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A LOW EMITTANCE LATTICE DESIGN FOR THE CANADIAN LIGHT SOURCE

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Abstract

The Canadian Light Source (CLS) presently has a 12 cell double bend achromat (DBA) lattice with a circumference of 170.88 m. Using conservative magnet designs an emittance of 18 nm-rad is achieved at 2.9 GeV. An emittance of less than 1 nm-rad (at 2.0 GeV) can be achieved replacing each of the DBAs with multi-bend achromats (MBAs) while preserving the 12-fold symmetry although with a reduction of the length of the straights. To achieve the strong focussing required for low emittance very strong field gradients are required in the dipoles as well as the quadrupole and sextupole magnets. Sufficient dynamic aperture for off-axis injection and good Touschek lifetime is possible.

INTRODUCTION

The MAX IV 3.0 GeV storage ring [1] using multi-bend achromats (MBAs) is now under construction. This 20 cell ring is 570 m in circumference and will have an emittance of 0.33 nm-rad. The low emittance achievable with MBAs has inspired many synchrotrons around the world to investigate possible upgrades using similar designs. One such upgrade of interest to the CLS is that proposed for the ALS [2]. This 12 cell 196 m machine is similar in size to the CLS [3]. An ALS upgrade using 12 nine-dipole MBAs can achieve an emittance of 0.1nm-rad at 2.0 GeV (or 0.05 nm-rad fully coupled). The magnet designs for this machine are challenging but doable. The strong focussing and strong chromatic corrections required result in a very small dynamic aperture (DA) requiring possible on-axis injection.

Following the example of the ALS a design study for a MBA lattice for the CLS was undertaken. The original design goal was for a 1 nm-rad machine at 2.9 GeV with a DA adequate for off-axis injection and good lifetime. While it was possible to produce a lattice with an emittance of 1.3 nm-rad and good DA the field gradients for 2.9 GeV were too large to be remotely practical. Similar to the ALS, however, 2.0 GeV operation is possible.

The CLS MBA lattice was 'morphed' from an early MAX IV 12 design [4] with 12 seven-dipole MBAs. The optics code DIMAD was used for this. The process consisted of squeezing the ~25 m MAX IV cell to the CLS cell length of 14.24 m. Consequently the dipole and quadrupole gradients increased significantly. Eventually a lattice suitable for 2.0 GeV operation was developed. The lattice retained the 'soft end' dipoles and combined quadrupole/sextupole magnets in use in the early MAX IV design.

CLS MULTI-BEND ACHROMAT

A possible MBA for the CLS is shown in Fig. 1. Each of 12 cells has 5 identical centre high gradient dipoles and 2 end dipoles of equal strength but half length. Along with the high gradient dipoles strong focusing is supplied by 10 quadrupoles. Chromatic and geometric corrections are achieved with 18 sextupoles. As shown, 6 each of the quadrupoles and sextupoles are combined function (quad/sext) magnets. With the distributed sextupoles the gradient requirements in each magnet is reduced and a good DA is achieved. Details of the magnet requirements are given in Table 4.

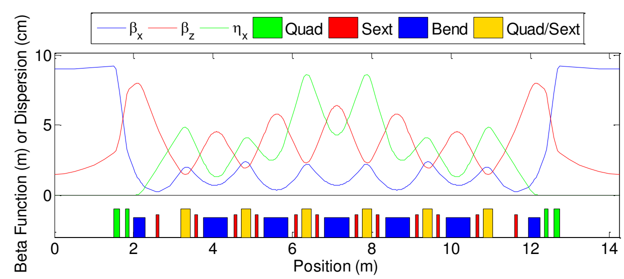

Figure 1: Machine functions for the CLS MBA lattice.

The lattice was developed keeping magnet gradients achievable with conventional magnets operating at 2.0 GeV. At the same time the machine functions in the centre of the straights were tuned to β_x = 9 m for off axis injection and β_y = 1.5 m as a reasonable match to β_{photon} when operating at the diffraction limit in the vertical plane. (see for example [5]). Some parameters for the CLS MBA lattice are given in Table 1.

Table 1: CLS MBA Parameters

Energy	2.0	GeV
Circumference	170.88	m
Cells	12	
ν_x	25.20	
ν_y	9.28	
χ_x natural / adjusted	-39.0 / +1.0	
χ_y natural / adjusted	-27.9 / +1.0	
Emittance	0.83	nm-rad
Momentum comp.	0.00085	
Straights	3.0	m
β_x	9	m
β_y	1.5	m
η_x	0	m

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BEAM DYNAMICS

From the onset the goal was to produce a large dynamic aperture (DA) suitable for conventional on-axis injection. For this the optics code OPA [6] was used to optimize the sextupoles. After the initial optimization some adjustment was made 'by hand' to somewhat reduce the magnet strengths. The DA achieved using OPA is shown in Fig. 2.

