CANADIAN LIGHT SOURCE PROPOSAL

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Abstract

The storage ring for a 2.9 GeV Canadian Light Source has been designed. The lattice is composed of twelve compact DBA cells resulting in a ring that is 148 meters in circumference with twelve drifts of 4.5 meters for the inclusion of insertion devices. The emittance is less than 20 nm-rad, resulting in radiation brightness competitive with other “third generation” sources. Details of orbit correction, beam stability and lifetime and the effect of insertion devices have been investigated. The RF requirements have been defined and preliminary magnet designs have been done.

The light source will operate with full energy injection and the injection scheme has been fully defined. Injection includes a 300 MeV linear accelerator, low energy transfer line, booster synchrotron and high energy transfer to the storage ring. With this configuration it will be possible to operate the storage ring with beam currents up to 500 mA, resulting in a source of very intense light over a broad range of photon energies. For example, with a state of the art undulator, it will be possible to produce 20 keV photons with a brightness close to 10^{18} photons/s/mm^2/mrad^2/0.1% bandwidth.

1 INTRODUCTION

Since the creation of the Canadian Institute for Synchrotron Radiation (CISR), in 1990, Canadian synchrotron radiation (SR) users and accelerator physicists have been actively involved in designing and promoting a light source that would satisfy the needs of most users. After several workshops involving the Canadian user community, it was decided that Canada required a source comparable to present third generation machines, capable of operating at a beam energy of 2.5 GeV. To keep the costs as low as possible design efforts concentrated on producing a lattice which was as compact as possible while keeping a large number of straight sections for insertion devices.

In May, 1996, an international peer review committee chose the Saskatchewan Accelerator Laboratory as the site for the Canadian Light Source (CLS). This committee recommended that the beam energy be increased to 2.9 GeV in order to accommodate hard X-ray users. A proposal incorporating this recommendation [1] was submitted to the Natural Sciences and Engineering Research Council (NSERC) which unanimously endorsed the peer review results and recommended that the CLS be built and located at SAL. We are optimistic that funding will be forthcoming in the near future.

The increase to 2.9 GeV was accomplished with a minor modification to the lattice and by upgrading the injection booster. This “final” design will be discussed below.

2 LATTICE

The CLS requires a machine with brightness comparable to existing “third generation” machines, with ten straight sections available for the inclusion of insertion devices (IDs). At the same time it is desirable to keep the machine as small as possible to keep the overall cost low. Both the triple bend achromat (TBA) and double bend achromat (DBA) were initially considered. For a given machine circumference the TBA has lower emittance, but the DBA, with its smaller cell size, can accommodate more straight sections. In the lattices studied [2,3], the DBA had better dynamic aperture, which would improve operations at higher currents. Consequently, the DBA cell structure was chosen to produce a compact design.

To produce photons of energy up 20 keV with high brightness, the CLS will operate with beam energies up to 2.9 GeV. At this beam energy the dipole field strengths are approaching 1.5 T. To have straight sections available for injection and for RF cavities, the total number of cells is twelve.

To create a compact cell structure, only three families of quadrupoles are used in each cell. For additional focusing, a gradient was introduced into the dipole magnets. This gave four focusing parameters to optimize the cell parameters. These parameters were adjusted to create the desired horizontal and vertical tunes, ν_x and ν_y; the horizontal betatron amplitude, β_x, in the ID sections; and the horizontal dispersion, η_x. During this process the lengths of the quadrupoles were adjusted so that the maximum pole tip field did not exceed 5 kG.

To reduce the emittance of the lattice, the requirement that the cell be an achromat was relaxed and some dispersion was introduced into the straight sections. During the optimization, the vertical betatron function, β_y, in the straight sections was allowed to float, but the final value resulted in a favourable amplitude. Finally the dipole gradient was “frozen”, leaving three free parameters to adjust the two tunes and either β_x or η_x.

