CANADIAN LIGHT SOURCE UPDATE

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Abstract

The Canadian Light Source (CLS) storage ring has been operating routinely since commissioning was completed in the spring of 2004. Beam currents up to 230 mA have been achieved with the single superconducting RF cavity. With steady improvement beam lifetimes (1/e) of 14 hours at 200 mA and 0.5% coupling are now possible. In the last year the vertical tune was increased by 1 integer to produce a smaller vertical beam size in the insertion device (ID) straight sections. This year the horizontal tune will be increased to reduce the beam emittance. The vertical coupling has been reduced both globally and locally using a skew quadrupole response technique. A wide range of photon energies are provided by an initial complement of five IDs and two infrared (IR) ports. The 5 m straights have room for two IDs. The light cones from these IDs are separated by about 1.5 mrad by "chicaning" the electron beam in the straights. To date two IDs have been installed in one straight using the chicaning technique. As well, a superconducting wiggler, an in-vacuum undulator and an AppleII type elliptically polarizing undulator (EPU) have been installed and are being commissioned.

MODES OF OPERATION

Tunes

The CLS [1] was originally designed and commissioned to operate at tunes of ν_x = 10.22 and ν_y = 3.26. A so-called low β_y option had been considered during the design stage as well [2]. By increasing the vertical tune from 3.26 to 4.26, β_y is decreased from 4.6 to 2.7 m. For the SGM and PGM IDs [1] in straight 11 the CLS has a vacuum chamber with an inner gap of only 7.5 mm. To improve the beam lifetime the low β_y option has become our normal mode of operation. Most recently the vertical tune was increased to 4.28 to reduce an observed coupling effect.

Also reported in [2] is an option to go to a horizontal tune of 11.22. At this tune the horizontal emittance is reduced from 18.1 to 14.1 nm-rad. This mode was recently achieved and once the injection is optimized it will likely become our new "normal" operating tune.

Machine parameters for the various tunes are given in Table 1. (The machine functions are for the middle of the straights.)

Other Modes

Single Bunch Mode: Currents up to 33 mA have been obtained in a single bunch and used to perform experiments. Work is in progress to improve single bunch purity.

Low Energy Mode: Storage ring operation at 1.5 GeV has been achieved. At this energy "green" light is produced by the PGM undulator. This light was used to aid in the commissioning of that beamline. At this energy it should be possible to reach stored currents in excess of 500 mA with our single superconducting RF cavity.

Short Bunch Mode: The momentum compaction can be reduced to near zero by adjusting the horizontal dispersion to -0.52 in the straights (see Table 1). In this mode it should possible to achieve bunch lengths (1σ) of 4 ps. Preliminary attempts have produced bunches of 8 ps as shown in figure 1. Tracking simulations indicate unstable motion near "zero" compaction and with chromaticities near zero. As well, going in going from positive to negative compactions shifts up to 2% are observed in the reference electron energy.

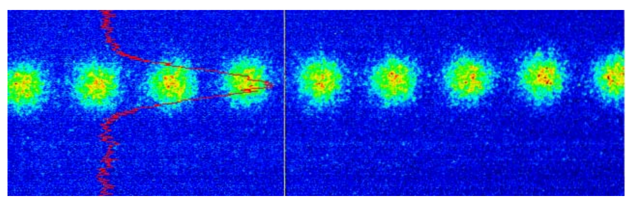

Figure 1. Steak camera images of 8 ps (1σ) bunches.

Table 1. Machine Parameters

ν_x	ν_x	β_x	β_y	η_x	σ_{bunch}	ε
		m	m	m	ps	nm-rad
10.22	3.26	8.5	4.6	0.15		18.1
10.22	4.26	9.5	2.7	0.15	33	17.8
11.22	4.26	16.7	2.6	0.15		14.1
10.22	4.26	14.2	2.8	-0.52	4	131

INSERTION DEVICE UPDATE

The installation of an in-vacuum undulator and an elliptically polarizing undulator (Table 2) (and a SC wiggler) have impacted on the storage ring operations.

In April 2006 the CLS installed an Elliptically Polarized Undulator (EPU) built in-house for the SM beam line in straight section 10-1. It is an APPLE-II type device made with NdFeB permanent magnets (Br~1.25). It has a 75mm period, and a 15mm minimum gap. The device produces linearly polarized light from 80-4000eV and circularly polarized light from 80-1000eV (figure 2).

Over the full operating range of gap and phase settings with no active correction coils, the magnetic field errors cause a horizontal(vertical) angular kick of the electron beam of <10μrad (<8μrad) and a displacement of <12 μm (<15 μm). Measured phase angle error is <7° r.m.s. over the entire range of gap and phase operation without any active correction, applying available active correction should improve this to <4° r.m.s.

