Commissioning a Second Superconducting Wiggler in the Daresbury SRS

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Abstract

A second superconducting wiggler magnet has now been installed on the SRS at Daresbury. This three pole device generates a field of 6 T on the beam axis and greatly extends the range of useful synchrotron radiation on the light source. The magnet properties are briefly reviewed, together with the necessary and major modifications that have had to be made to the SRS to accomodate this powerful addition to the lattice. Initial commissioning trials in the Spring of 1993 are described and a comparison made with expected influence on the beam behaviour. Successful operation has been demonstrated, including simultaneous excitation with the earlier 5 T wiggler.

I. INTRODUCTION

Since 1982 a 5 T superconducting wavelength shifter (W1) has been an important operating feature on the 2 GeV electron storage ring at Daresbury. Because the SRS has a simple FODO lattice such an insertion device has an inevitable effect on the beam emittance in addition to a significant vertical tune shift. Predicted and measured effects were compared in an earlier paper [1] and a method of focussing compensation using an active current shunt on an adjacent quadrupole has also been described [2].

Following this success in extending the available range of photon energies a second wiggler project was initiated and the outline design has been presented [3]. The magnet (W2) was specified to have a field strength of 6 T and to provide a usable radiation fan of 50 mrad to five experimental stations on a new beam line. Extrapolation of the 5 T design to the higher field suggested an unacceptable increase in source dimensions and so a new design was pursued in order to minimise the emittance blow up, particularly since the two superconducting devices were required to operate simultaneously.

II. SRS MODIFICATIONS

The SRS has been operated for users since 1981 and a large number of its sixteen bending magnets are now being exploited for beam lines. Few straight sections of the FODO lattice remain empty and the experimental area around the ring is also very congested. This has forced the selection of a straight immediately upstream of the injection area and the resultant beam line from the new wiggler must therefore cross the transfer line from the booster synchrotron injector. The septum magnet power supply has had to be relocated to avoid the emerging radiation beam and the opportunity has also been taken to redesign the septum itself.

In order to provide sufficient space for a realistic wiggler design it has been necessary to remove components from the straight and the most important is one of the four D-sextupoles used for chromaticity correction. Unfortunately both numerical simulations and subsequent experiments have confirmed that a breach of the present four-fold symmetry cannot be permitted since the dynamic aperture collapses [4]. This behaviour is due to the influence of resonance lines up to at least fifth order.

All four sextupoles have therefore been moved by one straight and this has only been made possible by a complete redesign of the injection kickers to make room in their straight sections. Together with a series of other major changes this necessitated a long shutdown of several months duration and the SRS did not return to full operational status until the second half of 1992. Following cryogenic commissioning the first tests of the new wiggler with beam became possible in the early part of this year.

III. WIGGLER MAGNET DETAILS

A contract for the detailed design and construction [5] of the superconducting magnet was placed with Oxford Instruments. The specification was based on a conservative design philosophy that would guarantee performance, with a warm bore avoiding unnecessary complications at the interface with adjoining UHV vessels. Use of magnetic steel poles generates additional field and also assists in reacting against the large forces arising from the central pole coils. These main coils are a racetrack geometry wound from rectangular Nb-Ti conductor and have a graded current density over three sections to exploit the varying field across them. The chosen coil design ensures that a comfortable calculated temperature margin of about 2 K exists. The main coil power supply needs to be rated to 700 A but an 80 A supply is more than sufficient for trim purposes on the small coils around the end poles.

The magnet has a relatively short central pole, sufficient only to provide the required field level over about 70 mm of beam orbit, but in contrast the end poles have been stretched to the maximum permitted by the available overall length in the straight of just over 1 m. The reason for this geometry is to reduce the cubic field integral, a requirement explained in the next section.

The cryogenic design is quite conventional and includes a nitrogen screen. There is provision for *in situ* bakeout of the beam pipe to 150 °C. The normal mode of operation is to provide liquid helium from a closed cycle refrigerator that also drives the first wiggler, but it is also possible to bulk fill if this supply is interrupted. The current leads are a major source of heat leakage, but despite this the helium usage is less than 5 liquid litres per hour even at 6 T and the magnet endurance exceeds 20 hours.

