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IMPROVEMENTS TO THE SLS BOOSTER SYNCHROTRON PERFORMANCE TOWARDS SLS 2.0

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Abstract

The Swiss Light Source (SLS) storage ring will undergo a major upgrade to a multi-bend achromat lattice. The existing injector complex will be reused with few modifications. However, the SLS booster synchrotron has not been studied since the initial commissioning in years 2000-2001. We plan to apply an emittance exchange in the booster to lower the horizontal emittance, which is a critial parameter for the injection. Here, we present improvements to the SLS booster as a preparation for SLS 2.0 upgrade project. The vertical beam size is decreased by 50% by the use of vertical orbit correctors without beam position monitors, leading also to suppression of vertical dispersion and a factor 10 reduction of the transverse coupling coefficient. The emittance exchange reflected these improvements in the horizontal emittance, achieving a factor of 9-10 reduction. Lastly, a fast head-tail instability limiting the injection rate into the storage ring is discovered and subsequently suppressed by correcting the chromaticities.

INTRODUCTION

Many existing synchrotron light sources are currently either planning or in the process of upgrading their storage rings to a multi-bend achromat (MBA) lattice. The goal is to minimize the electron beam emittance, thereby increasing the photon beam brightness for the users. Most facilities aim to reuse their current injectors in order to reduce costs and to minimize downtime. The Swiss Light Source (SLS) is one of the light sources planning an MBA upgrade called SLS 2.0 [1]. The existing injector complex, consisting of a 100 MeV linac and a 0.1-2.4 GeV booster synchrotron, will be kept with only minor modifications. Lately, an effort has been put into ensuring that the quality of the injection beam coming from the booster will meet the requirements for the SLS 2.0 upgrade. In this contribution, we will show two improvements of the booster performances.

Top-up injections into the SLS 2.0 storage ring will, as a first step, be performed using a traditional horizontal off-axis injection using a 4-kicker bump. Later, an injection scheme based on a short-pulse kicker will be used for single-bunch aperture sharing injections, perturbing only few bunches [2], and thereby lead to quasi-transparent injections.

To minimize the storage ring acceptance needed to capture the injection beam, we will be using the emittance exchange by coupling resonance crossing technique [3, 4], as was recently demonstrated at the SLS booster [5]. During emittance exchange the large horizontal emittance is swapped with the small vertical emittance.

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VERTICAL BEAM SIZE MINIMIZATION

In [5], a substantial transverse coupling of the booster was found with a coupling coefficient of $|C| \approx 0.02$. The skew quadrupolar fields lead to the transverse coupling can stem from the rotation of normal quadrupoles, but may also appear due to vertical beam offsets in sextupoles. This can be seen by analyzing the kick a beam will see by passing through a normal sextupole with such an offset [6]

$$\Delta x' - i\Delta y' = k_2 L[(x+iy)^2 + 2i(x+iy)\delta y - \delta y^2] \quad (1)$$

where $k_2 L$ is the integrated sextupole strength and δy is the centroid offset in the sextupole. The second term of Eq. (1) is equivalent to a skew quadrupole kick with a strength directly proportional to δy. All dipoles in the SLS booster contain sextupole gradients for rough chromaticity correction, and two sextupole families are incorporated into the matching sections for fine corrections [7]. In total 111 magnets contain sextupole components. In operation the orbit has only ever been corrected at the injection energy, i.e., the correctors are not ramped. The orbit is seen drifting during the ramp, and currently a proper correction cannot be done at maximum beam energy due to an insufficient number of beam position monitors. Therefore, we hypothesize that vertical orbit offsets are the cause of the large value of $|C|$ in the SLS booster.

The skew quadrupolar fields leads to not only betatronic coupling, but also substantial unwanted vertical dispersion. These effects lead to a large vertical beam size. A decoupling of the transverse planes would therefore improve the beam quality. However, since we cannot measure and correct the vertical orbit, we instead use the vertical beam size as measured in the booster-to-ring transfer line (BRTL) as an indicator of the transverse coupling.

To minimize the vertical beam size, we adjust the vertical orbit by ramping the corrector magnets and recording the beam size on a screen monitor in the BRTL. The measured beam size on the screen monitor (neglecting monitor resolution) is given by

$$\sigma_y = \sqrt{\beta_y \epsilon_y + \left(\sigma_\delta \eta_y\right)^2}$$

In order to maximize the beam size response to the corrector changes, we choose a screen monitor with large value of β_y.

