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Autor(en) / Author(s)	Masamitsu Aiba and Andreas Streun	Datum / *Datee*: 11.03.2021

Summary

A layout of injection straight section is discussed: two injection schemes, namely the conventional injection scheme and an injection with short pulse kicker, are applicable to SLS2. With a thin final septum, they can be quasi-on-axis injection, fulfilling the demand from the insertion device, i.e., the physical aperture can be ±2 mm in both plane. The layout proposed enables both injection schemes, providing a backup solution for one or the other.

The required aperture can be even smaller when these two injection schemes are combined: the oscillations of the beams can be limited to ±1 mm or less at in-vacuum undulator locations. It is noted, however, that the beam lifetime is deteriorated by a horizontal aperture below ~3 mm (full).

The injection is to be implemented in the horizontal plane. In the previous version of this note, an injection in the vertical plane was considered but it turned out that it does not work due to collective effects. The dynamic aperture at the septum is about ±6 mm in the horizontal plane (for β_x=23 m) with machine imperfections, which is sufficient for the proposed injection schemes.

History

From Version 1 to 2

The lattice B025 was used in the previous version. This updated version is for the lattice B038. The major changes between B025 and B038 are 1) the normal bend BN is converted to a flat dipole (no longitudinal gradient bend) and 2) the photon extraction issue is solved by inserting the sextupole SDM between BEH and BEV magnets. These changes do not directly influence the injection layout but vary the optics parameters at the end of the matching section.

The injection straight is slightly modified to have more space between elements. This result is going to be integrated, generating B039 lattice.

From Version 2 to 3

The kick angle of short pulse kicker, about 320 μrad, is added to Figure 6 caption.

From Version 3 to 4

The injection plane is switched from the vertical plane to horizontal plane.

Introduction

The injection into SLS2 and the layout of injection straight section are discussed, including relevant findings that we come up after CDR was published. It is important to fix the layout as soon as possible to build SLS2 as scheduled.

Changes and findings after CDR

The following points are important changes and findings since CDR:

1) "Pseudo symmetry lattice" is introduced by A. Streun in order to fit the SLS2 storage ring into the existing tunnel structure. It is realized by imposing a constraint that the phase advances in the horizontal and vertical planes over the straight section are identical while the length of the straight section and the beta functions are arbitrary. The super-periodicity of the lattice is as high as 12 for the on-momentum particle whereas the ring is geometrically three-fold symmetry. For off-momentum particles, the super-periodicity is three as well. Nonetheless, it turned out that the deterioration of off-momentum dynamic aperture is acceptable. With respect to the injection, it enables enlarging the beta function at the location of septum while keeping it low at the locations of insertion devices. It is noted that the dynamic aperture is proportional to the square root of the beta function value.
2) It was realized that the dynamic aperture in the vertical plane can be larger than that of the horizontal plane by 50% or more (for the same beta function value). Our understanding is that only even order resonances (2Qy, 4Qy, 6Qy, …) are excited in the vertical plane due to the upper-lower symmetry while both odd and even order resonances in the horizontal plane. In case, where the injection is implemented in the vertical plane, we may have more tolerance for the machine imperfections.
3) In the CDR, an injection scheme using "Anti-septum" was proposed, which offers a septum blade thickness of 1 mm equivalently. Such a thin septum enables a top-up injection into a small dynamic aperture. However, it may require a dedicated simulation study and a prototyping. Instead, it is considered to split the septum into two, i.e., strong thick septum and weak thin septum (Ch. Gough, 2nd TWIIS Workshop at PSI). We recently learned that such a device was built and installed into ALS (1.5-mm thick, see Fig. 1) [1]. It also turned out that the blade of Lambertson type septum can be also as thin as 1 mm when the field is rather low (~0.3 T, see Fig. 2).
4) It seems that a demand for on-axis injection is increasing from the insertion device point of view such that the apertures of the insertion devices can be eventually smaller to increase the photon beam performance. It is noted that a special device (Apple-X undulator) imposes a physical aperture in both planes and thus it is not compatible with off-axis injection.