The magnetic field specification is an onerous one. The quadratic field integral must not exceed 5.5 T^2-m and the (modular) cubic one must be less than 22 T^3-m. A first integral of 0.04 mT-m ensures an acceptably small closed orbit ripple but this can only be achieved by feeding a small trim coil on the end poles from a separate supply. Because the SRS is injected at a lower energy of 600 MeV the residual integral with the magnet switched off must be even smaller and the anticipated remanent level of over 1 mT-m will need to be corrected or removed.

Even the measurement of such small terms is a considerable challenge : for example the dipole field integral at full excitation is less than 3×10^{-5} of the modular one. An accurate rotating coil system was developed by the manufacturer and this could also be scanned laterally to monitor the transverse harmonics. These measurements confirmed that the magnet did meet its design specification at all field levels, although the resultant trim currents unexpectedly demanded a bipolar power supply. Supplementary data from a Hall plate gave measured second and third integrals of 4.8 T^2-m and 20 T^3-m.

IV. BEAM STUDIES

The initial trials before delivery had demonstrated excellent training with a first quench at 4.8 T and only three more to reach full field; high ramp rate tests thereafter only induced one further quench (at 6.1 T). After its delivery to Daresbury the magnet was set up in a temporary position outside the ring tunnel and briefly energised to full field to confirm there had been no transit damage. No quenches have been experienced in the ring and beam tests were able to commence once power supply checks had been completed.

A first trial at 600 MeV with the coil excitations set to values established during the magnet measurements showed beam loss due to horizontal orbit movements even at fields below 0.5 T and the trim was therefore adjusted empirically. At higher field levels there was good agreement and it seems that this minor discrepancy might have been associated with remanent field behaviour. With optimised trim settings resultant rms orbit displacements below 0.2 mm could easily be achieved up to the full 6 T. However with the magnet switched off orbit variations of up to 1 mm were in evidence, but these remanence effects have been readily compensated by small changes to the injection orbit steers. An alternative is to remove the unwanted field and suitable techniques have been established, employing either a proven degaussing cycle or a bucking current in the trim coils.

Initially the tune shift was corrected by a global change to the D-quadrupole family and routine 6 T operation was then established. It has previously been confirmed that for lattice calculations a three pole wiggler can be accurately simulated by a hard edge model [1] if the appropriate field integrals are used, with measured and predicted tune shifts on the first 5 T wiggler in excellent agreement [2]. Table 1 summarises the more important parameter changes caused by both the old and the new wigglers and it can be seen that the tune shifts are almost equal despite the increase of field to 6 T. All of the data

is for the present SRS working point (Q_r = 6.15, Q_v = 3.35) and the W1 shift is therefore somewhat greater than reported in reference [1].

Table 1

Calculated SRS Parameters at 2 GeV

	W1/W2 Off	W1 On	W2 On	W1/W2 On
Vertical tune shift		0.06	0.062	
Max. vert. beta (m)	11.7	12.5	12.7	13.8
Hor. damp. time (ms)	5.3	4.9	4.8	4.5
Energy spread (10^{-4})	7.2	7.6	7.9	8.2
Hor. emittance (nm-rad)	105	134	155	186
Overvoltage (Tq = 100 h)	2.73	2.80	2.88	2.90

With global correction there remains a very strong beta beating with increases up to 40 % but the data in Table 1 assumes the use of the local quadrupole shunt correction scheme which leaves only a small ripple. Identical active shunt designs can be used for each wiggler and these are rated well above the predicted requirement of about 55 A. The measured vertical tune shift is presented in Figure 1 and does exhibit the expected quadratic dependence on wiggler field level. However the best fit to this data has a coefficient about 20 % below the computed value so that clearly the model is inaccurate, a surprising result in view of the success of a similar model with the first wiggler.
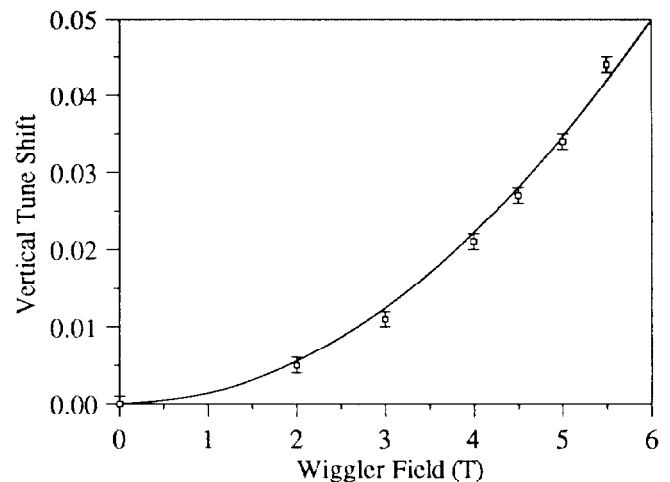

Figure 1. Measured variation of vertical tune with wiggler excitation, with best quadratic fit.

