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CLS 2.2: ULTRA-BRILLIANT ROUND BEAMS USING PSEUDO LONGITUDINAL GRADIENT BENDS

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Abstract

A preliminary design for a new storage for the Canadian Light Source was presented at IPAC'18. More recently, a reconfigured lattice was presented at the 6th DLSR workshop. The newer lattice employed large β_y and small β_x in the straights. This has several advantages including: increased transverse coherence (and brilliance) at small coupling; round beams at small coupling; flatter β_y in the straights; and possible off-axis vertical injection. Most recently, longitudinal gradients in the dipoles have been implemented. This led to the unit cell bends being replaced by a 'pseudo longitudinal gradient' bend array: B_1-B_2-B_1. This results in smaller emittance with simple magnet designs while maintaining good dynamic aperture.

INTRODUCTION

A preliminary design [1] for a new storage ring for the Canadian Light Source (CLS) strived for an ultralow emittance source with adequate dynamic aperture for off-axis injection in the horizontal plane. Consequently, a large β_x was required in the long straights. At the same time, β_y was made small in order to enhance the brightness by matching the beam to the photon source in the vertical plane. In such a configuration, it is difficult to produce round beams in the straights. In order to achieve round beams a configuration with $\beta_y > \beta_x$ was developed and presented at the poster session of the 6th DLSR workshop [2]. There are several advantages to this configuration: the beam brilliance and coherence fraction are optimized at small vertical coupling; round(ish) beams are achieved with smaller vertical coupling; β_y is relatively flat constant through the straights; and off-axis vertical injection is possible.

The beam parameters for the preliminary design (CLS 2.0), the DLSR workshop design (2.1) and a new lower emittance design (2.2) are given in Table 1. (Details of the new design are discussed in the next section.) From these parameters, the transverse coherence fraction [3] and relative beam brilliance are calculated for different vertical coupling, K, where $\varepsilon_x \approx (1 - K)\varepsilon$ and $\varepsilon_y \approx K\varepsilon$. Figure 1 shows the resutls for a 4 m undulator producing 1 keV or 10 keV photons. Also shown is the aspect ratio ($=\Sigma_y/\Sigma_x$) of the beam in the centre of the long straights. For the designs with $\beta_y > \beta_x$ the coherence is peaked at the lowest coupling and the aspect ratio reaches unity (round beam) at smaller coupling.

With a large β_y, injection into the vertical plane is possible. If a booster is used for injection, the beam is typically damped to a small beam size in the vertical plane. This allows injection in the vertical plane as shown in Fig. 2. A multipole injection kicker brings the injected beam to an orbit at $Y \approx 2$ mm.

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Table 1: Machine Parameters for Possible CLS 2 Lattice Configurations

CLS	2.0	2.1	2.2	
Energy		3.0		GeV
Size	590.4	589.8	588.0	m
Periodicity		16		
ν_x	62.2	68.2	66.15	
ν_y	22.3	20.3	21.3	
ε	37	39	**25**	pm
δ	0.08	0.08	0.10	%
Straights				
β_x	8.94	1.24	2.23	m
β_y	3.43	11.96	5.95	m
η_x	0.01	0.0	0.0	m
α_c	5.0	2.6	5.4	$\times 10^{-5}$
RF freq.		500		MHz
RF voltage		3		MV
Harm. #	984	983	980	
Current		300		mA
Coupling		10		%
Lifetime	9.9	5.1	9.2	hr

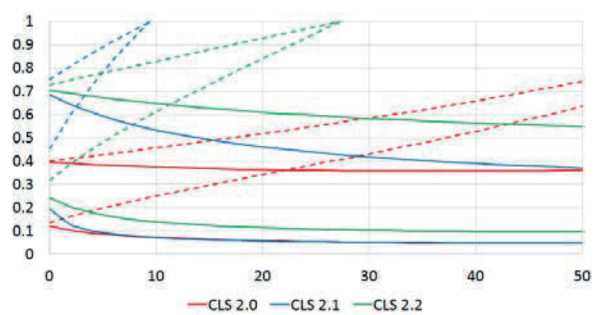

Figure 1: Coherence fraction (relative brilliance) and aspect ratio (dashed) vs K [%] for CLS 2.0, 2.1 and 2.2. 1 keV (upper) and 10 keV (lower) photons from a 4 m undulator are shown (K = 10% is considered for operations).

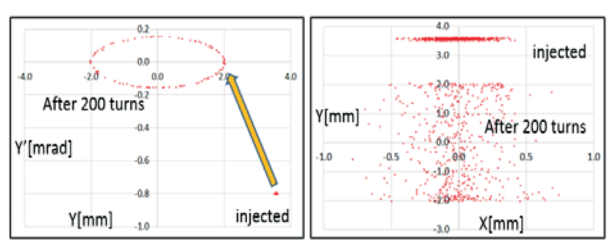

Figure 2: Off-axis vertical injection for the CLS 2.1 lattice shown at the injection point. A multipole injection kicker downstream brings the beam to the desired orbit.

