CANADIAN LIGHT SOURCE STATUS AND COMMISSIONING RESULTS

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Abstract

Construction of the storage ring for the Canadian Light Source (CLS) was completed in August 2003. By June, 2004, after several months of commissioning, beam currents of up to 100 mA with 2.1 hr lifetimes were achieved. Commissioning activities included global orbit correction and measurement of machine parameters supported by beam based measurements and a model based analysis of the real machine. By fall, 2004, when users operations begins, currents up to 100 mA with 4 hour lifetimes are expected.

INTRODUCTION

The CLS storage ring [1] is a 3rd generation light source operating at 2.9 GeV and designed to produce high brilliance x-rays up to 20 keV. Features of the CLS are a compact lattice (171 m), high performance magnets [2] and a superconducting RF cavity. The lattice is made up of twelve double bend cells with twelve 5 m straights. With one straight for injection, one for the RF cavity and one for diagnostics, nine straights are available for insertion devices (IDs). To maximize the number of IDs, most straights will be "chicaned" to allow the installation of two IDs per straight, producing light with an angular separation of about 1.3 mrad. To date, the storage ring has been commissioned and two IDs have been installed. First light was observed in the optical diagnostics beamline on December 9, 2003 and is shown in Fig. 1.

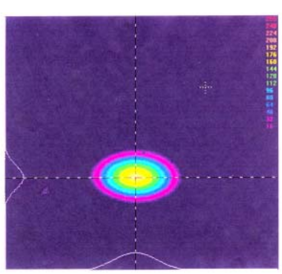


Figure 1. First light observed on the OSR beamline. At the source point $\beta_y / \beta_x \approx 25$. Using the theoretical horizontal dispersion and energy spread, the transverse coupling is estimated to be about 1.5%.

COMMISSIONING EXPERIENCE

Commissioning began in September, 2003, and proceeded until June, 2004, with about two weeks of beam time each month. Progress was delayed by several months due to some technical difficulties. First, in November, a single quadrupole was discovered to have a reverse polarity. Even after this was fixed, it was difficult to correct the orbit and injection efficiencies were poor.

In February, 2004, analysis of the orbit corrector response matrix revealed that a single button monitor was giving the wrong polarity for the beam position in both the horizontal and vertical planes. With this repaired, the orbit could be corrected at all locations, except at the entrance to the RF cavity. A visual inspection of the vacuum chamber in March, 2004, revealed a large obstruction across the centre of the chamber. Once the obstruction was removed commissioning went very quickly. The results are presented in the following sections.

Injection

Injection [3] is at full energy. For most of the measurements described below, 68 consecutive buckets out of 285 were uniformly filled. To achieve higher currents 204 buckets will be filled in the future. Injection times for 100 mA are about 30 seconds with injection efficiencies of up to 75%.

Orbit Correction

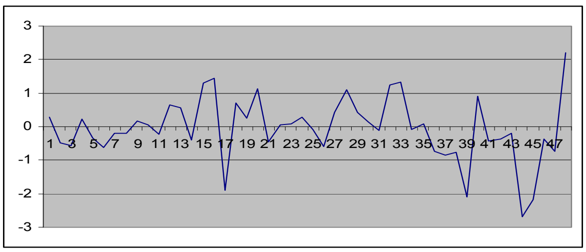
The orbit correction system [4], consisting of 48 position monitors and 48 correctors in each plane, is implemented with the program CORBIT [5] (Corrected ORBIT). BPM/corrector response matrices indicated a high degree of symmetry from cell to cell, giving confidence in the magnet excitations. Quadrupole centring techniques [6] were used to determine BPM offsets. To best match the orbit to the machine length the RF frequency was changed from the design value of 500.000 MHz to 500.018 MHz. indicating an error in the machine length of about 6 mm (out of 170.88 m).

Taking advantage of singular value decomposition, it was possible to correct the orbit with an rms orbit deviation of about 30 microns horizontal and 70 microns vertical. This is consistent with DIMAD [7] simulations [8] using 150 micron rms alignment errors. Although the present resolution of the commercial BPM electronics is about 10 microns, by averaging hundreds of BPM readings the rms stability of the orbit has been measured to be about 1 micron in both planes. It remains to be seen if this is the intrinsic stability of the beam or if further filtering and averaging on the BPMs can produce a better result. A sample measurement is shown in Fig 2.