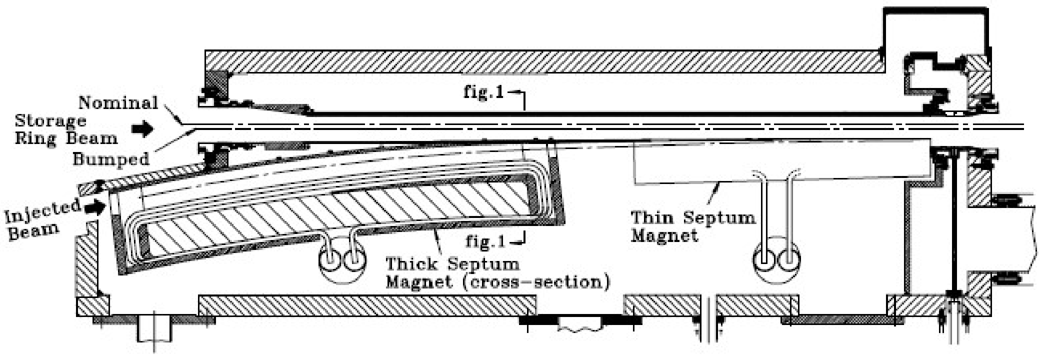

Figure 1. ALS septum. Taken from D. Shuman et al., PAC'05.

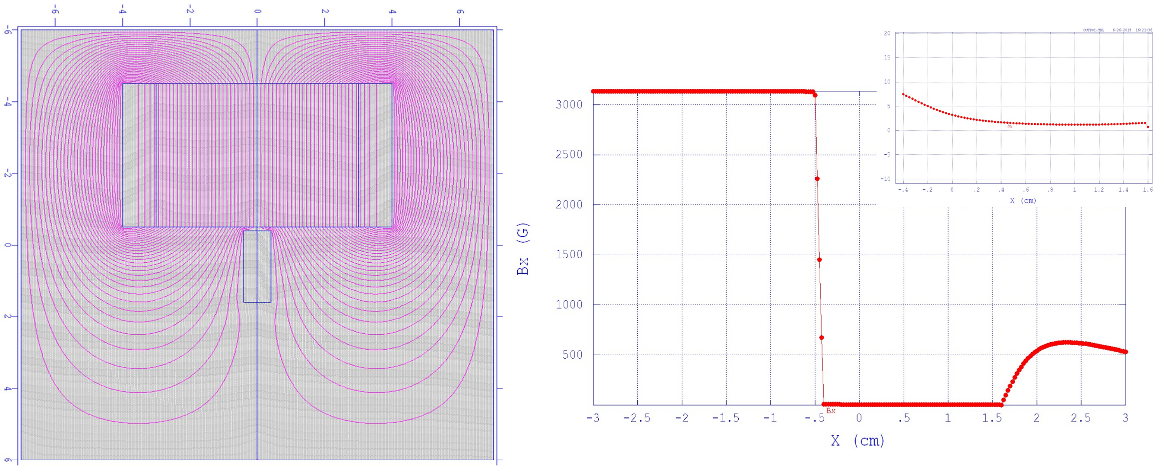

Figure 2. Lambertson type septum with 1 mm blade. 2D FEM field computation.

However, it turned out that the injection in the vertical plane is seriously affected by transverse wakefield, especially for aperture sharing, where the store beam bunch goes off-axis. Therefore, it is decided to implement the injection in the horizontal plane (spring/summer, 2020).

The injection-beam horizontal emittance can be lowered by a factor of 4 or more through an emittance exchange in the booster [2]. A horizontal emittance of 2 nm is assumed in this note.

Injection schemes and injection straight layout

With a thin septum together with the pseudo symmetry lattice, it is possible to inject a beam within a very small physical aperture, ±2 mm, at the location of insertion devices. The aperture can be magnified by a factor of two or more at the location of the injection septum in a pseudo symmetry lattice. Within the magnified aperture (±4 mm or more), the stored beam, the injection beam and the 1-mm thick septum blade can fit, and thus the conventional injection scheme is applicable.

