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TOWARDS AN UPGRADE OF THE SWISS LIGHT SOURCE

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Abstract

An upgrade of the Swiss Light Source (SLS) is planned for the period 2021–24. The existing 12-TBA (triple bend achromat) lattice will be exchanged by a 12-7BA (7-bend achromat) lattice in order to reduce the emittance from present 5.5 nm down to about 125 pm (IBS included) at 2.4 GeV and 400 mA. The new lattice is based on longitudinal gradient bends and reverse bends to realize low emittance despite the small circumference of 290 m. A conceptual design has been established. We present project status, lattice design and work in progress with emphasis on beam dynamics issues.

PROJECT STATUS

The SLS started user operation in June 2001 and has been operated in top-up mode since then. Today it is fully equipped with a set of 18 beamlines (11 based on undulators, 3 on super-bends, and 4 on normal bends). SLS delivers about 5000 hours of user beam time per year at an availability of 97.8 % (2008–2017 average). Research output has produced > 5000 peer reviewed papers including > 300 in journals of impact factor > 25. Thus SLS has proven a successful and productive synchrotron radiation facility. However, with the advent of the new generation of light sources it has become imperative to upgrade the storage ring of the SLS in order to increase brightness and coherence by 1–2 orders of magnitude. Design considerations started in 2013 and a letter of intent was submitted early 2014 to the responsible Swiss State Secretary. Late 2017 a Conceptual Design Report was issued [1], and early 2018 a proposal was submitted to the Swiss National Science Foundation in order to place the upgrade project, called “SLS 2.0”, on the Research Infrastructures Road Map 2021–24.

According to the proposed time schedule, lattice design will be determined this summer, and a technical design report will be completed by mid 2019. SLS will shut down in spring 2023 and come back to user operation in fall 2024 with a new storage ring providing 40 times lower emittance.

LATTICE CONCEPT

The upgrade of the storage ring has to address the issue of the comparatively small ring circumference because emittance scales approximately inversely with the third power of the number of lattice cells. In the new generation of multi-bend-achromat (MBA) lattices, this number is increased through reduction of beam pipe cross sections and magnet apertures until limitations due to impedance, acceptance and mechanical tolerances are met.

Scaling existing designs to SLS with its circumference of about 290 m is not sufficient to obtain a competitive emittance in the 100–150 pm range. Thus a new type of lattice cell was developed, which is based on the combination of longitudinal-gradient bends (LGB) and reverse-bending magnets (RB): LGBs minimize quantum excitation by adapting the field strength to the longitudinal variation of dispersion, and RBs decouple dispersion and horizontal beta function and thus enable suppression of dispersion at the LGB center, where the field is highest [2].

The twelve TBA arcs of the present SLS lattice are replaced by twelve 7-BA arcs: each arc contains seven LGBs, where the first and last ones are just half bending magnets, i.e. one arc has six full cells (counting from/to LGB centers) and two cells for matching to the straight sections. A specific dispersion suppressor is not required, since the RBs provide approx. zero dispersion at the LGB centers anyway. However, a minor modification of the end cells is introduced for matching the beta functions to the straights. Figure 1 displays optical functions and magnetic field strength for one of the arcs, where the center LGB has been replaced by a super-conducting LGB [3] to provide a source of hard X-rays, and Table 1 lists the most important lattice parameters.

Table 1: Main Parameters of SLS 2.0. The arrows (→) indicate the increase due to intra-beam scattering for 10 pm of vertical emittance and including a third harmonic RF system for bunch lengthening.

Parameter	Unit	Value
Energy	GeV	2.4
Beam current	mA	400
Circumference	m	290.4
Hor. damping partition J_x		1.71
Momentum compaction α	10^{-4}	-1.33
Total *absolute* bending angle		561.6°
Lattice tunes $\nu_{x/y}$		39.2/15.3
Natural chromaticities $\xi_{x/y}$		−95/−35
Radiated power	kW	221.6
Emittance	**pm**	**98 → 126**
Energy spread	10^{-3}	1.03 → 1.07

A 7-BA turned out as the best compromise between performance (emittance) and feasibility (miniaturization). With cell tunes of $\Delta\nu_x = 0.4285 \approx 3/7$ and $\Delta\nu_y = 0.1428 \approx 1/7$ all first and second order sextupole resonance drive terms (RDT) cancel over seven cells, which requires to install “harmonic” sextupoles in the matching cells [4]. For a horizontal tune slightly above 0.4 the RBs efficiently suppress the dispersion at the centers of the LGB, which have optimized longitudinal field variation, such that up to five times lower emittance is obtained in comparison to a conventional lattice cell. Since dispersion in the RBs is much larger than

