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SPECIAL OPERATIONAL MODES FOR SLS 2.0

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Abstract

The SLS 2.0 storage ring will achieve low emittance and high brightness while maintaining large dynamic aperture and lifetime comparable to the present SLS. Special operational modes are investigated to further explore the potential of the lattice. In this contribution, the first considerations on such modes for the SLS 2.0 are outlined. A promising high-brightness mode, increasing brightness by up to 25% at insertion devices with minor deterioration to dynamic and momentum aperture is presented. The use of round beams and its impact on beam dynamics and the beamlines in the SLS 2.0 portfolio is discussed.

INTRODUCTION

One of the main goals of the SLS 2.0 is to minimize the natural emittance of the machine, thereby generating significantly higher brightness than the existing SLS. This is achieved using a seven-bend achromat with longitudinal gradient bends and reverse bends [1, 2]. In this contribution we explore two possible operational modes for SLS 2.0. We investigate the option of a high-brightness mode which lowers the beta-functions at the insertion device (ID) source points. Finally, we show a possible implementation of round beams in SLS 2.0 in combination with one of the high-brightness lattice options, and evaluate the impact on both machine and beamline performance.

HIGH-BRIGHTNESS MODE

Motivation

The goal of the SLS 2.0 lattice design has been to create a lattice that provides an order-of-magnitude higher brightness and higher coherent flux than the existing SLS, without compromising with the dynamic and momentum aperture of the machine [2]. This leads to an ambitious, but realistic design. However, the brightness of IDs can be increased by optimizing the beta-functions in the straight sections further.

We follow the definitions of brightness and spatial coherence as given in [3], defined as:

$$\mathscr{B} = \frac{\Phi_{\mathrm{ph}}}{4\pi^2\sigma_{\mathrm{T}x}\sigma_{\mathrm{T}x'}\sigma_{\mathrm{T}y}\sigma_{\mathrm{T}y'}(d\omega/\omega)}, \tag{1}$$

and

$$\frac{\Phi_{\mathrm{coh}}}{\Phi_{\mathrm{ph}}} = \frac{\lambda^2}{16\pi^2\sigma_{\mathrm{T}x}\sigma_{\mathrm{T}x'}\sigma_{\mathrm{T}y}\sigma_{\mathrm{T}y'}}, \tag{2}$$

where Φ_{ph} and Φ_{coh} are the total and spatially coherent flux, λ is the photon wavelength, σ_{Tu} and $\sigma_{\mathrm{Tu'}}$ are the effective photon source size and divergence defined as

$$\sigma_{\mathrm{T}u} = \sqrt{\beta_u\epsilon_u + \frac{\lambda L}{8\pi}}, \tag{3}$$

and

$$\sigma_{\mathrm{Tu'}} = \sqrt{\frac{(1+\alpha_u^2)}{\beta_u}\epsilon_u + \frac{\lambda}{2L}}, \tag{4}$$

where β_u and α_u are the Twiss parameters at the ID source point. The SLS 2.0 portfolio contains IDs of several different lengths. The brightness and the coherence depends on the ID length, L, and we compute them for a range of $1 \le L \le 3$ m, corresponding to the actual IDs to be installed.

In the following, first the possibilities for brightness improvement without physically modifying the storage ring are investigated. Next, the option of increasing the gradient of quadrupoles will be considered.

The linear optics changes will be restricted to the straight sections to avoid modifying the optimized arc optics. This also means that the equilibrium emittances will remain unchanged.

The baseline SLS 2.0 lattice is designed such that the betatron phase advances along each straight section are the same constant values. The super-periodicity for on-momentum particles is therefore as high as the number of arcs: 12 (“pseudo symmetry”). To maintain good dynamic and momentum aperture, it is beneficial to keep the pseudo symmetry and, hence, the phase advance must be increased equally in all straight sections.

