THE CANADIAN LIGHT SOURCE

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Abstract

The Canadian Light Source (CLS), at the University of Saskatchewan, was funded in April, 1999. It consists of an injection system (250 MeV linac and full energy booster) and a 12 cell DBA 2.9 GeV storage ring. The injection system is now fully operational and construction of the storage ring is well under way with commissioning expected to commence in the summer of 2003. The compact lattice (171 m) requires space saving technologies including strong focusing in the magnets, a superconducting RF cavity and "chicaning" of two insertion devices (IDs) in the 5 m straights. IDs have been designed at the CLS and most will be built on site. Magnets and power supplies have been designed to maintain tight control over machine functions, orbit and transverse coupling. The vacuum chamber and the girder system for the ring incorporate modular designs best suited for a compact lattice. Front ends have been designed for all source points including the chicaned IDs. Development of the CLS subsystems has proceeded with a strong emphasis on a "design-build" project management style. For this, CLS developed detailed preliminary designs and worked with industry to engineer the final products. The project remains on budget and the CLS is expected to be fully operational by the target date of January, 2004.

CLS DESIGN GOAL

The goal of the CLS[1] design is to produce brilliant light in a compact source. Brilliance, $\mathcal{B}$, is proportional to the electron beam energy, E, the current, I, and inversely proportional to the transverse beam sizes, σ, and angular divergences, σ′, as:

$$\mathcal{B} \propto E\ I\ (\sigma_{Tx}\ \sigma_{Ty}\ \sigma'_{Tx}\ \sigma'_{Ty})^{-1/2}$$

where the source terms have both beam(e) and radiation(r) components:

$$\sigma_T^2 = \sigma_e^2 + \sigma_r^2 .$$

For medium energy sources such as the CLS the radiation dominates the angular terms so that the dependence of the brilliance of the electron beam is[2]:

$$\mathcal{B} \propto E\ I\ (\psi\ \varepsilon_x)^{-1}\ (\beta_x\ \beta_y)^{-1/2}$$

where $\sigma_e^2 = \beta\varepsilon$ and $\varepsilon_y = \sin^2\psi$. ψ, the coupling angle[3], is assumed to be small. The history of the CLS involves the optimization of the above factors with the constraint, early in CLS history, that the source circumference be about 100 m.

HISTORY

The early version of the present source, is described in the 1991 document: "A Proposal from the Canadian Institute for Synchrotron Radiation (CISR) to NSERC for a Collaborative Special Project and Program Grant for Study Funds for a Canadian Synchrotron". At this time the interest of the user community was with "soft" xrays and an electron energy of 1.5 GeV was chosen. To have control over the β-functions a racetrack design was contemplated. The design consisted of four to six I-cell bend regions surrounding straights with extra quadrupoles to allow for variable functions in the straights. The design contemplated the use of superconducting (SC) bends in some locations to boost the photon energies produced. Also proposed was the idea to replace one or more bends with an SC wiggle-bend. The drawback of this design is the limited number of straights in a compact lattice.

By 1994, a more conventional Triple Bend Achromat (TBA) lattice[4] was proposed. This design was a 1.5 GeV lattice with 8 cells. The emittance of this source was low at 6 nm-rad. The ring circumference was 104 m. At the same time, more hard X-ray users were interested. It was felt that 8 straights were too few and the beam energy too low.

By 1995 a Double Bend Achromat (DBA) lattice[5] was proposed. This lattice had twelve cells and a focussing configuration that remains to this day. The beam energy was increased to 2.5 GeV and the circumference to 127. The emittance increased to 14 nm-rad. Still, access to more straights and higher photon energies (20 keV undulator radiation) were requested.

The Present Machine

In 1999 funding for the CLS was secured. By this time the energy had increased to 2.9 GeV. Shortly, the straight sections were increased in length to 5.2 m and the circumference became 170.88 m. The lattice was 'frozen' and construction began. The increased straight length allows for doubling up (duplexing) of IDs in each straight. Furthermore, by using extra dipole magnets to "chicane" the beam through the straights the two IDs can delivery beam to separate beamlines. The chicanes[6] separate the photon beams by about 1.5 mrad. This allows the use of a single front end.