The minimization of the vertical beam size is split into two processes. First, we use vertical closed-orbit bumps around the ring with three correctors. Both positive and negative bump amplitudes are attempted. If a bump leads to a decrease of the vertical beam size we further increase the bump amplitude. When the amplitude is optimized we continue with the next three correctors. Second, after all

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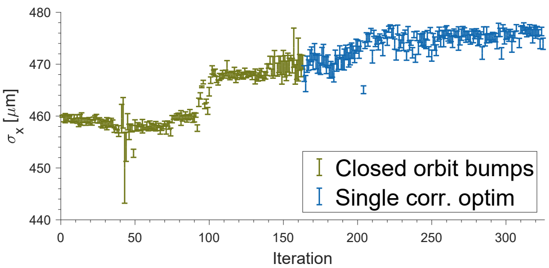

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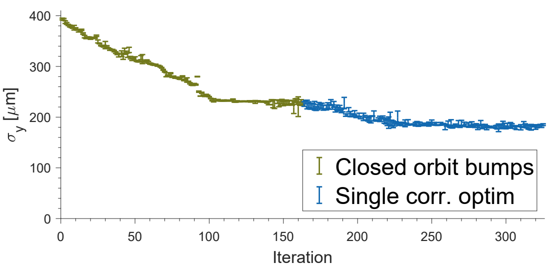

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Figure 1: Vertical (a) and horizontal (b) beam sizes measured on a screen monitor in the SLS booster-to-ring transfer line during the vertical beam size minimization.

combinations of closed-orbit bumps have been tested, we try to adjust each corrector individually one by one in small steps. The whole set of correctors are gone through a few times to ensure that a (local) minimum has been found. The convergence of the minimization is presented in Fig. 1. The first half of the procedure (green points) shows the minimization using closed-orbit bumps, while the second half (blue points) shows the minimization using single correctors. The result of the procedure is an approximately factor 2 decrease in the vertical beam size. The reduction in the transverse coupling is measured using the closest tune approach. We find $|C| \approx 0.002$, which corresponds to an order of magnitude reduction. We note that it is possible to control $|C|$ by simply scaling the corrector pattern as indicated by Eq. (1).

Changing the coupling of the booster influences the emittance exchange through coupling resonance crossing. With a smaller coupling, the stop-band of the resonance is thinner. This allows us to further optimize the emittance exchange setting, for instance, the working point beofre and after crossing to avoid emittance sharing.

The procedure introduced in [5] was repeated. The transverse beam sizes were measured during the resonance crossing by extracting the beam to the transfer line for different extraction timings as shown in Fig. 2. The achieved horizontal horizontal beam size of 137 µm is a factor 1.6 lower than in the initial emittance exchange experiments presented [5] made prior to the vertical beam size. These results indicate a factor 9-10 reduction of the horizontal emittance down to $\epsilon_x \approx 1$ nm rad.

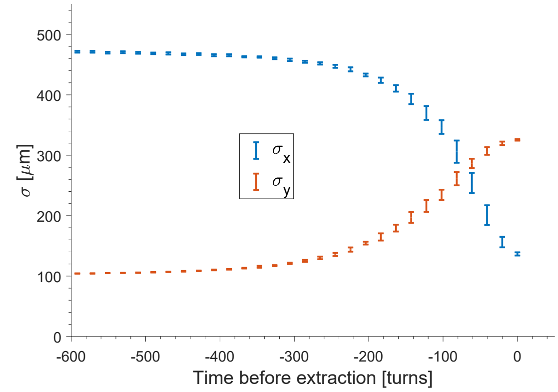

Figure 2: Beam size measurement for various extraction kicker delays on a screen monitor in the SLS booster-to-ring transfer line after applying the vertical beam size minimization.

INSTABILITY ENCOUNTER AND CURE

An unexpected consequence of the vertical beam size minimization was an observed increase in beam centroid jitter on the screen monitor. The cause was investigated by measuring the jitter as a function of the bunch current. At the same time, we scaled the corrector patterns used for the minimization in order to see if the jitter would scale with the vertical beam size. A plot for the standard deviation of the measured centroid position on the screen monitor is presented in Fig. 3. A clear correlation between bunch charge, beam size and jitter is seen. A similar behavior was observed during the initial commissioning of the SLS booster [8]. All dipoles in the SLS booster are built with sextupole components for chromaticity correction, ideally leading to $[\xi_x, \xi_y] = (+1, +1)$ without the need for extra sextupoles [7]. However, extra sextupoles are needed to ensure positive chromaticities due to eddy currents induced by the magnet ramping [9]. During the initial commissioning these extra sextupoles were turned off and an instability was observed [8]. The problem was then solved by setting the sextupole ramps that would, in calculation, lead to $[\xi_x, \xi_y] = (+5, +5)$. After that the instability was found to disappear [8].

