GLASS STUDY OF THE CANADIAN LIGHT SOURCE STORAGE RING LATTICE

W. A. Wurtz* and L. O. Dallin, Canadian Light Source, Saskatoon, Saskatchewan, Canada

Abstract

GLASS is a technique for finding all potential operating points of a storage ring lattice by examining all possible configurations of the linear lattice. The Canadian Light Source storage ring uses three quadrupole families, making it computationally efficient to use GLASS to study the lattice with unbroken symmetry. CLS does not employ harmonic sextupoles and has only two families of chromatic sextupoles. We can exhaust the sextupole degrees of freedom by requiring the horizontal and vertical chromaticities to be both zero. With no remaining free parameters in our lattice, it is possible to calculate dynamic aperture and momentum acceptance for select regions of interest uncovered by the GLASS scan. We find two regions with reasonable dynamic aperture and momentum acceptance: the region where we presently operate and a region that can be accessed by reversing the polarity of one quadrupole family.

INTRODUCTION

GLASS is the GLobal scan of All Stable Settings, a technique for finding all potential operating points of a storage ring lattice [1]. It works by generating all configurations of the linear elements of the accelerator lattice and computing quantities for each configuration. While such methods are often not practical as problem sizes become large, GLASS is a practical technique for the Canadian Light Source (CLS) lattice [2] with unbroken symmetry as CLS has only three quadrupole degrees of freedom.

Figure 1 shows one cell of the twelve-fold symmetric CLS lattice. There are three quadrupole families and these are labeled QFA, QFB and QFC with strengths K_a, K_b and K_c. CLS has only focusing quadrupoles and all defocusing is done in the dipoles. There are two chromatic sextupole families to control the horizontal and vertical chromaticities. CLS does not employ geometric sextupoles. Therefore, if we require the horizontal and vertical chromaticities to be zero, we exhaust all sextupole degrees of freedom.

* ward.wurtz@lightsource.ca

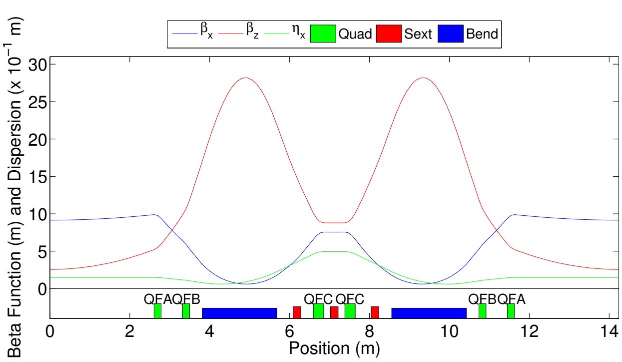

Figure 1: CLS lattice with beta functions (β_x and β_z) and horizontal dispersion (η_x) for quadrupole settings $K_a = 1.968\ \mathrm{m}^{-2}$, $K_b = 1.417\ \mathrm{m}^{-2}$ and $K_c = 2.045\ \mathrm{m}^{-2}$ giving the nominal tunes (10.22, 4.32).

In our GLASS study [3] we will generate a three dimensional array of operating points by varying K_a, K_b and K_c individually. We will look at various properties of the linear lattice: beta functions, tunes, horizontal dispersion, emittance and momentum compaction. With the sextupole degrees of freedom exhausted, we can compute a unique dynamic aperture and momentum acceptance for each operating point through particle tracking.

We use the optics code elegant [4] to perform the GLASS scan. For the dynamic aperture and momentum acceptance calculations we use the `&find_aperture` command (with 21 lines) and the `&momentum_aperture` command, respectively [5]. Dynamic aperture is computed for positive vertical coordinates only. We use the parallel version of elegant [6] for particle tracking. Particle tracking is performed on an ideal lattice with no physical apertures and no rf or synchrotron radiation.

Our goal for this study is to determine if there is a viable operating point with lower emittance than our current operating point, which elegant calculates to be 17.9 nm.

