EVOLUTION OF THE DIAMOND LIGHT SOURCE

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Abstract

The medium energy Synchrotron Light Source DIAMOND will be the replacement for the present SRS facility at Daresbury. During the period of several years of feasibility studies its design specification has evolved to a much higher brightness solution and the scale of the project has also greatly increased. Recognition of the need for highly optimised undulators delivering radiation in the range 10-20 keV has prompted a reappraisal of the storage ring energy, but a combination of modern insertion device technology and better understanding of the impact of small aperture restrictions allows a choice of 3 GeV to be confirmed. However the size of the ring has grown substantially, especially with the decision to increase to 24 cells. Associated with this has been a dramatic emittance reduction with an expectation of 2-3 nm-rads ultimately possible. The paper summarises this progress and also presents an overview of the project and its present status.

1 EARLY HISTORY

The origins of the project are rooted in a strategic review of UK needs in synchrotron radiation carried out initially nearly a decade ago; these concluded that the existing national light source, SRS, would no longer be internationally competitive by the turn of the Millennium. This led to a set of proposals [1,2] for a three ring scenario, based on ESRF for high brightness, high energy needs, together with two new rings at low and medium energy: SINBAD and DIAMOND. The VUV ring SINBAD has not so far been pursued in any detail but its potential future existence has influenced views on reduced provision of low energy (<100 eV) output from DIAMOND.

Initial plans had been for a 16 cell, 3 GeV storage ring with a TBA lattice, in part because of a proposed scheme to upgrade the source by replacing central dipoles of achromats by superconducting magnets of higher field strength. During the next design phase [3,4] a decision was made to adopt a flexible DBA lattice and also to include two superstraights with up to 20 m available for long insertion devices (IDs); this resulted in a racetrack geometry now about 345 m in circumference. This type of lattice geometry is notoriously difficult to optimise satisfactorily for nonlinear properties (eg dynamic aperture) and it was recognised that further work would be needed. Nevertheless it provided a useful basis for a Feasibility Study that also generated the first comprehensive, if approximate, cost estimates of the project.

More recently there has been significant design evolution. In 1998 the racetrack concept was abandoned in favour of a four-fold symmetric version, still with 16 cells and similar circumference [5]. As a result, and with careful optimisation of harmonic sextupoles, a more satisfactory dynamic aperture was achieved. Of the four enhanced long straights, now providing about 10 m free space, two were reserved for the injection and RF systems. By the following year [6] more significant design concepts had been adopted, partly in response to a changing user specification that took account of greatly increased demands of the life science community. In particular high brightness output in the range 10-20 keV was now specified, in contrast to earlier willingness to limit such a facility to below about 5 keV. Furthermore it was recognised that the relatively modest DIAMOND emittance of 14 nm-rad so far agreed to by the community was unlikely to be adequate. An increase of the number of cells, together with permitting non-zero dispersion in the straights, has allowed dramatic emittance reductions to be achieved.

In the Summer of 1998 the UK Government announced that the DIAMOND project would be funded, in partnership with the Wellcome Trust. During 1999 a series of user consultations refined the source specification and the latest solution to these needs is described in overview below; more detailed accompanying papers [7-12] can also be consulted. Another key event in 1999 was the decision by the French Government to subscribe to the partnership of sponsors at a substantial level, following the apparent cancellation of the French SOLEIL project; at the time of writing the exact French role in DIAMOND is being reviewed and an announcement on this is imminent. However the facility specification has now been increased to 24 cells in view of the huge user demand that can be anticipated for such a shared source.

2 LATTICE PROPERTIES

The target of low emittance is more easily met as the number of lattice cells increases, due to well known scaling effects. Even a 20-cell lattice at 3 GeV can reach 5 nm-rad or better and the recent decision to specify DIAMOND with 24 cells has allowed a target figure of 3 nm-rad to be met. The physical layout of cells now proposed leads to an overall ring circumference of about

490 m; however it is expected that more detailed engineering assessments are likely to force an increase to perhaps 530 m eventually. Standard straight lengths of almost 6 m will provide space of up to 4.5 m for IDs, whereas the superstraights envisage 8 m freely available for special IDs (or other equipment). One decision already taken is to define a 6-fold symmetry (ie not the alternative 4-fold one), based on two advantages: one is that two extra superstraights are available to users and the other that improved lattice dynamic aperture has been found to result.

All DBA lattices have similar properties and this is a mature subject after many years of application. Nevertheless there is still scope for a variety of design optimisation schemes, especially as regards improved nonlinear behaviour (ie dynamic aperture); earlier DIAMOND studies used conventional methodology including careful selection of working point with respect to resonance lines and their driving terms, but more recently an alternative procedure that relies on minimising higher order geometric terms in the one turn map by selecting suitable phase advances in different zones has been employed [8]. This method has been confirmed to give optimisation advantages, even in the less than ideal case of finite sextupole magnet lengths. As a result the dynamic aperture of the latest 24-cell version is much improved [7] and achieves up to ±25 mm horizontally and over ±10 mm vertically; an additional advantage of such a well behaved lattice is its associated tolerance of anticipated magnet errors.

The benefits of breaching the achromatic condition have been well known since it was first applied to the MAX-Lab lattice, with very successful demonstrations at ESRF and other facilities thereafter. Non-zero dispersion in the straights, at the level of a few centimetres, has a significant benefit for DIAMOND performance and is now assessed for all candidate lattice solutions. The latest reference value of 2.5 nm-rad is achieved in this mode and with 24 cells at 3 GeV is close to the ideal zero dispersion result. Another feature of all DIAMOND lattice studies is the emphasis on flexibility; in addition to both zero and finite dispersion modes there have been assessments of variable beta control in the straights and of ‘relaxed’ lattice modes, both for commissioning and other operational purposes [7]. In order to achieve this degree of flexibility it is proposed that all lattice quadrupoles should be individually powered.

