Design Considerations for a Swiss Light Source (SLS)

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Abstract

An outline of a design of an intense VUV to X-ray synchrotron light source at the Paul Scherrer Institute (PSI) is presented. Envisaged is a machine with very flexible parameters allowing several modes of operation. Among them: very small emittance(~1 nm) at lower energies; high flux, high photon energy operation at the maximum possible energy of around 2 GeV; a bypass option for production of very short pulses with possible operation of a single pass high gain FEL. Under study is the incorporation of superconducting bending magnets into the lattice to increase the critical photon energy into the 10 keV range. The lattice accommodates two long straight sections (~20m each) for flexible use of insertion devices including the production of switchable circularly polarized light.

1 INTRODUCTION

The idea for the construction of a synchrotron light source at PSI started to take shape in 1990. During 1991 the desirable parameters for such a facility became more clear and efforts on a feasibility study for an electron storage ring in the 2 GeV region started in earnest [1]. As a first step we chose for the light source project the acronym SLS, which in different languages stands for:

- Synchrotron Lichtquelle Schweiz
- Source Lumière Suisse
- Sorgente Luce Svizzera
- Sincrotron Luminus Svizzer
- Swiss Light Source
- Surtidor Luminoso Suizo

From discussions with potential users it became clear, that a future synchrotron light facility should offer some unique features with respect to the "third generation" machines that are coming on line within the next few years (e.g. ALS in Berkeley or ELETTRA in Trieste). This is why at PSI we are developing a machine layout with flexible lattice parameters which could allow us to offer the following features:

- very low emittance (about 1-2 nm) at E = 1.5 GeV. This gives a photon source with a very high brightness and a diffraction limit down to wavelengths of about 10-20 nm.
- significant flux of X-rays in the 10 keV region (at $E \geq 2$ GeV)
- possibility to obtain very short bunch lengths (a few ps)
- operation with flexible bunch repetition rates (from 1 to 500 MHz), leading, together with a short bunch, to time resolved experiments
- long straight sections (among them two each 20 m long) to accommodate future developments in the field of insertion devices, including possible schemes for the production of switchable circularly polarized light
- bypass option to be used for an FEL as well as for additional bunch compression schemes to locally further shorten the bunches.

In addition, long beam lifetimes are desirable as well, but may be in conflict with some of the above features. These wishes cannot be all fulfilled simultaneously. We have thus adopted a strategy with different modes of operation:

A) low emittance mode, very high brightness, E around 1.5 GeV. The lifetime is limited (as low as 2 h). Fast filling with on-axis injection is proposed.

B) relaxed lattice mode, intermediate emittance (few nm). Favoured for long life times and for "running-in" the machine.

C) high energy mode with significant flux of X-rays.

2 DESCRIPTION OF SLS

The price for this emphasis on small emittance and flexibility in the mode of operation is a rather complex lattice with many small bends and a large number of quadrupoles, which in turn requires a lot of space. In order to avoid an excessively large circumference we reduced the number of straight sections to six. Two of those are 20 m long and from the remaining four (each 7 m in length) one is reserved for injection and another for the RF cavities. To obtain X-rays in the region of 10 keV and above with 2 GeV electrons, one needs high magnetic fields produced by superconducting magnets.

An obvious choice would be a high flux superconducting wiggler installed in a straight section. In order to offer several X-ray beamlines (with medium flux) we are presently working on a hybrid lattice, where 8 of the 44 bending magnets are superconducting (B_{max} = 3.2T). This approach leaves the available four straight sections free for specialized insertion devices.

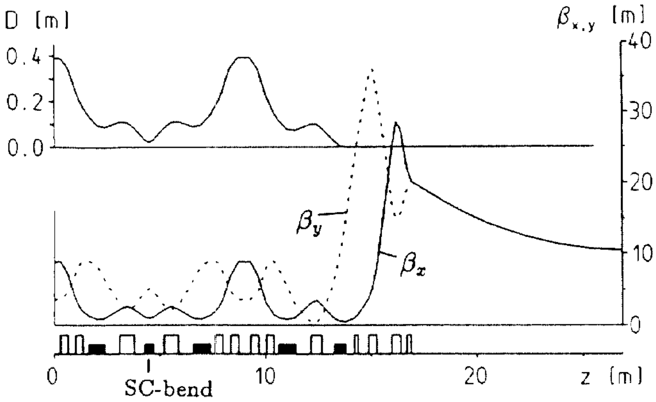

Figure 1: Lattice functions of the SLS hybrid lattice (relaxed mode). Shown is the portion from the middle of a big arc to the middle of the 20m long straight section. The big arc provides a total bending angle of 80^0.