For each proposed solution, a genetic algorithm is used to optimize the nonlinear magnets in the lattice to maximize Touschek lifetime, τ_T. Piwinski’s formula for the Touschek lifetime is used [4], with the nominal “flat beam emittances” $\epsilon_x = 149$ pm rad and $\epsilon_y = 10$ pm rad. All tracking simulations are performed in Accelerator Toolbox [5, 6].

We are interested in the relative increase in brightness and coherence between the baseline SLS 2.0 lattice and the new high-brightness solutions. The denominators of Eqs. (1) and (2) both scale as $(\sigma_{\mathrm{Tx}}\sigma_{\mathrm{Tx'}}\sigma_{\mathrm{Ty}}\sigma_{\mathrm{Ty'}})^{-1}$, meaning that the scaling of brightness and coherence will be the same, and we will therefore only report impacts on brightness.

Solutions-A: Unaltered Machine Layout

Two options are investigated for an unaltered machine layout: increasing the horizontal tune by a full integer (“solution A-1”) or increasing the vertical tune by 0.56 (“solution A-2”). A comparison between the baseline and new Twiss parameters in the straight sections is shown in Table 1, and the relative brightness increases for IDs of the three lengths are shown in Fig. 1 for solution A-1 and A-2 as solid and dashed lines, respectively. Qualitatively, short IDs have the largest gain in brightness. Solution A-1 provides the biggest increase around the soft x-ray region of 1 keV photon energies, while solution A-2 is most beneficial around hard x-rays at 10 keV. Long straight sections benefit in a broader spectral range; for high photon energies this stems from the smaller values of α_x and α_y at the source points.

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Table 1: Optics of baseline and high-brightness lattice solutions. Twiss parameters refer to the source points of short (SS), medium (MS), long straight #1 (LS#1) and long straight #2 (LS#2), respectively.

Lattice	Source	Baseline	A-1	A-2	B-1
Q_x	-	39.37	40.37	39.37	40.37
Q_y	-	15.22	15.22	15.78	15.78
β_x [m]	SS	2.5	1.4	2.5	1.5
	MS	3.4	2.0	3.5	2.0
	LS#1	9.3	7.2	9.5	7.0
	LS#2	7.8	5.0	8.0	5.3
β_y [m]	SS	1.3	1.3	0.6	0.5
	MS	2.4	2.3	1.2	1.0
	LS#1	6.5	6.4	5.4	5.9
	LS#2	5.8	5.7	3.3	3.0
α_x	SS	0.0	0.0	0.0	0.0
	MS	−0.1	0.0	−0.1	0.0
	LS#1	−0.4	0.0	−0.7	−0.1
	LS#2	0.4	0.0	0.5	0.1
α_y	SS	0.0	0.0	0.0	0.0
	MS	−0.1	−0.1	0.2	0.2
	LS#1	−0.9	−0.8	0.1	0.2
	LS#2	0.7	0.6	−0.1	−0.2
τ_T [h]	-	5.4	4.7	4.8	<1

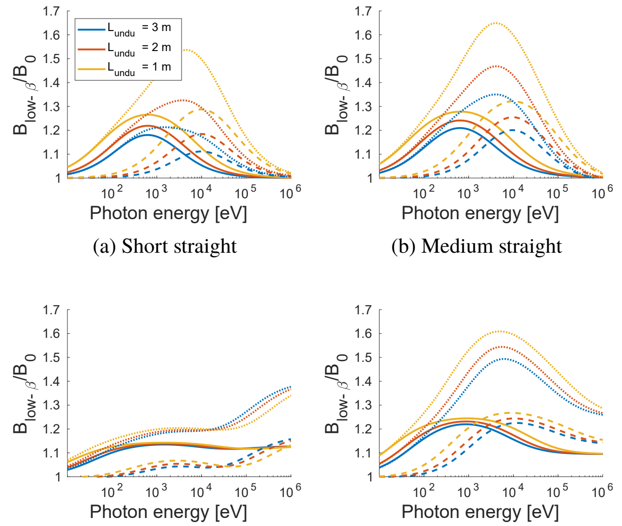
The results for the on- and off-momentum dynamic apertures without errors are shown in Fig. 2. The physical aperture restriction is 5.0 mm, i.e., the dynamic aperture is still outside the physical aperture of the chamber. The Touschek lifetime (with physical aperture but without third harmonic cavity) is found to be 4.7 h and 4.8 h for solutions A-1 and A-2, respectively, corresponding to a 13% and 11% reduction compared to the nominal lattice lifetime of 5.4 h.

