ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPJE046

INVESTIGATION OF THE INJECTION SCHEME FOR SLS 2.0

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Abstract

SLS 2.0, an upgrade of the Swiss Light Source (SLS), aiming at a natural horizontal emittance in the range of 100 pm, is planned and under study. This will be achieved by replacing the current magnet lattice of the electron storage ring by a new multibend achromat magnet lattice, while reusing the injector chain and most of the existing infrastructures. The new low emittance ring will impose more restrictive constraints on injection due to a smaller machine aperture and a very compact lattice, dominated by non-linearities. We performed a study to find the optimum injection scheme for SLS 2.0 among the conventional and more advanced schemes; namely multipole kicker injection (off-axis and also on-axis matched to the off-momentum closed orbit) and longitudinal injection.

INTRODUCTION

SLS 2.0, a low emittance upgrade of the Swiss Light Source (SLS) is planned and under study [1]. This will be achieved by replacing the current lattice of the storage ring by a new multibend achromat lattice [2], while reusing the injector chain and most of the existing infrastructures. Various lattices are currently being developed in an iterative process. The latest stable lattice version released, named *ah04n*, provides a natural horizontal emittance of 183 pm·rad in a 288 m ring circumference. But this lattice, as most low emittance lattices, imposes restrictive constraints on injection due to a small machine aperture (10 mm inner beam pipe) and dynamic aperture (~8 mm for on-momentum particles and <5 mm for particles with a momentum deviation of ± 3%). Additionally, the lattice is very strong-focusing and is dominated by non-linearities as natural chromaticities of -163/-70 in units of 2π (horizontal/vertical) have to be corrected. We investigated different injection options aiming to fulfill the following soft (S) and hard (H) constraints:

- (H) top-up compatible.
- (H) compatible with the booster output parameters: horizontal (vertical) emittance of 7 (1) nm·rad, bunch length of 19 mm and momentum spread of 0.08%.
- (S) avoid the use of a kicker bump, in order to improve the photon beam stability.
- (S) transverse on-axis injection in order to relax the requirements on dynamic aperture. The option of a round beam, under consideration at this stage of the design, could only be implemented if injection is (quasi) on-axis.
- (S) compact layout, ideally compatible with the installation of other devices in the same straight section.

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INJECTION SCHEMES FOR SLS 2.0

Different injection options for SLS 2.0 are briefly described. After their drawbacks are considered they are either discarded or further developed.

Conventional Injection

The conventional injection scheme, also used at SLS [3], employs a static septum and a dynamic magnetic chicane (or kicker bump). The bump rises to bring the closed orbit to the vicinity of the septum at the time of injection and falls within a few electron beam revolutions to prevent the injected bunch being lost at the septum. In this scheme, the injected bunch is transversely separate from the circulating bunches and performs large betatron oscillations before it is merged into the circulating beam due to synchrotron radiation damping.
We built an injection insertion into the lattice *ah04n* on the long (10 m) straight section where the present transfer line from the booster ends. The injection point (IP) remains located in the middle of the straight and the four dipole kickers are symmetrically positioned at both sides of the IP. Kicker deflections of 2.2 mrad would be needed to generate a bump of 7 mm amplitude. Assuming a bump half-sine time of 4 μs, the kickers would be active for 4 turns. If a septum thickness of 2.5 mm and a conservative clearance value of 2.5 mm are also assumed the beam could not be injected with a distance smaller than 7.5 mm of the bumped orbit. The resulting oscillations around the stored beam during the first turns would have amplitudes >10 mm, bigger than the physical and dynamic apertures and therefore not feasible. A horizontal beta function bump could also be created with the use of the matching sections at both sides of the straight, but the consequent break of lattice symmetry is not desired at this point of the design. Therefore this injection scheme is not our favourite option for SLS 2.0.