The principal parameters of the latest example DIAMOND lattice are given in Table 1, but at this stage are only for illustration as many further studies will occur before they are finalised.

Table 1: Principal DIAMOND Parameters

Energy	3 GeV
Beam current	300 mA
No. of DBA cells	24
Symmetry	6
Circumference	489.24 m
Harmonic no. (500 MHz)	816
ID space	18 x 4.5 m, 4 x 8.0 m
Dipole field	1.4 T
Emittance	2.5 nm-rad
Coupling	1 %
Betatron tunes	28.89, 10.70
Natural chromaticity	-85.7, -39.1
Dispersion: long,short sts	6.0, 4.1 cm
Momentum compaction	1.6×10^{-4}
Natural energy spread	9.62×10^{-4}

3 LIFETIME AND CURRENT LIMITS

DIAMOND is a facility requiring a combination of lifetime and current that is challenging for such high brightness facilities. The energy loss from the bending magnets is supplemented by a major contribution from the IDs, many of which will have high magnetic fields: a standard multipole wiggler at 1.6 T will emit 65 keV per turn and a 6 T wavelength shifter much more than this. In specifying the RF system a judgement must be made on the likely portfolio of IDs of different types and this suggests a combined loss from these of at least 0.8 MeV per turn, resulting in a total loss per turn of 1.8 MeV; the overall power loss for 300 mA then becomes about 550 kW. In order to ensure acceptable beam lifetimes it has been decided that a 4 % momentum acceptance target must be set and this implies an installed peak voltage of at least 4 MV from the accelerating cavities. Physical apertures in DIAMOND will be set to maintain a beam lifetime of at least 10 hours and this suggests a minimum vertical gap in the range 10-20 mm in the IDs, depending on their length and position within the lattice.

Preliminary assessment of probable instability limits suggested [9] that multibunch thresholds arising from normal conducting accelerating cavity HOMs will be safely above the projected current levels, although a cautious approach would still suggest provision of a transverse feedback system to provide adequate safety margins. However the combination of specified RF power and voltage makes a superconducting solution attractive for DIAMOND, not only on economic grounds but also as having upgrade potential despite being confined to a single straight section with 8 m of available space; furthermore such a system would eliminate HOM driven instabilities altogether [10]. A final decision will be taken at a later date.

A need for single or few-bunch modes of DIAMOND operation has also been identified by users. The maximum bunch current may be limited not by coherent instability issues but by beam lifetime (Touschek), depending on the degree of bunch lengthening encountered [9]; the inclusion of a higher harmonic RF cavity will assist the optimisation of these operating conditions. It is hoped to achieve at least 20 mA per bunch but this cannot yet be confirmed. As with all modern light sources DIAMOND will also employ a range of other bunch patterns, both for ion removal and possible instability suppression.

4 USER SPECIFICATIONS

As a 3rd generation light source the DIAMOND output specification is based on a wide range of IDs, providing high brightness from below 100 eV to at least 20 keV. An emittance coupling of 1 % has been assumed in spectral calculations, a realistic if conservative figure in modern sources. At least 21 of the straights will be exploited by users and there will also be many (10-20) bending magnet beam lines; the four long superstraights will provide a range of special possibilities, including perhaps a long period undulator to extend the output range well below 100 eV.

A major feature of DIAMOND has been the demand for high brightness at 12.7 keV for protein crystallography and careful consideration has been given to the associated ID requirements. It has been confirmed [11] that well over 10^{19} photons/s/mm^2/mrad^2/0.1% can be delivered at this energy from a realistic short period undulator, avoiding the need to increase the ring energy beyond 3 GeV: modern advances in both storage rings and undulators enables this specification to match that originally set for much higher energy facilities such as ESRF.

For most of the desired photon energy range (400 eV - 7 keV) a brightness of at least 10^{20} can be reached by a range of undulators. There continue to be many user demands for very high flux levels too, and beyond about 1 keV these are best met by multipole wigglers; at the highest energies (above 70-80 keV) one or more superconducting wavelength shifters will be needed [11]. As with the undulator lines, decisions on these exploitation issues are likely to be taken much later in the project.

5 ISSUES AND FUTURE PLANS

Although the general specification of DIAMOND requirements is close to completion a number of critical parameters have yet to be formally confirmed, including those in Table 1. During the next few months user consultations will continue on such issues and other important matters affecting the final design. It is still unclear what provision will need to be made for low energy users and this will depend on other available sources for them. One special case may be provision of infrared beams since there are significant user advantages to their inclusion on a higher energy ring (stability, lifetime, …), but this raises the question of providing sufficient physical aperture for their successful extraction. Another issue is the possible provision of a free electron laser on the ring: an assessment of DIAMOND operation at lower energy (1-1.5 GeV) suggests that this may be a viable option [12] but it may be judged inappropriate.

In March 2000, after a long period of uncertainty, a decision was taken by the UK Government, in conjunction with its two partners, to site the new facility at the Rutherford Appleton Laboratory near Oxford. The detailed implications of this are now being addressed and include an assessment of site dependent issues such as ground stability [13], buildings and provision of major infrastructure needed for a modern light source. There are also difficult challenges in continuing to operate the SRS at a high level during the many years of design and construction of the new source at a different laboratory.

It is the intention to commence a full Design Study by November 2000 and this will be undertaken largely by staff at Daresbury on behalf of the partners, with the construction phase then commencing in 2002 and first beam planned for 2006. It is hoped to appoint a permanent project team before too long, once the partners have agreed the details of management and funding.

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