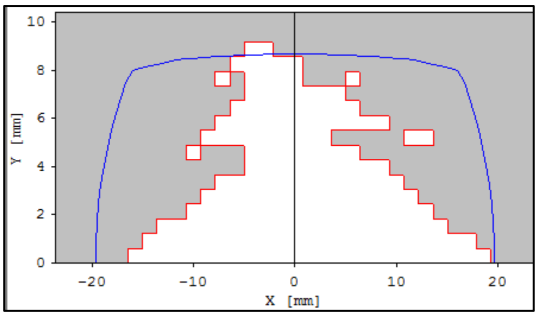

Figure 2: DA for ideal lattice and on momentum calculated by OPA. Chromaticity is adjusted to +1/+1. Particles are tracked for 3000 turns.

Further beam dynamics were investigated with **elegant** [7]. As shown in Table 2 the chromaticities calculated by three different optics codes have some discrepancies. Even so, the **elegant** analysis preceded with the OPA sextupole values. Fig. 3 and Fig. 4 show a survival plot and a diffusion plot. The diffusion plot shows a very "quiet" region (blue) in the heart of a large operating range (-10<X<10 and Y<3). Both these plots verify the DA shown in Fig. 2.

Table 2: Chromaticities from Different Codes

	OPA	DIMAD	**elegant** Twiss	**elegant** tracking
Horizontal	1.0	0.2	-3.2	-0.4
Vertical	1.0	-1.0	0.6	0.7

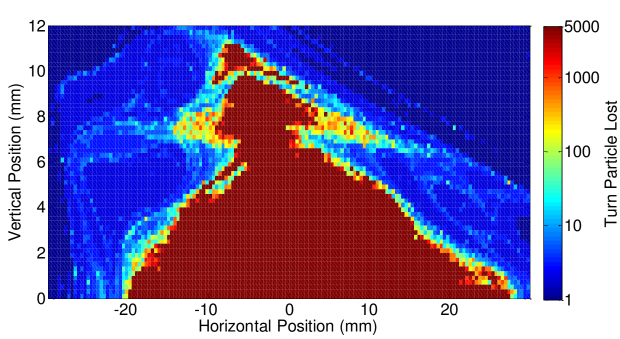

Figure 3: Survival plot as calculated by **elegant**. Particles are assumed captured at 5000 turns.

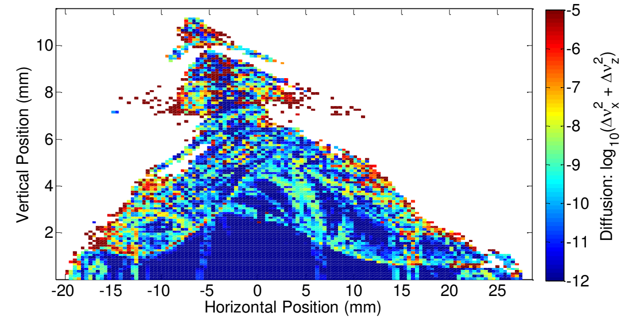

Figure 4: Diffusion plot as calculated by **elegant**. Particles are tracked for 512 turns.

Fig. 5 shows the DA for off energy particles. A single 2.0 MV RF cavity is used. Both synchrotron radiation losses and damping are included in the calculation. Good DA is maintained off energy.

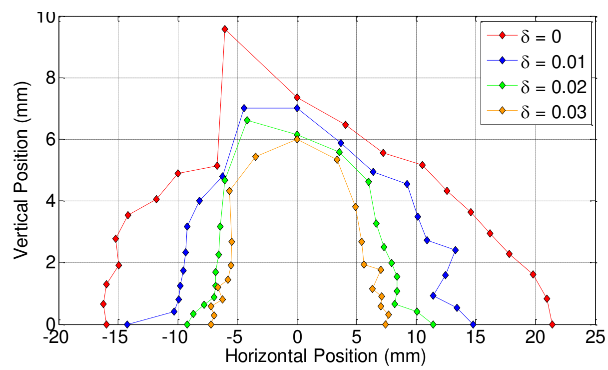

Figure 5: Dynamic aperture for off momentum particles calculated by **elegant**. Particles are tracked for 1000 turns.

Touschek lifetime was calculated with OPA through tracking. Table 3 gives the RF parameters used in the tracking. A Touschek lifetime of 5.4 hours is achieved.

