The Linear Lattice Design of an Advanced VUV/SXR Photon Source for Daresbury

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Abstract

The linear lattice design of an advanced VUV/SXR photon source, optimised to produce undulator radiation with high brilliance over the range 5-1000 eV, is discussed. The source is based on a 10 cell double bend achromat which will operate over the range 0.5 - 1.2 GeV. The linear lattice properties over the total available working region are presented for this structure. It is demonstrated that the circular lattice can be extended to a racetrack configuration by the inclusion of two long matched straights with free lengths of over 15 m each.

1. INTRODUCTION

The provision of an advanced SR source in the VUV/SXR region of the spectrum has been recommended to complement the existing SRS. The radiation output from such a source is dictated by the user requirement for optimised undulator emission over the photon energy range 5-1000 eV. The proposed facility [1, 2] is based on a double bend achromat lattice with 10 unit cells, insertion device (ID) straights of ~3 m and overall circumference of ~100 m. A standard circular lattice has been extended into a racetrack configuration by lengthening two diametrically opposite ID straights. A free straight length of 15 m is demonstrated here, although preliminary studies have indicated that matching is still feasible with 20 m straight sections. The racetrack design facilitates inclusion of long undulators or, with suitable bypasses, other novel insertion devices such as free electron lasers.

2. CHOICE OF LATTICE TYPE

The chosen lattice for the Daresbury Advanced Photon Source (DAPS) must contain sufficient insertion devices to fulfil its role as a national facility. This was decided to be at least 8 at an early stage of the design. As at least two straight sections must be given over to injection and RF, a 10 cell machine has been chosen for this study.

To avoid emittance blow-up by insertion devices and interaction between different devices via the stored beam, it is necessary to set to zero the dispersion in the insertion device straights. A large dispersion function in that part of the lattice where chromaticity correction is to take place is advantageous. These factors have a bearing on the type of lattice chosen for DAPS. FODO lattices were excluded from the study at an early stage because of the difficulty of including sufficient zero dispersion straights whilst maintaining a reasonably small circumference. Simple Chasman-Green lattices were also eliminated because of their known inflexibility.

DBA and TBA lattices were initially considered, both having the advantage of zero dispersion outside the achromat. However in the case of the TBA, in order to keep the beam emittance low, it is necessary to keep dispersion small in the centre dipole. This generally causes the dispersion function to be small throughout the achromatic arc, leading to strong sextupole requirements for chromaticity correction thereby causing a reduction in dynamic aperture. In addition, TBAs tend to have a larger circumference than DBAs with the same number of straights.

A DBA has been chosen for the DAPS lattice as it has the required flexibility without the strong sextupole problems which can occur with the TBA and suffers little emittance penalty. The form of the dispersion function in the achromat can be optimised by choice of the quadrupole positions. A representation of the unit cell is shown in fig. 1.

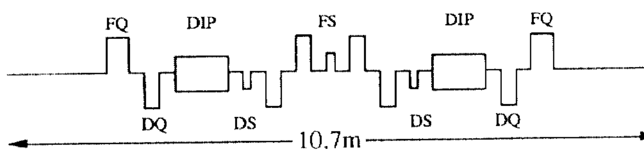

Figure 1. Unit Cell of the Circular Machine

3. STABLE REGIONS

The limits of the regions of stability for an accelerator lattice can be illustrated on a plot of F versus D quadrupole strengths. This is commonly described as a 'necktie diagram' and can be applied to achromatic arc lattices by using as variables the F and D elements in the ID straights. The quadrupole strengths within the arcs are determined mainly by the zero dispersion requirement. Extensive studies have been made of the properties of lattices with respect to position in the necktie diagram and the results have been used as a method to characterise a particular lattice structure.

The allowed betatron tune range of the stable regions for a given lattice is determined by its periodicity and the phase changes arising from its arrangement of quadrupoles. The horizontal phase change across the dispersive section of an achromat is constrained by the necessity to set the quadrupoles to produce zero dispersion outside the achromat. As shown by Jackson [3], for simple structures operating near the minimum emittance configuration this horizontal phase change tends to definite values. In a Chasman-Green or DBA cell this was shown to be about π.

Relaxation of the minimum emittance condition allows the overall behaviour of the lattice to be evaluated. For the proposed DBA circular lattice, the tune boundaries of the stable regions are found to be

$$n/2 < Q_r < 3n/2$$
$$0 < Q_v < n$$

where n is the number of unit cells. Each stable region is bounded by integer multiples of π across a cell. Although the exact position of the regions in the necktie diagram is governed by the strengths and positions of the quadrupoles in the achromatic arc, it has been found that the general capabilities of a lattice structure can be quickly assessed by studying the characteristics of the stable regions. Each region has a distinct set of properties, and these have been studied using an automatic scanning facility of the in-house lattice code ORBIT [4]. The necktie diagram for a 10 cell DBA is shown below in fig. 2.

