PAUL SCHERRER INSTITUT PSI	Projekt / *Project* **SLS 2.0**
Titel / *Title* **SLS 2.0 magnet specification**	Dokument Nummer / *Document Identification* **SLS2-SA81-007-9**
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Outdated. (Nov. 2021)
Please see SLS 2.0 Technical Design Report or tech note SLS2-SA84-004-17 Lattice

Summary

Specifications of SLS 2 magnet[illegible] beam dynamics point of view: magnet strength, magnetic length and t[illegible]

Related documents

Lattice description [illegible]04-**16**

Injection concept **SLS2**[illegible]**-003-3**

Lattice-files **B066_*****

Holy list **SLS2-SA81-005-23.xslx**

Naming convention version 7, **SLS2-SA81-001-9.pdf**

Documents are available on **afs/psi.ch/project/SLS2**
→ **Docs/Notes** for tech notes and → **BD/Lattices/Reference** for the lattice files.

Modification History

Version 9 – 3.12.2020

- Correct polarity of fields.
- Added an appendix on definition of field polarity.
- Rename BEV to VE (because it is very similar to VB but not to BE) and correct error on its edge angles in previous version
- Lattice B066: modification of injection straight layout only

Version 8 – 12.10.2020

- Lattice B064, DCR-SLS2-VV84-001-1: non-rotated magnets AN, ANM, BEV and BEH|BES.

Version 7 – 1.9.2020

- Lattice B063 with two mirror-symmetric quadrupole types
- Updated superbend field profiles.

Version 6 – 23.6.2020

- Final lattice B062 with modified dispersion suppressor and re-introduced M-straights.
- New magnet VBX
- Modifications of magnet types ANM, BEV, BE

Version 5 – 2.3.2020

- All parameters scaled to 2.7 GeV
- “Phase 2” abandonded.
- 2 SLS quads changed back to QA type

version 4 – 28.11.2019

- the stand-alone sextupole SXQ is a modified type (elliptic aperture, w.i.p.)
- all magnet specifications are fixed now, except the sextupoles SOQ and SXQ
- 2 SLS quads to be reused for injection straight have been changed from QA to QC type.

version 3 – 10.10.2019

- new standalone sextupole SXQ
- previous BE end magnet split into two standalone magnets BEV and BE

version 2

- modified parameters of QPH, QP: two types
- simplification of permanent dipole BN
- including large aperture quads type QA for injection

original version – 25.7.2019

Introduction and Status

Lattice B066 is the final lattice for the SLS 2.0 storage ring, it is described in internal report SLS2-SA81-004-15. The lattice defines the positions, deflection angles and [magnetic] lengths of all magnets, and, in case of permanent combined function magnets also the gradients, in case of electromagnets also the maximum multipole fields.

In the process it turned out that the magnet design is an iterative procedure between magnet design and beam dynamics, because due to the small inter-magnet distances magnets must not be treated independently but cross-talk has to be taken into account. Procedures have been established how to interchange data, e.g. field maps. Magnet tuning methods are developed for adjusting the focusing and bending properties of a complete group of magnets, e.g. a unit cell, because due to the heavy use of permanent magnets, tuning capabilities of the completed storage ring are rather limited.

This note gives magnet specifications, and, for cross-checking also derived quantities (→ ….) as they are used in lattice design calculations.

Open issues and work in progress are marked in blue text.

Parameters which have changed since previous version of this document are marked in red.

Bending magnets

By definition, these magnets affect the design orbit. Thus they must not be tuned in operation. All but the superbends are based on permanent magnets and thus are not tunable at all.

Bending magnets include two groups: combined function magnets with a transverse gradient, which are horizontally displaced quadrupoles, and pure dipoles, where the superbends have a longitudinal field variation.

