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A SECOND SUPERCONDUCTING WIGGLER MAGNET FOR THE DARESBURY SRS

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Abstract

A second superconducting wiggler magnet will be installed in the SRS as a wavelength shifter, adding a 6T radiation source to the present 5T one. A warm bore design with a short central pole will minimise the tune shift and emittance blowup of the electron beam. Relocation of a chromaticity-correcting sextupole magnet to provide space for the wiggler has potentially serious effects on the dynamic aperture that are examined.

1. Introduction

A 5T superconducting magnet has been operating as a wavelength shifter on the SRS since 1982; its design has been previously described[1,2] and its effect on the SRS beam properties has also been discussed[3]. The five existing experimental stations, together with two additional ones under development, have become heavily oversubscribed with the demand for synchrotron radiation in the range 10-50 keV and even higher energies are sought by some users. A second wiggler facility has now been fully funded and detailed planning and construction is in progress.

The scientific case for the new facility is based on the needs of x-ray diffraction, protein crystallography, small angle scattering and EXAFS (biological and dilute) and implies the utilisation of a wide fan of radiation to gain maximum advantage. For this reason a wavelength shifter with a single high field region and an opening angle of at least 50 mrads has been chosen, allowing its utilisation simultaneously by five major experimental stations. Recently it has been decided to add an extra high flux density station as close in to the storage ring as possible: when in use this Laue station will block off all other users of the line. It appears possible that this unique facility can be placed about 7.5 m downstream from the wiggler source point, where the power density will be several Wmm^{-2} and peak fluxes of more than 10^{11} photons $s^{-1}mm^{-2}$ per 0.1% band can be obtained. The normal stations will have a brilliance ~ 10^{13} photons $s^{-1}mm^{-2}mrad^{-2}$ per 0.1% band.

With beam lines already planned or in use from eleven of the sixteen dipoles or adjacent straights of the SRS it has become increasingly difficult to include further expansion of the facilities. Efficient exploitation of the new wiggler will demand considerable floor area and this will only be possible if the wiggler is installed in the straight immediately upstream of the injection one: the implications of this choice are addressed in this paper.

2. Cryogenic Requirements

The existing superconducting wiggler runs from a large, closed circuit refrigeration system supplied by Sulzer with surplus capacity for a second wiggler. A two-stage compressor about 100 m from the storage ring feeds helium gas to a local cold box which liquefies it using heat exchangers, two high speed turbines and the usual J-T expansion valve. The system is fully computer controlled and automates the cool-down of the wiggler over 3-5 days, maintaining tolerable temperature differentials. A short (~ 10 m) helium transfer line connects to the magnet cryostat in the storage ring, which contains only about 30 ℓ of liquid helium.

Although the refrigerator has at least 30 W available for the new wiggler differences in magnet design philosophy have required careful assessment of operations with two wigglers at the same time. As will be described in the next section, in order to achieve the highest magnetic field level a low pressure (~ 2 bar) cryostat has a clear advantage, whereas the present wiggler operates at 3.8 bar during cool-down. To avoid excessively long cool-down the new magnet will therefore employ liquid nitrogen precooling and include the possible addition of liquid helium directly from a dewar where necessary. Use of a much larger helium volume will also give the second wiggler an attractive endurance, perhaps in excess of one week when not energised. Not only does this make it relatively immune from compressor trips but it gives time for liquid helium to be siphoned off before planned maintenance, or alternatively to be topped up when the refrigerator returns to its gas mode during cool-down of the first wiggler. It is hoped that simultaneous cool-down of the two magnets can be achieved in about seven days.

The large volume of helium in the new system makes it undesirable to invest in a recovery/storage system for helium gas as employed at present. In any event, the present wiggler has not quenched during its seven years of operation so a gas pressure surge seems unlikely. However the opportunity will be taken to replace the refrigerator control system by a more modern option. The new transfer line for the second wiggler will need to be routed to the opposite side of the storage ring, a distance of at least 35 m.