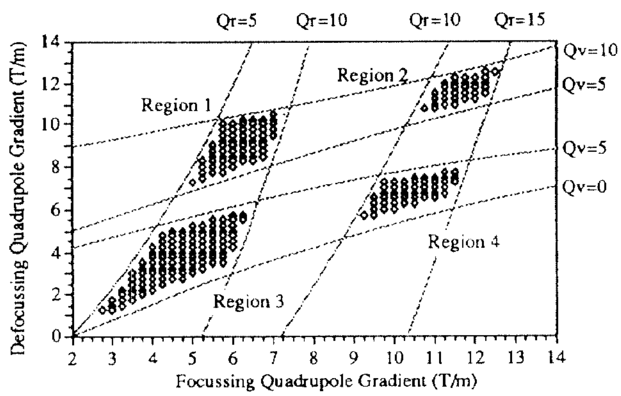

Figure 2. Stable Regions for 10 Cell DBA

4. EMITTANCE CAPABILITIES

It has been shown that the minimum emittance that can be achieved in a Chasman-Green or DBA lattice where the dispersion and its derivative are zero at one end of each dipole is given by [5, 6]

$$\varepsilon_x = \frac{C_q \gamma^2 \theta^3}{4\sqrt{15}\, J_x} \qquad (1)$$

where $C_q = 3.84 \times 10^{-13}$ m, γ = relativistic factor, θ = bend angle per dipole and J_x = horizontal partition number.

The minimum possible emittance of a 10 cell DBA at 1.2 GeV as predicted by equation (1) is 4.3 nm-rad. Figure 3 illustrates the computed variation of radial emittance across the four stable regions for the chosen lattice structure at 1.2 GeV. It shows that the smallest emittance achievable in this lattice is ~8 nm-rad. It is clear that the lattice is close to optimum from a minimum emittance viewpoint. However by relaxing away from the smallest achievable emittance it is apparent from fig. 3 that quite a wide range of tune points are available which would produce a reasonable working emittance of less than 15 nm-rad.

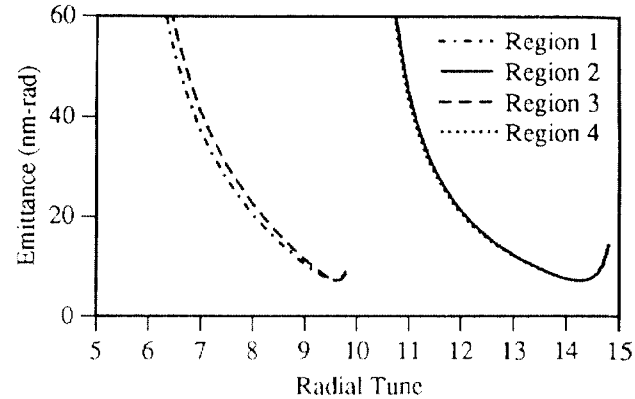

Figure 3. Emittance vs. Radial Tune

5. LATTICE FUNCTIONS

Dramatic differences are seen in the value of the beta functions at the centre of the ID straight in each of the four stable regions. This behaviour is characteristic of a DBA lattice with this arrangement of quadrupoles, although the particular beta values produced will depend upon their geometry. The variation in beta over the different regions is illustrated below in fig. 4. The radial beta is either large (≈10m) or very small (<1m) depending on the region. The vertical beta also has quite different behaviour in each of the four regions.