INITIAL SCAN

Our initial GLASS scan uses a quadrupole strength resolution of $0.1\ \mathrm{m}^{-2}$ and a range of -10 to $10\ \mathrm{m}^{-2}$. We find many operating points, most of which are not useful. In Figure 2, we show only those which have an emittance less than 30 nm. The color axis of Figure 2 shows the

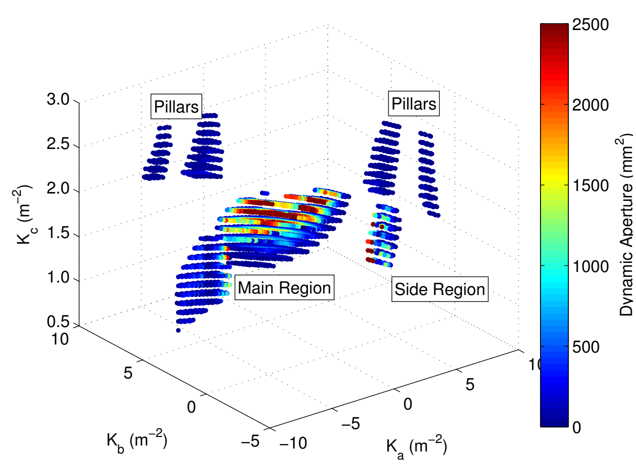

Figure 2: Operating points with emittance less than 30 nm.

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dynamic aperture of the operating points. For reference, the dynamic aperture calculated for our nominal operating point is 1040 mm^2.

There are six distinct regions in Figure 2. The four 'pillar' regions are not useful as they have very small dynamic aperture and momentum acceptance. We currently operate in the main region. The side region is accessible by reversing the polarity on the QFB family of quadrupoles. Only the main and side regions offer significant dynamic aperture.

Figure 3 shows an example machine function plot for the side region. One of the defining features of the side region is that the vertical beta function in the center of the cell is lower than in the main region. Correspondingly, the side region has vertical tunes in the range 7-11, which are much higher than our nominal vertical tune of 4.32. The emittance of points in the side region can be as low as 11-12 nm. The minimum emittance of the side region is no better than those of the main region, which we will examine shortly. The major disadvantage of the side region is that the QFA family of quadrupole has strength values 2.5 m^{-2} $< K_a <$ 3.5 m^{-2}, which are beyond the capabilities of our current hardware.

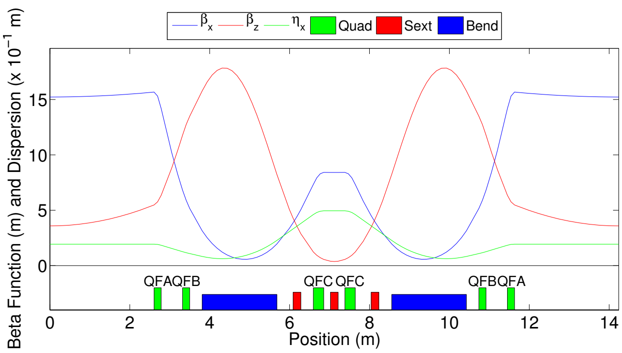

Figure 3: Machine functions for a sample working point in the side region with $K_a = 3.16\,\mathrm{m}^{-2}$, $K_b = -1.19\,\mathrm{m}^{-2}$ and $K_c = 2.04\,\mathrm{m}^{-2}$ giving tunes (9.91, 8.08), horizontal dispersion 0.19 m in the straight sections, emittance 17.0 nm and a dynamic aperture of 835 mm^2.

Since accessing the side region would require a hardware upgrade, and the benefits are marginal at best, we will concentrate on the main region.

LOW EMITTANCE OPERATING POINTS

The main region is a large region, and we will continue to increase the number of constraints on our analysis until we arrive at a set of candidate operating points. We increase the resolution of our scans to 0.01 m^{-2} and limit the range of K_a, K_b and K_c to the main region.

We begin our analysis by filtering out all operating points with emittance higher than 18 nm and eliminating those with very low dynamic aperture. The remaining operating points are shown in Figure 4. The K_c axis is suppressed in Figure 4 in order to better show how the main region relates K_a and K_b. The main region extends beyond what we can access with K_b, but we note that operating points with large K_b have large vertical beta functions in the straights, so they are not desirable.

