A Design Concept for the Inclusion of Superconducting Dipoles within a Synchrotron Light Source Lattice

M. W. Poole, J. A. Clarke, N. A. Mezentsev *, S.L. Smith, V. P. Suller, L. A. Welbourne

SERC Daresbury Laboratory, Daresbury, Warrington, WA4 4AD, UK

* BINP, Academy of Science Russia, Novosibirsk, Russia

Abstract

The advantage of using high field superconducting dipoles to provide hard radiation in a synchrotron light source is that, in contrast to using high field wigglers, scarce insertion device straights are not used up. A strategy is proposed for replacing selected conventional dipoles within a lattice with superconducting devices where and when required. The potential of both double and triple bend achromats is compared and contrasted. The properties of the superconducting dipoles as radiation source points are considered as also is their overall impact on the lattice behaviour. In a feasibility study for the advanced x-ray source DIAMOND, which is briefly described, it is concluded that a triple bend achromat is the best choice for a 3 GeV structure with 16 cells that meets the defined specification.

I. BACKGROUND

The SRS at Daresbury was the world's first high energy, dedicated (second generation) light source and its effective exploitation continues to be of high priority to the UK synchrotron radiation community. Recently a major review of existing and future requirements has been underway and a series of design options has been considered, initially concentrating on a single source called DAPS [1]. Finally a proposal has been made for a new VUV source (SINBAD) and for the eventual replacement of the SRS by an advanced facility called DIAMOND, that is designed to cover the intermediate spectral range between SINBAD and the ESRF. The lattice design of SINBAD is similar to DAPS but a different concept is considered here for DIAMOND.

II. GENERAL DESCRIPTION

The choice of 3.0 GeV for the storage ring energy has been dictated by the simultaneous requirements for high brightness soft x-ray beams from 150 eV to 3 keV and high flux x-rays in the 3 - 30 keV photon range. To match the anticipated experimental programme DIAMOND would require space for at least twelve insertion devices. To provide the necessary space for injection and RF systems a 16 cell lattice was chosen. The approximate circumference would be 300 m and either DBA or TBA designs could provide the required dispersion free straights for insertion devices. An important consideration in the design was that it should flexibly allow for the progressive replacement of conventional dipoles within the lattice by superconducting dipoles. These superconducting dipoles would satisfy the national requirement for harder x-rays without using up the limited supply of straight sections. The main parameters for the storage ring are shown in Table 1.

Table 1
Main Design Parameters

Energy	3.0 GeV
Circumference	~300 m
Number of cells	16
Normal conducting dipole	1.3 T
Superconducting dipole	4.5 T
Emittance	10-50 nm-rad
Beam current	300 mA
Insertion straight length	3.0 m

III. CHOICE OF LATTICE

Double Bend Achromat

In the case of a DBA structure two possibilities were considered:

1. Two dipoles per cell in a conventional design
2. Four dipoles per cell, installed in pairs

In the first case, the length of the normal conducting magnet is 1.3 m and the corresponding length of a replacement superconducting magnet is 0.45 m. The bend angle is large enough to permit full extraction and utilisation of the synchrotron radiation. In the second case, the length of the normal and superconducting magnets are 0.65 m and 0.2 m respectively. Here the superconducting magnets are too short, not only to create good field quality in an acceptable vertical aperture but also to provide adequate length of uniform field though the magnet. It is also clear that replacement of only one dipole in a cell is undesirable from the point of view of beam dynamics as it breaks the symmetry of the lattice.

Triple Bend Achromat

In the TBA lattice the cells contain three dipoles with equal bending angles. The central normal conducting dipole could be replaced by a superconducting one while still maintaining the symmetry of the cell structure. The magnetic length for normal and superconducting magnets is 1.0 m and 0.3 m respectively. The shorter length of the superconducting magnet in the TBA case is still acceptable in terms of providing synchrotron radiation. The design which produces acceptable beam performance and the best access to the superconducting magnet radiation with minimal impact on the insertion device beam lines is the TBA. For these reasons, early in the studies this was chosen as the best solution, although a limited amount of work has been carried out in parallel on the two magnet DBA lattice to allow the comparison of some basic parameters.

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Optimisation of the linear properties of the TBA structure was carried out using the in-house computer program ORBIT [2]. Various options were considered for the quadrupole type and order within the achromatic bend. Figure 1 illustrates the structure of the final optimised TBA lattice that was chosen.