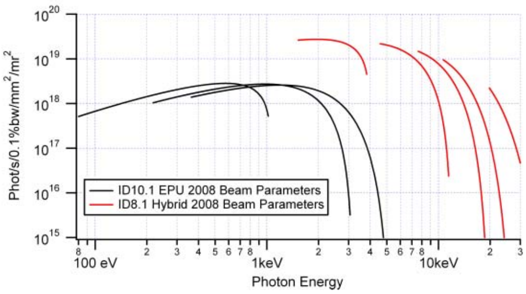

Figure 2. Theoretical Brightness of IDs.

Skew multipoles (figure 3) were larger than designed for, but simulations and commissioning results have showed only small effects on the electron beam. Horizontal(Vertical) tune shifts in the ring were measured and found to be <0.07(<0.06)% over the operating range of the EPU.

The transverse coupling (0.6%) changes a small amount with gap, ± 0.2%. A small air coil has been added downstream in the same straight section as the EPU and allows for correcting the skew quadrupole.

Phase-II beam lines will include a second EPU for the REIXS beam line to be installed in the same straight section as the current device. Chicaning will then allow light from either or both IDs to be directed to either beam line.

Magnetic assembly was completed for an in-vacuum hybrid undulator which was installed in straight 8-1 in August 2005. It is a 20mm period hybrid device made with Sm_2Co_{17} type magnetic material. Magnetic field measurements including applied corrections from a single correction coil(vertical magnetic field) show on-axis field errors causing a horizontal(vertical) angular kick of the electron beam of <0.5μrad (<11μrad) and a displacement of <0.5μm (<11 μm). Measured phase angle error is <2° r.m.s. for gaps between 6-10mm and <3.9° r.m.s. elsewhere. Continued operation and vacuum conditioning at small gaps is needed to improve beam lifetime while the device is operating below a 10mm gap.

Table 2. ID Parameters.

Summary	SM, ID	CMCF, ID
Photon energy range		
Planar	80-4000eV	6-18keV
Circular	80-1000eV	N/A
Undulator Type	APPLE-II	In-Vacuum Hybrid
Period Length	75mm	20mm
Full Sized Poles	41	157
Length of Magnet Assembly	1591mm	1583mm
Minimum Gap	15.2mm	5mm
Magnetic Flux at min. gap(Measured)	0.76 T	1.17 T

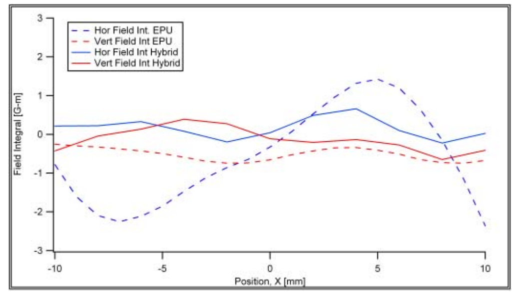

Figure 3. ID Integrated Multipole content.

TRANSVERSE COUPLING CONTROL

Requirements for small vertical beam sizes in some IDs along with the desire to maintain long beam lifetimes has lead to the development of a local transverse coupling correction scheme.

The brightness of light produced at any point in the ring is inversely proportional to the vertical beam size. The beam size is given by

$$\sigma = \sqrt{\varepsilon\beta + (\delta\eta)^2}\ .$$

To reduce the vertical beam size, both the vertical emittance ε_y and the vertical dispersion η_y must be minimized.

The coupling angle ψ(s) varies around the lattice and with the total invariant emittance ε determines the local horizontal and vertical emittances:

$$\varepsilon_x = \varepsilon \cos^2 \psi(s) \quad \text{and} \quad \varepsilon_y = \varepsilon \sin^2 \psi(s)\ .$$

As the coupling angles tend to be small we use $\varepsilon_x \approx \varepsilon$ and $\varepsilon_y \approx \psi^2 \varepsilon$. Thus,

$$\psi^2 = \varepsilon_y / \varepsilon_x \equiv Q, \text{ and } \sigma_y = \sqrt{Q\varepsilon\beta_y + (\delta\eta_y)^2}$$

where Q is the percent coupling and is the quantity referred to in the results.

The Touschek lifetime is inversely proportional to the beam density. When Q is small, a significant reduction in lifetime is observed. However, it can be advantageous to increase the average coupling to provide a longer lifetime, especially in modes such as single-bunch.

Correction Method

Similar to methods described earlier [3]. For the present work we measure the change in the vertical orbit due to a horizontal kick[4]. CLS is equipped with 36 skew quadrupoles (SQs), of which 12 are currently in use. A response matrix is created by measuring the vertical orbit shifts (10s of microns) due to each SQ while the beam is subjected to a large horizontal kick (~3 mm), and subtracting from it the perturbations due to each SQ with no horizontal kick:

$$S_{ij} = \left[\frac{y_{ij}}{SQ_j}\right]_{kick} - \left[\frac{y_{ij}}{SQ_j}\right] - \left[y_{i,kick} - y_i\right],$$

where the last term is the reference difference orbit measured with no SQs active. SQ currents of 1.5 amps were used, equivalent to k1 = 0.006 m^{-2}.

In order to include vertical dispersion in the correction, we measured responses for half of the SQs while the RF frequency was decreased by 2 kHz (from 500 MHz) to simulate particles orbiting at the extreme of the damped energy spread. Some response matrices were formed using the only a frequency shift instead of the horizontal kick to provide correction directly on the vertical dispersion.

