OPTIMISATION OF THE DYNAMIC APERTURE OF DIAMOND

M. Muñoz†, H.L.Owen and S.L.Smith, CLRC Daresbury Laboratory, Warrington WA4 4AD, UK

Abstract

The present design of DIAMOND, the proposed 3 GeV light source for the UK, includes the provision of two very long straight sections (greater than 18m) for unusual insertion devices. Such a racetrack solution poses a stringent design challenge for obtaining an acceptable dynamic aperture. This paper reports the methods used to maximise the dynamic aperture of this racetrack design, and presents the results found.

1 INTRODUCTION

The 3rd-generation DIAMOND storage ring [1] is intended to provide a large number of straight sections for insertion devices (IDs) in a lattice of less than 350m circumference; the presentdesign is based upon a double bend achromat configured to give alternating high and low radial β functions at the centre of the standard ID straights [2]. Two very long racetrack sections ~20m are included for future novel IDs; however, their inclusion has a major impact on the non-linear properties of the lattice, which poses a challenge in terms of finding an acceptable dynamic aperture. The methods used to find such a solution are described below.

2 OPTIMISATION

2.1 Choice of Working Point

Even with three families of quadrupoles in the standard ID straights and four families in the racetrack straights, the region of tune space over which a matched solution will meet the present design requirements is limited. In addition, the limited symmetry of the lattice also gives rise to a high density of resonance lines which further restrict the choice of working point. However, although alternating high and low radial β-functions are required in the standard ID straights they are not fixed to a precise value, and some variation is permitted when adjusting the tune.

Working points were chosen to minimise the strength of nearby resonances up to third-order; for each point the dynamic aperture was optimised using harmonic correction. The present tune point was chosen to maximise the dynamic aperture for momentum deviations up to 3%.

2.2 Chromaticity Correction

As with other highly-focusing 3rd-generation storage rings, the DIAMOND lattice has a large negative natural chromaticity which must be corrected or made slightly positive. Chromaticity correction is carried out using two families of sextupoles in the achromatic arc. Two options are possible for the placement of the D-Sextupoles, shown in Figure 1. Option 2 has a more favourable β-function split at the sextupoles than Option 1, giving a significantly reduced F-sextupole strength. However, the higher-order tune shifts with momentum,

$$\frac{\partial^2 Q_x}{\partial p^2},\quad \frac{\partial^3 Q_x}{\partial p^3},\quad \frac{\partial^2 Q_y}{\partial p^2},\quad \frac{\partial^3 Q_y}{\partial p^3},$$

are nearly an order of magnitude larger with Option 2; Option 1 is therefore used.

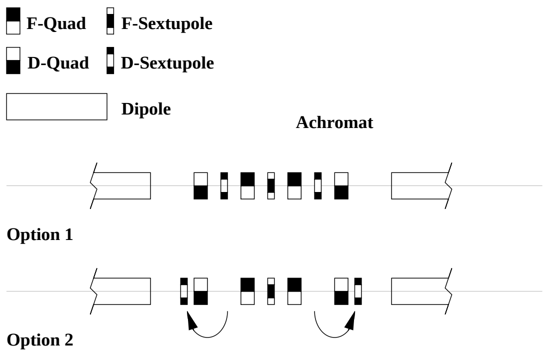

Figure: 1 Options for chromaticity correction. In Option 2, the D-Sextupoles are moved nearer to the dipoles.

2.2 Harmonic Correction

Harmonic sextupoles are commonly used to maximise the dynamic aperture [3]; these are placed as additional families in the non-dispersive regions of the lattice. The present position of the harmonic sextupoles is a compromise between achieving minimum tune shifts and the constraints upon the circumference of the lattice (see Figure 2).

The HARMON module in MAD [4] was used to minimise the tune shifts with amplitude

$$\frac{\partial Q_x}{\partial \varepsilon_x},\quad \frac{\partial Q_y}{\partial \varepsilon_y},\quad \frac{\partial Q_y}{\partial \varepsilon_x}$$

using different families in each of the three types of straight section. Optimising with four families of harmonic sextupoles (with the sextupoles in the racetrack

† Permament Address: Laboratori del Sincrotró de Barcelona - IFAE, Edifici Cn, Universitat Autònoma de Barcelona, E08193 Bellaterra (SPAIN).

sections powered with the high-β sextupoles) gives reasonably small tune shifts; this solution is then used as a starting point to find a better six-family solution.