An on-axis version of this scheme was implemented in LEP [4] and has also been investigated. In this scheme the kickers are situated on a dispersive straight section and the bunch is injected on-axis, but with a momentum offset, onto the corresponding closed orbit. We rapidly discarded this option for SLS 2.0 since the required dispersion (7.5 mm / 3 % = 2.5 m) is not compatible to the low emittance lattice design.

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Longitudinal Injection

In the longitudinal injection scheme [5], the bunch can be injected transversely on-axis because the separation is done in the longitudinal phase-space by injecting with a time offset from the circulating bunches. The longitudinal phase space in the presence of synchrotron radiation shows a separatrix with the shape of a "golf-club" with its shaft extending towards the neighboring bucket. Thus, not only the particles in the static bucket, but also on the shaft are stable. When the height and width of the tilted shaft are sufficient to accept the energy and time spread of the bunch, one can inject at such a point between two successive circulating bunches, at the expense of a higher energy from the injector. The injected bunch is finally merged to the circulating bunch through synchrotron radiation damping. For the injection to be transparent to the circulating bunches the kicker field has to be shorter than the bunch spacing.

Two RF frequencies are under consideration for SLS 2.0: 500 MHz (the RF frequency of SLS) and 100 MHz. The voltage of the RF cavities has been chosen such that the bucket height meets the target off-momentum transverse dynamic aperture (4%). For the 500 MHz case if injection is done with a phase-offset (or time-offset) equidistant between two buckets, the width of the tilted shaft is 3 times shorter than the booster bunch length. This phase offset has been chosen to relax the kicker pulse length requirements. Still, the pulse length should not be longer than 2 ns in order to be transparent to the circulating beam. Thus, the very tight requirements for the kicker pulse length together with the difficulties to accommodate the long bunch from the booster into the shaft without losses (feasibility of booster RF gymnastics in order to tilt the bunch such to match to the shaft should be investigated) make this injection scheme for the 500 MHz RF frequency not attractive. Instead, for the 100 MHz case the shaft is 1.7 times longer than the bunch length at 120° from the synchronous phase, enough to accommodate a bunch injected with +4.2% momentum offset. The kicker requirements are also more relaxed in this case, as the pulse length could have a maximum value of 6.6 ns. A bunch of 1000 particles with the booster output parameters has been tracked for 15000 turns using the code Elegant [6] to study the dynamics of the injection in 6D, including the RF cavities and synchrotron radiation effects. No particles were lost and the tracked particles on the longitudinal and transverse horizontal phase-space are shown in Fig. 1. It has to be noted that a higher harmonic cavity, which would enlarge the stable bucket, has so far not been included in this simulations.

Multipole Kicker Injection

In the multipole kicker injection scheme the injected bunch passes through a pulsed multipole magnet, typically a quadrupole or a sextupole, with an offset from its center while the circulating bunches pass through the center [7]. Thus, the scheme is compatible with top-up injection and the disturbance to the circulating bunches is significantly

