The Swiss Light Source Accelerator Complex: An Overview

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Abstract

The Swiss Light Source (SLS) is a dedicated high brightness synchrotron light source under construction at the Paul Scherrer Institute (PSI) in Villigen. The accelerator complex includes a 2.4 GeV small emittance electron storage ring with 288 m circumference, a full energy injector booster synchrotron and a 100 MeV linear accelerator pre-injector. Approved in June 1997, the facility, including the first set of five beamlines, is scheduled to start operation for users in August 2001.

1 DESIGN GOALS

The main goal of the SLS design[1] has been to achieve very high quality sources of synchrotron radiation. The source quality (*brightness*) is mainly determined by the electron beam quality (*low emittance*). The SLS storage ring design has been optimized to ensure the lowest beam emittance for a given ring size (cost). Summary of the main parameters of the storage ring[2] is given in Table 1.

Table 1: Main parameters of the SLS storage ring

Energy	[GeV]	2.4
Circumference	[m]	288
RF frequency	[MHz]	500
Harmonic number		(2^5x3x5 =) 480
Peak RF voltage	[MV]	2.6
Current	[mA]	400
Single bunch current	[mA]	≤ 10
Tunes		20.8 / 7.1
Natural chromaticity		-70/-20
Momentum compaction		0.0007
Critical photon energy	[keV]	5.4
Natural emittance	[nm·rad]	4.8
Radiation loss per turn	[keV]	512
Energy spread	[10^{-3}]	0.9
Damping times (h/v/l)	[ms]	9 / 9 / 4.5
Bunch length	[mm]	3.5

The first set of five beamlines includes:

- 5 - 200 eV diffraction limited, circularly polarised, fast switchable source based on a 10 m long, 200 mm period undulator for surfaces/interfaces spectroscopy
- 0.2 - 2 keV source based on a 38 mm period, 4 m long undulator for surfaces/interfaces microscopy
- 5 - 17.5 keV source for protein crystallography based on in-vacuum minigap 18 mm period, 2 m long undulator
- 5 - 40 keV source for materials science based on a mini-gap in-vacuum 40 mm period, 2 m wiggler
- bending magnet based source for micro- and nanostructuring

The originally planned substitution of some of the central magnets of the triple bend achromats by superconducting dipoles has been abandoned for the first installation phase, but is still kept as an option. The projected brightness curves are shown in Fig. 1, where the case of a superconducting wavelength shifter is given for comparison.

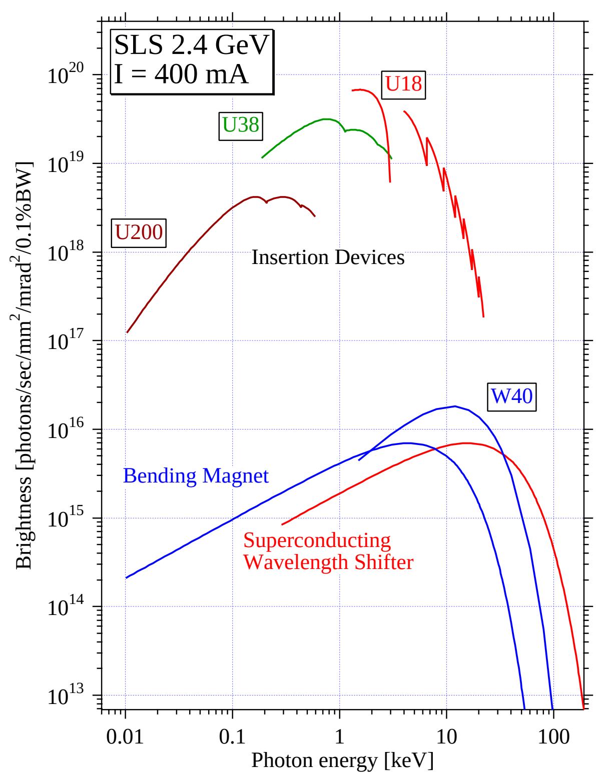

Figure 1: Brightness curves for the SLS sources

2 STORAGE RING

The storage ring has been optimised for 2.4 GeV operation, and consists of 12 Triple Bend Achromats (TBA). There are three superperiods, each containing one 11 m long, one 7 m long and two 4 m long straight sections. The basic lattice mode with zero dispersion in all straight sections corresponds to the natural beam emittance of 4.8 nm·rad. An alternative lattice mode with non-zero dispersion in the straights has been studied as well and would correspond to the effective beam emittance of 4.1 nm·rad[2].

