UPGRADING THE DARESBURY SRS WITH ADDITIONAL INSERTION DEVICES AND ITS IMPLICATIONS FOR THE STORAGE RING LAYOUT

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Abstract

Although the SRS is a second generation light source with only short straights it already has two superconducting wigglers and a permanent magnet undulator installed. In order to exploit the source to its full potential it is now proposed to make as many extra straights as possible available for new insertion devices. This major upgrade has been fully assessed and involves substantial modification to nine of the sixteen straights in the ring, necessitated by consequential movements of all four accelerating stations. Three new insertion device straights then become available. Two multipole wiggler sources and their beam lines have been designed and a bid for funding made. A feasibility study has also been undertaken of a possible helical field device for polarisation switching, utilising an elliptical permanent magnet undulator.

1 SRS STATUS AND CASE FOR AN UPGRADE

As the first example of a second generation X-ray light source in the world the SRS is now a relatively old and well developed facility that has operated since 1981. It runs for over 6500 hours annually and as the UK national facility has a community of some 2500 users for its up to 40 experimental stations. The SRS does have three insertion devices already: two superconducting wigglers (5 T and 6 T) and a short permanent magnet undulator supply a total of 15 user stations. Despite a lattice rebuild in 1987 giving an order of magnitude emittance reduction the SRS cannot be competitive on brightness with undulators installed in the latest third generation light sources. However there is a growing demand for X-ray beam lines delivering high flux output, especially in the 5-20 keV region.

The long term UK strategy for future provision of synchrotron radiation is to construct a third generation X-ray source DIAMOND [1]. The scientific case for this high brightness SRS replacement also supports provision of extremely intense fluxes from many multipole wigglers (MPW). However delays in funding imply that the SRS must continue to operate for at least another seven years and it is therefore important to optimise its performance during this period. A plan for an upgrade to add two new beam lines has now been approved in principle and these will be based on high field MPW devices. Although no final decisions on user stations have yet been made it is likely that one line will be dedicated to structural biology (eg protein crystallography) and the second to materials science studies, both being high priority research topics for the UK community. The insertion devices have both been optimised for output around 10 keV and will give a major improvement to SRS users with outputs comfortably exceeding those even from the present superconducting wigglers.

Consideration has also started to be given to the possible inclusion in the SRS of another insertion device of a more specialised nature. A feasibility study has confirmed that it would be possible to install a soft X-ray undulator with variable polarisation for a spectroscopy beam line, operating over the range from below 200 eV to at least 600 eV, extendable to about 1300 eV by use of third harmonic output. This device would be optimised as a source both of elliptical and linear polarisation in excess of 95 %, particularly useful both for magnetic studies and for experiments on liquid samples where a vertical undulator field (horizontal polarisation) is crucial. A planar helical undulator of the Sasaki type has been selected for detailed assessment [2].

2 MODIFICATIONS TO THE SRS LAYOUT

The difficulty with adding to the present complement of insertion devices is the severe space restriction in the SRS. Every one of the 16 straight sections is occupied with a variety of storage ring components and no free space remains. To overcome this an assessment has therefore been made of a number of schemes to relocate components to more favourable positions. The injection septum and three associated fast kickers cannot be moved, nor in practice can the 4 equi-spaced chromatic D-sextupoles whose symmetry must be preserved [3]. One strong contender emerged as a straight in a region of the storage ring where vacant beam line floor area exists but the second location caused problems. With 3 of the remaining 7 straights occupied by existing insertion devices this leaves only the 4 RF cavity straights as candidates and so a rearrangement of the RF system became inevitable. Several options have been explored and an optimum movement of the accelerating stations selected [4].

Since only one existing RF cavity straight is maintained the changes to the storage ring component layout become substantial. Cavities must be moved together with their vacuum isolation valves and ion pumps. The integrated nature of the vacuum enclosure, including the RF impedance liners, necessitates 8 modified quadrupole vessels (3 of which will be brand new together with their bpm pick-up buttons). The opportunity will also be taken to replace the existing total current monitor and quarter wave diagnostic strip with a combined unit. Every new chamber must be glow discharged and have its RF impedance checked before installation. Overall 9 of the present SRS straights will be rebuilt and this significant workload will require an estimated 2-3 month shutdown on the facility. Shield wall modifications include both the new beam lines and provision for the RF changes.