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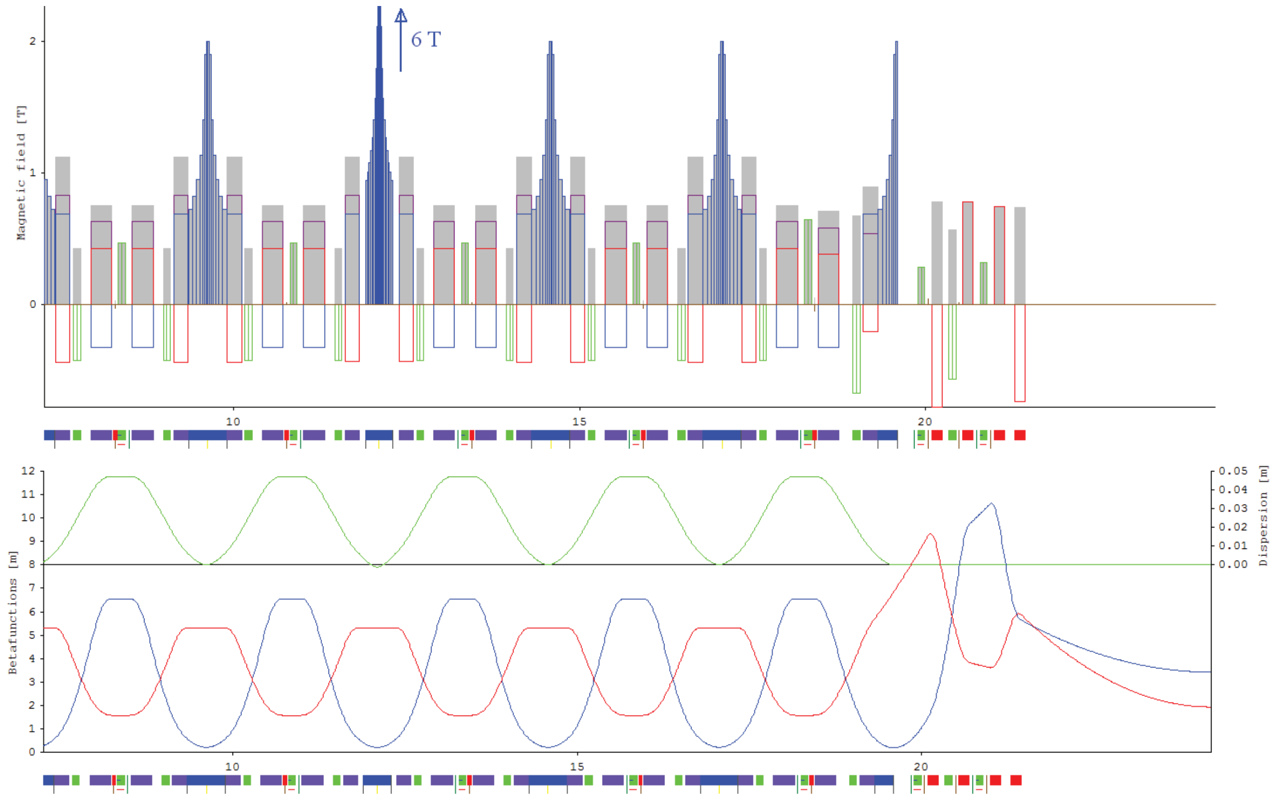

Figure 1: One 7-BA arc (2/3 visible) of the SLS upgrade lattice containing a central super-bend. Top: pole-tip fields for a bore radius of 13 mm (dipole blue, quadrupole red, sextupole green, octupole brown, total as gray bar, and pole-tip field for combined function magnets realized as off-set large aperture quadrupoles in purple). Bottom: optical functions (β_x blue, β_y red, dispersion green).

in the LGBs, the momentum compaction factor α becomes negative.

All twelve straight sections are about 5.5 m long. Eight full straights and three half straights are available for undulator installation, the others being required for injection elements and RF cavities. The higher lattice symmetry compared to the existing storage ring, which has straights of three different lengths, improves the non-linear performance by reducing the number of systematic resonances, and supports standardization of components. On the other hand the lattice footprint deviates by up to 1.8 m from the present one and thus necessitates partial modifications of the storage ring tunnel and displacements of some beam lines.

STORAGE RING OVERVIEW

Magnets will be mounted on girders, and different layouts are under consideration. The latest design assumes four girders and five pedestals per arc, which serve as pillars supporting the girders. Three pedestals also support the LGBs No. 2, 4 (center) and 6 of the 7-BA arc, which may be replaced by super-LGBs. The LGBs No. 1, 3, 5, 7 are supported by girders.