To achieve 20 keV undulator radiation it is necessary to exploit the higher undulator harmonics (up to n=15). To ensure quality control of the undulator construction, CLS will manufacture the undulators on site. Five insertion devices will be available for the first suite of CLS beamlines.

COMPACT LATTICE

The compact DBA lattice is achieve by making the magnet lengths as short as possible. At the same time the focussing is strong to minimizing ε_x, Consequently, the lattice requires magnets[7] with high field strengths. A low β_y option requires running some quadrupoles near their design limit.

The dipoles have a bending field of 1.354 T and a field gradient of –38.7 T/m. An upright coil design is used to minimize the total overall length. A smooth distribution of gradient errors in the lattice reduces perturbation of the optics[8].

The lattice uses the minimum number (three) of quadrupole families. This allows for reasonable control of the optics. Maximum field gradients of 22 T/m are achieved. The use of separate power supplies for each quadrupole helps with compensating for the effects of IDs.

The minimum number (two) of sextupole families is used. Harmonic analysis indicated that little was to be gained by introducing extra sextupoles to cancel geometric effects. The maximum sextupole strengths are 270 T/m^2. The sextupoles include extra windings to produce horizontal and vertical correctors in one family and skew quadrupole fields in both families. Orbit correction also includes 24 XY corrector magnets that will be capable of corrections up to 100 Hz [9].

Views of the lattice are shown in figures 1 and 2.

Q C Q B S Q S Q S B Q C Q

Figure 1. Compact Lattice Interior: Q: quad.; B: bend; S: Sextupole; C: Corrector.

Figure 2. Lattice Exterior

BRILLIANCE

The development of the compact lattice has determined the machine functions and beam energy. Two beam factors remain to enhance the brilliance: the beam current, I, and the coupling angle, ψ. Of course, brilliance is ultimately served by the development of undulators. Selected lattice parameters are shown in Table 1.

Table 1: CLS Lattice Parameters

Circumference	170.88 m
Periodicity	12
Tunes: ν_x,ν_y	10.22, 3.26 (*4.26)
Momentum compaction	0.0038
Straights length β_x, β_y, η_x (at centre) β_x, β_y, η_x (* low β_y option)	 5.2 m 8.5, 4.6, 0.15 m 9.1, 2.7, 0.15 m
RF frequency voltage harmonic number energy acceptance	500 MHz 2.4 MV 285 1.54%
Energy loss per turn	0.876 MeV
Horizontal emittance	18.1(*17.8) nm-rad
Energy spread	0.111%
Full bunch length	65 ps

SuperConducting RF cavity:

The choice for the CLS RF system is a SC cavity based on the Cornell design[10]. Two advantages are low higher order modes (HOMs) and a large voltage (2.4 to 3.0 MV) in a single cell. Both these features will result in long beam lifetimes. With the presently installed power levels (300 kW), it should be possible to store currents up to 280 mA at 2.9 GeV and 500 mA at 2.5 GeV. Future development of the cavity technology may allow 500 mA at 2.9 GeV. The high performance of the SC cavity allows delivery of the required RF power in a single straight. The CLS SC cavity is shown in figure 3.

Figure 3. Superconducting Cavity

Coupling Control

Control of coupling studied earlier[11] has been investigated further. The simplest technique is to deduce the coupling from motion in the vertical plane when a horizontal "kink" is introduced into the orbit. This technique requires measurements of the closed orbit that allows time average measurements.

Using twelve of the skew quadrupoles and measuring the motion in each of the twelve straights, simulations show it is possible to reduce the vertical coupling to 0.02%. This may be lower than desirable for achieving reasonable beam lifetimes. However, if beam "top-up" is used, lifetime becomes less of an issue. It may also be possible to reduce the coupling locally. By using a coupling angle monitor[11] it is possible to reduce the beam size in one straight to almost half the average value. This may have some application when small gap undulators are used.