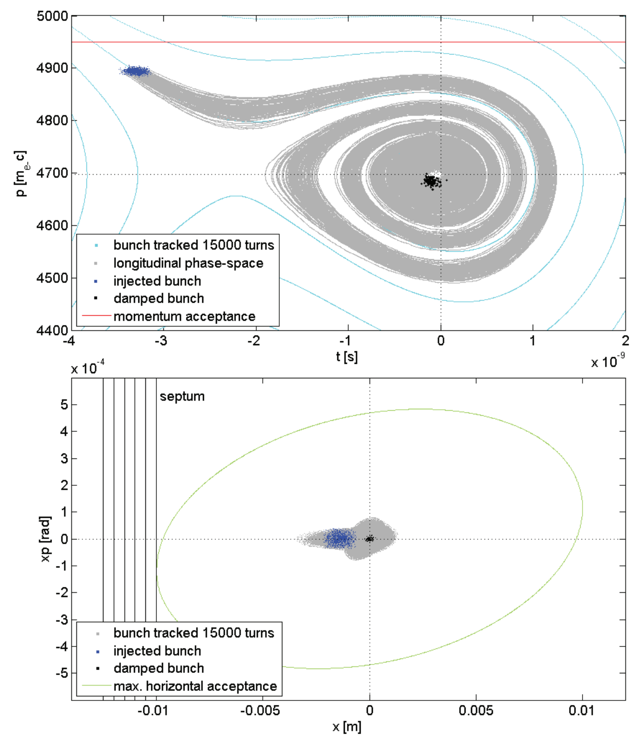

Figure 1: Longitudinal injection of a bunch from the booster on SLS 2.0 assuming an RF frequency of 100 MHz. Up: longitudinal phase space. Down: transverse horizontal phase space.

suppressed, but it is transversely off-axis by definition.

We built an injection insertion in the *ah04n* lattice, in which the beam would exit the septum at a position x_{inj}=-15 mm (inner side of the ring) with an angle x'_{inj}=1.3 mrad at the beginning of the long straight section. The multipole kicker, a pulsed sextupole magnet (PSM) in this case, would be placed 9.94 m downstream, at the end of the same section. Thus no magnets would be used to steer the beam to the multipole kicker, enabling a more robust injection scheme, whose performance does not depend on magnet alignment and/or field quality. The injected bunch would enter the PSM with a horizontal offset of 6 mm, corresponding to an invariant of A_0^2=35.2 mm·mrad. To be kicked into a reduced invariant of A^2_{red}=1.8 mm·mrad the PSM integrated gradient needs to be $b_3 \cdot L$=24.55 m^{-2}, corresponding to a pole-tip field of 0.1 T for a sextupole of 0.8 m length and 20 mm aperture radius. The injected trajectory kicked by the pulsed sextupole would perform oscillations around the closed orbit with maximum offsets of 6 mm, that is within the dynamic aperture for on-momentum particles, until it is damped.

A bunch of 1000 particles with the booster output parameters has been tracked using the code Elegant [6] to study the dynamics of the beam. In Fig. 2 the bunch is shown at the injection point (IP), just before the PSM, after being kicked by the PSM and the damping produced when tracked for 15000 turns including RF cavities and synchrotron radiation

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effects. 6% losses were observed during the tracking on an ideal lattice.

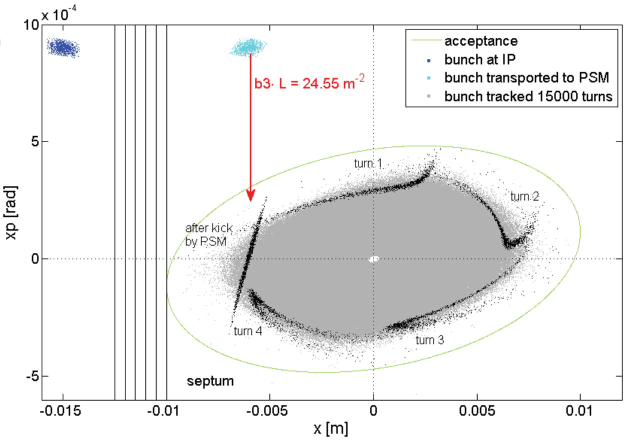

Figure 2: Multipole kicker injection of a bunch from the booster on SLS 2.0.

Off-momentum Multipole Kicker Injection

The off-momentum multipole kicker injection is an on-axis version of the standard multipole kicker injection. It also employs a static septum and a multipole kicker, but in this case the beam is injected with a momentum offset onto the corresponding off-momentum closed orbit, so it will not perform betatron oscillations. The multipole kicker has to be situated at a position of non-zero dispersion, ideally close to a dispersion peak in order to decrease the requirements on kicker gradient. The injected bunch merges the circulating beam as the momentum offset is damped.