Machine Parameter Measurements

The fractional tunes were measured by doing a Fourier transform of the turn-by-turn position of the beam when it was kicked by the (horizontal) injection kickers.

Sufficient coupling (about 1.5 %) existed between the horizontal and vertical motion that position information was available in both planes. For the turn-by-turn information, home made electronics were used to process information from a set of buttons installed for this purpose. The full tune was determined from the BPM/corrector response matrices noting that the number of oscillations in these measurements is the integer tune.



BPM position # (1 to 48)

Figure 2. Difference (in microns) between two horizontal orbit measurements, each averaged over 200 samples.

Chromaticities, χ, were determined by measuring the change in tune, $\Delta\nu$, for small changes, Δf, in the RF frequency. $\chi = -\Delta\nu\ \alpha\ f / \Delta f$, where α is the (theoretical) momentum compaction.

β-functions, at a given quadruople, were determined by measuring the change in tune for a change in quadrupole k value. $\beta = 4\pi\ \Delta\nu\ /\ (\Delta k\ L)$ where L is the quadrupole length.

Dispersion functions, η, were determined by measuring the change in orbit position, Δx, for a change in frequency. $\eta = -\Delta x\ \alpha\ f / \Delta f$.

Optical Synchrotron Radiation Measurements

The Optical Synchrotron Radiation (OSR) beamline was used to measure the beam emittances, ε, and the beam bunch length. The OSR beamline monitors visible light from one of the bend magnets. Using the theoretical β functions, horizontal dispersion and energy spread, the source emittances were determined from the observed beam size. A streak camera is used to measure the bunch length as shown in Fig. 3.

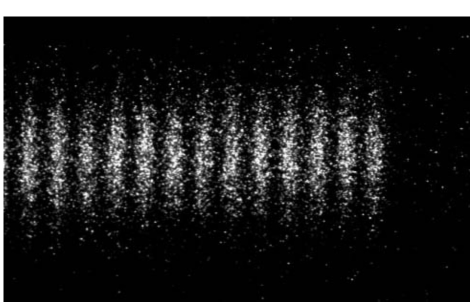


Figure 3. Streak camera view of successive bunches. The full vertical scale is 300 ps and $\sigma_{bunch} = 39$ ps.

With the sextupoles set to produce zero chromaticity, the vertical beam size was observed to increase at high beam currents. By adjusting the chromaticities to slightly positive values ($\chi_x \approx 1$ and $\chi_y \approx 2$) this "blow up", thought to be vacuum related, was kept under control up to currents of 100 mA. Measurements were made with the 65 bunch fill pattern. Tests were also performed with only 4 consecutive bunches filled. Under these circumstances it was possible to fill up to 7 mA per bunch without disturbing the beam size.

MODELLING THE REAL MACHINE

Throughout commissioning, a DIMAD model of the CLS storage ring was used to aid in the commissioning. The model uses the magnetic field measurements and power supply calibrations to define the field strengths for the quadrupole and sextupole magnets and to define the dipole field gradient, pole face rotation and fringe field integrals.

Very good agreement between the model and the real machine are obtained by adjusting only two parameters in the model. The relative strength of the quadrupole and sextupole magnets to the strength of the dipole magnets was adjusted by about 2%. This is likely due to uncertainty on the dipole hysteresis history. Secondly, the relative strength of the dipole gradient had to be arbitrarily adjusted by 1%.

Tune and Chromaticity Adjustment

Due to the bumpy commissioning history, when tune measurements were first made, it was discovered that the vertical tune was below 3 and not at 3.26, as desired. At that time, however, the tune measurements confirmed the model. Consequently, the model was used to predict quadrupole settings to get to both the desired horizontal and vertical tunes. During studies with the OSR beamline the vertical beam size increase was kept under control with the sextupole magnets. Using the model, the chromaticities could be adjusted to a variety of settings.

RESULTS

Machine Parameters

Parameters of the present CLS storage ring configuration are given in Table 1. The original design values and current model values are given as well.

The model suggests the machine is running at a dispersion in the straights larger than the design. This has no adverse effects and at the same time significantly reduces the emittance. Dispersion measurements were difficult due to the noisy position measurements. Preliminary measurements indicate rough agreement with the model.

