

# Update on Commissioning and Operations with the Second Superconducting Wiggler at Daresbury

J A Clarke, D M Dykes, S F Hill, E A Hughes, P A McIntosh, M W Poole, P D Quinn, S L Smith, V P Suller and L A Welbourne

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

## Abstract

A 6 T superconducting wiggler magnet has been added to the Daresbury SRS in order to extend the useful spectral range for synchrotron radiation users. Commissioning of this powerful magnet in the storage ring commenced during 1993 with the study of its interaction with the electron beam and was followed by the successful opening of the beam line port. The paper briefly reviews the wiggler design and presents details of these commissioning experiments, including comparisons with modelling studies of the electron dynamics. Finally the operational status of the new facility will be summarised.

## 1. INTRODUCTION

A second superconducting wiggler has now been added to the SRS at Daresbury, marking the culmination of the last major expected upgrade of this source [1]. As a second generation light source it has a FODO lattice structure that is not well suited to accepting powerful insertion devices in its straight sections, which are also rather short. However provision of the 6 T field together with a 2 GeV electron beam produces a hard radiation spectrum with a critical energy of about 15 keV, extending the range of hard x-rays available to SRS users into the vital region from 10-50 keV as is shown in figure 1.

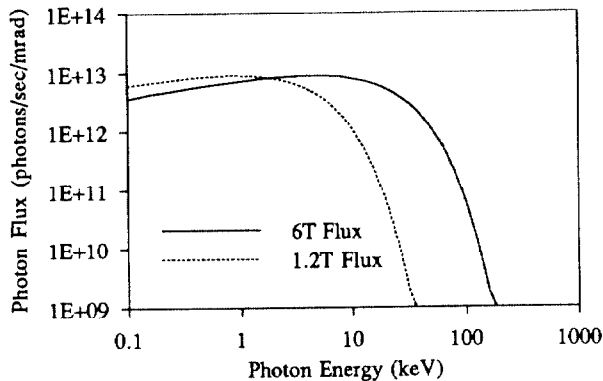


Figure 1. Flux from a bending magnet and the wiggler

This is a major enhancement of the source specification that justifies the extensive changes necessary to the ring layout. In particular the chosen straight immediately adjacent to the injection area required a redesigned transfer line from the booster synchrotron injector and the relocation of a complete family of chromatic sextupoles in the ring in order to preserve

the dynamic aperture [2]. These major changes were carried out in 1992 but the new wiggler was not energised until early in 1993. The construction and commissioning of a new beam line and its five experimental stations has also proceeded and scheduled usage is now commencing.

The SRS has been reoptimised for the simultaneous presence of both a 5 T and 6 T wiggler and has been scheduled for operation in this way every day for more than six months, gaining valuable experience not only of the ring behaviour but also of the magnet and its cryogenic systems.

## 2. WIGGLER MAGNET

The detailed design specification called for a magnet supplying a 6 T field on a central pole and generating useful radiation flux over a 50 mrad fan (a path length of 70 mm). Two end poles of opposite polarity ensure that the resulting large orbit displacement of 15 mm is localised, although to achieve an acceptable residual ripple around the remainder of the ring (specified as an overall field integral of less than 0.04 mT-m) a trim coil has been added to these end poles. The higher order field integrals are just as important and the quadratic one, which provides a beam focussing term in the vertical plane, was specified not to exceed 5.5 T<sup>2</sup>-m in order to restrict the betatron tune change to the same magnitude as had been successfully corrected for the first (5 T) wiggler [3]. In the SRS lattice the radiation emission in the wiggler leads to an inevitable emittance increase that is proportional to the modulus of the cubic field integral. This term can be minimised by employing a short central pole but extending the end poles as far as possible, with a consequent lowering of their fields. In practice this is restricted by an available space in the SRS of little more than 1 m and this sets an integral specification of 22 T<sup>3</sup>-m.

The wiggler was manufactured and tested under contract by Oxford Instruments [4]. It includes steel poles both to enhance the field strength and to balance the forces and it has a warm bore chamber. The Nb-Ti coils have a simple racetrack geometry, segmented to allow current density optimisation. The trim coil on the end poles is also superconducting. The magnet must meet its performance specification over the full field range from 0-6 T since it must be energised after storage of the electron beam has been completed.

The wiggler cryostat is fed from a cryogenic supply [5] that is shared with the first Daresbury wiggler, a 5 T device that has been operated since 1982. The large cryoplant supplies compressed helium to turbines and an expansion valve, ensuring a continuous supply of liquid helium in a coldbox from which it is syphoned to each magnet through coaxial transfer lines. This is a closed cycle system although the

magnet can also be filled directly from dewars in an emergency and has been designed with a long endurance for this eventuality.

