Design of a Swiss Light Source (SLS)

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Abstract

Conceptual design of a synchrotron light source based on an electron storage ring with maximum energy of 2.1 GeV is presented. The lattice provides small emittance (3.2 nm at 2.1 GeV) with large dynamic aperture and flexible matching of the beam parameters to the insertion devices. This insures very bright VUV/XUV undulator radiation with a high degree of transverse coherence. Six achromatic arcs incorporate superconducting dipole magnets that provide X-ray sources of up to 100 keV photons. Two very long (17 m) straight sections are intended for future developments, e.g. novel insertion devices for production of polarised light, high coherence sources for holographic applications, generation of very short light pulses, etc.

1 DESIGN PHILOSOPHY

The main goal of the SLS design [1], [2] has been to achieve very high quality sources of synchrotron radiation, perhaps at the expense of the maximum possible number of these sources. The source quality (brightness) is mainly determined by the electron beam quality (low emittance). The SLS design has been optimised to insure the lowest beam emittance for a given ring size (cost).

The VUV/XUV user community is best served by undulator based sources (see Fig. 1). To extend the spectral range to the hard X-ray region, we have incorporated six superconducting bends into the SLS lattice. Due to the comparatively small beam size in the bending magnets, the sources based on these dipoles will provide high flux and rather high brightness X-rays of up to 100 keV (Fig. 1).

The spectrum from the normal conducting dipoles has a critical photon energy of 4.5 keV, e.g. ideally suited for micro-mechanics and micro-fabrication applications.

On the undulator side, future developments will have an immediate impact on the overall performance of the light source. As an example we could mention the small gap micro-undulators which could push the available undulator radiation at SLS into the 10 keV region (Fig. 1).

In fact, having both the radiation from superconducting bends and from micro-undulators makes it possible to perform at SLS some experiments that otherwise can be done only at high energy synchrotron light facilities.

Another distinct feature of the design are the two 17 m straight sections. We plan to install in one of them a 12 m long electromagnetic, fixed gap undulator with a period of 200 mm. This will provide a diffraction limited source of VUV photons of up to 100 eV (Figs. 1,5). The other long straight is reserved for future "bright ideas"!

2 SLS LAYOUT

The layout (Fig. 2) of the storage ring consists of six achromatic arcs, two very long (17 m) and four 7 m long straight sections.

One of the straights is dedicated to injection, accomplished using a four kicker bump and two septum magnets. Place is reserved for a very fast kicker magnet for the on-axis injection option.
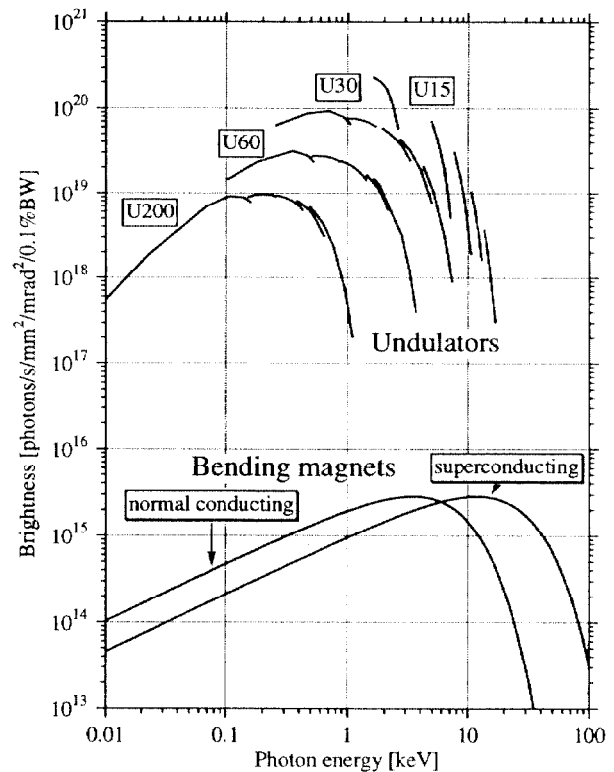

Figure 1: Design brightness for a few representative insertion devices (labelled with their periods in mm) as well as the brightness of the dipole magnets based sources. The data corresponds to the electron energy of 2.1 GeV, beam current of 400 mA and emittance coupling of 10%.