3. Wiggler Magnet Design

An outline design of the new wiggler has been carried out in order to confirm the feasibility of a 6T specification. Preliminary conclusions can be reported here but it should be noted that a final design has yet to be chosen. Conservative design criteria are preferred and, for example, it has been assumed that the Nb-Ti conductor will operate well below its notional rating. Warm bore operation has been selected to avoid complicated interaction with the adjacent storage ring UHV environment: with a beam-stay-clear vertical aperture of 34 mm the inter-coil gap is unlikely to be much less than 70 mm even in the absence of provision for in-situ bakeout of the beam chamber. Use of magnetic steel poles is therefore essential to achieve 6T on the beam centre line, and a return yoke is necessary both to enhance the useful field and to reduce unwanted leakage fields.

The preliminary design has been made with both 2D (PE2D) and 3D (TOSCA) electromagnetic design codes. The focusing effect of such a wiggler magnet depends on the second field integral[4], $\int B^2.dl$, but this can be adequately compensated by adjustment of other storage ring lattice magnets; a local compensation scheme has been adopted recently on the SRS to minimise the increase in vertical source size[5] and also has the advantage that the second wiggler effect no longer depends strongly on its exact location in the ring. However a serious effect remains in a lattice such as the SRS where no zero dispersion locations exist: the beam emittance is increased by the wiggler contribution to the third field integral, $\int |B|^3.dl$, in the storage ring[6]. To a good approximation the emittance change can be represented as follows in SRS-2:-

$$\varepsilon_x = \varepsilon_x^0 \left[\frac{1 + 0.03 \int |B|^3 .dl}{1 + 0.02 \int B^2 .dl} \right]$$

In the case of the existing 5T wiggler the measured field integrals were 4.4 T^2m and 14.1 T^3m and the above formula predicts an emittance of 1.4×10^{-7} m-rad, an increase of 34% which is in good agreement with the lattice computations[5]. Scaling these integrals to 6T operation would suggest an emittance blow-up of more than 60% due to the second wiggler alone and this is considered to be unacceptable. It is therefore very important to minimise $\int |B|^3 .dl$ in the new wiggler magnet and this will be achieved by adopting a short central pole together with end poles as long as can fit within the available space of a little over 1 metre. The resultant field distribution in one half of the magnet is illustrated in fig. 1, together with the existing wiggler for comparison; such a design should limit the emittance increase to about 50%.

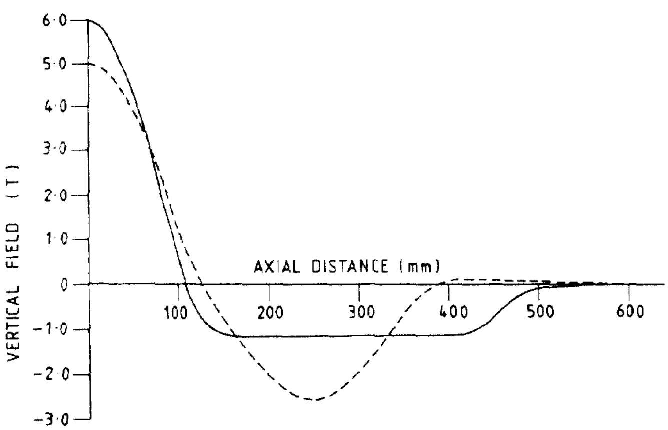

Fig. 1. Vertical field distribution on beam axis through half of wiggler magnet, for existing (5T) and proposed (6T) magnets.

The design example shown in fig. 1 is characterised by a major coil excitation on its centre pole with only a smaller trim coil being necessary on the end poles, about 5% of the ampere-turns assisting the production of the required 1T field level and ensuring a zero field integral through the magnet. The peak field on the central pole coils should be less than 7T, and these coils will probably adopt a graded current density mode of operation. The three-dimensional field studies suggest that a field integral homogeneity of about 0.5 mT-m should be attainable within the good beam aperture of ± 15 mm, leading to a transverse field harmonic error much smaller than the installed non-linear correction capability (for example, of the chromaticity correcting sextupoles).

In order to avoid the need for a water-cooled synchrotron radiation absorber within the wiggler a horizontal aperture of 160 mm has been selected for the beam pipe (the electron beam-stay-clear is 135 mm). The vertical attraction between the coils will be reacted by a stainless steel plate in the mid-plane whose thickness must be minimised at the beam centre line: however, its stiffness will be assisted by the coils themselves and the deflection should be acceptable with a steel thickness of 2-3 mm. Axial pre-stressing of the coils, probably using tie bolts, will also be necessary to overcome the axial magnetic forces of up to 1 MNm^{-1}.

