DEVELOPMENTS IN THE DIAMOND STORAGE RING LATTICE

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Abstract

Recent work on the storage ring for DIAMOND, the UK third generation light source, has led to the design of a lattice with low emittance, good dynamic stability, and flexibility for operating in different modes. The structure of the lattice and its principal properties are described.

1 LATTICE EVOLUTION

The DIAMOND light source project has developed to address the needs of synchrotron radiation users in the UK. A series of user consultations have led to the current specification, for high brightness output in a wide spectral range from infra-red through X-ray for protein crystallography. The original lattice was a 16 cell racetrack [1], with alternating high and low beta sections in the arcs, to provide for a variety of insertion devices. In the last two years, the design has evolved to the 24 cell six-fold symmetric lattice that is currently being studied. The energy has remained at 3.0 GeV, but changes to this are not ruled out. The increase in the number of cells has been driven by increases in projected user demand, but has had the benefit of allowing lower emittances to be reached. The target emittance is now 3 nm rad, compared with 14 nm rad for the original racetrack design. We have for some time been studying lattice solutions with non-zero dispersion allowed in the straight sections, as a way of further reducing the natural emittance [2].

One of the difficulties with the racetrack design was the relatively poor dynamic aperture [3]. It was found that six families of harmonic sextupoles were required to reach a horizontal dynamic aperture in excess of 20 mm. Some effort has been made with recent designs to improve the nonlinear properties of the lattice, and the methods employed are discussed in [4]. Despite the greater focusing strength associated with the lower emittance, and the greater chromatic sextupole strengths required with lattices having dispersion in the straights, a horizontal dynamic aperture of 20 mm or more can now be achieved with only four families of harmonic sextupoles.

2 PRINCIPAL LATTICE PARAMETERS

The principal parameters for the latest lattice are given in Table 1. The linear lattice functions in one periodic section of the ring are shown in Figure 1. The dispersion in the short sections is 0.04 m, and in the long sections is 0.06 m. In principle, an emittance of 1.9 nm rad can be reached in a 24 cell double-bend achromat at 3.0 GeV with zero dispersion in the straights. However, engineering constraints on the spacing of the elements makes it difficult in practice to achieve an emittance below 3 nm rad without allowing some dispersion in the straights.

Table 1: Principal lattice parameters.

Energy	E [GeV]	3.0
Number of cells	N	24
Symmetry		6
Circumference	C [m]	489.24
ID Straight Lengths	L [m]	18 × 4.5 6 × 8.0
Natural emittance	ε_0 [nm rad]	2.5
Assumed coupling	κ	1%
Tunes	Q_x, Q_y	28.89, 10.70
Natural chromaticity	ξ_x, ξ_y	-85.6, -39.9
Momentum compaction	α	1.60×10^{-4}
Dynamic aperture	A_x, A_y [mm]	±25, ±12

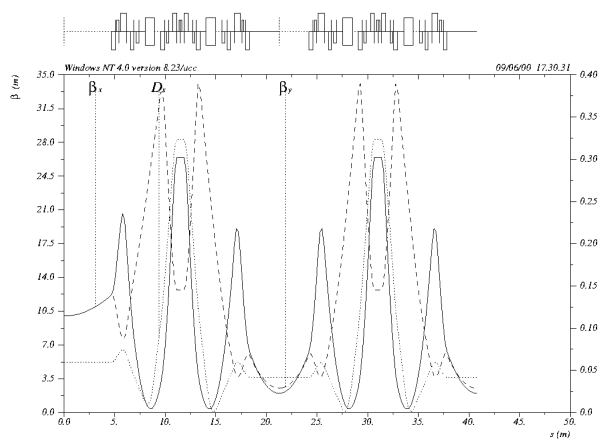

Figure 1: Linear lattice functions for half a superperiod.

The beta functions in the short straights are reduced to give low source sizes, and hence high brightness radiation output. In the long straights, the horizontal and beta functions are constrained to 10 m, to increase injection efficiency. At present, it is envisaged to place all the RF cavities in one long straight section, and all the injection systems in a second long straight section.

The harmonic sextupoles are positioned between the quadrupoles at the ends of the straight sections. One of the benefits of having some dispersion in the straight sections is that the harmonic sextupoles then have a chromatic effect. Although the dispersion here is small, the harmonic sextupoles can be used effectively to control the higher order chromaticities. The working point in tune space with momentum deviation up to 4% is shown in Figure 2. The tunes vary little with changes in momentum, suggesting that a good momentum aperture should be achievable.