A thin septum also enables an aperture sharing: a single dipole kicker (short pulse kicker) deflects both stored and injection beams, and they stay within the aperture. A rather weak deflection is enough to "pull out" the injection beam from the septum channel over a thin septum blade. The stored beam is not kicked out from the aperture. The septum should be close to the closed orbit (only 4 mm for a magnification factor of two) in this case. The beam impedance of the septum may not be critical issue given that it is much shorter with respect to the total length of insertion devices. In order to realize a full transparent on-axis injection, we need very fast kicker with a pulse length shorter than the bunch spacing in the longitudinal injection or a twice bunch spacing for the swap-out injection. However, in the above aperture sharing, the kicker pulse length can be arbitrary and a few times longer than bunch spacing when we accept an injection disturbance to a few bunches. In the future, the kicker can be upgraded to minimize or ultimately eliminate the disturbance.

A discussion with M. Dehler and L. Stingelin confirmed that transverse coupled bunch instability may not be an issue when we disturb a few bunches although their peak oscillation amplitude will be a few mm. The argument is that "an equivalent oscillation" is at least a factor of 100 smaller compared to a case where all the stored bunches are disturbed. At the SLS, all the bunches are disturbed during the injection and oscillating a few tens of μm or more that is equivalent to a few mm oscillation for a few bunches. The bunch-by-bunch feedback should be capable of switching off during the injection only for the rf bucket, where the beam is injected.

Acceptable minimum aperture in the horizontal plane at the standard straight section was evaluated from the viewpoint of Tauschek scattering: an aperture of >3 mm (full) does not deteriorate the lifetime significantly. It is, however, noted that the off-momentum beta beat may impose a more strict condition, a minimum aperture of >4.6 mm (Discussion on 13.11.2019). Therefore, the septum blade of the storage ring side is adjusted at -5 mm.

A layout to realize the two injection schemes described above (the conventional injection and the injection with short pulse kicker, i.e., aperture sharing) is outlined in Fig. 3 [3]. In case where the "ambitious" scheme with short pulse kicker does not work, we may switch back to the conventional injection scheme. It is of interest that, when the two injection schemes are combined, the injection beam can be brought even closer to the closed orbit.

BPMs are installed in the straight section (as well as in the transfer line [4]) to properly control the injection beam. Moreover, a profile monitor may be installed shortly after the thin septum to further ease the injection tuning. The kicker bump of the present SLS will be reused while new septa, thick and thin ones, are to be build. (Alternatively, the SLS septum can be reused as a thick septum. Final decision to be taken.)

Short pulse kicker is not included in Fig. 3 but it is installed in the next straight section. Ideally, the phase advance between the final septum (thin septum) and the short pulse kicker should a multiple of $\pi/2$. However, this condition is difficult to achieve since the straight section optics is not very flexible. Therefore, the kicker is divided into two parts and located at the beginning and the end of the next straight section. This configuration works well, making the phase advance condition unnecessary.

QP7YO/QP8YO/QP8YI/QP7YI magnets (see Fig. 3, red boxes before and after the thin septum) should be large aperture one to let the injection beam go through. Therefore, these magnets are longer than the normal SLS2 quadrupole magnet, assuming that SLS QA quadrupoles are reused (20 cm long, gradient of 20 T/m, bore radius of 33 mm).

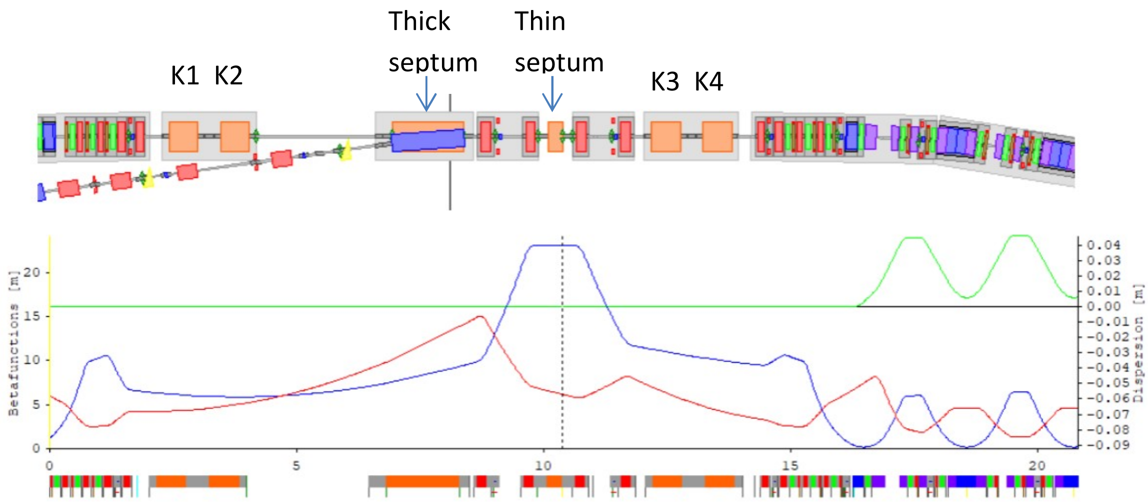

Figure 3. Layout of injection straight and optical functions.