Results of coupling simulations are shown in figures 3 and 4. The beams shown are arrays of particles tracked over 1000 turns. The initial beam is generated in six dimensions using the nominal damped beam. The initial vertical beam emittance is $\varepsilon_x x10^{-5}$. Coupling, introduced by random misalignments of the lattice elements, results in growth of the vertical beam emittance.

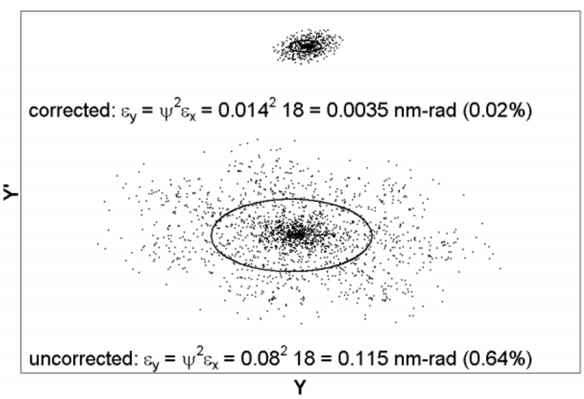

Figure 4. Coupling Correction Using Closed Orbit Measurements.

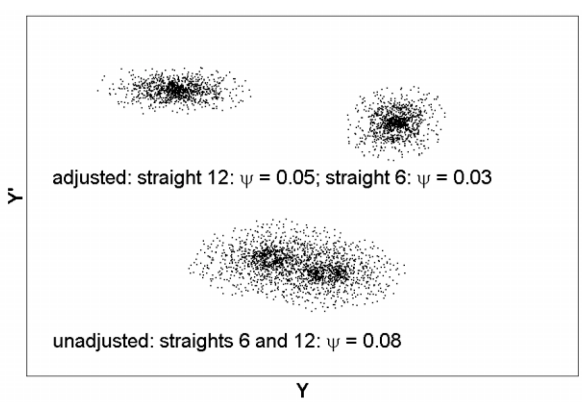

Figure 5. Coupling Adjustment Using Coupling Angle Monitor.

Insertion Devices

Five IDs are presently approved for the CLS. They are the four undulators and the SC wiggler shown in Table 2 and figure 6. As mentioned, the undulators will be built at the CLS. A high precision magnet mapping facility is now under development and the construction of the undulators will begin before the end of 2003. Specification of the SC wiggler has been completed. It is expected to be built, off site, by the end of 2004.,

Table 2: Approved CLS Insertion Devices

ID	Gap (min.)	Period	Poles	Photon energies
	mm	mm		eV
Undulators				
EPU	15	75	43	100 – 1000 (Circular) 100 – 3000 (Linear)
PPM	25	185	19	5.5 - 250
PPM	12.5	45	53	250 -1900
Hybrid	5	20	145	6k –18k
Wiggler				Critical energy
SC	15	35	60	10

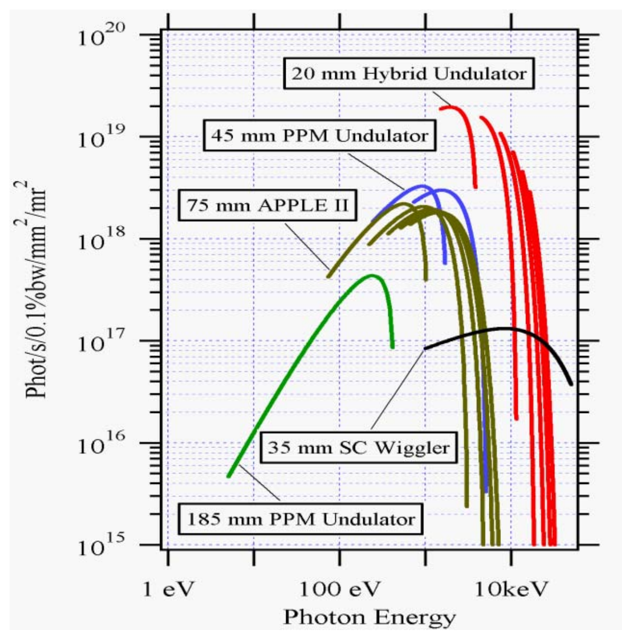

Figure 6. Brilliance: Tuning Curves for CLS Undulators and Photon Curve for the SC Wiggler.