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CLS 2.2

To reduce the emittance a longitudinal gradient bend [4] is considered. To achieve this the dipole in the centre of the unit cell is split into three bends to introduce a "pseudo longitudinal gradient" (PLG) bend as shown in Fig. 3. The three magnets are separated by drifts resulting in simple magnet designs. Furthermore, the gradients in the three bends are adjusted to help reduce the emittance. This results in a focussing gradient in the centre bend (B_2). As shown in the figure the dispersion through this bend is significantly reduced. As shown in Table 1 the emittance is reduced from 39 to 25 pm.

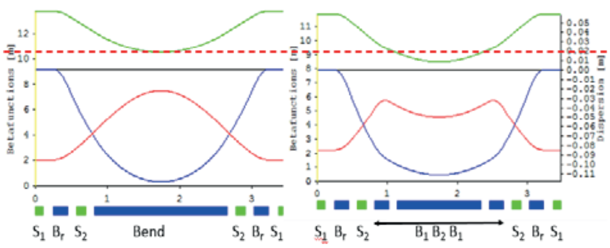

Figure 3: Reconfiguration of the unit cell with a pseudo longitudinal bend (B_1-B_2-B_1). A reverse bend (B_r) is also retained.

The entire MBA lattice is shown in Fig. 4. It is made up of seven unit cells flanked by matching sections. The tune phase advances through the seven cells are $\Delta\nu_x \approx 3$ and $\Delta\nu_y \approx 1$ reducing the geometric effects of the distributed sextupoles (see [1]). 5 m straights are available for IDs, injection, etc. β_y in the straights is reduced to 5.95 m in order to improve the vacuum lifetime (see Table 1). Lifetime is calculated considering a 6 mm full aperture in the long straights.

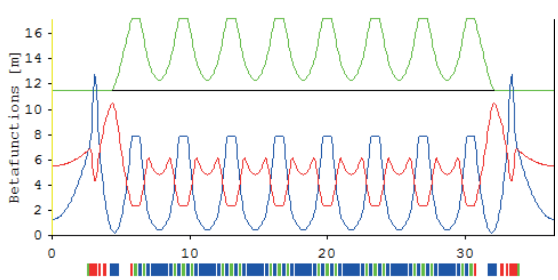

Figure 4: MBA lattice for CLS 2.2.

Dynamic aperture, DA, adequate for off-axis vertical injection is available as shown in Fig. 5. The DA was calculated with random 60 micron girder misalignments, 15 micron element misalignments and 10 mrad rotations on all elements. Orbit correction using 10 micron BPM alignment errors is used. Multipole errors were also included. Also shown is the momentum aperture, MA, in the vertical plane. As seen in the figure there is adequate DA and MA for off-axis vertical injection at an amplitude of 2 mm.

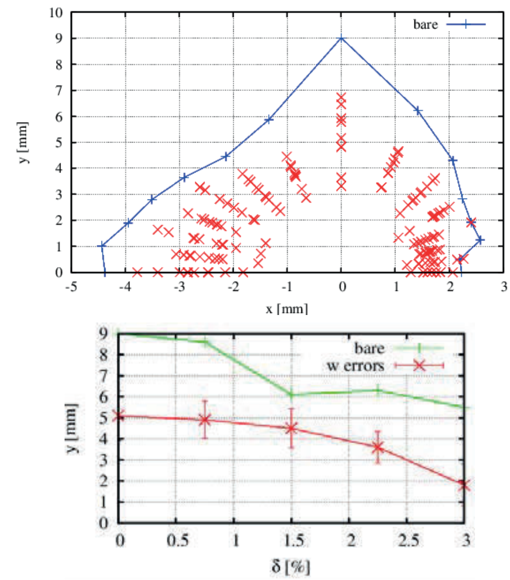

Figure 5: Top: Dynamic aperture; Bottom: Momentum Aperture (vertical) averaged over all misalignment seeds.

Magnets

By separating the unit cell bends into three bends, no special magnets are required. Rather the PLG bend array (B_1-B_2-B_1) is made of a centre bend (B_2) with a modest focussing transverse gradient flanked by two strongly focussing bends (B_1). The B_1 magnets can be realized as offset quadrupole magnets. Similarly, the reverse bend (B_r) is also an offset quadrupole. The bend magnets in the matching cells (B_m) have defocussing gradients that are not difficult to design. The transverse gradient bends are shown in Fig. 6.

Quadrupole magnets with gradients up to ~90 T/m are required. For this, quadrupoles with 24 mm diameter apertures are used. Offset quadrupoles for the strongly focussing bend magnets (B_r and B_1) have apertures of 30 mm to allow room for the vacuum chamber. For these magnets 48.5 T/m are required.