The design corrected orbit position is based on the average of a number of randomly misaligned configurations assuming 150 micron alignment tolerances on each fiducial of each magnet. It appears, in practice, the tolerances have been met. Stability values are over a few minutes. Long term stability awaits implementation of an active orbit correction program with improved position monitoring.

Table 1. Machine Parameters

Parameter	Design	Model	Machine
Length m	170.88	170.88	170.88
ν_x	10.22	10.22	10.22
ν_y	3.26	3.26	3.26
χ_x (adjusted)	-	0.7	0.4
χ_y (adjusted)	-	2.0	2.5
ε_x nm-rad	18	13	15
ε_y nm-rad	-	-	0.2
δ ($\Delta p/p$) %	0.11	0.11	-
Straights:			
β_x m	8.1	7.1	Fig. 4
β_y m	4.6	4.5	Fig. 4
η_x m	0.15	0.26	~ 0.25
η_y m	-	-	$\rightarrow 0$
RF			
Freq. MHz	500.000	500.000	500.018
Voltage MV	2.4	1.8	1.8
α	0.0038	0.0041	-
σ_{bunch} ps	33	40	39
Orbit position:			
X_{rms} µm	40	-	30
Y_{rms} µm	80	-	70
Stability:			
X_{rms} µm	-	-	~1
Y_{rms} µm	-	-	~1
Current	500 mA	-	100 mA
Lifetime 1/e hr	6	-	2.1

The results of the β function measurements are given in Fig. 4. While the horizontal data is in good agreement, the measured vertical data has been amplified by 10% to get better agreement with the model. Even so, in shape, the results are in good agreement with the model. If the variations are real, it appears that this machine would benefit from a linear optics (i.e., LOCO) analysis.

Insertion Devices and Chicaning

To date, two undulators have been installed in straight 11. These are the SGM and PGM IDs described in reference 1. Both devices have operated at minimum gap with next to no effect on the beam orbit. It has not yet been necessary to use the electromagnetic correction coils built into the devices.

The two IDs are surrounded by three "chicane" magnets. The first deflects the beam at angle of 0.65 mrad through the first ID. The second deflects the beam –1.30 mrad back through the second ID and the third puts the beam back "on orbit" with another 0.65 mrad kick. Hence, the IDs produce two beams of x-rays separated by 1.3 mrad. Both beams have successfully passed through a single beamline front end to be delivered to the two beamlines. Activating the chicane magnets to "book" values produced a small ripple in the orbit which was easily corrected by the global correction system.

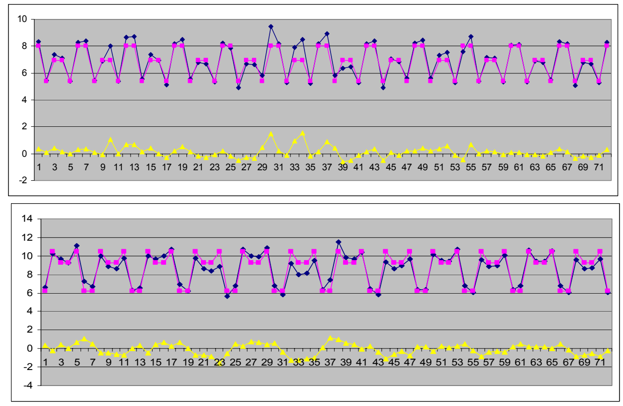


Figure 4. Top: β_x at the 72 quadrupoles. Measurements vary from the symmetric model. Lower trace is the difference. Bottom: β_y at the quadrupoles (normalized).

Lifetime

After a modest amount of vacuum conditioning, currents of up to 100 mA can be achieved. At 100 mA the 1/e lifetime is just over 2 hours. Much more conditioning is required to achieve longer lifetimes. Increasing the RF voltage from 1.8 MV to the design value of 2.4 MV will also help.

CLS STATUS

The storage ring has been successfully commissioned. The CLS will officially open in the fall of 2004 and by January, 2005, five beamlines with ID sources will be ready to provide light to the CLS user community. Future machine development will include improved position monitoring and coupling control.

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See also: http://www.lightsource.ca