The beam lifetime will be dominated by the Touschek scattering and the lattice was optimised for large energy acceptance[3].

2.1 Magnets and girders

Quadrupole and sextupole magnets are pre-aligned on girders to 30 μm precision (four straight girders per TBA), further ring alignment is achieved with the help of girder movers that are equipped with DC motors[4]. This allows for fast installation of the pre-assembled girders into the ring tunnel. The dipole magnets form bridges between the girders and are powered in series. Quadrupoles have individual power suppiles to allow for beam-based alignment BPM calibration[5]. Chromatic and geometric sextupoles are grouped into 9 families.

Sextupole magnets have additional windings to provide dipole correction fields. The closed orbit correction schemes with either SVD or sliding bump algorithms have been studied for the case of 72 correctors and result in residual orbits of about 200 μm rms.

The girders are designed to have fundamental frequencies above 40 Hz and to avoid the 50 Hz.

Furthermore, the girders are equipped with the hydrostatic leveling system for vertical as well as with the wire positioning system for both horisontal and vertical alignment.

2.2 RF system

Four single cell 500 MHz RF cavities occupy two short straight sections and are individually powered by four 150 kW klystrons. To combat the coupled bunch instabilities, the higher order modes frequencies of the cavities will be controlled by the proper setting of the cavities temperature[6].

This conventional RF system could be complemented in the future with an idle superconducting RF cavity to improve the beam lifetime. This could be achieved by either improving the energy acceptance[3] (500 MHz) or by lengthening the bunch (higher harmonic cavity).

2.3 Vacuum system[7]

The vacuum chamber has an antechamber, is made of stainless steel and most of the synchrotron radiation is intercepted by discrete absorbers. There will be no in-situ bakeout and the 12 TBA arcs chambers will have no bellows and will use flat seal flanges, minimising the impedance seen by the beam.

2.4 Beam diagnostics[8]

Tight stability tolerances on the storage ring beam and large dynamic range needed to support different operating modes (single bunch, multibunch and top-up) place stringent requirements on the beam diagnostics system of the SLS accelerator complex.

The storage ring BPM system will provide closed orbit measurements to micron precision, as well as turn by turn position information. In addition to the first turn position measurement this will allow fast (revolution time) orbit measurement with < 50 μm precision.

The same design readout electronics will be used both throughout the accelerator complex. The four channel system will keep the gain in all the channels matched. Direct intermediate frequency sampling and digital demodulation insures excellent linearity and stability of the design. The solid stainless steel BPM vacuum chambers containing the button electrodes are fixed to the girders and their position relative to the adjacent quadrupoles is monitored using photosensors with sub-micron resolution.

The same system, thanks to the broad bandwidth available, allows precise and fast tune measurements in booster and storage ring. The stripline kickers will be used to excite the beam with white noise.

An undulator based diagnostics beamline in one of the short straights will be used for emittance measurements applying techniques of X-ray microscopy.

In order to observe low charge bunches in the injector chain during the top-up mode, high sensitivity strip-line BPMs will be built into the linac and the transfer lines.

2.5 Injection and Extraction Elements

Booster injection and extraction are done in a single turn, using an eddy-current septum and a lumped unductunce kicker. The kickers have a relaxed rise-time specification of 200 ns. The prototype eddy-current septum is showing encouraging results.

Injection into the storage ring is achieved with the help of a symmetric 15 mm bump of the stored beam in one of the long straight sections. The symmetric bump is produced by four bumper magnets with identical currents. For top-up injection mode with minimum disturbance to the stored beam, the four bumper magnets must be very closely matched. The storage ring septum is a copy of the design used in the booster.