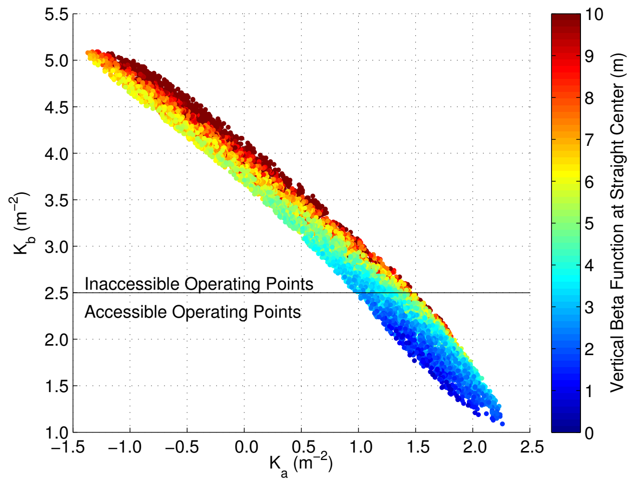

Figure 4: Operating points in the main region with emittance less than 18 nm and dynamic aperture greater than 100 mm^2; the K_c axis is suppressed.

Since we are searching for an operating point with smaller emittance, we now look at only operating points with emittance less than 13 nm, vertical beta function less than 5 m, and dynamic aperture of at least 100 mm^2. The results of the GLASS scan for these operating points are given in Figures 5 and 6. We see that there are a number of operating points with emittance between 10.4 and 13 nm. However, most of these operating points have small dynamic aperture. The operating points uncovered in this scan with sufficient dynamic aperture have tunes near our nominal tunes of (10.22, 4.32) and horizontal dispersion $\sim$0.3 m.

In order to decrease emittance without increasing horizontal dispersion, we must consider and upgrade to the lattice. The addition of geometric sextupoles should be examined to determine if we can increase the dynamic aperture of a low emittance operating point with moderate dispersion.

ACKNOWLEDGMENT

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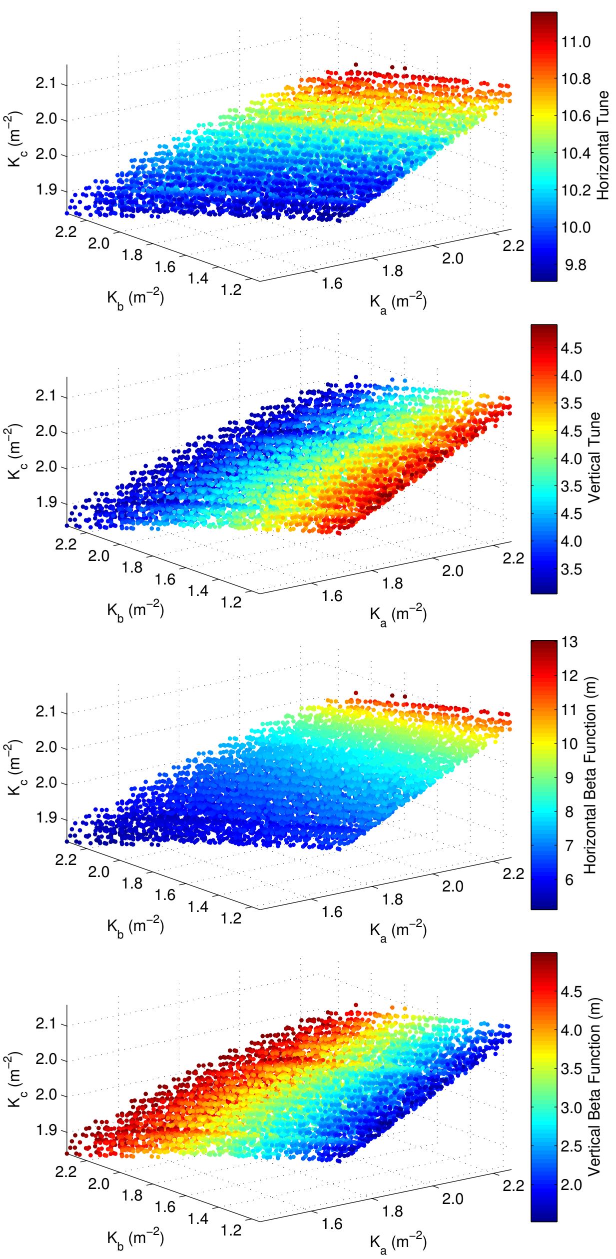

