Preliminary Lattice Studies for the Proposed X-ray Source DIAMOND.

J A Clarke, S L Smith and L A Welbourne
DRAL Daresbury Laboratory, Daresbury, Warrington, WA4 4AD, UK.

Abstract

This paper summarises studies carried out to optimise and characterise the lattice for the proposed 3 GeV electron storage ring at Daresbury. The ring has a novel design to allow planned expansions of facilities for higher energy X-rays by progressive replacement of some of the conventional magnet dipoles in the lattice structure by superconducting magnets. The consequences of such a scheme and the basic lattice behaviour are reported.

1. INTRODUCTION

The SRS at Daresbury was the world's first storage ring dedicated to the production of high energy synchrotron radiation. The ring was commissioned in 1980 and since then has undergone one major lattice upgrade (1987) and three insertion devices have been installed. A recent review of synchrotron radiation science in the UK recognised the contribution that the SRS has made to the international science community but also noted that in the next few years some of the experiments carried out on the SRS would no longer be at the cutting edge of modern science.

One of the recommendations of the review was for the provision of a new national medium energy X-ray source, DIAMOND, to replace the SRS [1]. The proposed specification was for a high flux photon source covering the wavelength range 150 eV to 30 keV or more. This paper describes the lattice studies carried out in an initial feasibility study of such a source.

2. DESIGN STRATEGY

The 3 GeV energy of the DIAMOND storage ring has been dictated by the requirements for high brilliance undulator radiation from 150 eV to 3 keV and high flux multipole wiggler radiation up to 30 keV. The premium beamlines in DIAMOND will be derived from insertion devices, although a substantial fraction of the scientific programme will use bending magnet sources. The normal bending magnets will be usable up to about 25 keV.

Many anticipated experiments require high flux rather than brilliance and can accept a relatively large horizontal radiation angle. In addition to multipole wigglers, another method to generate such radiation would be to use superconducting bending magnets. The strategy adopted has been to design a ring with conventional dipole magnets but to allow for the progressive replacement of single dipoles by superconducting dipoles as and when they are required.

To meet the anticipated experimental programme for DIAMOND at least twelve insertion straights are needed. A 16 cell lattice has been chosen allowing two straights for injection and one or two for RF systems.

3. CHOICE OF LATTICE

Since the lattice will be heavily dependent upon insertion devices an achromat lattice is desirable. The two well known options are the double bend achromat (DBA) and the triple bend achromat (TBA); both have been considered.

3.1 Double Bend Achromat

A DBA with two dipoles is a popular choice for many lattices. Such a lattice could provide excellent characteristics using conventional dipoles. It would not be desirable to replace just one of the dipoles with a superconducting counterpart as this would disrupt the cell symmetry substantially. Therefore both dipoles would have to be replaced. It is thought that the bend angle would be sufficient to utilise both dipoles simultaneously.

Another possibility considered was to use four dipoles, in two pairs, and to replace the two outer ones with superconducting ones. However, this lattice appears to have no clear advantage over its simpler two dipole cousin.

3.2 Triple Bend Achromat

In a TBA with three equal bend angle dipoles the central one could be replaced by a superconducting magnet. This would allow excellent access to the photon beam, without interfering with nearby insertion straights. Another advantage would be that only one superconducting dipole would be needed per cell whilst still retaining local cell symmetry.

For these practical considerations the TBA option was chosen for the feasibility study. Little time was spent comparing possible DBA and TBA lattices, this will be revisited during a more detailed design phase.

4. LATTICE PARAMETERS

The optimisation of the linear properties of the TBA structure were carried out using the in-house lattice code ORBIT [2]. Several options were considered for the order and number of quadrupoles within the lattice. The final structure chosen is illustrated in figure 1. Four families of quadrupoles are used; two in the achromatic arc and two in the insertion straight. The main parameters of the basic lattice with only normal conducting dipoles are given in Table 1. The lattice functions are shown in figure 2. For illustration a relaxed working point has been selected because maximum brilliance is not the only parameter of importance in this light source [1]. The theoretical minimum emittance of ≈1 nm-rad is significantly smaller than that for the relaxed lattice, consequently a relatively high beam current for a 3rd generation source can be specified with confidence.