Table 1: SLS parameter list

Circumference L	[m]	252	
Harmonic number		$420 = 2^2 \cdot 3 \cdot 5 \cdot 7$	
RF frequency	[MHz]	500	
Design current	[mA]	400	
Single bunch current	[mA]	≤ 10	
Horizontal tune Q_H		20.2	
Vertical tune Q_V		5.4	
Chromaticity ξ_x/ξ_y		-55/-18	
Momentum compaction α		0.0006	
Energy	[GeV]	1.5	2.1
Natural emittance ε_{xo}	[nm·rad]	1.6	3.2
Radiation loss per turn	[kev]	124	477
Energy spread σ_e/E	[10^{-3}]	0.8	1.1
Transv. damping times	[ms]	20.3	7.4
Longit. damping time	[ms]	10.2	3.7
Bunch length σ_s	[mm]	4	4
Peak RF voltage V_{RF}	[MV]	1	2

Another straight will contain four single cell RF cavities that (including tapers) will occupy about 4 meters, leaving enough space for the installation of a 2 meters long undulator nearby. The system will be powered by two 300 kW klystrons and will be able to provide up to 3 MV peak RF voltage with a stored beam current of up to 500 mA.

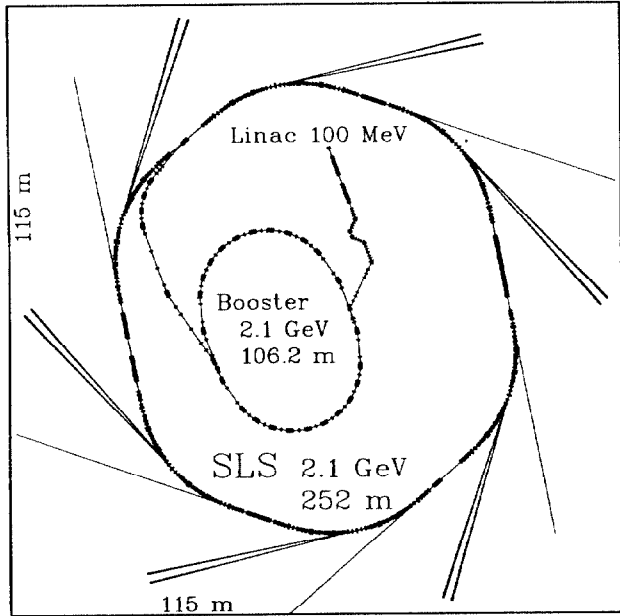The middle cell of each arc incorporates a short superconducting dipole (bending angle 10°, B = 4.7 T) [3].

Figure 2: Layout of the SLS facility with linac, booster and storage ring. Shown are the photon beamlines from insertion devices and the twin beamlines from the six superconducting bending magnets.

Flexibility of the lattice was emphasised during the design, providing for:
a) possibility of several operating modes
b) ideal matching to the insertion devices
c) top-up injection
d) on-axis injection option

In Fig. 3 are shown the optical functions for one quarter of the ring. The main parameters of the storage ring are summarised in Table 1.

Sextupole correction was done using the harmonic compensation scheme [4]. The computer code OPTIK (developed by K. Wille) was extended at PSI for this purpose. The *dynamic aperture* studies indicate rather large values for the ring acceptance: horizontally 50 μm·rad, vertically 60 μm·radand energy acceptance of ±4% (no errors).

In the presence of errors (transverse displacements of all elements with $\sigma = 100\mu$m), simulations with the code TRACY (written by J. Bengtsson, ALS, Berkeley) show 20% reduction of the transverse dynamic aperture, as well as reduced energy acceptance of ±3% (without synchrotron oscillations). In future studies we expect to see an improvement in the stable acceptance due to taking into account the effects of placing the elements on girders (preliminary estimates indicate a reduction of the lattice magnification factors by a factor of 5 to 10).

Estimates of the *collective effects* so far indicate no major obstacles in the way of achieving the design current of 400 mA. Currents per bunch of 10 mA seem to be feasible.