Following the girder pattern, the vacuum system is based on a 20 mm inner diameter round beam pipe, where seven sections with antechamber in the LGB regions alternate with eight plain round tubes in the RB regions. With a NEG coating of 500 nm thickness or less (1 μm in the antechambers) it is expected to reach a pressure $< 10^{-9}$ mbar in less than 100 Ah of integrated beam dose.

Simulations on turbulent bunch lengthening included impedance contributions from vacuum chamber, beam position monitors, tapers and cavities and resulted in a threshold bunch current of 1.5 mA without, and 3.5 mA with a third-harmonic RF system for bunch lengthening. Thus it is above the desired beam current of about 1 mA per bunch (400 mA total current) [5].

It is planned to re-use the existing 500 MHz RF-system after some modernization. The four cavities of Elettra-type will be operated at reduced voltage of 450 kV maximum (now 520 kV) with additional higher order mode dampers. The super-conducting passive third harmonic twin cavity will probably be re-used as well with the option to enable active operation.

Off-axis top-up injection is based on the new "anti-septum" scheme, where the center kicker in a 3-kicker bump is shielded by a very thin septum to comply with the small apertures of the storage ring [6]. Alternative schemes for off-energy or off-phase longitudinal injection [7] are also under consideration.

The SLS booster of 270 m circumference, mounted to the inner wall of the storage ring tunnel, delivers a 2.4 GeV

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beam with horizontal and vertical emittances of 10 nm and 2 nm [8], and thus is well suited for various modes of injection into the new storage ring.

For further reading see the Conceptual Design Report [1].

WORK IN PROGRESS

Moving from the conceptual design to the technical design, conflicts and difficulties are encountered and require modifications of lattice details without calling the basic concept into question:

It was planned to integrate the orbit correctors as additional coils into the sextupoles as had been done in the existing storage ring. However simulations indicate that the decapole components excited by creating a dipole field in a sextupole configuration cause a 20% deterioration of dynamic aperture with the risk of reduced injection efficiency as depicted in Fig 2[1]. Furthermore, the poletip field of the sextupoles already is quite high (up to 0.68 T), which raised concerns that superimposing another 2×0.04 T for the orbit correctors might result in cross-talk due to saturation effects. Therefore a discrete corrector is under development. It would combine horizontal and vertical correctors as well as a skew quadrupole on a laminated yoke for fast orbit feedback including fast coupling control, which is realized by regulating on emittance monitor signals and implementing fast feed-forward schemes (e.g. for polarization switching orbit bumps).

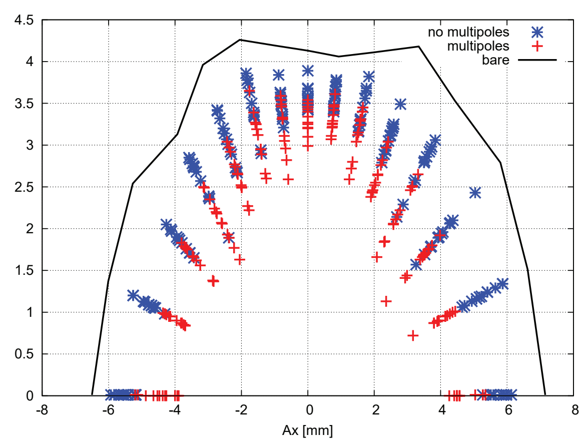

Figure 2: Dynamic aperture for the ideal lattice (solid line) and for 12 seeds of misalignment errors (60 μm girder position, 20 μm girder to girder, 30 μm element to girder, cut 1 sigma) without (blue) and with (red) decapole moments from orbit correctors in sextupoles. The region down to $x = -5$ mm is required for off-axis injection.

Space required to accommodate 144 discrete correctors is recovered by shortening the RBs and the LGBs. The LGBs most likely will be realized as permanent magnets (PM). Inspired by recent designs [9], a peak field of 2.3 T may be envisaged. The RBs could be realized as off-set quadrupoles of approx. 18 mm instead of 13 mm bore radius. A PM design is under consideration for the RBs too, since small tuning quadrupoles may be integrated into the adjacent octupoles. The vertically focusing combined function magnets close to the LGBs may either be of similar type like the RBs or they will be integrated into the LGB end regions, where the field is low. A possible lattice cell based on the latter option is shown in Fig. 3 in order to outline the direction of further developments: a slight increase of cell length results in a reduced straight section length of 5.0 m. Emittance is lowered further down to 89 pm (zero current) due to higher radiation loss and better suppression of quantum excitation based on LGB optimization with higher peak field, while the energy spread is only moderately increased to $1.07 \cdot 10^{-3}$ thanks to lower horizontal damping ($J_x = 1.58$).