### 3. INITIAL COMMISSIONING

The magnet had been thoroughly tested by the manufacturer before delivery and therefore only needed confirmation of no transit damage before it was installed. Cryogenics commissioning has included the establishment of a fully automated cool-down from ambient to 4 K, a complex operation when it is recalled that both wigglers are involved. The initial checks with beam have already been reported [6] and concentrated on establishing conditions that permitted the magnet to be energised at progressively higher levels whilst minimising the effect on the circulating beam. This required an optimisation at 0.5 T intervals in order to avoid beam losses during the slow ramp (7 minutes) to maximum strength. The trim coils easily achieved orbit ripple control to less than 0.5 mm and the new dynamic shunt [3,6] on the adjacent D-quadrupole also worked well for tune compensation.

### 4. ORBIT CONTROL

The wiggler ramp takes several minutes and it is therefore possible to monitor and to control the SRS orbit in both planes whilst this takes place. In the horizontal case it is necessary to compensate two large, opposite polarity field integrals ( $> 1 \text{ T}\cdot\text{m}$ ) to an accuracy of about 1 part in  $10^4$  if the effect of the wiggler being energised is to be negligible. This is able to be achieved at any fixed wiggler field level but it has been observed that during the magnet ramp the compensation cannot be maintained and the orbit can move by several millimetres at some ring locations. Fortunately this does not lead to operational problems with the 2 GeV beam. Under user conditions it has been confirmed that essentially perfect compensation can be achieved since the wiggler is always operated at its full field strength of 6 T.

In an ideal situation the wiggler should have no effect on the vertical orbit but in practice any misalignment can lead to undesirable orbit movements. The displacement introduced at each of the ring beam monitors as the field strength of the wiggler is progressively increased has been found to increase monotonically, preserving the same orbit pattern. The rms value of this distribution is plotted in figure 2.

These orbit errors have been removed by application of the on-line program CORRECT that can select best correctors for SRS orbit control, based on a process of minimising the squares of the residuals. The program predicts that a single vertical steering magnet adjacent to the wiggler can reduce the rms from 0.9 mm to 0.2 mm by a setting giving 11.6 mT·m. Although this orbit displacement might in principle have arisen from a rotation of little more than 1 mrad in the wiggler the data in figure 2 is a good fit to a quadratic function, implying that the source of the error is in fact a vertical height offset of the magnet of nearly 2 mm. This is a surprising result but it is now difficult to confirm by a direct physical survey check because of the amount of lead shielding necessary around the wiggler.

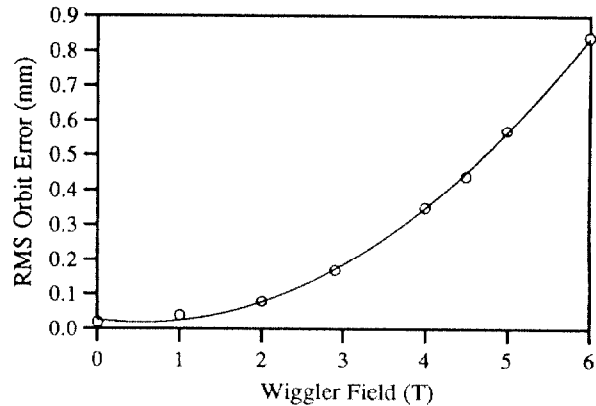


Figure 2. Rms vertical orbit dependence on wiggler field

### 5. TUNE SHIFT COMPENSATION

Any planar periodic magnet has a focussing action in the direction orthogonal to its median plane. The predicted vertical tune shift for the new wiggler is 0.062. In order to avoid a strong residual beta beating (40%) associated with a global correction of this tune shift, a dynamic shunt is placed across the nearest D-quadrupole to the wiggler [3]. At the maximum field level this diverts 52 A from the quadrupole windings and allows the tune to be held constant to about 0.002. Despite the large tune shift it has been possible to maintain a circulating beam without the shunt and the direct effect of wiggler excitation is shown in figure 3. The figure exhibits the expected quadratic dependence and it also includes the predicted shifts based on a careful lattice modelling. The measured figures are about 6% less than expected, a discrepancy that is presumed due to non-ideal lattice functions. Previously reported [6] larger differences have not been confirmed by more comprehensive checks and the required shunt settings are also found to have a similar reduction from those calculated (56 A).

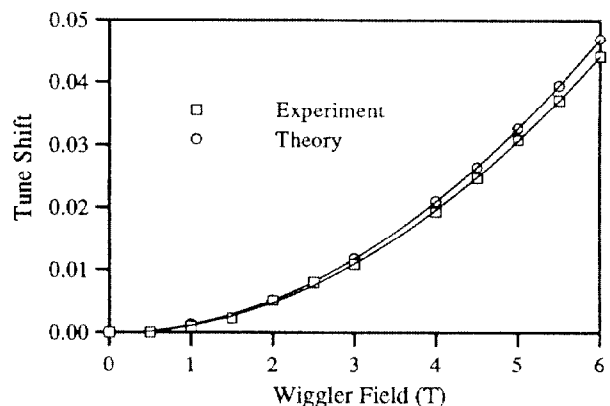


Figure 3. Vertical tune shift from wiggler excitation

The shunt can also be used to confirm the value of the vertical beta function at that quadrupole. A measured tune slope of 0.001 per shunted ampere is equivalent to a beta of

10.9 m, which is to be compared with the computed value of 10.3 m. This implies that the beta in the wiggler straight is not less than expected and hence this is not a likely explanation for a lower than anticipated tune shift.

