SYNCHROTRON SOLEIL UPGRADE PROJECT

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Abstract

SOLEIL is working on an upgrade project plan based on Multi-Bend Achromat (MBA) lattices. The Conceptual Design Report (CDR) of the project is now complete and the work to produce a Technical Design Report (TDR) will start very soon. The achieved equilibrium emittance in the CDR reference lattice (80 pm.rad) is about 50 times smaller than that of the existing Storage Ring (SR) (4000 pm.rad). Round beam sizes in Insertion Devices (IDs) straight sections of less than 10 µm RMS in both planes can be produced. This performance relies on the use of a 10 (to 12) mm inner diameter circular copper vacuum chamber with NEG-coating allowing reaching strong quadrupole gradients and very strong sextupole and octupole strengths. As all these technical challenges push the engineering technologies to their limits, they are being investigated through an intensive R&D program based on extensive numerical simulations, prototyping and measurement. The use of pure permanent magnet technology is largely considered in this project which can halve electrical energy consumption and significantly reduce operating costs.

OBJECTIVES AND CONSTRAINTS

While maintaining the broad spectrum of photons ranging from the far infra-red (IR) to hard X-rays, the upgrade project of synchotron SOLEIL facility aims at maximizing the intensity of coherent photon flux especially for the beamlines working in the soft to tender X-ray range. To achieve this goal, the electron beam emittances in both horizontal and vertical planes must be close to the single-electron photon beam emittance in this energy range. As the diffraction limited emittance for a single-electron photon beam emitted by an undulator at the wavelength λ is approximately $\lambda/2\pi$ [1], an electron beam emittance of at most 50 pm.rad in both planes is needed for X-rays energies up to 4 keV. Our strategy is based on the objective to obtain a natural horizontal emittance of less than 100 pm.rad which provides the target of 50 pm.rad in each plane after equal sharing. Together with equal β-functions in the two planes, this will produce at ID source point round electron beams that are more suitable for imaging or diffraction techniques and reduce scattering effects like Touschek and Intra-Beam Scattering (IBS). With such ultra-low emittances, it is also necessary to properly match the electron and photon phase spaces to maximize the coherent flux. Horizontal and vertical β-functions close to the matching value of L_u/π [1] where L_u is the ID length, are set as a goal at each ID source point. To further mitigate the IBS effects and achieve more comfortable beam lifetime, the bunch length will be increased by a factor of three to four, in the limit of 100 ps FWHM, with the use of a harmonic Radio-Frequency (RF) system. These objectives will have to be achieved while maintaining the stability and reliability presently achieved in SOLEIL.

In addition, the project must take into account a number of constraints and fulfill several requirements, among them: reuse the existing tunnel and its radiation shielding walls; reuse much of the existing technical infrastructure; limit downtime to a maximum of two years; minimize the impact on the existing ID source point positions; preserve infra-red (IR) beamlines and provide alternative radiation sources to existing bending magnet-based beamlines.

While maintaining the same circumference, the geometry of the new lattice must allow on the one side not to modify the source point of the MARS beamline (heavy-shielded hutches for radioactive samples) and have it downstream a bending magnet. On the other side, to ensure that the two long NANOSCOPIUM and ANATOMIX (~200 m) beamlines fit into their current experimental hutches by using canted in-vacuum IDs.

STORAGE RING LATTICE

The CDR reference lattice, detailed in [2, 3], 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 ID straight sections. Figure 1 compares the arrangement of the magnets in the 7BA cell of this new lattice (Fig.1 a) and the one in the Double Bend Achromat cell of the existing machine (Fig. 1 b). The length of the new cell is rather short (~16 m) which increases the problem of compactness.

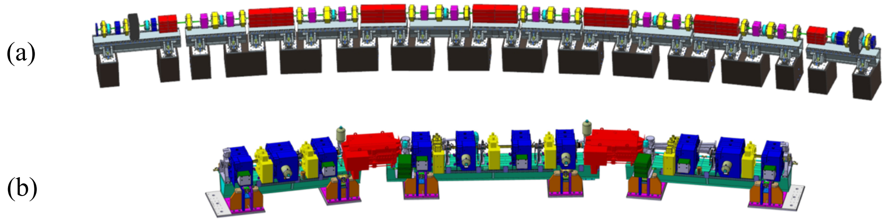

Figure 1: Engineering layout of the 7BA cell type of the new MBA-ARC (a) and the SOLEIL DBA-ARC cell (b).