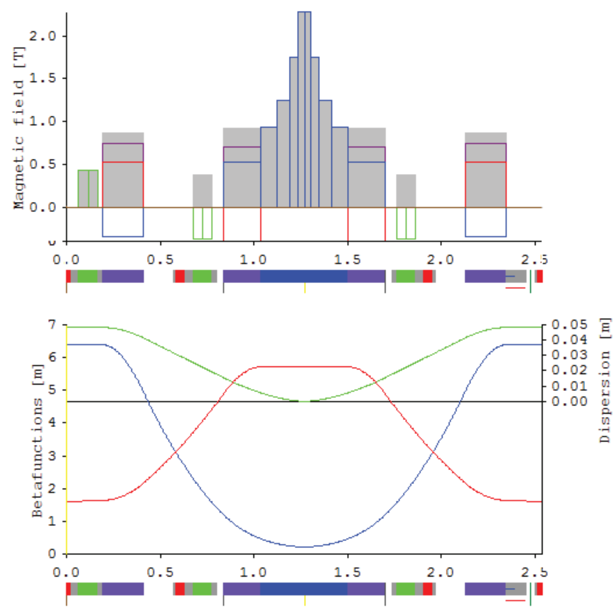

Figure 3: Optics and pole-tip fields for an alternative lattice cell based on high field PM-LGBs and discrete correctors. See caption of Fig. 1 for explanation of plot.

CONCLUSION AND OUTLOOK

The new storage ring of the SLS will provide an emittance of about 125 pm at 2.4 GeV and 400 mA, which is rather low in relation to the small circumference of 290.4 m, and which corresponds to an improvement by a factor 40. A conceptual design of the lattice and all technical systems has been established. Work in progress mainly concerns iterations between magnet and lattice designs, which of course involves other systems like vacuum chambers, girders etc too. It is expected to freeze the lattice in summer 2018 and continue with detailed technical designs to be completed one year later. A proposal for funding has been submitted, and assuming a positive decision the new storage ring may start operation in fall 2024.

[1] In the existing SLS lattice this effect is negligible: for large misalignments the regions, where the decapoles affect the dynamics, are outside the dynamic aperture anyway, and for small misalignments the correctors are too weak for the corresponding decapoles to deteriorate perceivably the dynamic aperture.

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REFERENCES

[1] A. Streun (Ed.), "SLS-2 Conceptual Design Report", Paul Scherrer Institut, Villigen, Switzerland, Rep. 17-03, Dec. 2017.

[2] A. Streun, M. Aiba, M. Böge, M. Ehrlichman, Á. Saá Hernáandez and H. Xu, "Upgrade of the Swiss Light Source storage ring based on a lattice combining longitudinal gradient bends and anti-bends", *ICFA Beam Dynamics Newsletter*, no. 71, J. Gao (Ed.), Aug. 2017, pp. 213–223.

[3] C. Calzolaio, S. Sanphilippo, S. Sidorov, A. Anghel and A. Streun, "Design of a superconducting longitudinal gradient bend magnet for the SLS upgrade", *IEEE Trans. Appl. Supercond.*, vol. 27, no. 4, June 2017.

[4] J. Bengtsson and A. Streun, "Robust design strategy for SLS-2", Paul Scherrer Institut, Villigen, Switzerland, Rep. SLS2-BJ84-001, June 2017.

[5] M. Dehler *et al.*, "Conceptual design for SLS 2.0", presented at FLS'18, Shanghai, China, Mar. 2018, paper WEP2PT038.

[6] C. Gough and M. Aiba. "Top-up injection with 'anti-septum'", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 774–776, https://doi.org/10.18429/JACoW-IPAC2017-MOPIK104

[7] M. Aiba, "Review of injection schemes for electron storage rings and synchrotrons", presented at IPAC'18, Vancouver, BC, Canada, Apr.–May 2018, paper WEXGBE1, this conference.

[8] W. Joho, M. Muñoz and A. Streun, "The SLS booster synchrotron", *Nucl. Instr. Meth.* vol. A 562, pp. 1–11, 2006.

[9] M. A. Domínguez Martinez, F. Toral, H. Ghasem, P. S. Papadopoulou and Y. Papaphilippou, "Longitudinally variable field dipole design using permanent magnets for CLIC damping rings", *IEEE Trans. Appl. Supercond.*, vol. 28, no. 3, Apr. 2018.

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