To confirm that the sextupole ramps were indeed correct, we measured the chromaticities at the very end of the ramp. The chromaticity can be measured by first shifting the rf frequency which leads to a beam energy shift and then measure the tunes. The measured tune shifts as a function of the beam energy shift, $\frac{\Delta P}{P}$, are [10]

$$\delta Q = \xi \frac{\Delta P}{P} = -\frac{\xi}{\alpha_c} \frac{\Delta f}{f_{\mathrm{rf}}}$$

The horizontal and vertical chromaticity measurements are shown in Fig. 4. Surprisingly, we found the chromaticities to be $[\xi_x, \xi_y] = (+7.9, -2.1)$. By increasing the SD sextupole families, it was possible to bring the chromaticities to $(+5.5, +4.8)$. After the chromaticity correction we found that the instability had indeed disappeared. See Fig. 5 for a

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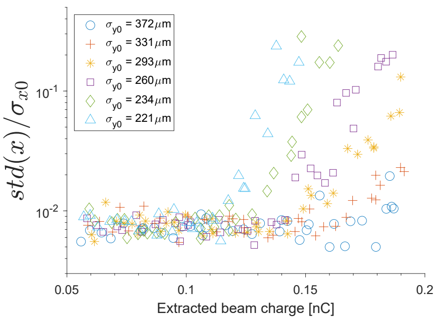

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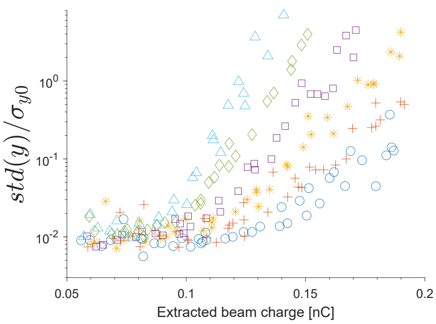

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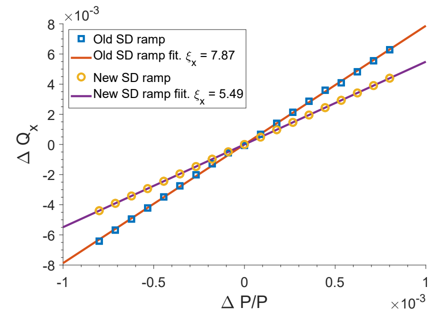
Figure 3: Beam jitters as a function of beam charge and vertical beam size measured at low beam charge in the SLS booster-to-ring transfer line.



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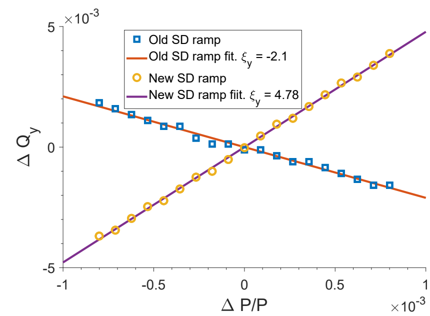

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Figure 4: Chromaticity measurements at the end of the booster ramp with the old and new magnetic ramps for the SD sextupole family. The modified ramp leads to a change in chromaticity $[\xi_x, \xi_y] = (+7.9, -2.1) \Rightarrow (+5.5, +4.8)$.

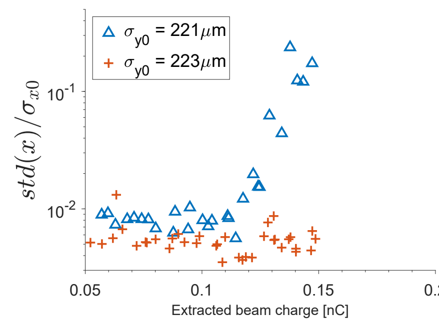
comparison of the transverse centroid jitter before/after the instability compensation.

Until recently, the SLS booster bunch charge in operation was kept at around 0.18 nC, since increasing the bunch charge would introduce the instability, leading to a limited accumulation rate of $\approx$ 25 − 30 mA min^{-1}. After the introduction of the new SD sextupole ramp and subsequent vertical beam size minimization, we were able to increase the injection rate to 50 mA min^{-1}.

CONCLUSION

The SLS booster synchrotron will serve as the injector for the upgrade SLS 2.0 multi-bend achromat storage ring. Therefore, we have sought to improve the beam quality of the booster beam. A vertical beam size minimization using orbit bumps was performed to decouple the beam transversely. A 50% reduction of σ_y was found together with a factor 10 decrease in $|C|$ from 0.02 to 0.002. After the minimization procedure, we used the emittance exchange by coupling resonance crossing technique. We achieved a horizontal emitances of the booster beam of around 1 nm rad.

An instability was observed in the booster, which was found to be correlated to both bunch charge and vertical beam size. It was concluded that the instability was stemming from negative vertical chromaticity. A subsequent correction of the chromaticities suppressed the instability, allowing for higher bunch charge operation in the booster.



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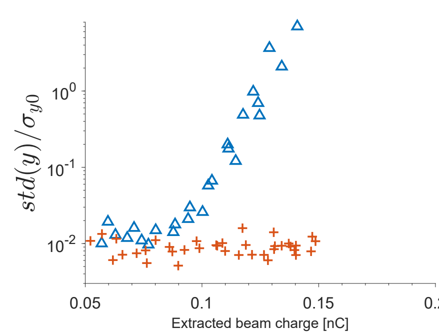

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Figure 5: Beam jitters as a function of beam charge before (blue triangles) and after (red crosses) chromaticity correction.

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