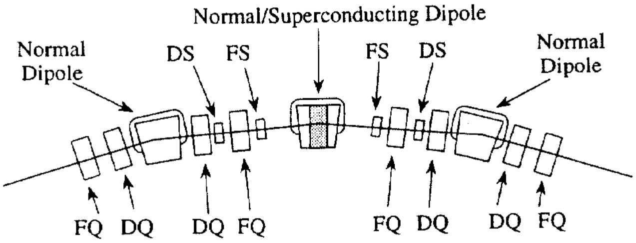

Figure 1. A sketch of the DIAMOND lattice.

Energy	3.0 GeV
Circumference	300.8 m
Number of Cells	16
Normal Conducting Dipole Field	1.31 T
Superconducting Dipole Field	4.36 T
Beam Current	300 mA
Emittance	19.2 nm-rad
Insertion Straight Length	3.0 m
Radial Betatron Tune	16.74
Vertical Betatron Tune	7.53
Momentum Compaction	0.0016
Radial Chromaticity	-20.5
Vertical Chromaticity	-31.5
Energy Loss per Turn	0.94 MeV
Critical Photon Energy from Normal Dipole	7.8 keV

Table 1. Main parameters of the TBA version of DIAMOND.

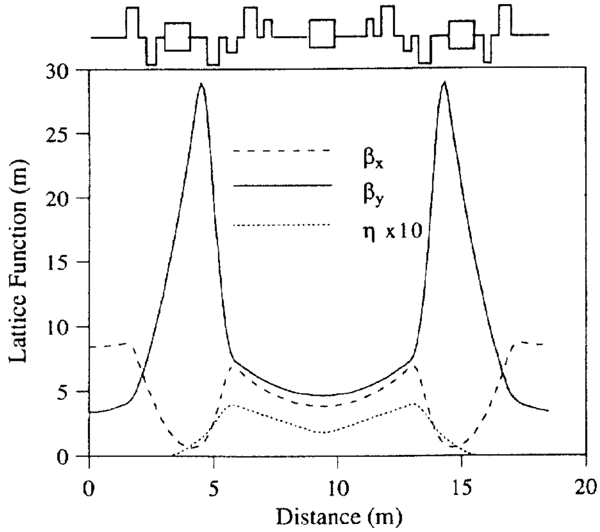

Figure 2. The lattice functions for the all normal conducting dipole phase of DIAMOND.

5. INCLUSION OF SUPERCONDUCTING DIPOLES

As the central superconducting dipoles are installed they will inevitably disrupt the dynamics of the lattice due to symmetry breaking. To minimise this disruption the first two dipoles will be installed diametrically opposed to each other. Further dipole installation would proceed in a similar manner with another pair being installed so as to split the lattice into quarters and so on. When the dipoles are installed the lattice functions will be matched so as to minimise the effect on the other source points. A cell containing a superconducting magnet has been matched to a normal cell using the program LATTICE [3]. To achieve an acceptable match the program was allowed to alter all four quadrupoles locally and asked to match the beta functions and to keep the dispersion to zero at the centre of the insertion straight. The results of such a match have been published elsewhere [4].

If both sets of quadrupoles in the achromatic arc are set to approximately equal levels then the emittance with the full complement of 16 superconducting dipoles lies in the range 30 - 50 nm-rad. In fact the emittance can be greatly reduced by lowering the strength of the D-quadrupole in the achromatic section. In this case 5 nm-rad can be achieved but at the expense of high beta values and chromaticity. This low emittance mode could provide a challenging opportunity for upgrade at a mature stage in the project. The growth of the emittance for the relaxed lattice as superconducting dipoles are installed is illustrated in figure 3.