Table 1 and 2 summarize the parameters of the pure dipoles and the combined function magets

Table 1: Pure dipole magnets

Name		BN	BS2	BS4	BS5	BE	
			Superbends			BEI	BEO
Length	mm	405	(370) < 405	(254) < 405	(360) < 405	242.500	
Bpeak	T	−1.351	−2.11	−3.57	−5.04	−1.228	
Half gap	mm	11.000	11 mm net half gap (same vac. chamber)			11.000	
LGB	?	No	Yes (“bell + hump” shape)			(yes, step)	
angle	deg	3.480	3.480	3.480	3.480	1.660+0.100	
edge in	deg	1.740	1.740	1.740	1.740	1.76	0.0
edge out	deg	1.740	1.740	1.740	1.740	0.0	1.76
Number		56	1	2	1	12	12

Table 2: Combined function magnets

Name		AN	ANM	VB		VBX		VE	
				VBI	VBO	VBXI	VBXO	VEI	VEO
Length	mm	140.000	150.000	185.000		185.000		240.000	
Field	T	+0.269	+0.272	−0.849		−0.849		−0.6545	
Gradient	T/m	−77.96	−82.52	+40.642		+33.110		+46.023	
angle	deg	-0.24	-0.26	1.000		1.000		1.000	
radius	mm	10.500	10.500	11.000		11.000		11.00	
→ $\|B_{poletip}\|$	T	0.996	1.050	0.919		0.817		0.894	
→ Rquad	mm	12.825	12.716	22.588		24.657		19.405	
→ Shift	mm	-3.470	-3.299	-20.892		-25.644		-14.216	
edge in	deg	-0.12	-0.13	0.5	(-1.74)	0.5	(-1.74)	0.0	1.0
edge out	deg	-0.12	-0.13	(-1.74)	0.5	(-1.74)	0.5	1.0	0.0
Number		120	24	48	48	12	12	12	12

- Design change request DCR-SLS2-VV84-001-1 [V. Vrankovic] required that AN, ANM, VE (former BEV) are installed in the lattice (B064) such, that the edges facing the adjacent SOQ and

SXQ magnets are parallel to these. But they stay to be rectangular magnets as before. So there are **not** two mirror-symmetric types, it's only one type which is installed in different ways. This modification requires tiny adjustments of the all magnets gradients (probably within tuning range).

- Length is magnetic length as used in beam dynamics models. It is larger than the iron length, which, in case of PM magnets may be equal to the total length.
- Radius or half gap = beam pipe inner radius (= 9 mm) + beam pipe thickness (1 mm for round pipes, 1.5 mm for antechambers) + 0.5 mm space.
- All parameters are for a beam energy of 2.7 GeV
- Rquad is the pole inscribed radius if the combined function magnet is a shifted quadrupole, and
- Shift is the distance of quadrupole center to beam orbit.

Standard bending magnet BNV

The main bending magnet is a compound magnet made from a BN between two VBs, BNV = {VB|BN|VB}. Actually, there is only one type of VB, which is a rectangular magnet of 1° deflection and 0.5° edge angles. However, due to the proximity of the two magnets, the space between is filled with field. So for the simplified lattice design model (OPA code), VB is modeled as two types, incoming and outgoing, VBI and VBO, with the edges facing BN aligned to the BN edge of 1.74° inclination. Figure 1 compares the magnet model and the beam dynamics model. Work is in progress to import 3D field maps from magnet design into TRACY.