Table 1: Parameter list for the SLS (relaxed lattice)

Circumference L	[m]	230.4	
Harmonic number		384	
RF frequency	[MHz]	500	
Horizontal tune Q_H		15.75	
Vertical tune Q_V		7.64	
Chromaticity ξ_x/ξ_y		-27/-20	
Momentum compaction α		0.0017	
Energy	[GeV]	1.5	2.1
Emittance ϵ_{x0} (no IBS)	[nm·rad]	3.6	7
Energy spread σ_ϵ/E	$[10^{-3}]$	0.78	1.1
Radiation loss per turn	[MeV]	0.108	0.414
Horizontal damping time	[ms]	15.5	5.6
Longitudinal damping time	[ms]	13.2	4.8
Vertical damping time	[ms]	21.4	7.8
Bunch length σ_s	[mm]	6	7
Peak RF voltage V_{RF}	[MV]	1	2

The lattice consists of four big arcs (each with 80^0 bending) and two double bend achromats (each with 20^0 bending). The big arcs connect the long straight sections with the medium ones, and contain each two superconducting bending magnets, similar to the Novosibirsk proposal [2] for a light source. The double bend achromats are similar to the ones used for the ELETTRA machine in Trieste. For the relaxed mode the lattice functions for half of an arc are shown in Fig. 1. Fig. 2 shows a first tentative layout of the SLS storage ring and table 1 lists some important parameters (for the relaxed mode).

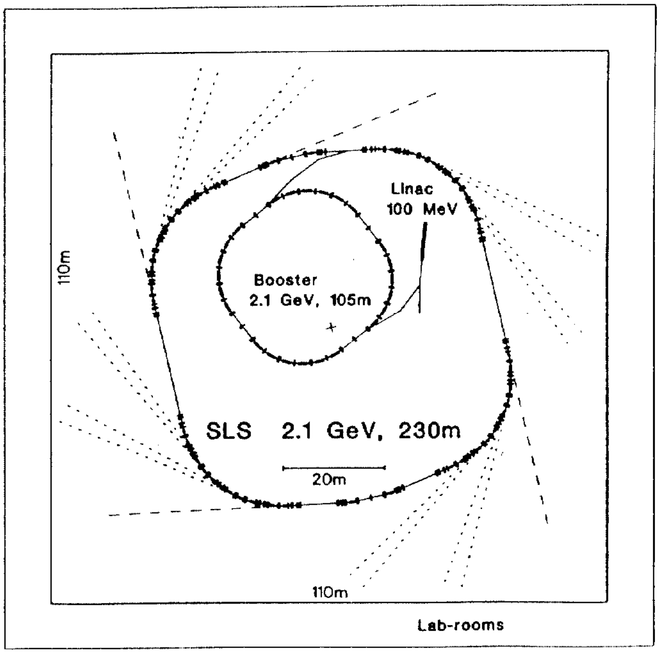

Figure 2: Preliminary layout of the SLS facility with linac, booster and storage ring. Shown are the photon beamlines from insertion devices in two 20m long and two 7m long straight sections (- - -) and the twin beamlines from the eight superconducting bending magnets (...).

Fig. 3 shows a universal diagram of the photon wavelength (or energy) obtainable from undulators in an electron Linac or storage ring. Indicated is the range for some existing or soon to be commissioned facilities. The SLS could cover essentially the same photon spectrum as other rings in the E $\sim$ 2 GeV region, of which we have given the ELETTRA machine in Trieste as an example. Thanks to the superconducting bends, SLS could offer an enhanced flux of X-rays, which, at an electron energy of 2.1 GeV, corresponds to the radiation from a typical bend in a 3.4 GeV storage ring. This x-ray spectrum is attractive in several fields like: spectroscopy, microscopy, spectromicroscopy, structural investigations including biological crystallography and medical applications (e.g. mammography and angiography).

Another interesting topic is industrial applications in the field of nanotechnology and micromechanics. For the fabrication of 3-dimensional microstructures with the so-called LIGA-process [3] a photon energy of about 6 keV, corresponding to a wavelength of 0.2 nm, seems to be optimal. An electron energy of about 2 GeV is ideally suited to produce these photons, but even running SLS at the low energy end with 1.5 GeV one gets a sufficient flux of such soft X-rays.

A unique opportunity for material research also exists because of the close proximity of the synchrotron light facility to the neutron spallation source SINQ (presently under construction at PSI). It would e.g. be feasible to bring a neutron- and a photon-beam together in the same apparatus. With the neutrons one would probe the bulk properties and with the photons the surface properties of a sample.

