optimization). This corresponds to electron transverse beam sizes between 2 and 20 µm-rms depending on the location around the storage ring. This small transverse emittance being one of the critical parameters of the future machine, it must be accurately (with sub-micron resolution on the beam size) as well as rapidly (~ 100 Hz repetition rate) measured. The robustness of the device is also a crucial point to decide the type of instrument to be implemented since the resulting measurement will be used as input for a beam size feedback. The chosen strategy is the use of two different technics on the same Xray extraction port. Depending on the required performance (high resolution/high speed) we can switch between the two following measurements:

- Pinhole Camera: this well-known system already in use at SOLEIL could achieve a 5 µm RMS resolution measurement with enough flux to allow high speed acquisition rates.
- Fresnel Diffraction: adding a spectral filter on the beam path and slightly increasing the pinhole size, the beam size could be inferred from the Fresnel diffraction pattern with a 1 µm RMS resolution however with a slower (~10 Hz) repetition rate (due to the reduction of flux from spectral filtering).

A high repetition rate measurement requires a high field dipole. To achieve 100 Hz the dipole source must be around 3 T (simulations performed at 50 keV). To ensure highest availability of the measurement, two identical (redundant) systems will be implemented downstream two dedicated 3 T superbends.

In addition to X-ray measurements, an additional one in the visible range is foreseen, taking benefit of the visible light extraction port that will be designed for other purposes (length and filling pattern monitors). Direct imaging or diffraction in sigma/pi polarization would give 2-5 µm RMS resolution measurements (at 200 nm).

To validate the proposed solutions for transverse beam monitoring, different prototypes will be tested on the current machine:

- A new visible light extraction mirror (with improved cooling capacities) has been designed and is planned to be installed in January 2022. This new mirror will make possible visible range beam size measurements in slit mode even at full current during user operation.
- A setup for Fresnel diffraction measurement should also be mounted on one of the two X-ray extraction port of the current machine for validation of this technic.
- A test bench to acquire and process video stream in hardware with the objective of reducing the latency and processing time compared to current software processing.

### *Beam Position*

CDR lattice has 176 RF-Beam Position Monitors (RF-BPM) located at the start and end of each matching section and next to each focusing sextupole in the arcs [3]. The RF-BPM are the fixed points of the vacuum chamber, standing on low thermal expansion supports. At least one bellow positioned between two RF-BPM will ensure the absorption of the vacuum chamber mechanical stress. Table 2 summarizes the main specifications for the RF-BPM system.

Table 2: BPM Specifications (Rms Values)

| | **Bandwidth** | **Specification** |
|---|---|---|
| Resolution | 10 Hz | 1µm @ 0.1 mA |
| | 2 kHz | 50 nm @ 500 mA |
| | TbT | 100 µm @ 0.1 mA |
| | TbT | 1 µm @ 500 mA |
| Beam current dep. | - | 10 µm |
| Absolute accuracy | - | < 500 µm |
| Stability | One day | 500 nm |
| | One week | 1 µm |
| Temperature dep. | - | 500 nm/°C |
| Latency (FOFB) | - | 50 µs |

The RF-BPM block has a circular shape with enlarged 16 mm inner diameter (compared with the 12 mm of the other vacuum chambers) to keep it in the shadow of the upstream synchrotron radiation. The button shape is being optimized to find the best compromise between amplitude of the collected signal and impedance budget on the machine [4]. A prototype is being manufactured with 5 mm diameter buttons (Fig. 3).

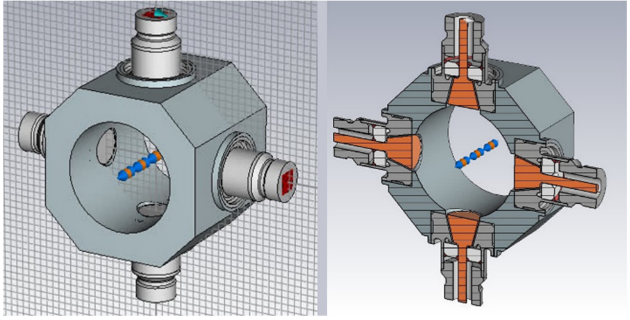

Figure 3: First drawings of the beam position monitor for SOLEIL-Upgrade. Internal BPM diameter is 16 mm, button diameter is 5 mm.

