AN UNDULATOR SOURCE FOR THE SRS AT DARESBURY

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A 1 m long undulator magnet has been installed in the SRS 2 GeV electron storage ring. The results of magnetic tests on the permanent magnet system are presented and the observed effects on the electron beam are discussed. Studies of the visible radiation produced by the device have commenced and initial results are described.

Introduction

An undulator radiation source was installed in the Daresbury SRS during 1984 and an associated beam line for its utilisation is now under construction. The source has been optimised for output in the soft x-ray region (10-100 Å) and planned initial experiments will exploit this for microscopy purposes, commencing in 1986. At present the influence of the undulator magnet on storage ring performance is being studied and the output radiation properties will be measured in a diagnostic facility separated from the user beam line.

Design Features

The space in the SRS for installation of additional components is severely limited, but by removal of a beam position indicator a length slightly in excess of 1 metre has been made available. With a vertical beam aperture of 30 mm and suitable allocations for the vacuum vessel a minimum undulator gap of 42 mm was defined. A conventional permanent magnet periodic structure[1] has been chosen, see fig.1. The performance of such systems has been described previously[2-4]. The magnet parameters were selected after careful assessment of their effect on the radiation properties[5], taking account of the relatively large electron beam emittance in the SRS, which substantially smears out the interference effects.

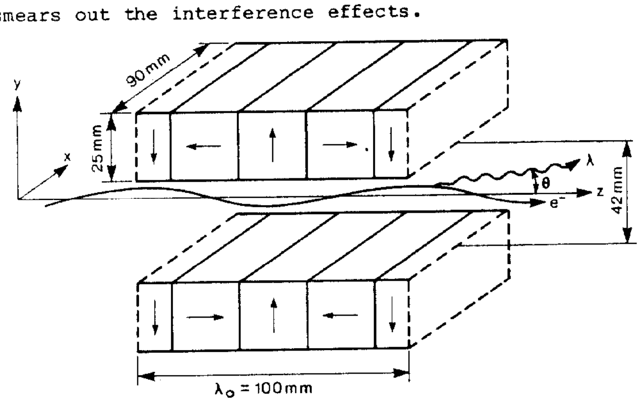

Figure 1. SRS undulator magnet geometry.

A magnet period of 100 mm allows the radiation brightness to be broadly optimised over the full range 10-100 Å at an electron energy of 2 GeV and also permits visible radiation to be emitted on axis at the lowest conceivable SRS operating energy of 450 MeV, a valuable feature for alignment and other diagnostic purposes. The detailed magnet design considerations have been reported elsewhere[3] and will only be briefly summarised here. The samarium cobalt block dimensions ($90 \times 25 \times 25$ mm^3) were determined to give the required peak field on axis and a transverse field homogeneity avoiding significant radiation line broadening. The magnet end design adopts half length blocks to achieve minimal net beam displacement and divergence arising from integral field errors. With ten periods the overall magnet length is 1 metre.

The magnet block material, Hitachi Hicorex 22A, was chosen to meet the required remanent field strength. Every block was physically and magnetically checked[3] and the mean magnetisation strength (main component) was 0.924 T, with a spread of 2.5%, half that guaranteed by the manufacturer. Such errors were sufficiently small to allow assembly into arrays in random order. Blocks were bonded into individual stainless steel holders to provide a modular system and the two arrays mounted on lead screws to permit gap variation over the range 42-100 mm; in addition the whole magnet can be completely withdrawn 300 mm from the storage ring vacuum vessel to confirm any effects on the circulating electron beam. Figure 2 shows the magnet in place in the storage ring.