Once the response matrix S_{ij} is calculated the response due to any set of SQs can be found. The above system is solved for the SQ values using Singular Value Decomposition to invert the S_{ij} matrix. The number of singular values can be adjusted for solutions that are in the linear region of the SQs (< 4 A) but still large enough for an effective correction. The SQ values are given by

$$SQ_i = S_{ij}^{-1}(F_j - 1)\Delta y_{ref,j}$$

The F_j are factors which scale the size of correction at each position. For zero global coupling, all 'F's = 0, for double global coupling, all 'F's =2. Local corrections can be found if the 'F's are varied around the ring. In this way, it is possible to decrease the coupling in parts of the ring while increasing it in others to maintain a larger average coupling and lifetime.

Results

Beam sizes are measured at the XSR (X-Ray Synchrotron Radiation) diagnostic beamline, located off a bend magnet. Horizontal and vertical emittances and the percent coupling are calculated from the measured beam sizes and known lattice functions. With no SQ correction, the percent coupling in the CLS storage ring is around 0.6%. The 1σ beam size at the XSR is about 85 microns (β_y = 27m), which corresponds to about 18 microns (β_y = 2.6m) in the ID straights.

Initial correction attempts using the horizontal kick with half the measurements at the dispersed orbit position gave reasonable results, we could routinely decrease the percent coupling by half. The most significant correction was calculated using the dispersion-only response. Using this matrix, we corrected the global coupling to less than 0.2%. The corresponding vertical beam size in the straight is about 10 microns.

Local coupling correction was demonstrated using the dispersion response matrix. The 'F's were adjusted so that the dispersion was minimized near the XSR and increased on the other side of the ring as shown in figure 5. Dispersion measurements show a flat region near the XSR and larger dispersion on the other side of the lattice. For comparison, we examined the beam size and dispersion of one-third of the global correction. For the two cases, the beam size at the XSR remained unchanged. Lifetime measurements show an increased lifetime for the local coupling correction as shown in figure 5. Here the average coupling is larger than for the 1/3 global correction.

These results are very promising, but there is much work yet to be done. The next step is to include the dispersion information as well as the vertical difference

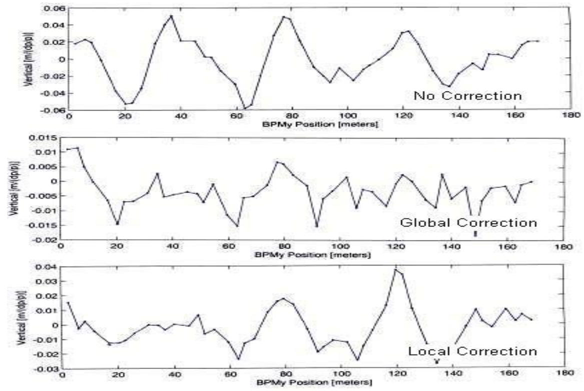

Figure 4. Vertical dispersions for no correction, global correction and local correction. For the local correction attempts were made to keep the dispersion large in the middle of the lattice.

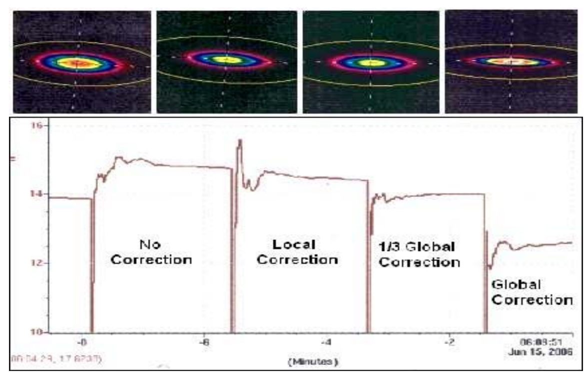

Figure 5. Lifetime as the SQs are varied from zero correction, local correction, 1/3 of the global correction and the full global correction. Inset are the beam sizes at the XSR.

orbits from a combination of horizontal kicks in a single over-determined system. Using just two horizontal kicks separated by 90 degrees in betatron phase is sufficient to sample the coupling at every point in the lattice.

The addition of the remaining 24 SQs in the near future is expected to improve both global and local correction capability.

REFERENCES

[1] L. Dallin, R. Berg, J. Bergstrom, M. de Jong, X. Shen, R.M. Silzer and J.M. Vogt, "Canadian Light Source Status and Commissioning Results", EPAC2004, p. 2269.

[2] L. Dallin, "CLS Lattice Performance Analyses", CLS Report 8.2.69.1 Rev 0, November 27, 2000.

[3] L. Dallin, "Local Transverse Coupling Control", PAC2001, p. 2677.

[4] J. Safranek and S. Krinsky, "Coupling Correction Using Closed Orbit Measurements", Orbit Correction and Analysis Workshop, Upton, New York, 1993.
See also: http://www.lightsource.ca