The RF-BPM electronics will be renewed since its components are already obsolete but also to fit the new specifications. In particular, the resolution and the dependencies (to beam current and temperature) must be improved (Table 1). The reduction (by a factor 10) of the latency of the data used for the fast orbit correction is also a strong objective. This latency is currently the main limitation for the Fast Orbit Feedback (FOFB) bandwidth which could then be pushed up to 1 kHz. Extensive beam-based tests are conducted to evaluate and compare the performances of the two possible compensation mechanism that are the switching (currently in used at SOLEIL) and the pilot tone [5]. The upgrade of the RF-BPM electronics will be performed ahead of the machine shutdown in order to have a fully ready and tested system for the commissioning of the future machine.

Most of the SOLEIL beamline frontends are currently equipped with tungsten/copper blade X-BPMs based on photo-emission principle. Those devices are reliable on dipole-based beamlines and on planar undulator but hardly usable downstream helical undulators. Moreover, some drawbacks due to this technology are painful for the operation like their sensitivity to low energies (including upstream dipole radiation), but also the apparition with time of increasing leakage currents. The strategy for the upgrade would be to have two different kinds of X-BPM:

- Diamond blades X-BPM operated in photoconductive mode for the planar sources (dipoles, wigglers and planar undulators). Those devices are less sensitive to low energy photons. Since the mechanical principle is close to our current X-BPM design (4 blades holder), the in-place X-BPM heads could be eventually refurbished.
- Diamond imaging for helical magnetic devices. An envisioned solution would be to insert a diamond disk in the photon beam to allow a quasi-imaging of the complex photon beam distribution.

Those two new X-BPM types must be validated on the machine by prototypes during the TDR phase.

### *Fast Orbit Feedback*

The FOFB system is currently embedded on the BPM electronics. With the upgrade of the latter, the FOFB must be previously moved to a new external platform. This future implementation, to be deployed in the next two years, must already fulfil the specifications for the future machine and in particular (with the objective of increasing the loop bandwidth) the reduction of the data transfer latency by a factor 10. The new architecture will be versatile, being able to deal with both old and new BPM electronics and their respective data rate and communication protocols (10 kHz distributed with the Diamond Communication Controller [6] for the current system, and ~100 kHz on a protocol still to be defined for the new one).

The prototype under development for the FOFB is a flexible platform based on a µTCA crate embedding an FPGA board with System on Chip and FMC cards for the interfaces (SFPs for the data distribution and serial links for the command of the correctors). This platform will serve as a cell gateway to aggregate the BPM data and drive the correctors (Fig. 4). The processing will be computed on a central platform to allow more complex controller scheme (mode control) and will give the possibility to add additional measurement data (photon BPMs, injection events…). The corrector settings will be distributed back to cells on the same dedicated network. Corrector set points will also be archived in addition to the BPM data at the FOFB rate.

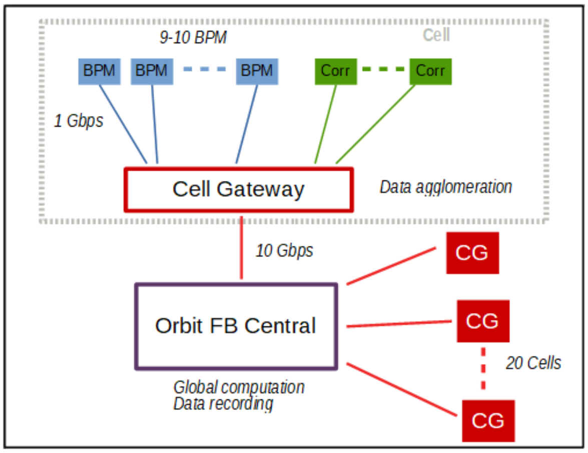

Figure 4: FOFB network topology.