To control the chromaticity of the lattice, two sextupole magnets are included between the two dipole magnets. The resulting lattice is shown in Figure 1a where a half cell is shown. The complete cell is obtained by reflective symmetry about the centre of the sextupole on the right. The machine functions for a complete cell are shown in Figure 1b, with the dipoles and quadrupoles shown schematically below.

Some important parameters for the CLS are given in Table 1. The ring circumference of 147.377 m is small for a low emittance lattice operating at 2.9 GeV, resulting in savings in construction cost while still providing a bright source of photons up to x-ray energies from 10 possible ID locations. An earlier version of this lattice [4], with 3.5 meter

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straights, was only 127 m in circumference. The DIMAD [5] input for the present lattice is given in Appendix I.

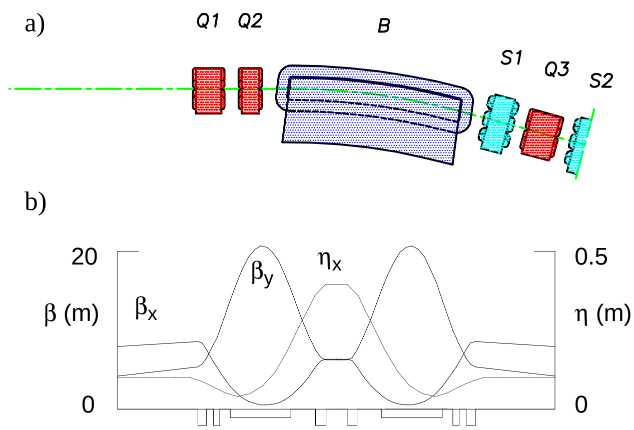

Figure 1 a) Physical layout of one half cell. b) Machine functions for one full cell.

Table 1. CLS machine parameters

Circumference	m	147.377	
Periodicity		12	
Optics ν_x (tune) ν_y		 10.22 3.26	
Straights length β_x (betatron amplitude at centre) β_y η_x (dispersion)	 m m m m	12 4.5 8.0 4.2 0.15	
RF Cavity frequency voltage	 MHz MV	 476 2.25	
E (energy)	GeV	1.5	2.9
B_{dipole}	Tesla	0.771	1.490
Total Rad. Power	kW @500 mA	35	482
Rad. Power/m	kW/m (dipoles)	0.86	11.81
ε_x (emittance)	nm-rad	4.4	16.3
δ (energy spread)	%	0.060	0.115
Bunch length (full)	ps	43	74

The optimization of both the brightness and critical energy for the CLS lattice is shown in Figure 2. Brightness and critical energy are plotted for several third generation sources now in existence. For the sources shown, brightness increases proportional to the machine circumference. The CLS is especially well optimized for critical energy, especially among the smaller machines. The values shown assume the same ID on each machine, operating at the same beam current and normalized to Spring-8 = 1. The CLS parameters are those given in this paper. For the other machines, parameters are taken from reference [4], with the exception that the ALS is evaluated at 1.9 GeV. For the ESRF the high β straights were considered. The ESRF lattice also has low β straights optimized for short IDs.

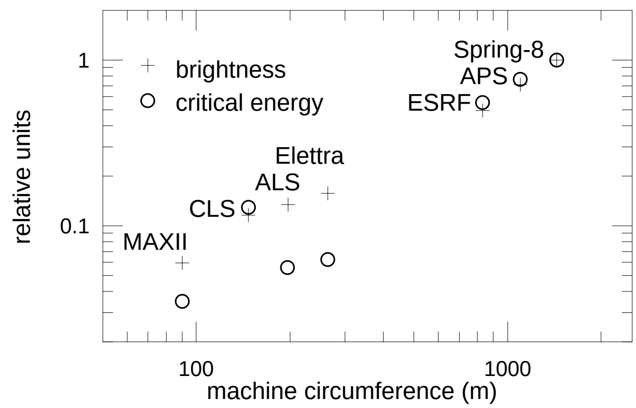

Figure 2: Relative brightness and critical energy vs machine circumference.