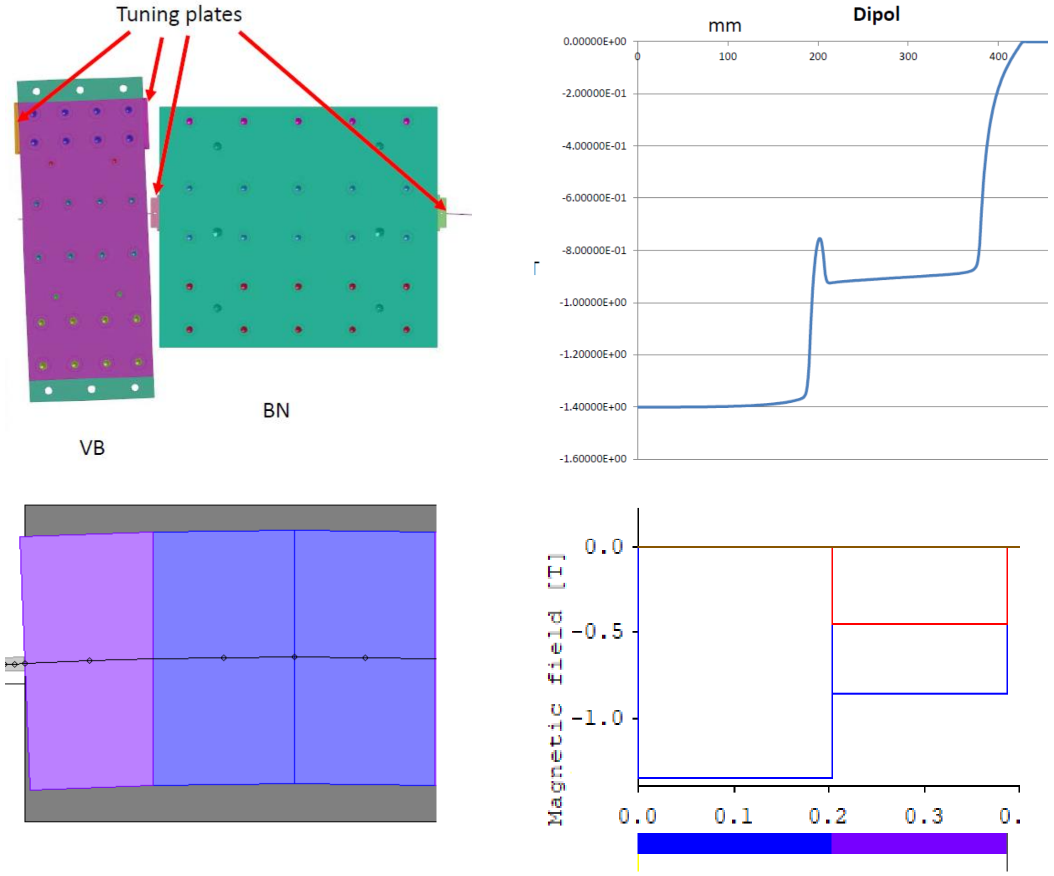

Figure 1: Magnet design model [M. Negrazus, 17.6.2020] and simplified beam dynamics model for the {VB|BN|VB} compound magnet: layout and field shape.

Modified magnet VBX

The 2^{nd} and 6^{th} BNV compound magnet in the arc need a modified VB at the side facing the straight for a new optics in the dispersion suppressor (which increases brightness by 50%). This magnet has the same angle like VB but a weaker gradient. So the line up of bending magnets in the arc is

BEI - BEV – {VBX|BN|VB} – {VB|BN|VB} – {VB|BN|VB} – {VB|BN|VB} – {VB|BN|VBX} – BEV - BEO

Dispersion suppressor bends VE and BE

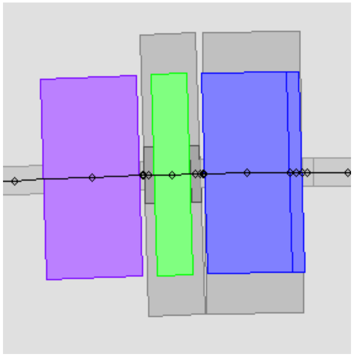

Figure 2: VE-SXQ-BEO assembly

The first and last bend of the arc started as half BNV, but later had to be split with the sextupole SXQ inserted between in order to provide a sufficiently wide open channel for the photon beams coming from the straight. VE and BE thus started as VB and ½BN, but were modified further in the process.
In the context of introducing VBX, some bend angle was transferred from BE to VE as required for matching, and with the additional advantage to increase the photon beam clearance by 0.5 mm. Further, in analogy to the VB design, the magnets aree assumed to be rectangular as outlined in Fig.2 with the inner edges parallel to the sextupole edges.
BE has assumed a soft end (30 mm) of reduced field of about 0.524 T to reduce the X-ray contamination of the straight section, so there are two mirror symmetric version, BEI and BEO. The shape of the soft end field is not defined yet.