The bandwidth of the correctors (and vacuum chamber) used for the FOFB must be higher than 1 kHz. The type of correctors that will be used and the number of sets (slow/fast) is still to be defined during the TDR. An architecture, similar to the one currently in operation [7], with two different sets of correctors (slow ones located in the arcs and fast ones installed upstream/downstream of each straight section) should fit SOLEIL Upgrade needs.

### *Beam Loss Monitors*

Beam Loss Monitors (BLM) will be a key diagnostic system for the commissioning of SOLEIL Upgrade and its small aperture vacuum chambers (12 mm diameter). The 80 freshly installed monitors [8] will be reused and extended (on the injector) for the upgrade. They are made of plastic scintillators combined with fast photosensor modules (Fig. 5) and a dedicated commercial acquisition electronics. With a very high sensitivity and short temporal resolution this system will ease a lot the detection of potential obstacle and the optimization of the future machine.

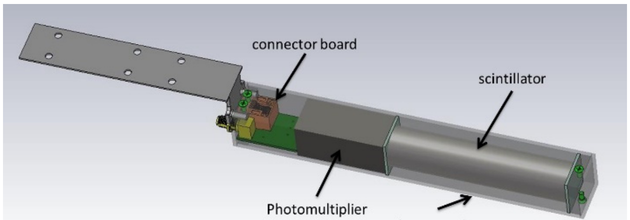

Figure 5: Beam Loss Detector made of plastic scintillator and a fast photosensor module.

Thanks to a careful relative calibration of the monitors, the radioprotection group will also use the BLM measurements on the current accelerator to crosscheck the results given by their simulation codes for SOLEIL Upgrade.

### *Beam Charge*

Beam current will be monitored by two (for redundancy) commercial DCCT associated to a newly developed acquisition electronics [9].

The bunch distribution will be either detected on a combined/splitted BPM signal or on the visible light with an Avalanche Photo Diode (APD) installed in a dedicated path of the visible light diagnostics line. Downstream a fast acquisition (>8 GHz) of those signals will give a relative distribution of the beam charge into the 416 buckets.

The bunch purity will use the statistical Time Correlated Single Photon Counting method on another APD, this time in the X-ray path of the synchrotron radiation (more precisely in the fluorescence emission of the PHC copper absorber). For both distribution and purity, the acquisition electronics will have to be renewed due to obsolescence of the current ones.

### *Other Diagnostics*

Table 3 summarizes the diagnostic systems that are foreseen for SOLEIL Upgrade:

Table 3: SOLEIL Upgrade Diagnostic Systems

| **Parameter** | **Type** | **Quantity** |
|---|---|---|
| Emittance | X-ray: PHCs/Fresnel | 2 |
| | Visible: Interferometry/Pol. | 1 |
| Position | RF-BPM | ~176 |
| | X-BPM | ~30 |
| Current | DCCT | 2 |
| Filling | BPM + fast digitizer | 1 |
| | APD + fast digitizer | 1 |
| Purity | APD +TCSPC | 2 |
| Length | Streak Camera | 1 |
| Losses | Scintillators + PMT | ~80 |
| Dosimetry | RadFET | ~40 |
| Tune | BPM + Shaker Magnet | 1 |

## CONCLUSION

Cutting-edge instrumentation must be designed to answer the SOLEIL Upgrade tight specifications. On such a compact machine the mechanical integration of the diagnostics will also be a challenge and must be anticipated (beam extraction, pinhole integration as close as possible to the source, etc…). In order to ease and speed-up the commissioning of the new machine the FOFB and the BPM electronics will be upgraded ahead of the machine shutdown. The current machine will also be used as a testbench to validate concepts of Fresnel diffraction and adjustable pinholes for beam size measurements, and the BPM feedthrough prototypes.

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