Preliminary checks of the beta modulation confirm that the residual ripple after compensation is less than 10 % but it is known that the SRS does have unexpected beta variations

from cell to cell that might explain the discrepancy. A secondary check is to examine the experimental values of quadrupole shunt current and these are plotted in Figure 2.
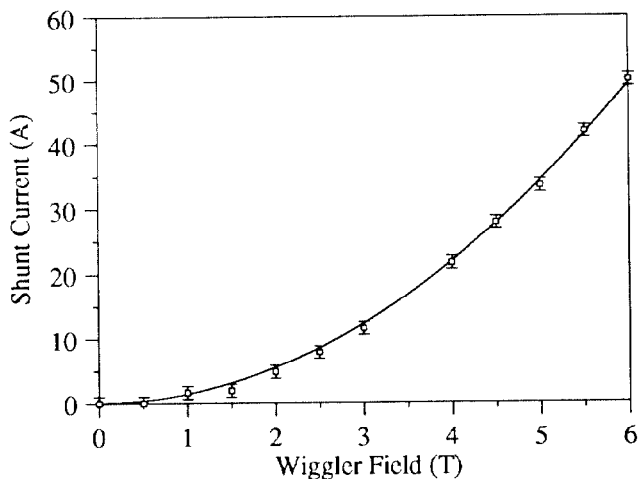

Figure 2. Best quadratic fit to values of D-quadrupole shunt current for fixed vertical tune with wiggler excitation.

These shunt values hold the tune steady to better than 0.002 and exhibit the correct functional dependence. Moreover the figure of 50 A at 6 T is to be compared with a prediction of 56 A, a difference of about 10 % in the demanded 1.36 T/m gradient reduction of the D-quadrupole in the wiggler straight. This suggests that at least half of the difference between the actual tune shift of 0.050 and the computed value of 0.062 is due to an overall reduction of the beta at the locations of both the wiggler and the quadrupole, with the remainder perhaps arising from a difference in their relative betas.

The finite dispersion of the SRS lattice at the location of the wiggler implies that there will be an inevitable emittance increase when the magnet is energised, to first order proportional to the cubic field integral [3]. As shown in Table 1 the horizontal emittance is expected to grow by almost 50 % for the measured $\int |B|^3.dl$ of 20 T^3-m. This would produce a noticable increase of the source dimensions and in the vertical plane the beta variation is also important. Such effects, but with a smaller emittance change, have previously been encountered on the first wiggler [6] and that magnet also appeared to induce a reduced overall coupling between the planes. For the new wiggler few measurements have yet been taken but there does seem to be negligible change of vertical source dimensions. The magnitude of the horizontal blowup (10 %) is similar but more linear with field than on the first device.

The additional radiation loss of 24 keV per turn from the second wiggler, together with the need for a higher overvoltage factor, demands a 25 % enhancement of the rf power delivered to the accelerating cavities but this is well within the capacity of the installed system. Other implications, such as reduced damping times and bunch length, are too small to be noteworthy. Finally it can be reported that during the last period of tests both wigglers were energised simultaneously and their tune shifts fully compensated. As anticipated from Table 1 the horizontal source dimensions then increased significantly, but no unexpected beam effects were encountered.

V. CONCLUSIONS

A 6 T superconducting wiggler magnet has been successfully designed, constructed and installed in the SRS. Its field properties have been carefully measured to high accuracy and lattice simulations have been compared with recent operating experience.

This second wiggler can now be used routinely with high current beams and few commissioning tasks remain. The only significant anomaly so far discovered is a vertical betatron tune shift much smaller than expected, probably due to a non-ideal beta function distribution around the storage ring. Following planned commissioning of the port and beam line scheduled user beams will commence in August 1993 when the SRS will become the first light source with two such insertion devices.

VI. REFERENCES

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