Bunch lengthening as a function of current (calculated with the program BBI [5]) was taken into account in estimates of the beam lifetime and intra beam scattering (using the code ZAP [6]). Equilibrium emittance blow-up due to IBS was below 10% for the worst case of single bunch current of 10 mA and operating energy of 1.5 GeV. Beam lifetime is dominated by the Touschek effect, at low energies becoming as short as 4 hours.
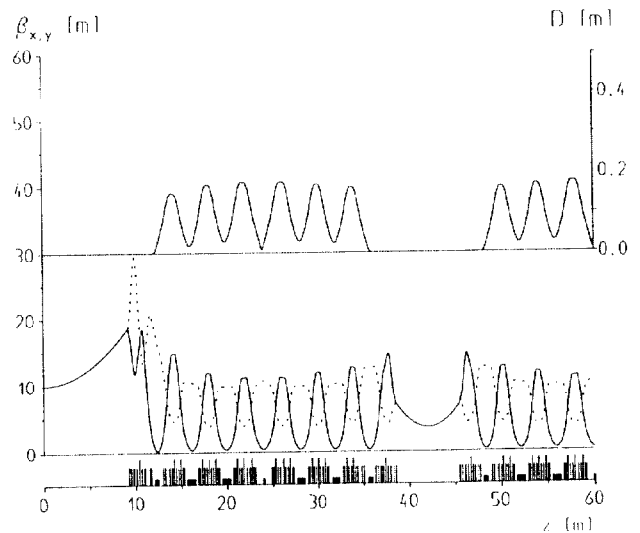

Figure 3: Lattice functions for one quarter of the SLS lattice.

To control the coupled bunch instabilities, we plan for a passive damping system for the cavities, complemented by an active feedback system. The power requirements of such a feedback system that will assure stability of the beam up to the design current are expected to be rather modest.

3 EFFECTIVE PHOTON SOURCES

There are two different contributions to the effective photon source and thus to the peak brightness: diffraction limited photon emittance, given by $\epsilon_R = \lambda/4\pi$, and the emittance of the electron beam. Assuming Gaussian distributions, represented by 1-σ ellipses, Fig. 4 shows an example of the effective photon source parameters for a 5 m long undulator. This case corresponds to a photon energy of 400 eV ($\lambda = 3$ nm) and $\beta_x = \beta_y = 2$ m. Due to the very low electron beam emittance, the contribution from the diffraction limited photon emittance is clearly noticeable.

An important advantage of low emittance electron beams, besides giving high brightness photon beams, is the high degree of transverse coherence of the photon sources. A useful figure of merit is the fraction of the photon flux contained in the diffraction limited phase space area (in both x and y). Using the half-Airy disk criterion [7], the coherent fraction is given by

$$f_c = \frac{(2.44 \cdot \epsilon_R)^2}{\epsilon_{xtot} \cdot \epsilon_{ytot}}$$
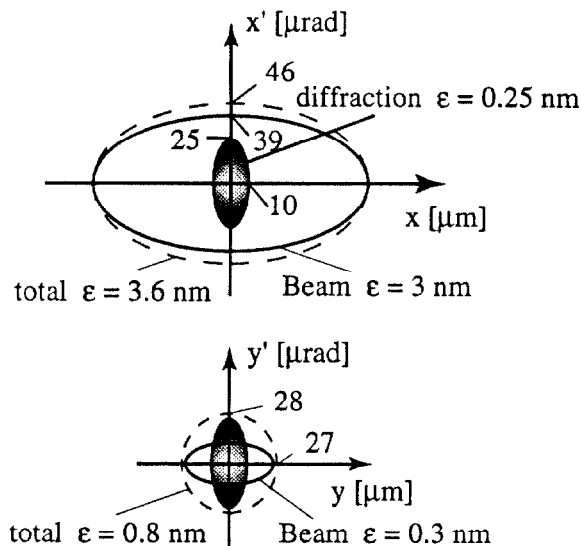
and is shown in Fig. 5.

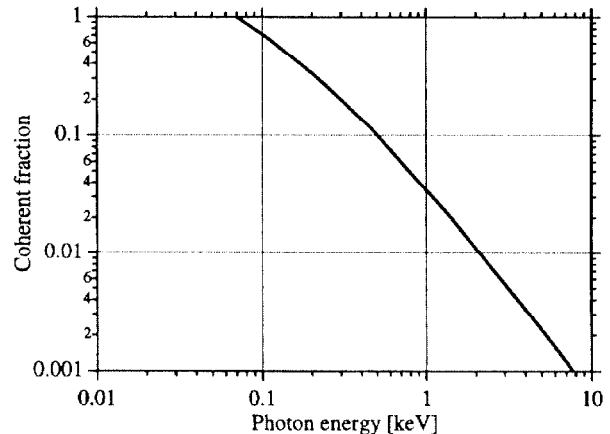Figure 4: Effective photon source of an SLS undulator.

Figure 5: Fraction of the photon flux from the SLS undulator sources that is transversely coherent (half Airy disk criterion).

4 PRESENT STATUS

The budget for this project has been estimated at about 180 MSFr (without salaries). To increase the chances for approval by the Swiss government we are looking at possible ways to reduce the project costs, e.g. reducing the magnet apertures, putting the booster into the same tunnel as the main ring, etc.

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