Three families of distributed sextupoles are used to adjust the chromaticities and establish a good DA. Horizontal and vertical correctors are built into these magnets. The combined sextupole and corrector fields are low enough so that saturation effects are not a problem with the superposition of the magnet functions.

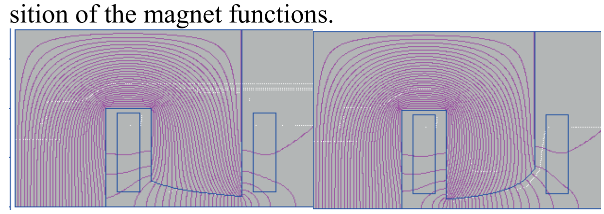

Figure 6: Cross-sections of the transverse gradient bends. Left: B_2; Right B_m. For both magnets, the beam.

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Choosing the Reverse Bend

The input file for the CLS 2.2 lattice is given in Appendix I. For this lattice Br and B1 have equal but opposite bend angles (-/+0.2 degrees) and equal but opposite field gradients. As they are considered to be offset quadrupole magnets, they both require the same offset: namely offset = B[T]/B'[T/m] → 3.6 mm.

Other equal offsets can be considered to shape the closed orbit through all the bends in the unit cell as shown in Fig. 7. Small changes in drifts have negligible impact on the beam optics which remain more or less unchanged except for the dispersion. Changing the reverse bend, B_r, (and B_1) results in other options for emittance, the J_x partition number, and the momentum compaction, α_c, as shown in Table 2. A angle of -0.15° could be considered to decrease J_x and increase α_c at the expense of a slight increase in emittance.

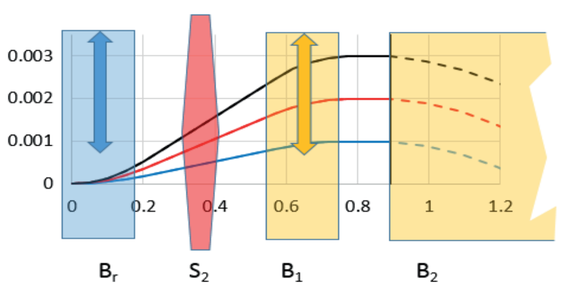

Figure 7: Beam paths with changing offsets (equal but opposite bend angles) of the B_r and B_1 bends.

Table 2: Beam Parameters for Different Bend Angles, B_r. (B_r and B_1 Have Equal but Opposite Angles)

B_r [°]	J_x	α_c [e-5]	ε [pm]
-0.00	0.81	11.2	124
-0.05	1.30	9.7	68
-0.10	1.75	8.3	44
-0.15	2.16	6.8	32
-0.20	2.50	5.4	25
-0.25	2.78	3.9	22
-0.30	2.99	2.4	21

CONCLUSION

An ultralow emittance (ε = 25 pm) is achieved using simple magnets to create a pseudo longitudinal gradient bend. This is achieved in a 16 MBA lattice with a circumference of 588 m. Using $\beta_y > \beta_x$, ultra-brilliant, highly coherent round beams are produced with low vertical coupling. Sufficient dynamic aperture is achieved to facilitate off-axis vertical injection.

APPENDIX I

The CLS 2.2 lattice can be constructed from the following:

```
{drifts}
long : drift, l=2.503400,ay = 3.00;[mm]
d11:drift, l=0.11; d12:drift, l=0.12; d15:drift, l=0.15;
d18:drift, l=0.18; d20:drift, l=0.20; d33:drift, l=0.33;
d83:drift, l=0.831638;
{quadrupoles}
qm1:quadrupole, l=0.12, k= -8.52240;
qm2:quadrupole, l=0.20, k= 8.658014;
qm3:quadrupole, l=0.12, k= 0.958858;
qm4:quadrupole, l=0.12, k= -3.53309;
qm5:quadrupole, l=0.12, k= 6.615875;
{offset quadrupoles}
br:bending,l=0.20, t = -0.20, k = 4.85; [°]
b1:bending,l=0.20, t = 0.20, k = -4.85;
{bend magnets}
b2:bending, l=1.2, t = 2.712, k = 0.421,
    t1= -1.356, t2 = -1.356;
bm : bending, l = 0.8, t = 1.758, k = -0.6,
    t1= 0.0, t2 = 0.0;
{sextupoles}
s1 : sextupole, l = 0.10 k = 252.3;
s1b: sextupole, l = 0.10, k = -62.0;
s2 : sextupole, l = 0.15, k = -212.6;
s2b: sextupole, l = 0.15, k = 0.0;{corrector}
{segments}
pbend : b1, d12, b2, d12, b1;{pseudobend}
cell:s1,d15,br,d11,s2,d11,pbend,d11,s2,d11,br,d15,s1;
match:long,s2b,d12,qm4,d18,qm3,d20,qm2,d18,qm1,
    d33,bm, d83, qm5, d12, s1b;
mba:match,7*cell, -match;
ring:16*mba
```

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