One of the MPW lines will cross the injected beam path from the booster synchrotron. The injection line already has one such crossing from the 6 T wiggler beam line and this poses no particular problems other than the link to the storage ring vacuum, but it does imply some component moves.

On completing the component relocations the free space available for new insertion devices becomes about 1.2 m between flanges in each case. In order to extract radiation from them the downstream main bending magnet vessels will also need modifying to add suitable exit spouts.

3 MULTIPOLE WIGGLER DESIGN FEATURES

Optimisation of the spectral output from an MPW involves a compromise between achieving high magnetic field levels and the greatest number of magnet poles to contribute to flux increase. As is well known the ratio of period to gap in such devices is the crucial parameter in setting attainable on-axis fields. Given the 2 GeV SRS operating energy similar fluxes are obtained around 10 keV for fields in the range 1.6-2.0 T. However there is a need to maximise exploitation by feeding 2 experimental stations from a single MPW so it is necessary to examine the angular dependence of the output.

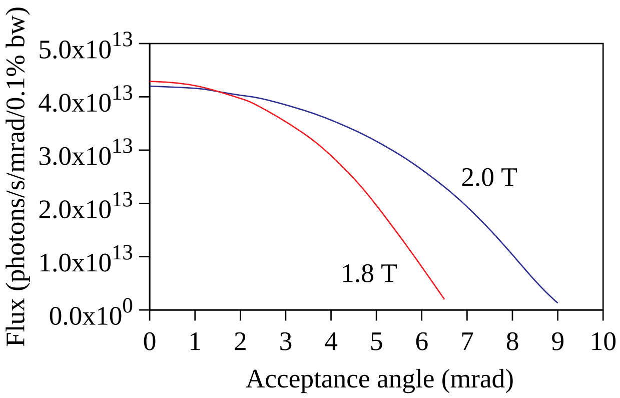

Figure 1. Photon flux vs horizontal acceptance angle for two MPW designs at 10 keV.

Figure 1 shows a comparison between 1.8 T and 2 T options and demonstrates the advantage of the higher field value. This calculation is based on a magnet period of 200 mm which produces electron orbit oscillations of about 400 μm amplitude with a maximum angular range of ±10 mrad: of course radiation originates from very low field regions when emitted at the extreme angles, but the critical wavelength is only 15 % longer at half this maximum angle. With this 2 T output it is possible to consider a centre station accepting ±2 mrad and a side station with similar acceptance but situated at an angle of 4.5 mrad.

Existing insertion devices in the SRS have a minimum vertical aperture of 42 mm, based on conservative criteria set at the design stage. For a successful MPW it is necessary to reduce this significantly and a series of accelerator physics studies has confirmed that this is feasible [5]. A beam-stay-clear allocation of 15 mm (full aperture) at the insertion device is now considered as acceptable and this can be translated into a magnet gap specification by assessing the insertion device vacuum vessel requirements. As is usual in a storage ring the horizontal beam-stay-clear is much greater at ±53 mm and this must be further enhanced to 80 mm on the outer side to prevent synchrotron radiation striking the wall. Both wall deflection and stress levels must be considered and these also affect the choice of chamber material. Almost the whole of the SRS vacuum enclosure is constructed from high quality stainless steel but the possible use of a titanium alloy (Al16-4V) for the MPW vessels is under consideration. This material has a number of attractions, being strong and light, having half of the thermal expansion of the steel, low vacuum outgassing and unit magnetic permeability. However its greatest advantage may be its good welding properties and it also has a much lower stress relieving temperature. A prototype chamber is being constructed and adopts a ribbed structure with thin walls immediately over the magnet poles to give an overall magnet pole gap of about 19 mm. If successful this technology will be directly applicable to future third generation sources such as DIAMOND.

At an early stage in the magnet studies an electromagnetic MPW was assessed but this proved impractical at the 2 T design specification. The chosen solution is a hybrid permanent magnet system with vanadium permendur poles to avoid undue saturation. The design has so far been optimised under 2-D approximation using the PANDIRA code and a very high remanent field (1.3 T) grade of NdFeB. These calculations have confirmed that a device with 200 mm period can produce 2 T (K=37) and this allows 9 poles to contribute to the spectral output of X-rays.

