PROPOSED UPGRADE OF THE SLS STORAGE RING

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Abstract

A new storage ring is planned for the upgrade of the Swiss Light Source (SLS). It will replace the 12 triple bend achromats by twelve 7-bend achromats, which are based on low aperture longitudinal gradient bends (LGBs) and anti-bends (ABs), thus reducing the emittance from 5.0 nm to about 150 pm at 2.4 GeV while maintaining the source points of the undulator based beam lines. Sextupole and octupole strengths are determined using a multi-objective genetic algorithm (MOGA) and result in sufficient dynamic aperture for off-axis injection and several hours of Touschek lifetime. Superconducting LGBs of 5–6 T peak field will extend the photon range of the SLS up to 80–100 keV. The vacuum system will be based on a 20 mm inner diameter copper beam pipe with ante-chamber, and discrete getter pumps. It is planned to reuse the existing injector complex and the dynamically adjustable girder system.

INTRODUCTION

An upgrade of the storage ring of the Swiss Light Source (SLS) is planned for the period 2021-24 in order to keep research with synchrotron light at PSI competitive to other places, where new or upgraded machines of significantly higher brightness and coherence will come to operation within the next years.

The concept for the new storage ring lattice and some of its critical issues as dynamic aperture optimization, orbit correction and injection, and also a round beam scenario have previously been presented [1–5]. In this paper we will summarize recent activities, present the status of lattice design and report on first technological developments.

STORAGE RING LATTICE

The horizontal equilibrium emittance of the storage ring determines the brightness and the coherent fraction of the synchrotron radiation. Due to its inverse cubic scaling with the number of bending magnets in the ring, low emittance requires a miniaturization of components and a large circumference in order to have very many lattice cells. The design of magnets and vacuum chambers is based on a 20 mm diameter beam pipe aperture in order to realize a 2.4 GeV 7-bend achromat arc of only 18 m length. However, the circumference of the ring is limited to 288 m in order to maintain the existing building and beam lines. In order to achieve a competitive emittance in the range of 100–200 pm, a new lattice cell was developed making extensive use of bending magnets with longitudinal field variation (LGBs), in which the field varies along the longitudinal axis. Low emittance optics requires suppressing the dispersion at the LGB center, where the field is highest. Dispersion suppression in a periodic cell of moderate focusing cannot be done with quadrupoles alone but requires small bending magnets of inverse polarity, called anti-bends, in order to disentangle dispersion and horizontal beta-function [1, 6, 7]. In this way, a low emittance of 137 pm (ideal lattice, zero current) is achieved at moderate chromaticity. Any of the LGBs can be replaced by a super-LGB of 5–6 T peak field to be used as hard X-ray source. Figure 1 shows optics and magnet fields for one of three super-periods, and Table 1 lists the most important parameters of the ideal lattice using LGBs with optimum field variation, with 3 of them replaced by super-LGBs.

Table 1: SLS-2 Storage Ring Parameters

Circumference	C [m]	287.25
Working point	$\nu_{x,y}$	37.38, 10.28
Chromaticity	$\xi_{x,y}$	–65.0, –34.5
Momentum compaction	α	$-1.41\cdot10^{-4}$
Beam energy	E [GeV]	2.4
Horizontal emittance	ε [pm]	137
Energy spread	$\sigma_{\Delta E/E}$	$1.03\cdot10^{-3}$
Energy loss/turn	ΔE_{rad} [keV]	579
Damping times	$\tau_{x,y,s}$ [ms]	4.5, 7.9, 6.4

The existing SLS lattice has straight sections of 6 × 4 m, 3 × 7 m and 3 × 11 m length. Since there is little need for long straights, they will be turned into double straights for installation of canted or twin undulators, this also alleviates matching the optics. The upgrade lattice will provide straights of 6 × 2.9 m, 3 × 5.0 m and 3 × 2 × 5.1 m.

The circumference of the lattice is reduced by 0.75 m in order to maintain the source points of all undulator beam lines. However, the source points of the dipole based beam lines will shift inwards by 0.22 m. It is preferred to reuse the existing 500 MHz RF-system if any possible. The reduction of circumference corresponds to 5/4 wavelengths, but inelastic deformation of the cavities allows them to be detuned by –260 kHz in order to adjust the harmonic number to the nearest integer of 479.

Intra-beam scattering (IBS) will increase the emittance by 11% to 150 pm for 400 mA of beam current in 400 bunches, assuming 10 pm of vertical emittance and stretching of bunches to triple length by means of third harmonic cavities. Energy spread will be 0.108% and bunch length 67 ps FWHM.