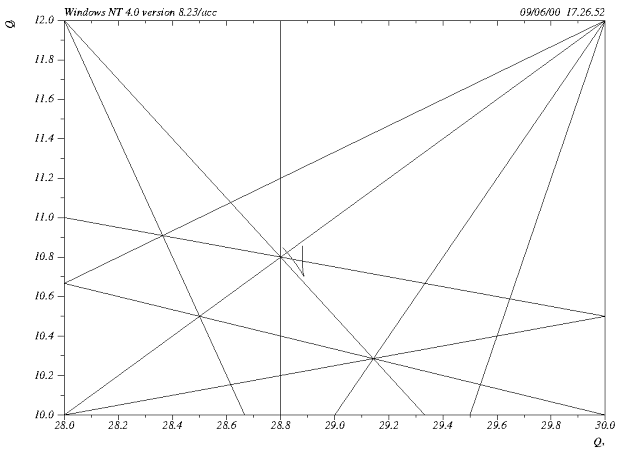

Figure 2: Working point in tune space. Resonance lines up to fifth order are shown, as are tune changes with momentum deviation up to ±4%.

The present tune point is not ideal from a number of considerations. Although the nearest resonance lines are all fifth order, there is a strong coupling resonance close by, which could make it difficult to achieve the target 1% coupling. In addition, both horizontal and vertical tunes have fractional parts greater than one half, which will lead to large values for the resistive wall impedance. Further studies will investigate the possibility of moving the working point to potentially more satisfactory areas in tune space.

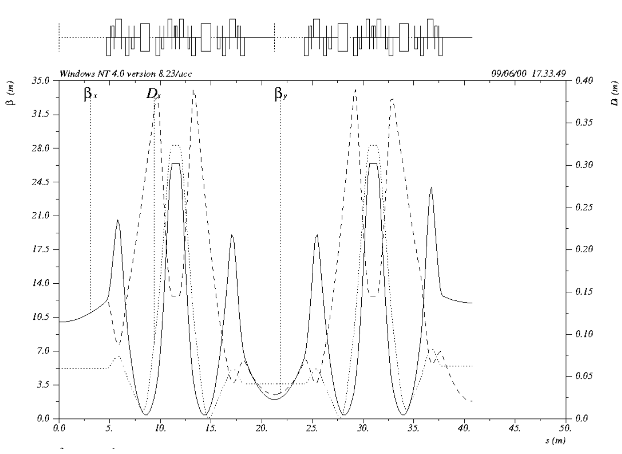

Figure 3: Alternative operating mode with high horizontal beta function in a short straight.

There may be requirements during commissioning or operations for different tune modes; for example a zero-dispersion solution allowing larger dynamic aperture, or a solution alternating high and low beta values in the short straights. Initial studies suggest that the current lattice should allow a good degree of flexibility, facilitated in practice by having separate power supplies for every quadrupole. A zero-dispersion mode can easily be produced, for example (emittance 4.4 nm rad). A possible lattice with high beta values in some short straights (emittance 2.6 nm rad) is shown in Figure 3.

3 BEAM SIZES

The beam sizes and divergences at the centres of the straights and in the dipoles are important parameters for the source brightness. Relevant values are given in Table 2. 1% coupling has been assumed. There are small differences in the dipole properties, according to whether the dipole is adjacent to a long straight or not.

Table 2: Beam sizes at different source locations around the lattice. The natural emittance is 2.5 nm rad, and 1% coupling is assumed.

	short straight	long straight	centre of dipole
σ_x [μm]	79.9	166	33
σ'_x [μrad]	35.0	15.6	89
σ_y [μm]	7.82	15.6	23
σ'_y [μrad]	3.11	1.56	4.5

4 NONLINEAR PROPERTIES

The strong sextupoles required to correct the high chromaticity, and hence reduce the effects of the head-tail instability, make third generation light sources strongly nonlinear systems. A large dynamic aperture is required, however, both for injection efficiency and for good Touschek lifetime.

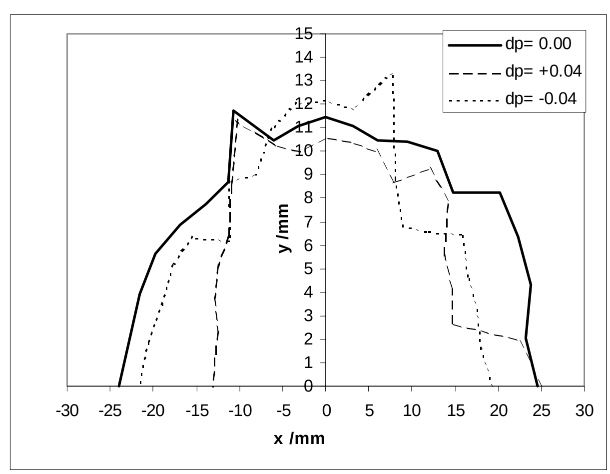

Figure 4: Dynamic aperture for on-momentum, and ±4% momentum deviation particles, in the error-free lattice.