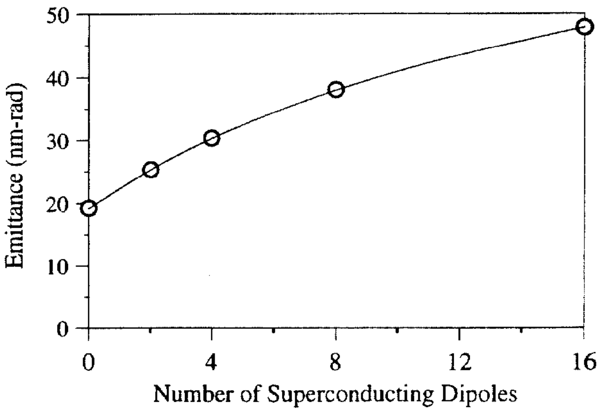

Figure 3. Emittance increase with the inclusion of superconducting dipoles.

The energy loss per turn of 0.94 MeV increases sharply when superconducting dipoles and insertion devices are installed. Such high losses place a significant demand upon the RF system. The proposed scheme for the RF system including possible upgrade details are given in reference [5].

A preliminary design for a possible superconducting dipole has been assessed. The predicted performance of this magnet is very good and a prototype has been built and tested to 6 T at Novosibirsk [6].

6. LIFETIME

At 3.0 GeV the limiting lifetime will be due to gas scattering. Calculations have been made to assess the typical expected lifetime figures for DIAMOND. The RF bucket height has been assumed to be 3%. With a gas (N_2) pressure of 1.0 nTorr and a limiting half aperture of 10.0 mm in the insertion device section the lifetime is estimated to be as high as 63 hours. The variation of gas lifetime with insertion device half aperture is shown in figure 4. Clearly very small apertures could be possible whilst still maintaining a very reasonable lifetime, so that short period insertion devices are feasible.

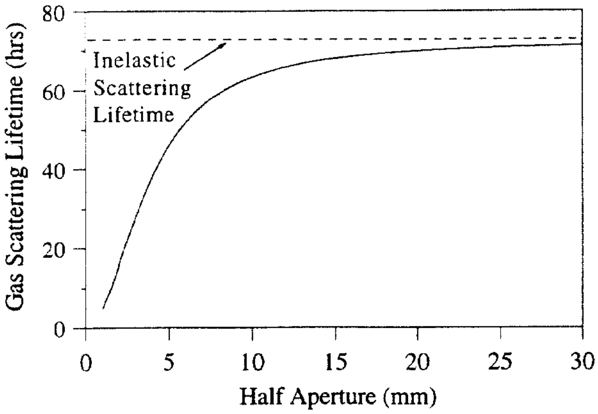

Figure 4. Gas scattering lifetime vs half aperture in the insertion device straight.

7. CONCLUSIONS

The feasibility of a source which has the potential for progressive upgrade by replacement of normal dipoles by superconducting ones has been discussed. Such a source would replace the SRS. If DIAMOND was to be given approval then detailed studies would commence.

8. ACKNOWLEDGEMENT

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9. REFERENCES

[1] M.W. Poole and V.P. Suller, "Proposals for New UK Light Sources", these proceedings.
[2] S.L. Smith, "ORBIT User Guide", Daresbury Laboratory Internal Report.
[3] J. Staples, "LATTICE ... a beam transport program", LBL, Revised August 1989.
[4] M.W. Poole et al, "A Design Concept for the Inclusion of Superconducting Dipoles within a Synchrotron Light Source Lattice", Proceedings of the 1993 Particle Accelerator Conference, Washington, USA, May 1993, pp 1494 - 1496.
[5] D.M. Dykes, "An RF System for the Proposed DIAMOND 3 GeV Light Source", these proceedings.
[6] G.N. Kulipanov et al, "Development of Superconducting Compact Storage Rings for Technical Purposes in the USSR", Rev. Sci. Inst. 63 (1), January 1992, pp 731 - 736.