Solutions-B: Modified Machine Layout

The potential phase advance increase is limited in the short straight sections due to the limited strength of quadrupoles in the matching sections. An option of installing stronger quadrupoles is evaluated as a hypothetical future upgrade option. We investigated a working point of [40.37, 19.78], i.e., combining the features of solutions A-1 and A-2, that requires the stronger, but still achievable, quadrupole strength $118\,\mathrm{T\,m^{-1}}$.

The relative increase in brightness is shown as the dotted lines in Fig. 1. This solution exceeds the previous two with significant gains particularly in the tender and hard x-ray range. For one of the flagship beamlines, I-TOMCAT, a hard x-ray beamline based on a 1 m high-temperature superconducting undulator in a short straight section [1, 7], the expected increase in brightness at 10 keV is around 50%.

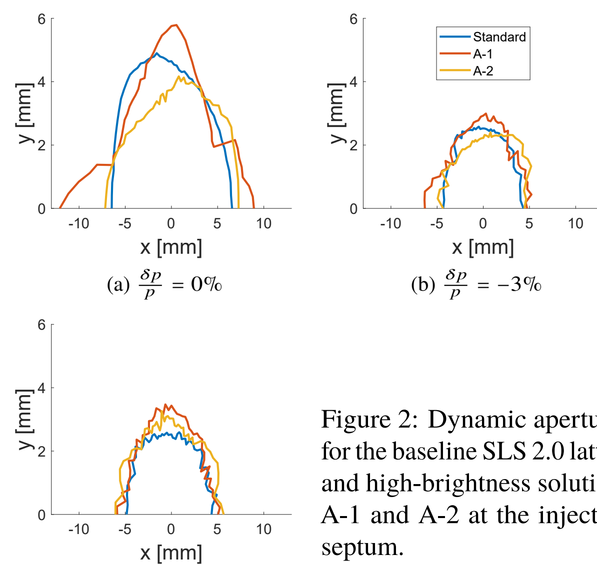
The nonlinear optimization of this solution has yet to yield satisfying Touschek lifetime; the working point is close to the $Q_x + 2Q_y = 72$ resonance, which is systematic for a twelve-fold symmetric machine, and is suspected to be the limitation for this lattice solution. Other modified lattices



(a) Short straight (b) Medium straight

(c) Long straight #1 (d) Long straight #2

Figure 1: Ratio of brightness between the nominal SLS 2.0 lattice and high-brightness options A-1 (solid lines), A-2 (dashed lines) and B-1 (dotted lines) in each straight section for various undulator lengths.



(a) $\frac{\delta p}{p} = 0\%$ (b) $\frac{\delta p}{p} = -3\%$

(c) $\frac{\delta p}{p} = +3\%$

Figure 2: Dynamic apertures for the baseline SLS 2.0 lattice and high-brightness solutions A-1 and A-2 at the injection septum.

with, e.g., working points [40.37, 16.22] are currently under development.

Further Considerations

For the high-brightness lattices with increased horizontal tune, the smaller β_x at the source points comes with the increased horizontal phase advance. Due to the twelve-fold pseudo symmetry it becomes more challenging to maintain a large value of β_x at the injection point, which is used to increase the dynamic aperture for off-axis injection. Nevertheless, the nonlinear optimization provides on-momentum dynamic apertures exceeding the physical apertures.

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Increasing the focusing gradient of the quadrupoles is technologically challenging, and it might therefore be simpler to install additional quadrupoles within the straight sections. This would, however, limit the available length for IDs. The trade-off between ID length and stronger focusing at the source points must be thoroughly evaluated.