We have applied the technique of geometric cancellation of nonlinear terms in the map by control of the phase advance between the sextupoles to achieve an acceptable dynamic aperture [4]. The results are shown in Figure 4; the observation point for tracking was the centre of the long straight, where the horizontal and vertical beta functions are 10 m. The dynamic aperture is close to 25 mm horizontally for on-momentum particles.

5 EFFECTS OF FIELD ERRORS

To investigate the effects of magnetic field errors on the dynamic aperture, we added multipole components to the dipoles, quadrupoles and sextupoles. We assumed that the closed orbit was corrected so that the beam passes through the centre of all magnetic elements, and that focusing errors are corrected by adjusting the tune. This neglects the effect of local variations in focusing, which could be significant, but remain to be investigated. The systematic errors were chosen to meet the limits of the tolerances given in Table 3.

The random errors assumed were based on those used in the SOLEIL Design Report [5], and are somewhat larger than the errors measured for the ESRF magnets [6].

Table 3: Tolerances applied for systematic magnetic field errors. g is the field gradient, and g_s the second derivative of the field.

Magnet	Good Field Radius	Parameter	Tolerance
Dipole	20 mm	$\Delta B/B_0$	±0.02%
Quadrupole	30 mm	$\Delta g/g_0$	±0.05%
Sextupole	30 mm	$\Delta g_s/g_{s0}$	±1%

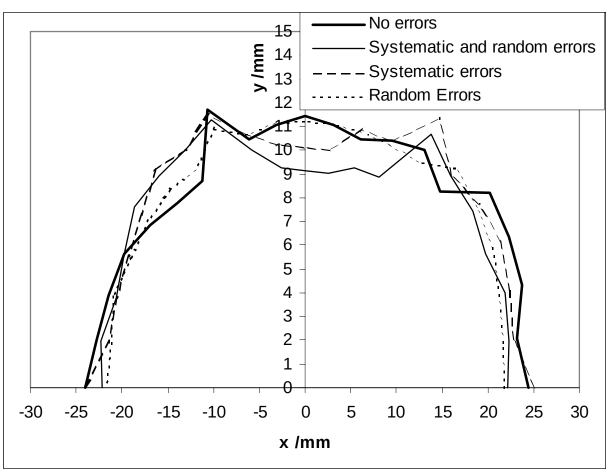

Figure 5: Dynamic aperture in the presence of magnetic field errors. The random error line shows the mean taken over six seeds of random errors.

The dynamic aperture with systematic and random field errors is shown in Figure 5. The reason that the dynamic aperture shows such good stability is probably partly a result of the fact that for the ideal lattice, we count only particles as stable where the dynamics is highly regular, and nonlinear effects are very small. It is possible to optimise the lattice to such an extent that strongly nonlinear orbits appear stable over a large number of turns, but when errors are applied, the stability of such orbits is generally lost very quickly.

Studies of other effects of field and alignment errors, including requirements for closed orbit and coupling correction, are in progress.

6 CONTINUING DEVELOPMENTS

Figure 6 shows the development of the DIAMOND lattice since 1996. It is clear that there have been significant improvements in the emittance and dynamic stability. The present lattice meets many of the criteria as they currently stand for the DIAMOND storage ring, though it is expected that a number of changes will be required as the project enters a formal design phase.

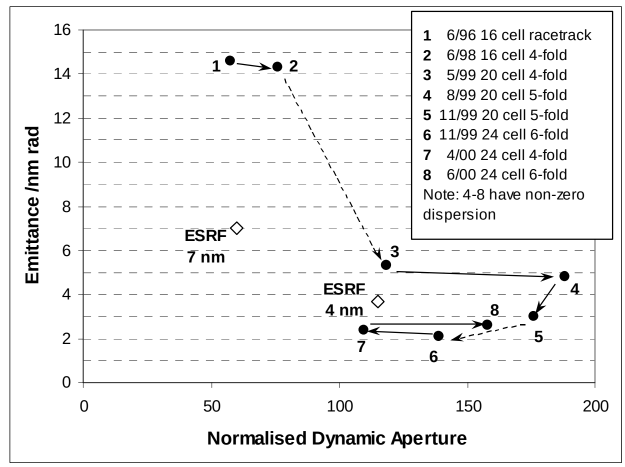

Figure 6: Development of the DIAMOND lattice. The normalised dynamic aperture $A_x/\sqrt{\beta_x \varepsilon_0}$ is used to allow comparison of lattices with different focusing strengths.

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