The choice of the lattice emerged from considerations and constraints which are developed in [2, 3]. In particular a great effort was invested to minimize the impact on the beamline photon source points and to preserve the radiation shielding walls. The lattice presents a workable solution but can be further improved. The achieved natural horizontal emittance is about 50 times smaller than that of the existing SR 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. By operating on a linear coupling resonance, it is possible to produce round beam sizes in ID straight sections of less than 10 μm RMS in both. Figure 2 shows a beam size comparison between the current and the upgrade SRs.

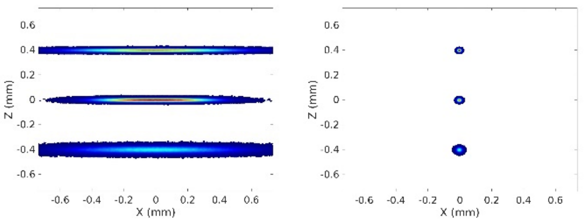

Figure 2: Comparison of the transverse beam profiles of the present SOLEIL (left) for the three straight sections with 1% coupling and SOLEIL Upgrade CDR reference lattice (right) with 50 pm.rad emittance in each plane.

The performance of this lattice in terms of on and off-momentum dynamic apertures seems compatible with the implementation of a betatron off-axis injection scheme. As off-axis injection with full coupling is complex and needs careful investigations to validate all aspects, another scheme based on synchrotron on-axis injection is also being studied in the CDR phase together with first general considerations on the swap-out injection [4].

The new lattice will provide 20 straight sections: 4 long straight sections (2 of 7.66 m and 2 of 7.35 m), 8 medium straight sections (4.15 m) and 8 short straight sections (2.71 m). One long straight section will be dedicated to the injection system, two long straight sections will accommodate two canted undulators each and the fourth one will be shared for an ID and for the harmonic RF system. With the exception of one medium straight section which will host the fundamental RF cavities, all medium as short straight sections are available for beamline IDs. This corresponds to a total of 20 possible ID-based beamlines Since the dipole fields become weaker, the source for the bending magnet beamlines will be replaced by superbends with either 1.7 T or 3 T fields.

Using several candidate IDs, Figs. 3 and 4 show the dramatic increase of the photon beam brilliance and its coherent fraction, respectively, due mainly to the lower emittance but also to the possibility of using IDs with lower gaps. It can notice that the brilliance and coherent flux should be improved by more than two orders of magnitude.

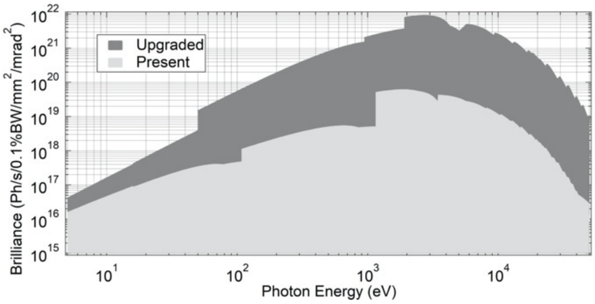

Figure 3: Comparison of undulator photon brilliance between upgraded and present SOLEIL storage ring.

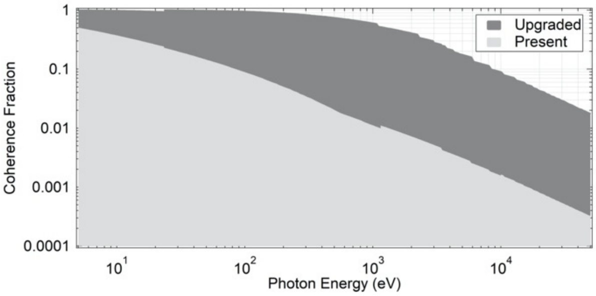

Figure 4: Comparison of coherent fraction between upgraded and present SOLEIL storage ring.