Due to the anti-bends, the total *absolute* deflection angle of the ring amounts to 585°, and the momentum compaction factor (MCF) becomes negative. With regard to head-tail instability, the ring could be operated at slightly negative chromaticity. If the small absolute value of the MCF gives

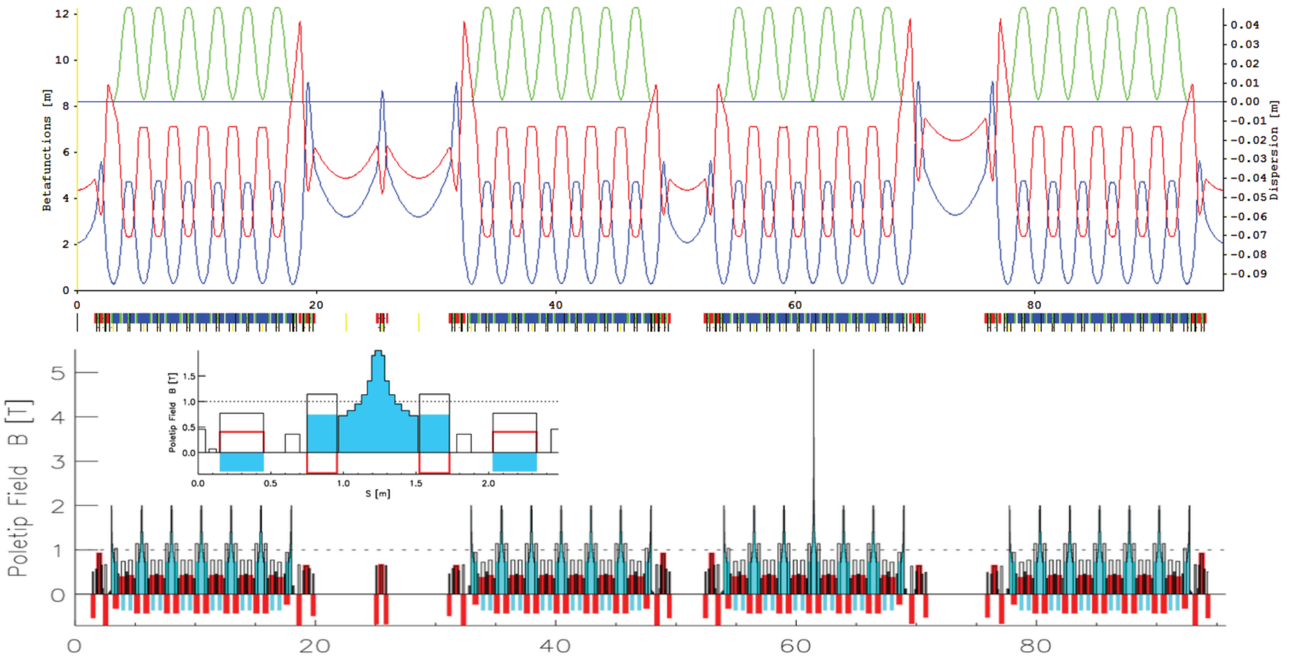

Figure 1: One super-period of the SLS-2 lattice. The upper plot shows the optical functions: β_x in blue, β_y in red and dispersion in green. The lower plot shows the components of the vertical magnetic field $B_y(s)$ at $x = 13$ mm, corresponding to the magnet bore radius: dipole in turquoise, quadrupole in red and total field in black. The insert shows one cell magnified.

rise to microwave instability, the lattice cell could be detuned to trade MCF for emittance. However, studies so far indicate sufficiently high threshold currents although the resistive wall impedance of the narrow copper beam pipe is rather large [8].

Nonlinear Optimization

The horizontal/vertical tune advances of the lattice cell were set to 0.4/0.1 in order to cancel most first order sextupole and octupole resonances over five full cells. The horizontal tune of the ring was set near 37.5, because amplitude dependant tune shift is minimized for a tune of $(k{+}½)N$, with N the super-periodicity and k any integer [9] (Eq.5.87).

There are 4 chromatic sextupole families and 1 chromatic octupole family located inside the MBA arcs, and 3×3 harmonic sextupole and octupole families located in the matching sections for the 3 different types of straights. Small dispersion leads to strong sextupoles although the chromaticity is moderate.

Perturbation theory based methods for optimization of dynamic acceptances do not succeed, instead a tracking based multi-objective genetic algorithm (MOGA) was developed. For highest efficiency it combines objectives like on- and off-momentum dynamic apertures with dominance constraints: these depend on quantities like magnet strength, nonlinear dispersion or chromatic tune footprint, which can be evaluated with little computational effort. Vectors of multipole strengths, called individuals, first compete to fulfill the constraints before the more time consuming optimization with regard to the objectives is started. From the group of successful individuals, some are picked by hand and analyzed further with respect to robustness to misalignments. Thus an on-momentum dynamic aperture of $> (\pm 4) \times (\pm 5)$ mm^2 (trackpoint $\beta_{x/y} = 3.2/6.5$ m) was obtained for all error seeds, which is sufficient for off-axis injection, and a Touschek beam lifetime of 4.5 h for the ideal lattice and $>$ 3.6 h for 95% of the seeds (parameters: 1 mA/bunch, 500 MHz, no harmonic RF, 10 pm vertical emittance, no IBS) [10].