4. SRS Modifications

The selection of a straight section so close to the SRS injection area has serious implications that will necessitate additional modifications. The radiation beam line must cross the injection transfer line from the booster synchrotron close to the storage ring. The UHV environment of the ring is at present protected by differential pumping stages and this isolation factor will reduce significantly when the new beam pipe is in place. At present it is hoped that it will not prove necessary to convert the whole transfer line to bakeable, UHV quality. However the opportunity will be taken to make a series of other improvements, such as a better beam position monitoring system.

There is a general problem that will also arise due to shortage of space. For example the septum pulsed power supply, located immediately adjacent to its magnet, will need to be made smaller and the septum drive mechanism may need to be modified for similar reasons. The problem is exaggerated by the need to accommodate the new high flux density station as close to the ring as possible. The proposed scheme has a shield wall very close to the ring components and careful design will be required to ensure acceptable access to this part of the storage ring. The existing labyrinth access to the ring tunnel will also have to be relocated.

Within the ring itself space for the new wiggler can only be found by removing some existing components. Each SRS straight has immovable upstream (D quadrupole and vertical steering magnet) and downstream (F quadrupole and multipole corrector) modules which leave little space for insertion devices. Furthermore this straight has one of the vacuum sector valves whose movement would have major consequences for the control system philosphy. The two components that can be more readily relocated are the beam scraper, that only needs shielding reinforcement wherever it goes, and the D sextupole, one of four used to control the SRS vertical chromaticity. The resultant space thereby made available is about 1.2 m, and it is within this allocation that the second wiggler is being designed.

Although mechanically easy, the sextupole magnet movement is causing some concern over its effect on the SRS beam properties. In a series of accelerator physics experiments in recent months it has been demonstrated that injection and subsequent accumulation of beam is very difficult if this magnet is shorted out. This investigation has been accompanied by dynamic aperture computations seeking to explain the poorer SRS performance. Figure 2 shows the results of some tracking calculations, illustrating a significant aperture reduction on breaking the four-fold symmetry of the sextupoles. The beam-stay-clear aperture at this location is ± 20 mm horizontally and ± 8 mm vertically. Replacement of the sextupole to a nearby straight achieves some advantage compared with a complete removal. It is already known[7] that the betatron tune working point in SRS-2 is sensitive to a number of resonance lines, for example the structure resonance $Q_R - 2Q_V = 0$, but the sextupole move results in beam loss on the following:

$$\begin{aligned} 3\,Q_R \qquad &= 19 \\ Q_R + 2\,Q_V &= 13 \\ Q_R - Q_V \quad &= 3 \\ 2Q_R - Q_V \;\; &= 9 \end{aligned}$$

This considerably reduces the available tune space and may well explain the experimental injection results. Theoretical and experimental studies are now receiving high priority in order to find the optimum solution to this problem.

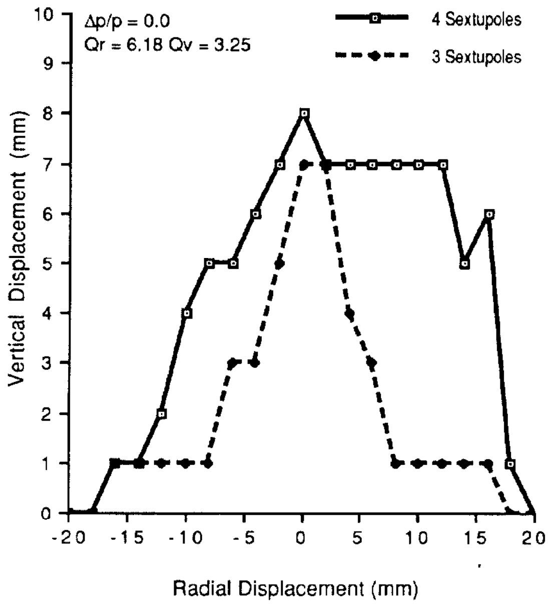

Fig. 2. Dynamic aperture comparison before and after sextupole magnet removal from one straight.

5. Conclusion

Design of the second superconducting wiggler magnet is now well advanced and it is planned to place a contract for manufacture later in the year. Preparations for the modifications to the storage ring and transfer line are also under way and detailed assessments of the implications for SRS performance are in progress. It is hoped to instal the new magnet in the second half of 1991.

Acknowledgements

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