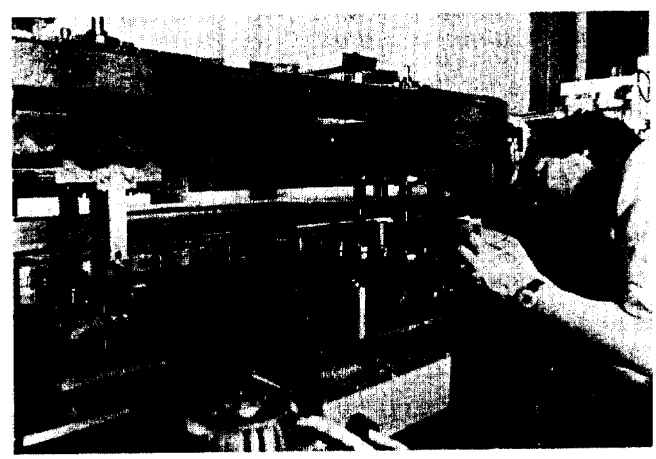

Figure 2. The undulator installed in the storage ring.

A new vacuum vessel with a spout to allow the undulator radiation to emerge has also been installed, together with a port and its associated valves, absorbers and other UHV equipment. An important feature of the beam line is the retractable mirror that can be used to deflect long wavelength radiation at 90° through a fused silica or sapphire window onto the roof of the storage ring shielding enclosure for diagnostic purposes. The high power in the undulator beam (up to 100W) necessitates interlock protection to avoid exposing the mirror to such damaging radiation above the SRS injection level of 600 MeV. The diagnostic facility has allowed an extensive programme of investigations to be initiated, including spectral and angular distribution studies.

Magnetic Field Measurements

A series of measurements of the vertical component of magnetic field has been carried out on the magnet at various gap settings using a Hall plate system. Primarily this consisted of a detailed measurement of the distribution along the length of the undulator (50 points/period) and through the fringe field. The result for 42 mm gap is shown in fig.3. Various quantities were derived from this data. The

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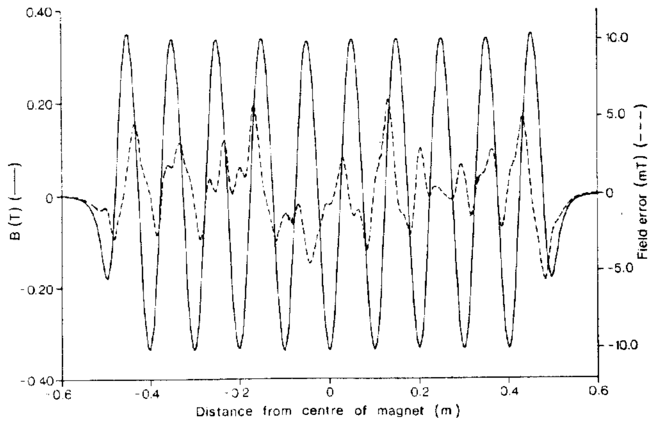

Figure 3. Comparison of measured and computed field distributions.

average magnetic periodicity of 100.5 mm was determined by accurately locating the peak field and zero crossing points. The average peak field value, B_o, and rms spread in peak field, $\Delta B/B_o$, were calculated for the central 6 periods, to eliminate end effects, and the results for various gaps are presented in Table 1. The corresponding K value is also given. A least squares fit indicates that the variation of peak field with gap is accurately represented by an exponential, as expected, with a coefficient of 3.27% mm^{-1}, close to the ideal 2D result of π/λ_o = 3.13% mm^{-1}. By comparison of these values with the results of a 3D magnetic field computation[6] for an ideal undulator it was deduced that the effective remanent field of the material was 0.907 T, lower than the result produced by measurement of the individual blocks (0.924 T)[3]. This could be due to the finite permeability of the stainless steel holders or irreversible losses due to the increase in temperature during the process of bonding the blocks into their holders. Figure 3 also shows the difference between the measured field values and those computed with B_r = 0.907 T. The maximum error is about 1.8% of the field amplitude. Values of the field integral are also given in the table, and it can be seen that they are close to zero. The residual value contains contributions from the earth's field as well as Hall plate calibration errors. The values indicate that at 600 MeV the undulator should introduce at most a 0.09 mrad angular change. The electron trajectory has also been calculated and at most a 0.03 mm position error would be introduced.

Measurements of the transverse field distributions have also been made. Figures 4 and 5 show the field variation in the x and y directions respectively at the centre of the magnet. For comparison the results of 3D magnetic field computations are also shown and it can be seen that the agreement is very good. The quadratic variation of field near the origin

Table 1. Summary of magnetic measurements on the undulator.