3 INJECTOR COMPLEX

The SLS injector complex consists of a 100 MeV linear accelerator and a full energy booster[10] that shares the tunnel with the storage ring.

3.1 Pre-injector linac

Small size of the booster vacuum chamber and minimisation of electron losses throughout the injector chain lead to stringent requirements on the linac beam quality. To achieve clean capture into the 500 MHz booster RF buckets the linac will deliver electron beam with 500 MHz structure that has 1% purity. This will be achieved with the help of a DC gun pulser that will provide 500 MHz trains of 1 ns pulses. The requirements on the transverse emittance and energy spread, as well as other main linac parameters are summarised in Table 2.

Table 2: Main parameters of the SLS linac pre-injector

Energy	[MeV]	> 100
RF frequency	[MHz]	2997.92 @ 40°C
Max. repetition rate	[Hz]	10
Energy stability		< 0.25%
Energy spread		< 0.5%
Normalised emittance	[mm·mrad]	< 50
Single bunch charge	[nC]	< 1.5
Multibunch train	[µs]	0.2 - 1
Multibunch charge	[nC]	< 1.5
Normalised emittance	[mm·mrad]	< 50

The 90 kV DC gun is followed by the 500 MHz subharmonic buncher, 3 GHz single cell pre-buncher and a 3 GHz buncher. The energy of the electrons at the output of the bunching system will be 4 MeV.

The linac will use two 5.2 m long accelerating sections developed at DESY in the context of the S-Band linear collider study[9]. They will be powered by two 35 MW modulator/klystron units.

3.2 Booster

The novel design 2.4 GeV booster[10] will have 270 m circumference and very low power consumption (less than 200 kW in regular injection mode and less than 30 kW in the top-up mode). The chosen repetition rate of 3 Hz will allow to fill the ring in 2-3 minutes. Extracted beam emittance of 7 nm·rad and energy spread of 0.08% should insure very clean injection into the storage ring.

An electrolytic capacitor bank (400V, 80·10mF) serves as an energy buffer for the switch mode power supply of the booster bending magnets, allowing flexible ramping profiles B(t). This would also allow the operation of the booster as a storage ring up to the energy of 1.7 GeV.

The FODO cell, combined function magnets lattice has an equilibrium emittance of 4.5 nm·rad at 1.7 GeV.

4. SLS BUILDING

The 140 m diameter ring shaped building contains the tunnel with the storage ring and booster, the linac vault, the experimental floor for the beamlines (max. length from the source point of about 40 m) and the technical gallery area. Ring shaped office building will form part of the main building in between the courtyard (32 m diameter) and the technical gallery.

Main features of the attractively designed structure (see Fig. 2 below) include windows that pass only indirect daylight. Monolithic 40 cm thick floor that supports the tunnel and the experimental area is separated from the rest of the bulding's foundation. The technical gallery will contain the power supplies, laboratory space, as well as girder assembly and vacuum bakeout areas.

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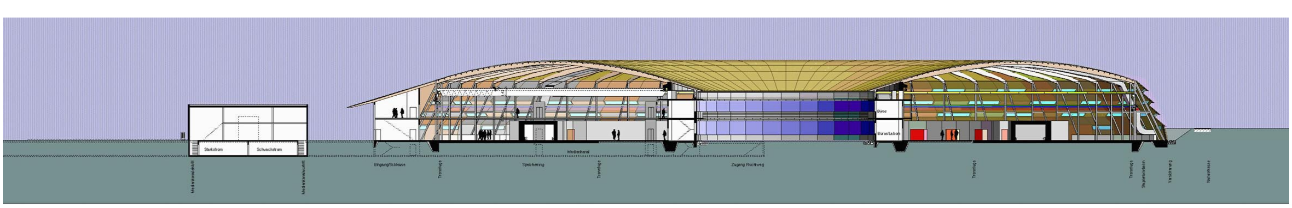

Figure 2: Cut view of the SLS building