The deflection angle of the thin septum is about 10 mrad. The thick septum deflection angle is assumed to be 7 deg (new septum). The orbit bump for the conventional injection scheme is induced by the kicker bump (four kickers, K1-K4). The bump height will be 4 mm with deflection angles of -1.27, 1.02, 2.39 and -2.55 mrad, respectively. For the aperture sharing, the short pulse kicker deflection angles will be about 200 and 300 μrad.

In Fig. 4, the particle distributions in the horizontal phase space at the location of the thin septum are shown. Elegant code was used to obtain these tracking results. For the aperture sharing, we find that the amplitude of the injection beam oscillation was reduced by increasing the injection beam energy up to 1.5%.

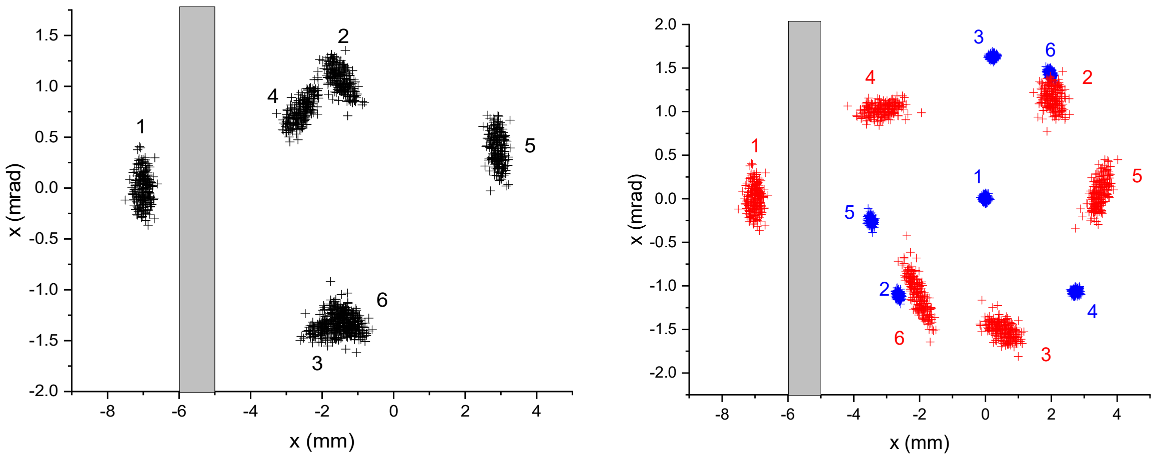

Figure 4. Tracking results for the conventional injection scheme (left) and the aperture sharing (right). The integer numbers indicate the number of turn after the injection. The red plots are for the injection beam and blue ones are for the stored beam in case of the aperture sharing.

Summary

Two injection schemes, namely, the conventional kicker bump injection and the aperture sharing are proposed, and the injection straight layout is designed to implement them in the horizontal plane. The specifications of the injection devices are summarized in the following table.

Table 1. Specifications of the injection devices.

	Total length	Deflection angle	Pulse length	Remark
Thick septum	1.8933 m	7 degree	~200 μsec ?	Alternatively the SLS septum is reused
Thin septum	0.71 m	~13 mrad	<1 μsec?	
Short pulse kicker	2x0.8 m	~300 μrad	20-30 ns	Possible upgrade in the future with shorter pulse
Kicker bump	4x0.85 m	<3 mrad	6 μsec	Reusing the SLS kicker

References

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[3] A. Streun, ‘SLS 2.0 baseline lattice’, SLS2-SA81-004-16

[4] A. Streun, ‘SLS 2.0 booster-to –ring transfer line’, SLS2-SA81-008