Gap (mm)	B_o (T)	K	$\Delta B/B_o$ (%)	$\int B_y dz$ (Tm)$\times 10^{-4}$	a_x (%mm^{-2})	a_y (%mm^{-2})
42	0.33676	3.160	0.48	1.75	0.011	0.204
50	0.26100	2.449	0.49	1.74	0.013	0.207
60	0.18778	1.762	0.56	1.19	0.016	0.210
70	0.13512	1.268	0.65	1.05	0.018	0.214
80	0.09727	0.913	0.78	0.82	0.020	0.214
90	0.07031	0.660	0.94	0.95	0.021	0.218
100	0.05054	0.474	1.11	0.93	0.022	0.222

can be described by coefficients a_x and a_y. Table 1 gives values of these quantities as a function of gap setting. Both agree very well with the expected results. The value of a_x is small, being mainly determined by the block width, and a_y is close to the theoretical 2D result: $2(\pi/\lambda_o)^2$ = 0.195% mm^{-2}.

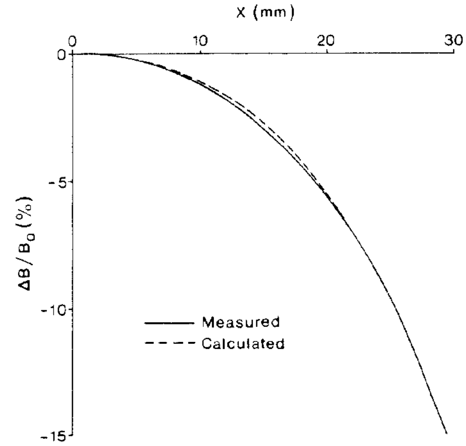

Figure 4. Field distribution in the horizontal direction

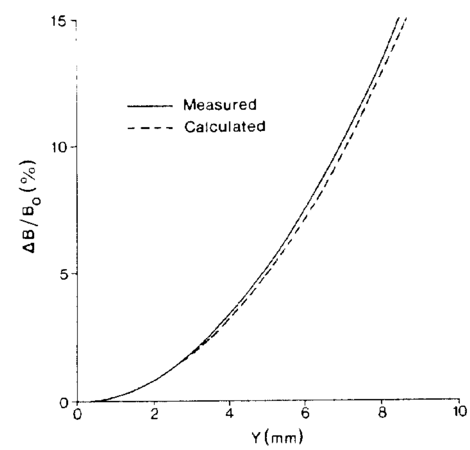

Figure 5. Field distribution in the vertical direction.

Undulator Performance

Effects on the electron beam

The most immediately noticeable feature of setting the undulator to minimum gap was the dramatic reduction in injection efficiency. The stacking rate dropped by about a factor of 7. Measurement of the betatron tune (Q) values showed that there was a change of ΔQ_R = -0.0090 ± 0.0008 and ΔQ_V = +0.0086 ± 0.0008. Although small it was known that the injection performance was critically dependent on the Q values and indeed resetting to the standard values improved the rate by roughly a factor of 2. No deviation of the closed orbit was detected to an accuracy of about 0.2 mm. Later observations of the undulator radiation revealed that the electron beam was not passing through the magnet at the correct angle and when corrected using a steering bump it was found that the stacking rate improved by a further factor of 2. There remains however a final factor of 1.5 which has not yet been recovered.

The measured Q shift is larger than expected. Ideally, for a perfect 2D magnet, $\Delta Q_R = 0$ and

$$\Delta Q_v = \frac{\beta_v}{4\pi}\left(\frac{0.3}{E_{GeV}}\right)^2 \int B_y{}^2 dl$$

In this case $\beta_v = 4.8$ m, $\int B_y{}^2 dl = 0.0567$ which results in a value $\Delta Q_v = 0.0054$. The measured vertical tune shift is therefore somewhat larger than expected, but the main discrepancy is the horizontal shift. The largest known contributing factor is that resulting from the quadratic field variation in the x direction which produces a shift

$$\Delta Q_r = \frac{\beta_r}{4\pi}\left(\frac{K}{\gamma}\right)^2 a_x L = 0.0011$$

where L is the magnet length. This is much smaller and of the opposite sign to that observed. No explanation of the effect can therefore be given at present.