The tunability of the lattice was checked by changing the transverse tunes by ±1 , while keeping the dispersion fixed. This is done by varying the three families of quadrupoles. The lattice is stable over all combinations of retuning, but the beam size is optimum for the nominal tunes given in Table 1.

The effects of possible dipole gradient errors were also checked. This showed that systematic errors up to 5% in the dipole gradient and random errors up to 2% are tolerable.

The horizontal betatron amplitude, β_x, in the centre of the straights is as small as possible while maintaining enough amplitude for horizontal injection. The horizontal beam size, $\sigma_x = (\varepsilon_x\beta_x + \delta^2\eta_x^2)^{1/2}$, is 18% smaller than for the lattice tuned for no dispersion in the straights. The vertical size is 26% smaller.

The RF frequency was chosen to be one-sixth of 2856 MHz, the frequency of the existing 300 MeV linac injector. The voltage of 2.25 MV is adequate for Touschek lifetimes of over 80 hrs at 2.9 GeV.

Magnets, including septa and kickers, have been designed with parameters comparable to elements at existing facilities. The ALS design report [2] was especially helpful. Similar to the ALS design, sextupole magnets will have windings so they can be used as both horizontal and vertical orbit correctors. At this time, the possibility of using back leg windings on one family of quadrupoles (Q1) is being investigated. With this set-up there will be five horizontal and three vertical correctors per cell.

3 INJECTION SYSTEM

Injection into the CLS will be done with a full energy booster. The layout of both rings is shown in Figure 3. Injection into the booster will be from the existing 300 MeV electron linac at the Saskatchewan Accelerator Laboratory. The linac is located in a vault which will be 6.5 m below the level of the booster.

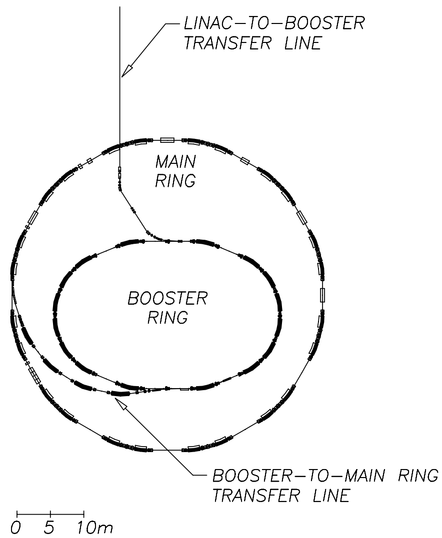

Figure 3: Layout of main ring, booster and transfer lines.

To allow time to ramp injection and extraction kickers, a 126 ns pulse train will be injected into the booster, filling 60 out of 144 buckets. Successive pulse trains will be stacked in the main. ring filling 180 of 234 buckets. Accounting for transmission efficiencies throughout the injection process, 15 mA of current should be injected into 60 buckets of the main ring during each injection cycle. To reach circulating currents of 500 mA, 97% of the beam in the ring must be retained during each cycle. Analyses [6] of beam instabilities indicate that 500 mA of current will introduce no bunch lengthening or emittance growth. At these currents, however, a few coupled bunched modes may need to be suppressed.

4 RADIATION CHARACTERISTICS

For an initial compliment of beamlines, six IDs and five bend magnets will be in service on the CLS. The IDs have been selected to cover a broad range of photon energies and brightness or flux. They include a single pole superconducting wiggler at 5.1 T, a 15 pole wiggler at 1.4 T, and four undulators with periods ranging from 3.6 to 19.2 cm. The undulators are all about 3 m long.

The ideal brightness curves for the IDs and the bend magnets (dipoles) are shown in Figure 4. All are for 2.9 GeV operation except where indicated. The beam size has been evaluated at the center of the straight sections for the IDs and at the centre of the bend magnets for those curves. For the undulators, harmonics up to n = 5 have been evaluated. The K values for the undulators range from K = 1 to K = λ_u, where λ_u is in cm. This results in a minimum gap of 9 mm for the 3.6 cm undulator assuming neodymium-iron permanent magnets.