Superbends

For the superbends, temporarily, a coarse step approximation of field profiles provided by C. Calzolaio were used. BS2 is a 2.1 T permanent magnet, BS4 and BS5 are 3.57 T and 5.0 T peak superconducting bends. The lengths in brackets in Table 1 are values used in beam dynamics only. In any case, the magnet length has to be less than 405 mm, which is the distance between flanking VB magnets. Figure 3 shows the approximated field profiles. Normal bend BN and end bend BE have are also shown:

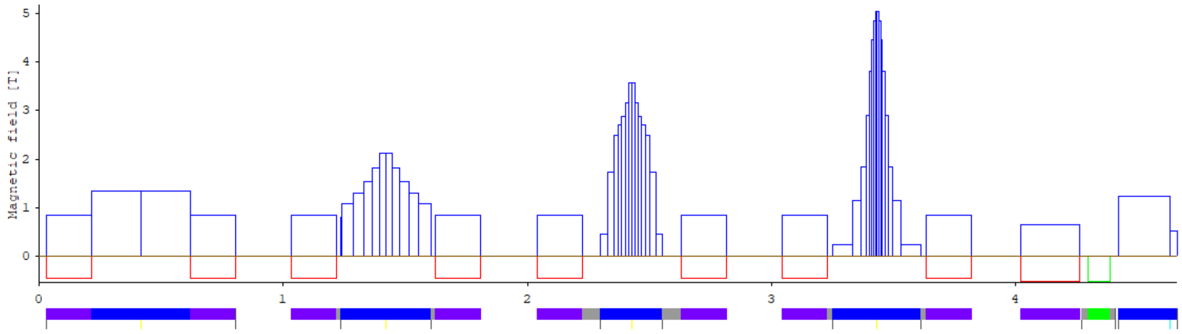

Figure 3: field profiles of BN, BS2, BS4, BS5 and BE including adjacent VBs, resp. BEV/SDX:
(Field B , gradient B' × R, curvature B"/2 × R^2, for 11 mm radius). (field polarity in figure is wrong, see appendix)

Reverse bend ANM

The reverse bend in the new dispersion suppressor became stronger and thus had to be made 10 mm longer. As a consequence ANM becomes a new magnet, before it was based on the same body like AN, just using more PM blocks of the same type. Now AN and ANM will be optimized independently.
[V. Vrankovic, 5.6.2020].

Electromagnets

In the lattice model protected spaces before and after each magnet were inserted to take into account space for coils, and the magnetic length was used for calculations. The iron length may be shorter by approx. 2R/n, with R bore radius and n multipole order.

Quadrupoles

Table 3: quadrupole parameters

Name		QPI/QPO	QPHI/QPHO		QA-SLS
Length total	mm	170	210		340
Length magnetic	mm	100	140		(~230)
→ Iron length	mm	**90**	**130**		**200**
Max. |gradient|	T/m	93	98		23.2
Radius	mm	10.5	10.5		30
→ $\|B_{poletip}\|$	T	0.977	1.029		0.696
Number		31/24	29/24		4

Design change request request `DCR-SLS2-SS84-001` from Aug. 11, 2020 [S. Serguei] required that the QP and QPH quads, which are located in the matching straights alternating with SOQ-magnets, have to be made in two mirror-symmetric types with regard to coil connections, in order to avoid interference with SOQ coils. The reason is that the SOQs exist in two mirror symmetric types too (see below). For other QP/QPH quads located in the straights, the chirality does not matter, so they are assumed to be of QPI and QPHI type.

In lattice B066 at nominal optics, the maximum gradients for QP / QPH / QA-SLS are around 92 / 76 / 20 T/m, but the full tuning range [see Table 6 in SLS2-SA81-004-15] requires the gradients given in Table 3. An integrated gradient of 14.1 T can be reached with QPH, corresponding to 100.7 T/m [M. Negrazus, 9.9.2019].

QP* and QPH* have same cross section and same coil type but only different length. Coils have 75 turns. This is compatible with the existing 70 A 1-quadrant (i.e. unipolar) power supply ($\int$Hds = NI → 98 T/m require 75×60 A; + reserve for end fields), and it helps to save 30% power (compared to a 52 turns/100 A design) on the expense of a rather wide yoke (652 mm in square).

For the injection scheme based on the concept developed in SLS2-MA81-003, four wide-aperture quadrupoles from the existing SLS will be re-used. The QA-SLS type reaches a gradient of 23.2 T/m with the existing power supply at 120A maximum current, however it can take up to 140A, providing a gradient of 25.8 T/m [http://ados.web.psi.ch/slsdesc/optic/typeData.dat.txt]. The old power supply could be re-used and replaced later, as it is also planned with other power supplies in booster and transferlines. Alternatively it could be operated with a 200A power supply, which is used also for the superbends [B. Ronner, 15.6.2020].