In SPEAR a resonance was detected with their undulator in place[7] when: $3Q_x + Q_y = 21$. A careful search was made in this case for a similar resonance at: $2Q_x + 2Q_y = 11$, but nothing was observed at this setting.

Observation of Undulator Radiation

Direct visual observations of the radiation produced by the undulator have been made at 8 m from the source point after reflection through 90° out of the storage ring tunnel. Theory predicts that at injection energy (605 MeV) and minimum gap (K = 3.16) the central wavelength of the first harmonic is 2148 Å and that visible radiation should be produced between $\gamma\theta = 2.3$ and 3.7 in the first harmonic and between $\gamma\theta = 4.0$ and 5.7 in the second. Both harmonics were clearly seen within the available aperture (± 5 mrad). The pattern was not circularly symmetric but elongated horizontally and indistinct along the horizontal axis, probably because of the much greater electron beam divergence in this plane compared to the vertical. In the vertical direction however there was good agreement between the measured positions of the coloured bands and theory. The electron beam has also been decelerated, to the minimum energy imposed by power supply restrictions of 455 MeV, and the coloured rings were observed to shrink in size by the expected amount.

A smaller circular pattern has also been seen within the undulator radiation pattern. This has been identified as due to interference between the radiation emitted by the edges of the main dipole magnets on either side of the undulator, as evidenced by the fact that the pattern remains when the undulator is removed. Such an effect has been reported by Nikitin[8] and has also been observed by Kitamura et al[9]. Theory predicts that a fringe pattern is produced with intensity maxima at wavelength λ given by

$$\frac{D}{2\gamma^2\lambda}\left(1 + \gamma^2\theta^2\right) = \text{positive integer}$$

where D is the straight section length. In this case the pattern is indistinct since several harmonics overlap at any given angle. It was found that the undulator and dipole radiation patterns could be moved relative to each other using a steering bump. Figure 6 shows a photograph of the radiation produced at maximum gap (K = 0.47) and in this case the first harmonic undulator radiation (on the left) has been deliberately offset from the dipole radiation (on the right). Optimum beam stacking in the storage ring has however been shown to require mutual alignment of these two outputs. There has been some evidence also of undulator-dipole interference effects.

The radiation has also been viewed through a polarizing filter. With the filter set to transmit vertically polarized radiation a black band was seen along the horizontal axis, due to the usual high degree of polarization of synchrotron radiation in the orbit plane, and there was some minimisation of intensity of the first harmonic along the vertical axis also, in agreement with theory[10].

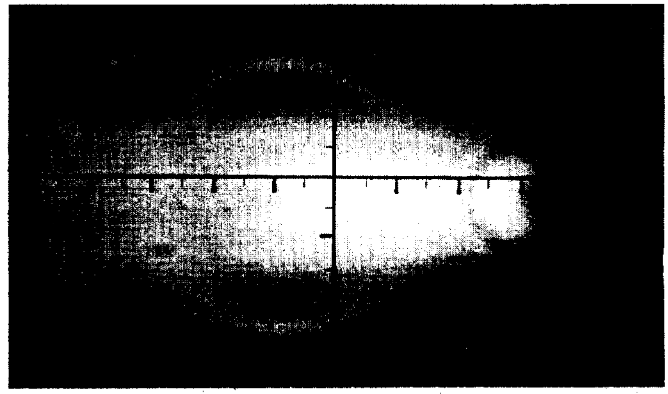

Figure 6. Undulator radiation, E = 605 MeV, K = 0.47.

Conclusion

Magnetic measurements on the undulator showed that its properties were very similar to those expected. Some unexpected effects on the electron beam have been observed, however these are sufficiently small not to result in operational difficulties. Visible radiation produced by the undulator has been observed and found to be in general agreement with theory. More detailed studies of spectral linewidths and angular distributions will commence shortly.

Acknowledgements

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