With the duplexing of the straights it will be possible to install two Elliptically Polarizing Undulators (EPUs) in tandem. Under normal operations, the chicane magnets will separate the beam produced into two beamlines. With some extra chicanery (two more chicane magnets) it will be possible to direct both beams down the same line. In this way it should be possible to rapidly switch between polarization states using optical components in the beam line.

Beamlines

The layout of the initial CLS beamlines is shown in figure 7. The storage ring is located asymmetrically in a square building about 85x85 m^2. This allows for a variety of beamline lengths. For future expansion the north wall (top of figure) can be removed and beamlines developed in that direction.

As well as the beamlines associated with the IDs mentioned above, two Infrared (IR) beamlines are under development on bending magnet sources. Two beam diagnostic beamlines are also being built.

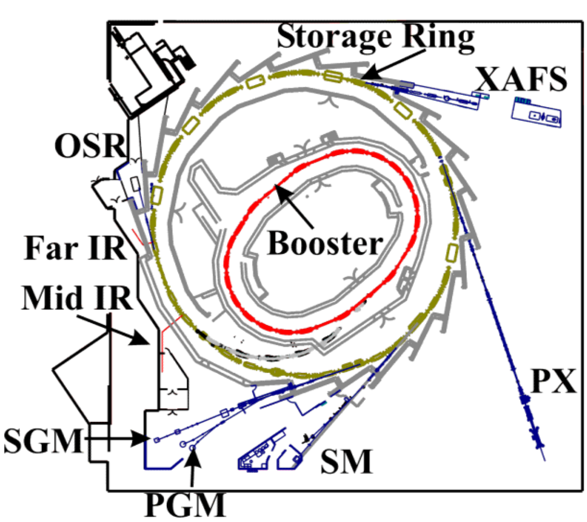

Figure 7. Initial CLS Beamlines. Also shown are the booster and the storage ring (SR1).

CLS STATUS

Figure 8. CLS Building.

The CLS building is shown in figure 8. Construction began in 1999 and was completed by the end of 2000. The full energy booster has been installed has was fully commissioned by September, 2002. Installation of the storage ring is expected to be complete by the summer of 2003 when storage ring commissioning will begin. At the same time, the beamlines will be installed for commissioning by the end of the year.

Booster Commissioning

A final result achieved during booster commissioning is shown in figure 9. Signals from the Fast Current Transformer (FCT), the Parametric Current Transformer (PCT) and a dipole field are shown. A 40 mA peak current was injected at 250 MeV and a 20 mA peak current was extracted at 2.9 GeV. Beam losses occur due to inefficient capture in the RF bucket at injection and reduction of relative RF overvoltage at extraction. This is shown by the average current measured by the PCT.

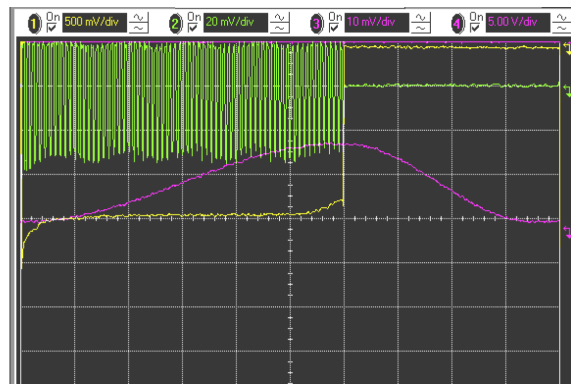

Figure 9. Booster Ramping. Upper: FCT; Lower: PCT (negative signal); Middle: Dipole Field.

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More is available at the CLS website. See http://www.lightsource.ca/