Misalignments

The existing SLS storage ring is equipped with a dynamic alignment system based on 48 girders which can be moved remotely in 5 degrees of freedom with stored beam [11]. It is planned to re-use this system and connect the new magnets, which will be smaller than the existing ones, by intermediate support blocks. Presently ongoing upgrades of the system are already a preparation for SLS-2. An element-to-element alignment of less than 20 μm is expected and a girder alignment of less than 50 μm relative to a reference curve. The lattice is equipped with 150 BPMs and 150 combined horizontal and vertical correctors. The maximum corrector strength will be $< 300\mu$rad. Simulations of optics corrections (aka LOCO) indicate, that beta-beating could be reduced to $<$ 1% with simultaneoous dispersion correction to $<$ 1 mm.

TECHNOLOGY DEVELOPMENTS

Vacuum System

Due to rather high peak field in the LGBs the synchrotron radiation has high power density and requires an antechamber for extraction and discrete crotch absorbers, which probably will be made from GlidCop®. Small but powerful getter pumps, probably of NEXTorr® type, will be attached to the antechamber by CF63 ports and provide an average pressure of $< 10^{-9}$ mbar after 1000 Ah of beam dose. The beam pipe of 20 mm inner radius will be connected to the antechamber by a continuous slit. It will be made from copper or from copper plated stainless steel. The radiation from the anti-bends is emitted towards the inner side of the ring, but since the anti-bends have low field, it can be well absorbed by the beam pipe, which will have a cooling pipe attached locally to its inner side. NEG coating is not foreseen, because for a 1 μm NEG layer the resistive wall impedance in the relevant frequency range of 0.1–1 THz is an order of magnitude larger than for copper, and the activation of the NEG film requires either local heaters or a complex procedure to remove the magnets.

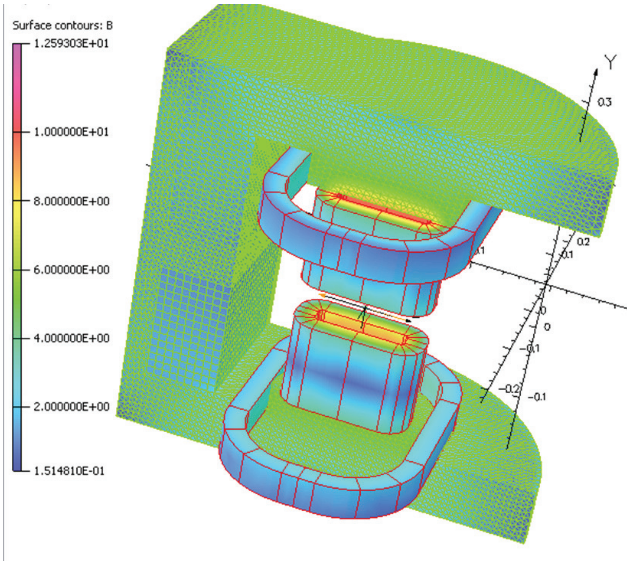

Figure 2: Design of a super-conducting longitudinal gradient bending magnet.

Magnet Design

The longitudinal field profile optimized for low emittance has to be approximated by a feasible magnet. In particular for the super-LGB this is difficult, since the central peak of high field should be rather narrow. A warm bore design is preferred for reasons of operational safety, however, taking into account the thickness of the insulation and the support structure, the distance of the coils to the beam will be larger than the optimum width of the high field peak. Thus a wider peak has to be accepted, which will result in higher radiation loss, larger energy spread and larger emittance.

Figure 2 shows a design of a C-shaped super-LGB of 6 T maximum peak field. The longitudinal field variation is created by two pairs of racetrack coils wound with Nb_3Sn PIT (powder in tube) wires. A cell based on this magnet has 30% larger emittance and 50% larger energy spread compared to the optimum field, however, since only 3 of them would be installed, the increase would be < 4% which is acceptable.

For the normal LGBs it is easier to approximate the optimum field. A first design with 1.7 T peak field provides 2% larger emittance but 2% lower energy spread, which is perfect. In general, the emittance is rather tolerant to deviations of the field profile from the optimum contour.

CONCLUSION AND OUTLOOK

Work is in progress for an upgrade of the SLS storage ring. The lattice provides about 150 pm emittance at 2.4 GeV and fits in the existing circumference of 288 m. Confidence has been acquired, that the lattice acceptances will be sufficient for off-axis injection and to provide several hours of Touschek lifetime even in the presence of misalignments. Orbit and optics corrections have been simulated. It is planned to reuse at least parts of the existing dynamic alignment and radio-frequency systems. Design of normal conducting and superconducting longitudinal gradient bends is in progress. Further work will include detailed studies of impedances and coupled bunch instabilities, mechanical integration of girders, magnets, vacuum systems and diagnostics, possible modifications of the injector and optimization of undulators. It is planned to issue a conceptual report early 2017.

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