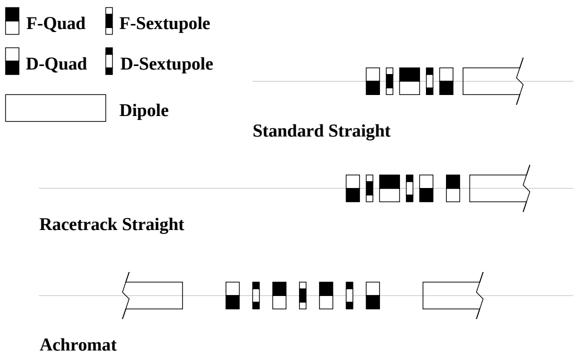

Figure: 2 Schematic layout of the DIAMOND lattice, showing the sextupoles in their chosen position.

3 DYNAMIC APERTURE

The optimised working point using six families of harmonic sextupoles is shown in Figure 3 together with resonance lines up to fifth-order; the lattice properties are summarised in Table 1.

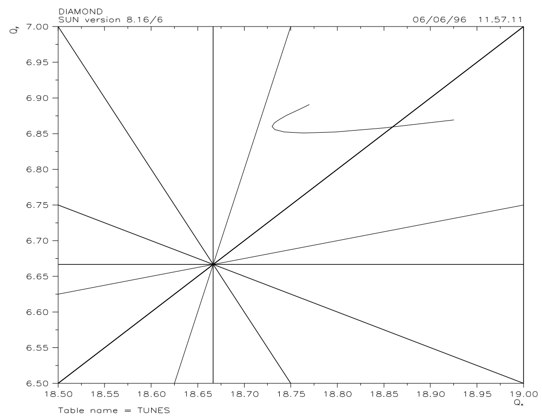

Figure: 3 Working diagram showing the chosen working point, for momentum deviations up to $\Delta p/p=\pm0.03$.

Table: 1 Chosen working point.

Betatron Tunes	Q_x	18.73
	Q_y	6.86
Natural Emittance	ε_0	14.6 nmrad
Natural Chromaticity	ξ_x	-56.9
	ξ_y	-25.8

Dynamic aperture calculated using the lattice code Racetrack [5] is shown in Figure 4 for an observation point at the centre of the racetrack straight ($\beta_{x,y}$=10m). These results agree well with tracking for 1000 turns using MAD. The reduction in dynamic aperture at $\Delta p/p$=-0.03 is from a tune shift toward the Q_x=19 resonance at this momentum (see Figure 3).

A comparison of the dynamic apertures for different numbers of harmonic sextupoles (Figure 5) shows that six families are needed to exceed the physical aperture of 20mm in the horizontal direction.

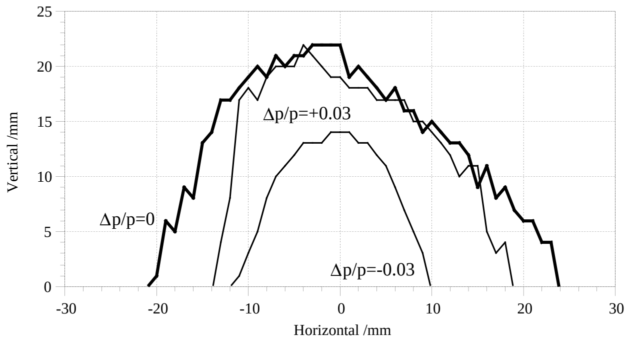

Figure: 4 Dynamic aperture of the nominal working point for momenta $\Delta p/p$=-0.03,0,+0.03, tracking for 1000 turns.

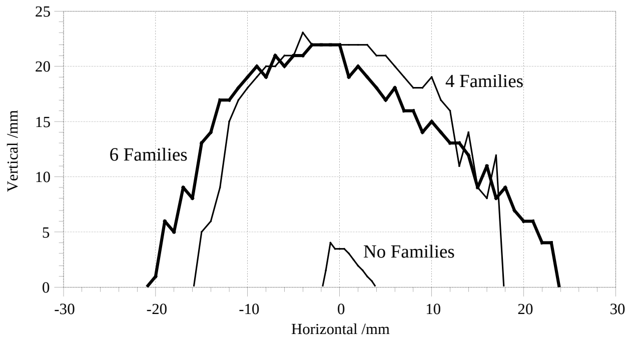

Figure: 5 Dynamic aperture of the nominal working point for the four-family and six-family solution for on-momentum particles, tracking for 1000 turns. The dynamic aperture with no harmonic sextupoles is also shown.