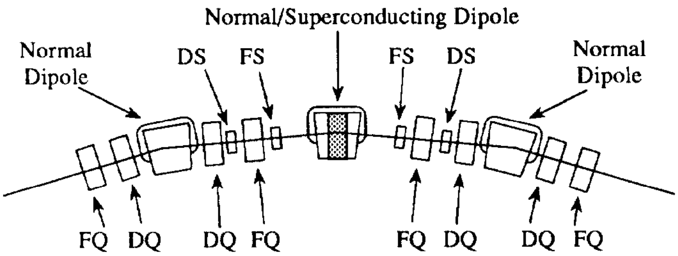

Figure 1. Sketch of TBA unit cell

With both sets of quadrupoles in the achromatic arc at approximately equal values this lattice with 16 superconducting magnets has a reasonable emittance of around 30-50 nm-rad and relatively low chromaticity. Some basic parameters of the lattice with all conventional dipoles, at a representative tune point, are summarised in Table 2. Reducing the level of the D-quadrupole in the achromat produces a very low emittance lattice : at the extreme an emittance of around 5 nm-rad can be achieved, even with 16 superconducting magnets installed, but at the expense of high beta values and chromaticity. The existence of this low emittance mode could provide a possible, but probably very challenging, additional upgrade path for the future development of DIAMOND.

Table 2
Lattice Parameters of the TBA

Radial , vertical tune	16.74, 7.53
Emittance (nm-rad)	19.16
Energy loss per turn(MeV)	0.94
Momentum compaction	0.00158
Radial , vertical chromaticity	-20.5, -31.5

IV. DESIGN OF SUPERCONDUCTING DIPOLES

A superconducting dipole has been designed with a field of 4.36 T and the required bending angle of 7.5°. A diagram of the proposed superconducting magnet is shown in Figure 2. It uses a steel yoke to improve the field quality and minimise the stray fields at the superconducting windings and to give excellent field uniformity. The predicted performance of this type of magnet is very good and a prototype [3] including several of its features has been built at Novosibirsk and tested to 6 T.

The change in photon output when replacing the normal conducting 1.3 T magnet with the high field superconducting 4.36 T magnet is shown in Figure 3 together with the expected output from representative insertion devices. The calculations were carried out using the Daresbury program SPECTRA [4]. These curves illustrate the resulting enhancement in photon output at the higher energies. It has also been shown that the small radius of curvature of the superconducting dipole would allow very short beam lines which would provide very high flux at the sample.

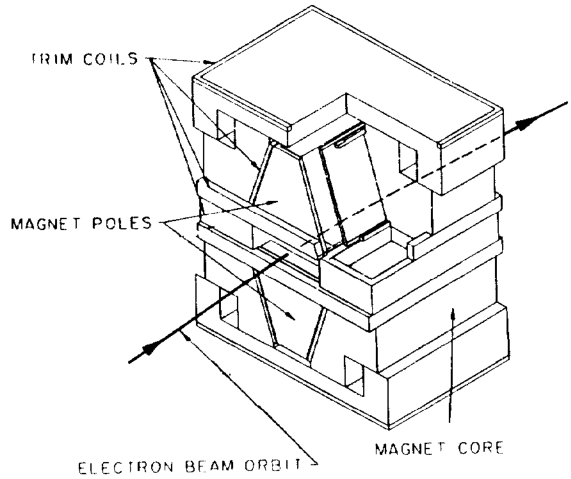

Figure 2. Proposed superconducting dipole magnet.

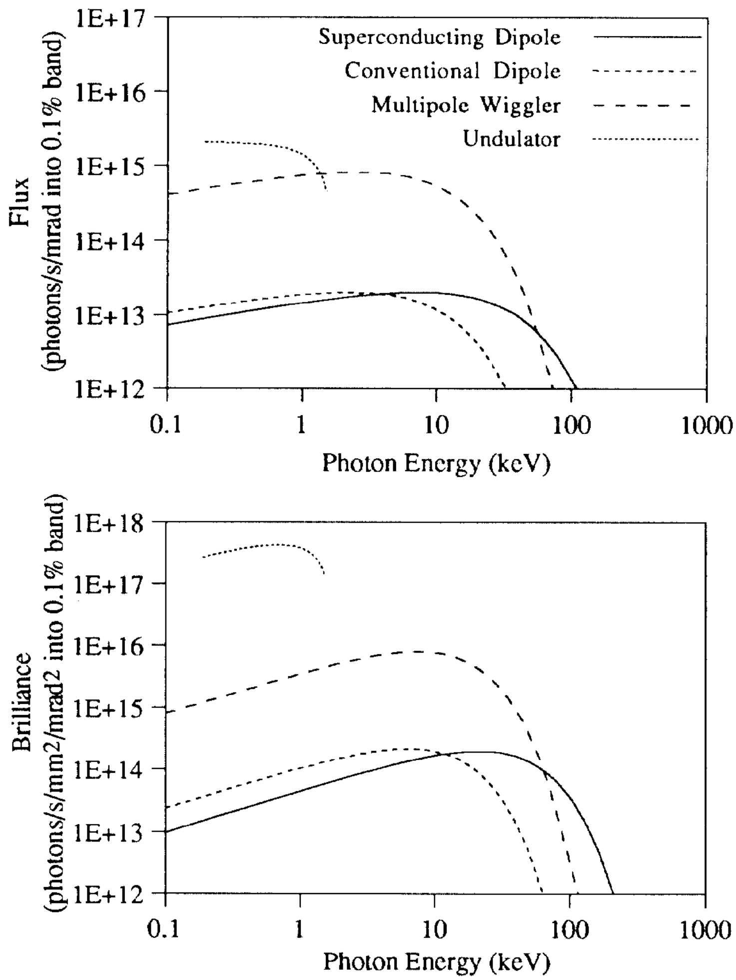

Figure 3. Flux and brilliance of sources in DIAMOND including output from representative insertion devices.