Also shown in Figure 4 is a curve for a 2.0 cm undulator which shows promise in producing high brightness ($\rightarrow 10^{18}$) at photon energies up to 20 keV. For this curve an undulator length of 4 m was used and odd harmonics up to n = 15 included. At K = 2 the gap size is 5 mm. The ideal curve will be somewhat diminished by the energy spread of the electron beam in the ring as well as imperfections in undulator construction. Simulations using the measured fields of an existing undulator (N =70, λ_u = 3.3 cm) and a lattice similar to the CLS show that the n = 13 harmonic can be reduced to about 20% of its ideal value. If the same efficiency can be achieved with a 4 m ID and considering an operating current of 500 mA, a brightness of about one tenth of the plotted value can be expected.

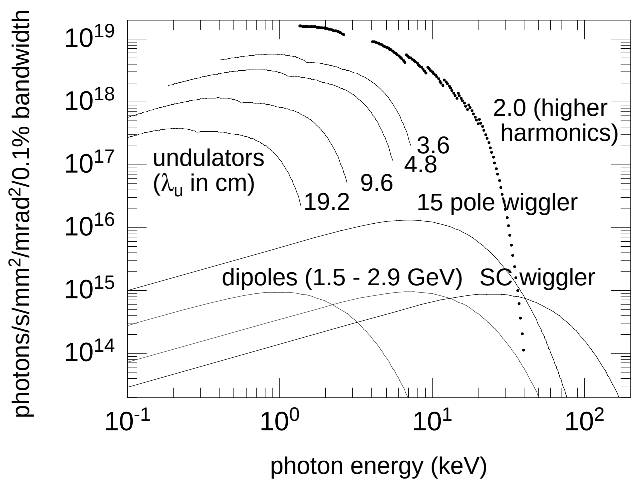

Figure 4: Brightness curves for CLS.

5 REFERENCES

[1] Canadian Light Source, The Proposal for Construction of a National Synchrotron Light Source for Canada, September, 1996 (SAL).

[2] 1-2 GeV Synchrotron Radiation Source. Conceptual Design Report, LBL PUB-5172 Rev. (1986)

[3] A. Andersson, et al. Design Report for the MAX II Ring, MAX-lab, University of Lund, ISSN 0284-1258 (1992)

[4] J. Murphy, Synchrotron Light Source Data Book, Version 4, BNL 42333, May, 1996.

[5] R.V. Servranckx, "USERS' GUIDE TO THE PROGRAM DIMAD", TRIUMF-DN -93-K233

[6] M. Zisman, S. Chattopadhyay and J. Bisognano, "ZAP User's Manual", LBL-21270 ESG-15.

APPENDIX I

Dimad input file:

```
TITLE
CLS
D1:DRIFT,    L=2.24071
D2:DRIFT,    L=0.2
D3:DRIFT,    L=0.3
D4:DRIFT,    L=.3
D5:DRIFT,    L=.2
D6:DRIFT,    L=.2
S1:SEXTUPOLE, L=0.2,K2=-44.341435,APERTURE=.035
S2:SEXTUPOLE, L=0.1,K2=64.73617638,APERTURE=.035
Q1:QUADRUPOLE,L=0.25,K1=2.25622,APERTURE=.035
Q2:QUADRUPOLE,L=0.17,K1=0.435394,APERTURE=.035
Q3:QUADRUPOLE,L=0.28,K1=2.23194,APERTURE=.035
HC:SBEND,L=1.7,ANGLE=0.2617994,E1=0.1308997, &
E2=.1308997, K1=-.46454, HGAP=.025,FINT=0.5
HCELL:LINE=(D1,Q1,D2,Q2,D3,HC,D4,S1,D5,Q3,D6,S2)
CELL:LINE=(HCELL,-HCELL)
RING:LINE=(12*CELL)
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