A users group, organized by Prof. G.Margaritondo (ETH Lausanne), is presently examining the scientific goals of the SLS and the experimental facilities requirements. It is also charged with the forwarding of the special requests from the users to the accelerator team.

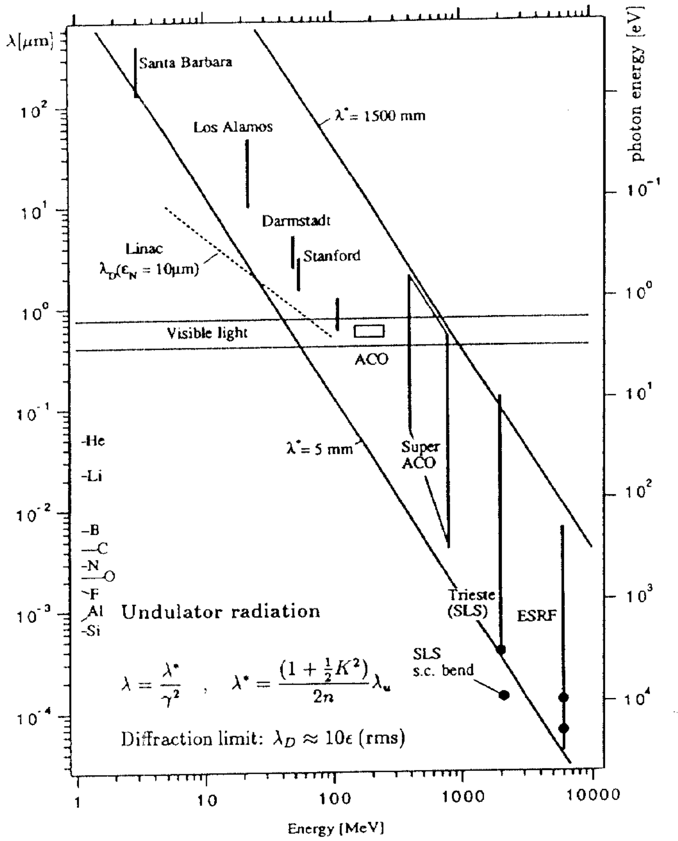

Figure 3: Wavelength range of undulator radiation (in μm) as a function of electron energy for a selection of linacs (infrared FEL) and storage rings (VUV and X-ray) region. The dotted line shows the diffraction limit for a Linac with a normalized emittance of 10μm. The solid circle indicates the critical wavelength of the radiation from the storage ring bends. The K-absorption edges of some elements are shown as well.

3 CHALLENGES

3.1 Control of bunch length

Small desired emittances result in a very high particle density in the transverse plane; this leads to a rather short Touschek lifetime. To achieve a longer lifetime in the modes of operation when the short bunch length is not required, we plan to employ a higher harmonic RF system to lengthen the bunch.

On the other hand, when very short light pulses are desired, the same system can be used to reduce the bunch length, e.g. when operating with a single or a few bunches.

Careful design of the vacuum system components should result in a very low value of the equivalent broad band impedance with rather low resonant frequency (f_r < 3GHz). The effective impedance seen by a short bunch would then be further reduced, making it possible to achieve short bunch lengths (before the turbulent bunch lengthening sets in).

3.2 Injection schemes

We are investigating single turn, on-axis injection schemes for both many bunch and the few bunch operating modes. Using this approach greatly relieves the demands on the dynamic aperture needed for injection.

The linac should be capable of creating trains of 150 bunches to be accumulated and accelerated in the booster. In the few bunches operating mode it will provide full current bunches.

3.3 Low emittance configuration

The chromatic correction schemes and dynamic aperture optimization studies for the low emittance mode (1nm at 1.5 GeV) are in progress. Under investigation are also the tolerances on the alignment and vibrations as well as the effects of insertion devices on the dynamic aperture and emittance.

4 PRESENT STATUS

We are working on the SLS design report, to be submitted to the political authorities in the summer of 1993, with the approval by the Swiss parliament expected in the fall of 1994.

In the meantime we are preparing a test stand for an RF gun with a photo cathode. We are expecting several benefits from such a facility:

- "hands on" experience with some accelerator hardware relevant for SLS.
- production of very short pulses with a high charge, suitable for further acceleration in the Linac injector. If successful one could count on a fast filling scheme for the storage ring with on-axis injection.
- production of a high current beam with very low emittance and short bunch length. Such a beam could be used for future FEL experiments in the infrared region.

5 ACKNOWLEDGEMENTS

We would like to thank S. Adam for help with the lattice programs and the layout of SLS.

6 REFERENCES

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