## 6. EMITTANCE CHANGES

Despite efforts to optimise the wiggler design a substantial cubic integral of  $20 \text{ T}^3\text{-m}$  has been unavoidable and leads to an expected emittance increase of about 50 %, an unfortunate penalty for inclusion of a strong insertion device in a finite dispersion location. As a result with both superconducting wigglers energised the SRS emittance is calculated to increase by up to 80 % with a corresponding reduction in source brilliance for all users. The vertical source dimensions will also be affected by the remaining (small) beta variations in that plane as even the shunt system is not a perfect solution. It is also possible that the wiggler will change the emittance coupling.

The beam profile has been accurately measured at a number of wiggler field levels and does not produce the expected result. At the normal multibunch working point (6.19,3.36) and with 50 mA current a 10 % increase in horizontal size was recorded, less than half the anticipated variation. Vertically the size was observed to actually decrease, although by such a small amount as to be explained by a small coupling change. A new check on the effect of the other superconducting wiggler exhibited much better agreement, to about 10 % in dimensions, based on an identical modelling procedure.

In an attempt to resolve this issue the experiment was repeated for a similar beam current at a very different working point (4.22,3.27) which is also used operationally for single bunch running. The results are shown in figure 4, together with the modelled prediction, and a significant discrepancy can again be seen under these quite different lattice conditions. The vertical size also showed a small increase that again is difficult to model because of its sensitivity to coupling.

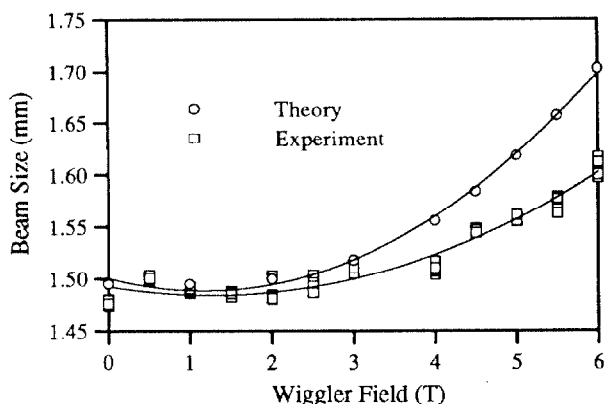


Figure 4. Horizontal beam size dependence on wiggler field

Together with the tune shift results already discussed the beam size data confirms that an improved model for the addition of this wiggler to the SRS lattice is needed, despite previous success with the first superconducting magnet.

## 7. PROJECT STATUS

Commissioning of this second superconducting wiggler has now been successfully completed and an SRS operating regime for its routine use established. Orbit and betatron tune shift effects have been compensated and the effect of the wiggler on beam dimensions shown to be less than expected. Further studies to understand this small but welcome discrepancy are still in progress.

An efficient strategy for energising both wigglers has been adopted. To obtain the highest operational SRS efficiencies requires the refill time to be minimised. To assist this it has been possible to link the field ramps of the two superconducting wigglers, making simultaneous adjustments to the orbit and tune compensations. Such dual ramping is now a standard feature on the SRS, saving about six minutes on each fill.

The front end engineering for the new beamline was completed in mid-1993 and the port was then opened for initial alignment and radiation shielding checks. The first experimental station was commissioned before the end of the year and recently was able to take real diffraction data on muscle tissue. This has confirmed that a resolution of 3 Å can be attained, almost one order of magnitude improvement on previous SRS capabilities and allowing atomic resolution studies to be undertaken in this important research area. The remaining stations will be commissioned over the next few months and by 1995 the SRS will have a source of hard x-ray radiation that extends its competitiveness by many years.

## 8. REFERENCES

- [1] M W Poole et al, "A Second Superconducting Wiggler Magnet for the Daresbury SRS", in Proc IEEE Part Accel Conf, Chicago, 1989, Vol 2, p 1250.
- [2] M W Poole et al, "Dynamic Aperture, Tune Space Characteristics and Sextupole Distribution in the Daresbury SRS", in Proc Euro Part Accel Conf, Nice 1990, p 1533.
- [3] M W Poole et al, "Wiggler Tune Shift Compensation on the Daresbury SRS", in Proc IEEE Part Accel Conf, Chicago 1989, p 208.
- [4] J S H Ross and K D Smith, "Design and Manufacture of a 6 T Wiggler Magnet for the Daresbury SRS", Rev Sci Instr, Vol 63(1), (Part IIa), p 309, 1992.
- [5] M T Heron et al, "A Common Cryogenics System for Two Superconducting Wigglers on the Daresbury SRS", in these Proceedings.
- [6] M W Poole et al, "Commissioning a Second Superconducting Wiggler in the Daresbury SRS", in Proc IEEE Part Accel Conf, Washington 1993, p 1638.