4 CIRCULAR LATTICE

To examine the effect of the reduced symmetry of the racetrack design, a circular version of the DIAMOND lattice has been studied. On replacement of the racetrack sections with high-β sections, the lattice must be rematched to obtain an acceptable working point. To make a comparison between the two lattices this was done using a similar procedure to the racetrack case, preserving the emittance of the lattice. Four families of harmonic sextupoles are used to compensate the non-linear effects. In this case it is relatively easy to find an acceptable working point since the density of resonance lines is much reduced; a typical point is shown in Figure 6 with resonance lines up to 5th-order; the lattice properties are summarised in Table 2. Although the working point of the circular lattice is not as optimised as in the racetrack case the tune shifts with momentum and amplitude are significantly smaller, and obtaining an acceptable dynamic aperture is much easier.

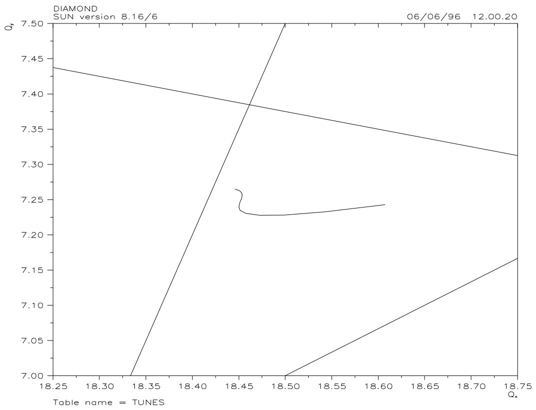

Figure: 6 Working diagram of the chosen working point for the circular lattice, for momentum deviations up to $\Delta p/p=\pm 0.03$.

Table: 2 Chosen working point for the circular lattice.

Betatron Tunes	Q_x	18.45
	Q_y	7.24
Natural Emittance	ε_0	14.0 nmrad
Natural Chromaticity	ξ_x	-60.0
	ξ_y	-30.2

Tracking was again performed with the lattice code Racetrack. Scaling the β-function values at the high-β observation point to those at the centre of the racetrack sections give the comparison of dynamic aperture shown in Figure 7.

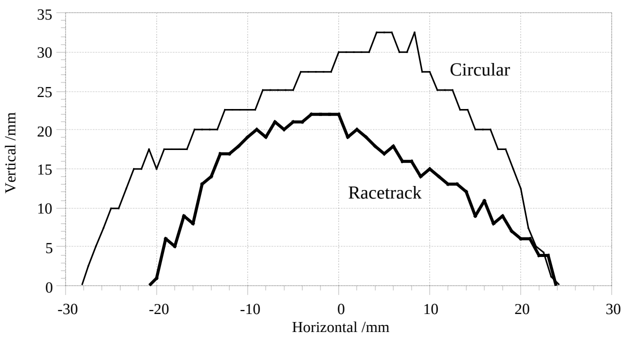

Figure: 7 Comparison of the dynamic aperture of the racetrack lattice with a typical circular lattice working point. Tracking was again performed for 1000 turns.

5 DISCUSSION

With a careful choice of working point and proper compensation of non-linearities a reasonable dynamic aperture can be obtained for the DIAMOND racetrack lattice, amounting to around 50σ of beam size both horizontally and vertically (with 100% coupling).

Comparison with a circular lattice shows the expected reduction of the dynamic aperture as the lattice symmetry is reduced. Even after optimisation of the racetrack lattice, the tune shifts with momentum and amplitude are still large, and after extensive studies only a single small working area has been found which provides an acceptable dynamic aperture. Additional work is required to determine whether this is practical for a real machine.

The effect of including IDs in the racetrack lattice has already been assessed [6], and shows little reduction in the dynamic aperture. Future studies will extend the above work to assess the effect of including superconducting dipoles in the lattice, and to study physical errors.

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