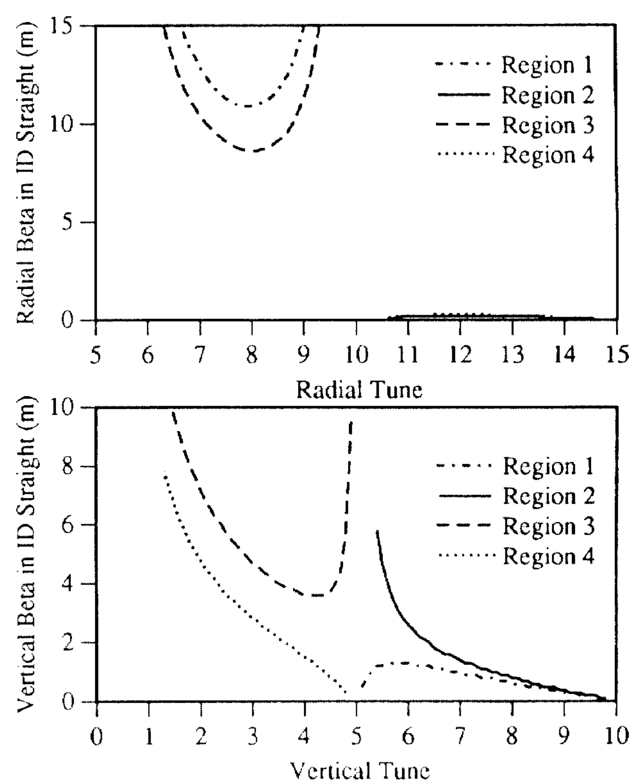

Figure 4. Radial and Vertical Beta in ID Straights

As a consequence of the differing beta in the ID straight in each region, DAPS can have two modes of operation. The high radial beta mode (Region 3) has been chosen for initial operation of the machine, as this region has lower chromaticity, more favourable dynamic aperture and hence longer beam lifetime [2, 7]. The lattice has been designed for flexible operation and an alternative low beta mode (Region 2) has also been assessed for later operations. The reduced dynamic aperture in this region may cause maximum stored beam current to be slightly less, and lifetime to be shorter. However, the low beta mode results in a substantial increase in brilliance due to an improved match of the electron beam properties to the ID [1]. Up to a factor of 6 increase in brilliance is predicted in the VUV region.

6. RACETRACK LATTICE

The design of DAPS has been based around a circular lattice which has then been elongated into a racetrack configuration. It is a fact that if the super-long straight sections are perfectly matched to the rest of the machine then the lattice functions in the standard cells remain unperturbed, and the linear properties of the circular machine can generally be maintained in the racetrack version. The reduction in symmetry from 10-fold to 2-fold will, however, be reflected in the nonlinear properties of the racetrack ring. These properties are discussed in detail elsewhere [7].

In order to match correctly over a wide range of tune settings, additional quadrupoles are required in the super-long straights. A minimum of four quadrupoles is necessary to obtain a match over all tune regions. Matching of the lattice functions in radial and vertical planes simultaneously was carried out using the accelerator code MAD [8]. Four quadrupoles at each end of the super-long straight have been used to match the straight into the circular machine, which leaves 15m of drift space for insertion devices. With focussing elements only at the ends of the long straight beta functions are large, particularly in the quadrupoles, which has implications for the aperture requirements, nonlinear properties and sensitivity to errors. Important parameters for a representative tune point in Region 3 are included in Table 1 for the racetrack lattice.

Table 1. DAPS Parameters

Energy		1.2 GeV	
Circumference		139.3 m	
No. long ID straights		2 x 15 m	
No. short ID straights		8 x 3 m	
Bending Radius		3.1 m	
Dipole strength		1.3 T	
Radial emittance		26.5 nm-rad	
Betatron tune	(r,v)	8.29	2.24
σ in long ID straight	(r,v)	0.21	0.07
σ in short ID straight	(r,v)	0.18	0.05
σ in dipole	(r,v)	0.06	0.07
Chromaticity	(r,v)	-11.0	-11.9

The beta and dispersion functions in the racetrack machine are illustrated in fig. 5.

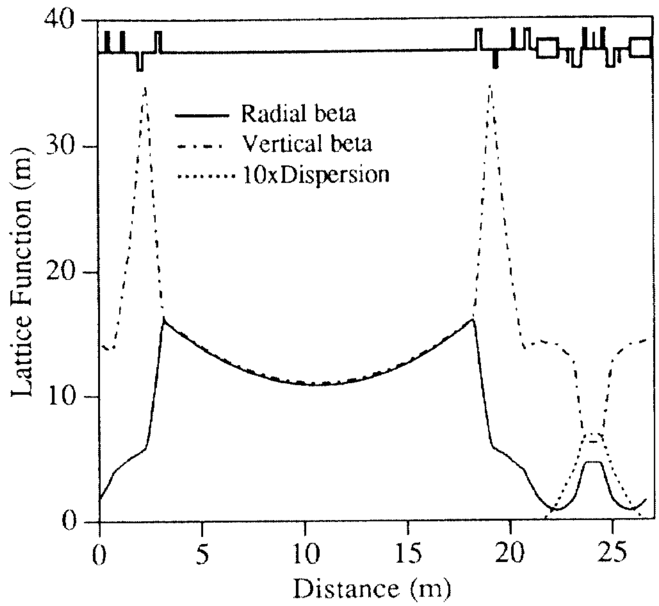

Figure 5. Lattice Functions of the DAPS Long Cell

7. CONCLUSIONS

The linear lattice properties of a novel racetrack lattice have been presented, and the feasibility of such a design confirmed. Nonlinear properties and the inclusion of insertion devices into this lattice are detailed elsewhere [2, 7]. A proportion of the work carried out on the racetrack lattice has been implied by comparisons with the circular machine on which it is based. The test of its feasibility has not uncovered any issues of major concern.

8. REFERENCES

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