We built an injection insertion using two pulsed sextupole magnets (PSM 1 and PSM 2) with integrated gradients of 25 m^{-2} and 45 m^{-2} (0.1 T and 0.18 T pole-tip fields, resp.). A bunch injected horizontally with coordinates x_{inj}=-12.1 mm, x'_{inj}=-0.42 mrad and a momentum offset of +4% matches the closed orbit with a resulting reduced invariant of 0.1 mm·mrad after being kicked by the two pulsed sextupoles. Tracking simulations performed with Elegant [6] for 15000 turns and a bunch of 1000 particles with the booster output parameters show 2% losses for this scheme. The footprints in longitudinal and transverse horizontal phase-space are shown in Fig. 3.

Swap-out Injection

A swap-out injection scheme has been proposed for the APS upgrade [8]. In this scheme full current bunches are injected onto the closed orbit and the circulating bunches, which are occupying the on-axis phase-space volume, are kicked out. It can work on a bunch-by-bunch mode or even swapping the entire bunch train at once when the beam current decreases below a threshold of the top-up injection.

A septum and a dipole kicker with a short/long pulse length are needed for the bunch-by-bunch/entire train modes.

The swap-out injection is an on-axis scheme that does not need an injection chicane. However, we may discard this

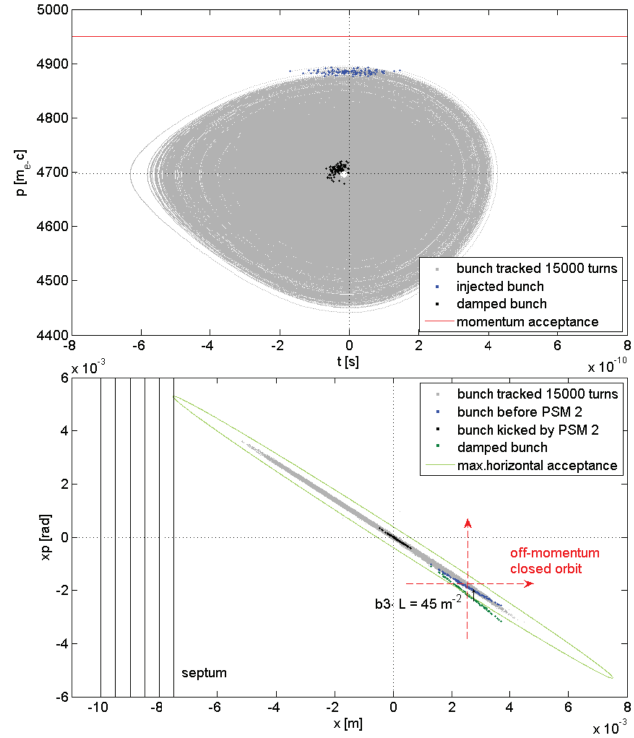

Figure 3: Off-momentum multipole kicker injection of a bunch from the booster on SLS 2.0. Up: longitudinal phase space. Down: transverse horizontal phase space.

option for SLS 2.0 because it is difficult/impossible for the injector chain to provide full charge bunches for 500 MHz (1 mA) / 100 MHz (5 mA). In order to swap the entire train at once we would need an additional storage ring, which would make this option very expensive and, furthermore, would not fit on the present tunnel.

CONCLUSIONS

Different schemes have been considered for the injection of the beam from the booster into SLS 2.0. To do so injection insertions have been built, the parameters of the corresponding injection elements (dipole or sextupole kickers, RF voltages, etc) have been optimized and 6D tracking simulations have been performed. The conventional injection results not so attractive because the large initial betatron oscillations do not fit well with the reduced physical and dynamic apertures of the lattice. The on-axis version of the conventional injection has already been discarded since the required dispersion is not compatible to the low emittance lattice design. Also the swap-out injection has been discarded due to the technical difficulties and cost. Instead, the application of alternatives schemes like the multipole kicker injection (on and off-momentum) and the longitudinal injection seems feasible, though further investigations including a 3^{rd} harmonic cavity and injection errors are needed.

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