The perturbation of the stored 2 GeV electron beam although not negligible is much less than in the case of the existing superconducting wigglers. The additional energy loss per turn is 9 keV for each MPW, or a total enhanced power loss of less than 6 kW from a 300 mA circulating beam; there is no problem for the installed RF system to replace this loss [4]. Similarly the associated vertical tune shift from each insertion device is readily corrected using active current shunts on adjacent main D-quadrupoles of the FODO lattice [6], which also minimises any residual beta beating. These estimates are based on an ideal sinusoidal field variation along the MPW whereas in fact the distribution is as shown in fig 2 which falls away from the peak more rapidly. Emittance blow-up effects are negligible. Steering trim coils will be incorporated to help deal with any non-zero field integrals and the well established SRS orbit feedback control [7] will compensate for dynamic effects.

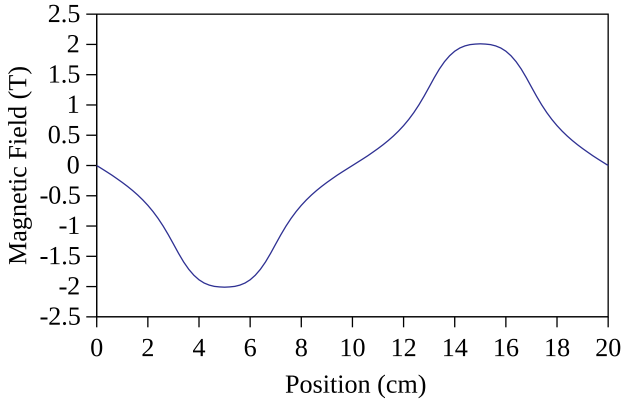

Figure 2. Magnetic field variation for one period of the proposed MPW.

As with any such MPW a major concern is the very high power levels that are produced: the estimated angular density of about 180 W/mrad is 3 times that from the 6 T superconducting device and a power density of nearly 1 kW/mrad^2 poses real problems for the beam line design, especially since 25 % of this power is at energies beyond 10 keV.

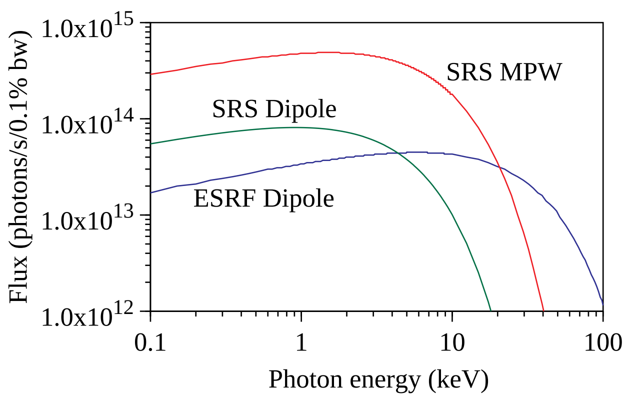

Figure 3. Comparison of photon fluxes from the SRS and ESRF dipoles and the proposed MPW.

The output spectrum from a MPW is given in fig 3 and it can be seen that it gives a major enhancement of SRS flux capability in the range up to about 20 keV with useful output even beyond that. This output is also well in excess of that from an ESRF bending magnet over the same photon energy range (of course it cannot compete with the brightness of ESRF undulators at 10 keV).

4 IMPLEMENTATION

Although the MPW upgrade has been accepted in principle funds have not yet been made available by the sponsoring agencies (EPSRC, BBSRC and MRC) to commence the detailed preparation work. It is hoped to start the project for the storage ring modifications in late Summer 1996, with a major shutdown for installation early in 1998. Before finalising details of the experimental stations a public meeting to discuss scientific opportunities has been scheduled for July 1996 and it is hoped that resources for this phase of the project will become available in Spring 1997. The intention is to complete the upgrade with fully operational stations by mid-1999.

As yet there is no official support for a third new beam line of the type mentioned briefly here and any such development would be expected to be the last in the lifetime of the SRS, a successful national facility that will nevertheless soon enter its third decade of operation. All of the upgrade plans discussed in this paper are seen as having direct relevance to the longer term DIAMOND strategy, both in developing technological solutions and in building sources and beam lines that could be readily transferred to a new storage ring.

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