ROUND BEAM MODE

Motivation

The use of round beams means redistributing the equilibrium emittance between the two transverse planes. Two benefits arise from this: the horizontal emittance is lowered, while the Touschek lifetime is increased and intrabeam scattering is reduced. Round beam operation is being considered and tested at several light source including SLS 2.0 [8–13]. The simplest way to generate the round beam is by operating the storage ring on the linear difference resonance $Q_x - Q_y = p$, where p is an integer. On the resonance the emittances will become [14]:

$$\epsilon_x = \epsilon_y = \epsilon_0 \left(\frac{J_x}{J_x + J_y} \right), \tag{5}$$

where ϵ_0 is the natural emittance, J_x and J_y are the horizontal and vertical damping partition numbers, respectively. For SLS 2.0, with a natural emittance of 149 pm rad, $J_x = 1.85$ and $J_y = 1$, the emittances will become $\epsilon_x = \epsilon_y =$ 96 pm rad.

The "A-1" high-brightness lattice setting has the attractive feature that the horizontal and vertical beta-functions at the ID source points in all sections are approximately equal. This means that, by coupling the beam transversely, it is possible to create photon beams with approximately identical sizes and divergences in both transverse planes.

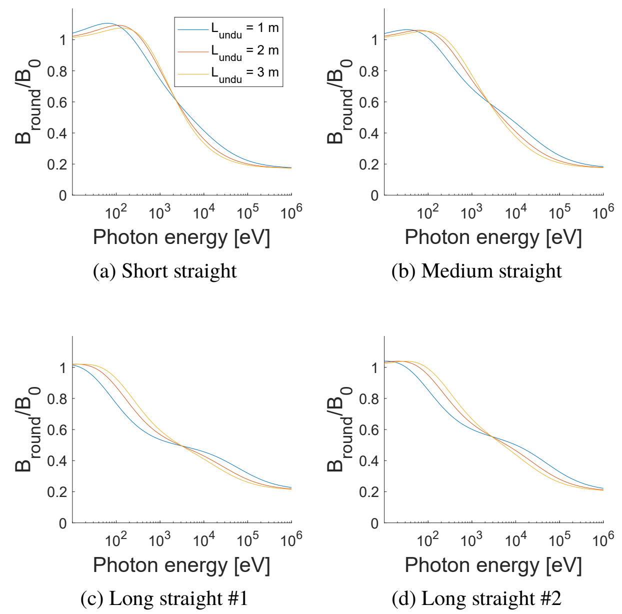
Optics Options

For this purpose, a special version of the "A-1" solution is developed, henceforth called "A-1R", with the working point [40.37, 15.37]. Optical functions do not differ significantly from the values in Table 1. A coupling coefficient of $|C^-| =$ 0.01 is introduced using 72 non-dispersive skew quadrupoles. This value is selected to ensure that all particles within the equilibrium bunch experience resonant coupling [13].

To quantify the effect of the coupling sources on the lattice performance, we calculate the Touschek lifetime for both the uncoupled and coupled lattices using the flat beam emittances including the physical apertures. The lifetimes become 4.3 h for the uncoupled and coupled lattice. Next, the Touschek lifetime is evaluated using the round beam emittances (Eq. (5)). This leads to $\tau_T = 10.6$ h, around a factor two larger than for the baseline SLS 2.0 lattice.

Beamline Perspective

The denominators of Eqs. (1) and (2) contain the electron beam sizes and divergences and, hence, the emittances. The larger vertical emittances will thereby lead to lowering the brightness and spatial coherent flux for the round beam mode.



(a) Short straight (b) Medium straight

(c) Long straight #1 (d) Long straight #2

Figure 3: Ratio of brightness between the nominal SLS 2.0 lattice and round beam lattice solution A-1R with working point [40.37, 19.37] in various straight sections for different undulator lengths.

Figure 3 shows the brightness of the round beam lattice relative to the baseline lattice as a function of photon beam energy. Not all beamlines may benefit from the round beam mode, but it can be enabled upon request and by agreement with the users.

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