Table 3: RF Parameters and Lifetime

Energy	GeV	2.0
Coupling	%	1.0
Beam current	mA	250
Number of bunches		280
Cavity voltage	MV	2.0
Harmonic number		285
Touschek lifetime	hr	5.4

MAGNET DESIGN

The high gradients required in all the magnets resulted in choosing 2.0 GeV as the operating energy. At this energy magnets can be designed using conventional room temperature magnet technology. The combination quadrupole/sextupole magnets present an extra challenge and a completely satisfactory solution has still to be found. The magnet requirements are given in Table 4.

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Table 4: Magnet Requirements

Magnet	Length (m)	Half gap (mm)	Field (max)	Amp-turns
Dipole	0.304 0.608	12.0	1.60 T (-)18.7 T/m	16430
Quadrupole	0.10 0.14	12.0	79.4 T/m	4800
Sextupole	0.075	12.0	3395 T/m^2	3160
Quadrupole/ Sextupole	0.24	9.0	57.4 T/m 1867 T/m^2	see text

Dipoles

The MBA lattice incorporates dipole magnets with a 'soft' bend end region to reduce bend magnet radiation downstream. The parameters given in Table 4 are for the main body of the dipole (Fig. 6). Using a half gap of 12 mm it is possible to achieve the requirements in a conventional C-magnet configuration.

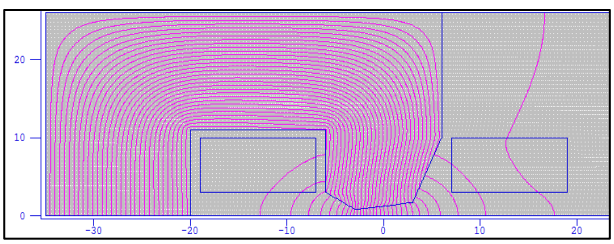

Figure 6: Dipole magnet cross-section. (Dimensions in cm.)

Quadrupole/SextupoleMagnets

The quadrupole/Sextupole (Fig. 7) is based on a multi-function corrector magnet design [8]. This design uses superposition of different magnetic functions. Due to the high gradients involved the superposition is non-linear. However, it is possible to achieve the desired quadrupole and sextupole gradients while suppressing the dipole and octupole content.

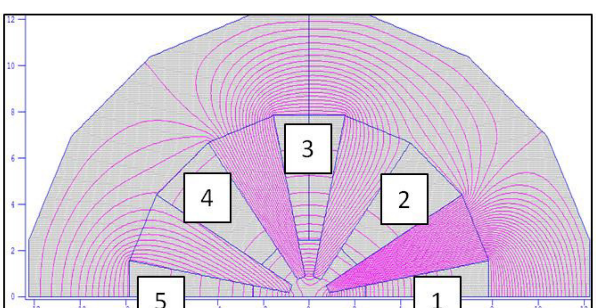

Figure 7: Quadrupole/Sextupole cross-section. The Amp-turns required for the individual coils are 1:6960; 2:-2152; 3: -3150; 4:732 and 5:2180.

Unfortunately higher order multipoles are present. The deviation from the ideal fields is about 10% at ±5 mm. The effects of these higher multipoles has yet to be studied with tracking but it is expected the horizontal DA will be somewhat reduced.

Quadrupoles and Sextupoles

Quadrupole and sextupole magnets requirements can be achieved with conventional designs as shown in Fig. 8.

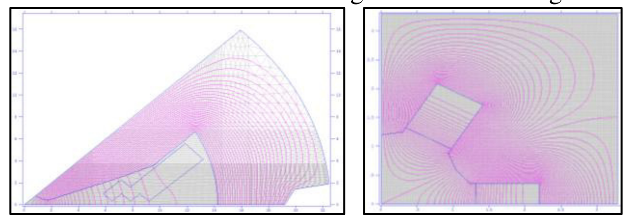

Figure 8: Quadrupole and sextupole cross-sections.

OUTLOOK

A low emittance lattice for the CLS presents an interesting option for future development. Compared to the present lattice it is estimated that brilliance would be increased by over fiftyfold operating at 1% coupling (see Fig. 9). Maintaining present day photon energies could possibly be achieved by using undulators optimized to operate at higher harmonics. The shorter straights present some challenges for the cavity design and injection. Increased straight lengths are being investigated. A start has been made on a possible MBA upgrade. Another option is a new machine in the green fields of Saskatchewan.

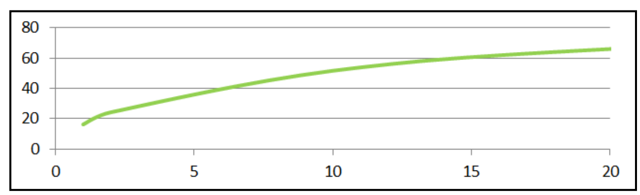

Figure 9: Relative brightness increase vs photon energy in keV for a 2 m undulator. (1% coupling)

ACKNOWEDGEMENT

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