Figure 5: Tunes and center-of-straight beta functions for operating points in the main region with emittance less than 13 nm, center-of-straight vertical beta function less than 5 m and dynamic aperture greater than 100 mm^2.

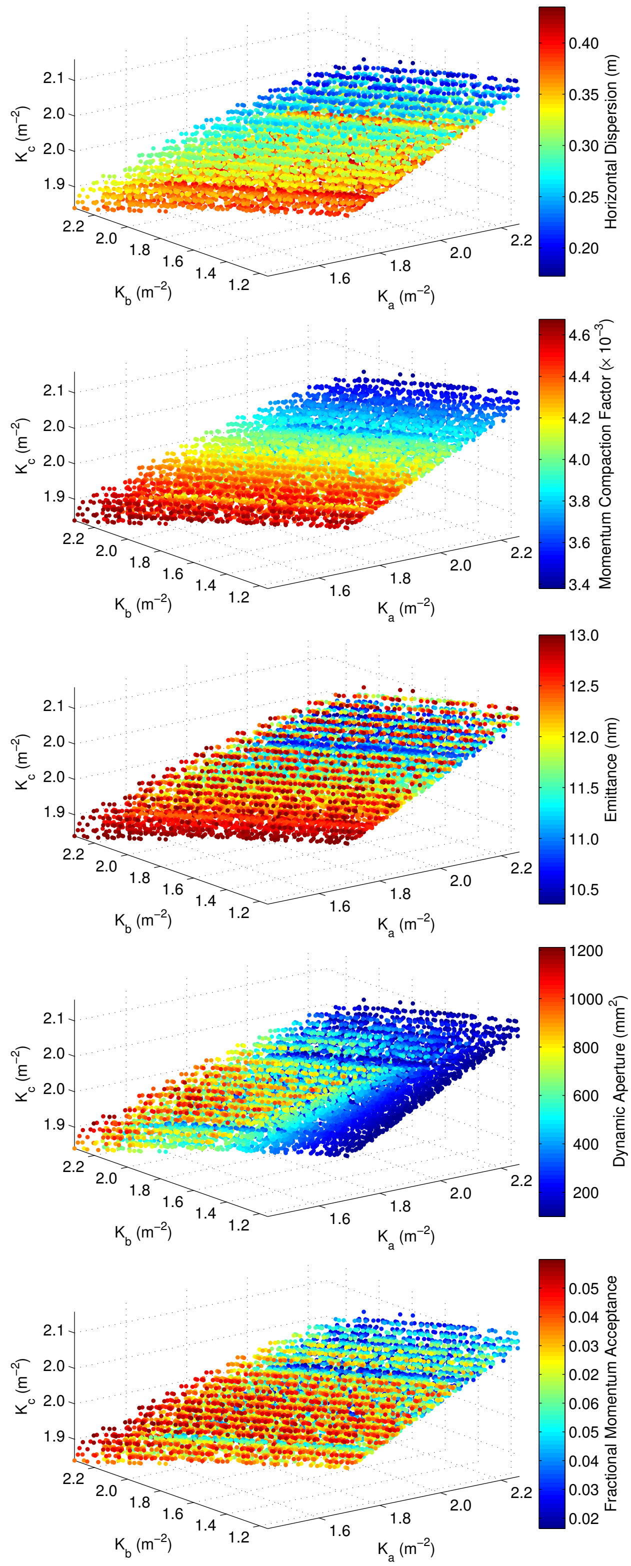

Figure 6: Dispersion, momentum compaction factor, emittance, dynamic aperture and momentum acceptance for operating points in the main region with emittance less than 13 nm, center-of-straight vertical beta function less than 5 m and dynamic aperture greater than 100 mm^2.