Figure 4 shows to which percentage of its maximum each quad is powered for the five different optics modes of lattice B062 (which is almost identical to the latest B063):

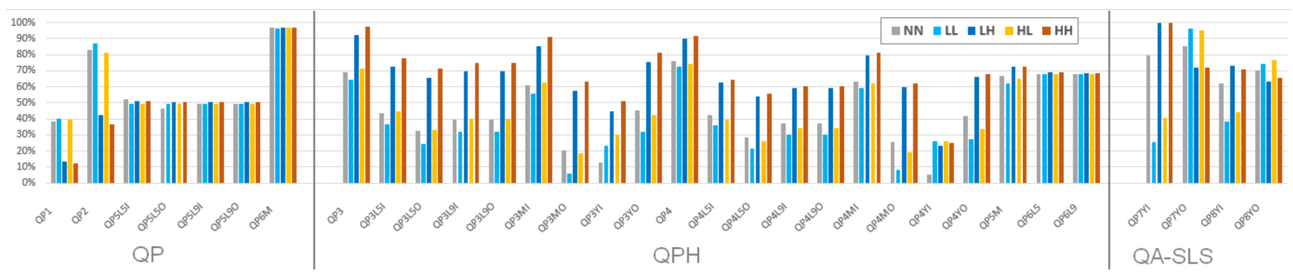

Figure 4: Quadrupole strength as percentage of maxium strength for five optics modes of lattice B062. Quads QPn* (n=1…4) are located in the matching sections to the straights. QPn* (n=5…8) are located inside the straights. Characters M, L, Y indicate medium, long and injection straights.

Maximum feasible QP / QPH / QA-SLS gradients of 95 / 100 / 23.2 T/m were assumed in Fig. 4 .
If a QPH quad never exceeds 68% (= magnetic length ratio 100/140 × max. gradient ratio 95/100) of its maximum strength, it could be replaced by a shorter QP in principle in order to gain more straight length – or to relax the very tight packing. However this applies to only 13 QPH*s ("QP3/4MO" appear each three times), and it would lead to different vacuum chambers for the matching sections, which may be more expensive than the larger quads.

Within the tuning range tested (5 optics modes) no quad ever changes polarity, i.e. all quads can be operated with 1-quadrant power supplies.

SOQ magnet (sextupole-octupole compound magnet) and standalone sextupole

Parameters are given in Table 4 next page.

There are two SOQ types for installation, depending if octupole or sextupole comes first (in beam direction): SOQI = {OC|SX} and SOQO = {SX|OC}. However the sub-magnets OC and SX are the same type in both cases, only the order is reversed. Since the magnets will have neither horizontal (C-magnets) nor vertical (mounting, alignment) symmetry, one cannot reverse SOQI to get SOQO and v.v.

For accomodation of photon beam pipes, modified types SOQIW and SOQOW are required, which have a wider yoke. For placement of the 4 different SOQ types, see the Holy List [SLS2-SA81-005-22].

The octupole OC also constains quad and skew quad windings. The requirement for skew quad strength was doubled in the process of lattice design, but it could be covered by a modification of magnet design, which exceeds the specifications, giving following gradients after renormalizing integrated strengths to 50 mm length as used in beam dynamics: |B'''/6| = 65700 T/m3, |B'| = 3.26 T/m, |A'| = 5.77 T/m [V. Vrankovic, 28.4.2020].

The total SOQ length of 230 mm includes extra spaces (beyond *magnetic* length) of 2x25 mm for sextupole coils, 2x15 mm for octupole/quad/skew quad coils, and 10 mm distance between sextupole and octupole coils.