STORAGE RING LATTICE ENGINEERING

Strong quadrupole gradients (max ~110 T.m^{-1}), sextupole (max ~8 000 T.m^{-2}) and octupole strengths (max ~250 000 T.m^{-3}) are necessary to reach such low emittance, low β-functions and a dynamic aperture large enough to allow betatron off-axis injection and an acceptable beam lifetime. In order to reach these values, the SOLEIL upgrade SR must rely on a 10 (12) mm inner diameter circular copper vacuum chamber with NEG-coating. This allows for a small magnet bore diameter (16 mm) and a very dense magnetic lattice. The other key to ensure the feasibility of the lattice and in particular efficient injection of the electrons, is the need to develop a new high-performance nonlinear multipole kicker (MIK) allowing the electrons to be injected at a very short horizontal distance (3.5 mm) from the SR beam axis, in Top-up transparent mode [3]. As all these technical challenges are pushing the engineering technologies to their limits, they are being investigated through an intensive R&D program based on extensive numerical simulations, prototyping and measurements with beam. All combined bending magnets, all reverse bends and 70% of the quadrupoles would be based on the pure permanent magnet technology. The sextupoles and octupoles will be electromagnetic and will incorporate dipolar and quadrupolar (normal and skew) correction coils, respectively. Furthermore, to fully explore the potential of this new source, it is necessary to optimize other variables such as the possibility of using new kinds of IDs [3]. The use of very small beams and very small vacuum chambers will require state of the art diagnostics systems [3]. Other major design decisions are being discussed as the choice for the fundamental RF system technology, normal conducting cavities powered by solid state-state amplifiers and the technical options for the harmonic RF system, the choice between ex-situ and in-situ bake-out and first solutions for the extraction of the photons from such small vacuum chambers, the strategy to define the optimal number of girders and for the power supplies. A new booster is required to have a beam with smaller emittance and shorter bunch length to allow efficient injection into the new storage ring [5].

The prototyping program is primarily focused on the areas with the highest technical risk such as Ti-Zr-V NEG coating efficiency in very small vacuum chamber diameters (10 - 12 mm), extensive use of permanent magnets and high performance in-vacuum nonlinear injection kicker. The program has been expanded to equipment such as BPM blocks (10 mm diameter and 3 mm feedthrough) and RF-shielded bellows (60 mm length) for their unprecedented small dimensions and includes innovative insertion devices. Sorption capacity tests for NEG-coated chambers of 20- and 10-mm inner diameter. are in progress [3, 6]. Permanent magnet prototyping is essential to study their sensitivity to temperature variations, risk of demagnetization, tuning complexity and magnetic field quality. We have started with the prototype of the quadrupole and first magnetic measurement results using single stretched wire technique are promising. An in-air MIK magnet prototype has already been fabricated and has been magnetically measured in-house with excellent results, as a step towards proving the feasibility of these new MIK [4]. Some difficulties still have to be overcome such as the final mechanical integration, with great care on the conductor position tolerance or the voltage withstand of such new compact magnets. These difficulties should be resolved during the TDR phase. The process of filing a patent for these new MIK topologies is ongoing. The BPM sensors for the SOLEIL upgrade will be the usual RF button pickups installed at 45° on the vacuum chamber. If the technology is well known, it will be the first time the pickups are mounted on such a small vacuum chamber aperture (10 mm diameter). The challenge will be the manufacturing of a small dimension pickup (with a 3 mm diameter button) and to position it on the BPM body within tight tolerances in order to maintain an absolute position measurement error below 300 µm. A first prototype (simplified version) has been realized in order to validate such a tight mechanical integration and to try new ideas for the button positioning during the welding process. Resulting metrology is promising and improvements on the dedicated mechanical tools are already foreseen. The vacuum chamber connections (flanges, bellows) where the RF continuity is required need a particular attention to reduce their impedance budget contribution. We have launched two prototyping programs based on an adaptation to the SOLEIL upgrade needs of successful designs already used on different accelerators projects [3]. Innovative IDs are being studied to make the most of the unique features of the new lattice. For the intermediate photon energy range, three technical options are being explored to cover the energy range 10 eV - 5 keV with adjustable polarization: dual EPU, bi-periodic, cryogenic APPLE III undulators (CPMUE). The bi-periodic undulator is a new type of ID capable of switching the magnetic period value from its original value λ_u to $3\lambda_u$. The studies started under the CDR are ongoing and a prototype will be launched as part of the TDR. Although it is giving the best performances in terms of flux and brilliance, the cryogenic APPLE III undulator is a very challenging ID. A prototype of CPMUE32 is under construction, in order to validate the assembly of the magnets, the magnetic force compensation (extra row of magnets) and the liner holding. In the hard photon energy range, the search for small period length with thin magnets and poles pushes the technique of pole-magnet-pole keeper to its mechanical limits. A prototype of few periods of 12 mm (Proto-CPMU12), installed on 8-period keepers, is under construction to verify the mechanical tuning, the accuracy of the positioning of the magnets and the poles, and the rigidity of keepers.

CONCLUSION

The design of the SOLEIL upgrade is well suited to the stated scientific requirements for the upgrade of the facility, giving a very high gain in performance in the required areas of photon energy. The accelerator design is very ambitious and so inevitably involves some technical challenges. The CDR is now in press and provides a solid basis for moving into a more detailed TDR phase.

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