V. EFFECT OF SUPERCONDUCTING DIPOLES

To minimise the disruption to the beam dynamics as the ring is upgraded with additional superconducting magnets, it is planned to install in the first stage two magnets diametrically opposite. The next two would then also be installed diametrically opposite, but at 90° to the first pair and so on. The conversion to a superconducting magnet must be carried out with minimal effect to the other source points in the lattice. To this end, the linear lattice functions of the cell with superconducting magnets have been matched to those of the all-conventional magnet cells. This matching process was carried out using the program LATTICE [5]. The lattice functions at an illustrative tune point for two matched unit cells, one with a normal conducting dipole and one with a superconducting dipole, are shown in Figure 4.

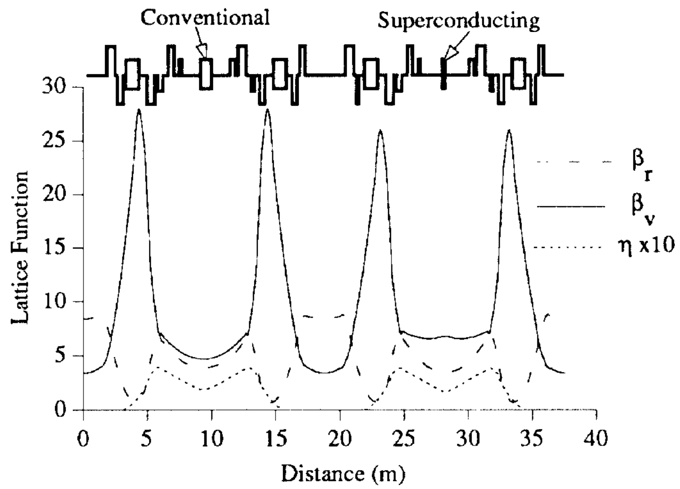

Figure 4. Matched lattice functions in DIAMOND

The central superconducting dipole inevitably has a larger contribution to the storage ring emittance than the replaced normal conducting one. This will lead to an increase in emittance as the source is developed and the number of installed superconducting magnets increases. Figure 5 shows the calculated increase in emittance as a function of the number of superconducting dipoles inserted in the lattice. This level of emittance increase is an acceptable compromise given the requirements of the experiments envisaged on DIAMOND. The introduction of the superconducting dipoles also increases the energy loss per turn and the design of the RF system has included an assessment of the requirements to allow an expansion to a possible 16 superconducting magnets and 10 multipole wigglers, although this would require two straight sections to be reserved for the accelerating cavities.

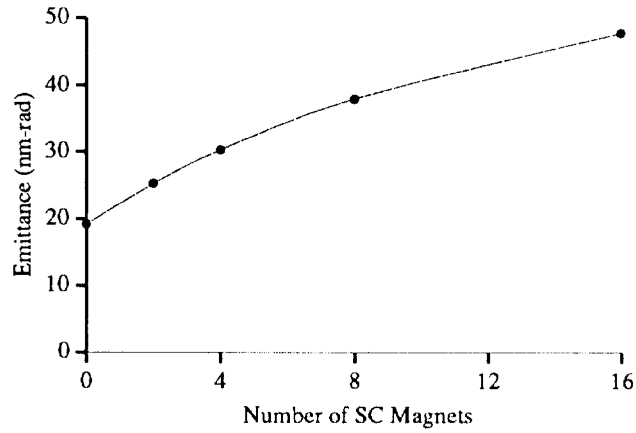

Figure 5. Emittance increase with number of superconducting dipoles.

VI. CONCLUSION

The studies carried out so far have enabled the feasibility to be assessed of a source which has the potential for progressive upgrade by the replacement of normal conducting dipoles with superconducting magnets. This has allowed reasonable estimates to be made of the costs and performance of such a source as a possible replacement for the Daresbury SRS. Such an assessment was required in order that the future strategy for the provision of synchrotron radiation to UK scientists could be developed. Clearly if this concept is approved further work would be required to optimise the nonlinear aspects of the design.

VII. ACKNOWLEDGEMENTS

We would like thank P. N. Vobly for his contribution in the design of a suitable superconducting dipole.

VIII. REFERENCES

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