SXQ is a standalone sextupoles with larger aperture. The most probable design [Discussion Nov. 12, 2020, presentation by V. Vrankovic, and follow-ups] plans for tapered (slightly longer) poles but same yoke length like the other sextupoles, to provide the required integrated gradient. Furthermore, the risk may be acceptable, to reduce its strength by 10%, since larger values up to now were not encountered in non-linear optimizations. SXQ should contain a small quad coil to enable beam based alignment (to be specified), because there is no octu/quad nearby. Due to the redistribution of bending angles between VE and BE, the aperture could be reduced from previus 13.0 to 12.5 mm to maintain the same photon beam clearance (of course, the more the better…)

Table 4: SOQ and SXQ multipole parameters

Name			SOQ		SXQ
			SOQI SOQIW	SOQO SOQOW	
L total		mm	230.000		140.000
Sextupole	L mag	mm	90.000		100.000
	B''/2	T/m2	5850		5850 [→ 5270?]
	Radius	mm	11.000		12.5
	→ Bpoletip	T	0.708		
Octu/Quad	L mag	mm	50.000		
	B'''/6	T/m3	63000		
Regular quad	B'	T/m	2.8		2.8 ?
Skew quad	A'	T/m	5.6		
	Radius	mm	14.500		
	→ Bpoletip	T	0.273		
total space for coils etc.		mm	90.000		50.000
Numbers			108 24	108 24	24
		total	264		24

CHV magnet (horizontal/vertical corrector) and BPMs

Table 5: Corrector/BPM parameters

Name		CHV	BPM	CHV-Y	BPM-Y
Length, total	mm	105.000	25	?	?
Half gap	mm	12.500	10.500	30_H x 15_V ?	30_H x 15_V ?
Integral B.dL H/V	mTm	3.6[+1.8] / 3.6	-	?	
max. deflection H/ V	mrad	0.4[+0.2] / 0.4	-	?	
Number		112 + 3 ?	112 + 3 + 12 ?	2	2

There are 9 CH|CV|BPM stations in each of the 12 arcs, and two in each of the L-straigths 5 and 9, making a total of 112. Further it may be reasonable to install another station in the 3 M-straights (to be investigated).

Another BPM after the BEO magnet would be desirable for better control of the beam in the straight sections. Work is in progress (with vacuum section) to find out, if this additional BPM and the absorber (which is only half size than the others) can be combined within the available space.

The model assumed thin correctors allocated as: { 30 mm | CV | 45 mm | CH | 30 mm },
taking into account that CH and CV are of same type but rotated by 90° such that their coils do not interfere. CV is always first in beam direction.

During commissioning a larger horizontal deflection angle is required due to the limited precision of permanent magnet tuning. Therefore an additional coil is added to the horizontal correctors, which later, after beam based alignments etc., will be disconnected in order to reduce the range and thus increase the precision of the correction.

In the injection straight the apertures are much wider and the standard stations cannot be used. Two special stations are probably required. Design of injection straight is work in progress, and devices have not yet been specified.

Appendix: Field Polarity

This is a summary of Werner Joho's note (polarity.doc) from Sept. 16, 1999

Beam coordinate system is right-handed with *s* forward, *x* radial to outside, *y* vertical up.

Electrons move clock-wise, so bends deflect to the right side (to negative *x*). The dipole field thus is negative, i.e. the upper pole is North, the lower pole is South.

An horizontally focusing quadrupole (i.e. quad strength $b_2 > 0$) bends a beam stronger at +x, so the first pole (positive x and y) is North, the field is negative at +x, so it's gradient dB/dx is negative too.

A sextupole for correction of horizontal chromaticity (i.e. sext strength $b_3 > 0$) provides additional focusing at +x, so the first pole (positive x and y) is North, the field is negative at +x and –x, and the derivative B'' is negative too.

A horizontal corrector kicks the beam to the outside (+x) for positive current, so its field is positive, i.e. the upper pole is South, opposite to the dipoles.

A vertical corrector kicks the beam up (+y) for positive current, so it's field Bx is negative, pointing towards the ring inside (-x).

In beam dynamics codes, the deflection angles (curvatures) of the dipoles and the strengths of horizontally focusing quads are defined as positive, so the strength is related to the field by

$b_n = - B^{(n-1)}/(n-1)!/(B\rho)$ with n=1,2,.. dipole, quad… and $B^{(n-1)} = d^{(n-1)}B_y/dx^{(n-1)}$ the (n-1)-th field derivative.