PERFORMANCE OF THE DARESBURY SRS WITH AN INCREASED BRILLIANCE OPTIC

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Following a five month shutdown for major modifications the Daresbury Synchrotron Radiation Source (SRS) now operates with a much reduced emittance. This is achieved by the addition of extra quadrupoles which double the number of FODO lattice cells. Other changes include additional correction magnets and major revisions to the vacuum system. Recommissioning started in March '87 and scheduled operation resumed in June '87 with beams of 75 mA at 2 GeV. After a year of scheduled operations the standard operating current had been increased to over 200 mA with 25 hour beam lifetime. Measurements of source dimensions confirm that the expected emittance reduction has been achieved.

Introduction

The SRS was designed in 1975 as the first dedicated x-ray source of synchrotron radiation. It used a simple but flexible FODO lattice which permitted easy physical access to the synchrotron radiation. The horizontal electron beam emittance at the normal working energy of 2 GeV was relatively large at $1.5\ 10^{-6}$ m.rads, but low coupling of less than 1% gave a reasonably high brilliance in the vertical plane. The majority of radiation experiments used this to advantage by dispersing in the vertical plane.

Once the SRS was operational in 1981 consideration was given to increasing the radiation brilliance through reducing the electron beam emittance by means of a suitable modification to the lattice. Several schemes were studied but the overall constraint was that the dipole magnets and their attached beam lines must remain unaltered. The scheme finally selected was again a FODO structure but with the unit cell number increased from 8 to 16. This had the advantage of allowing much of the equipment in the straight sections, such as injection and rf equipment, to remain unchanged, but still gave over a factor of 10 reduction in emittance. A description of the proposal has been given by Saxon[1] and final approval to proceed was obtained in June 1983.

Figure 1 shows a comparison between the original lattice SRS-1 and the modified lattice SRS-2. Their parameters are listed in Table 1. It is apparent that the major difference between the two structures is the doubling of the number of cells in SRS-2 by the installation of a new D quadrupole magnet at the upstream end of each straight. This permits the storage ring to be operated at a much higher radial tune, 6.2 as compared with 3.2, and with a greatly reduced dispersion function and momentum compaction factor. The net increase in photon beam brilliance expected is 15, as detailed in Table 2.

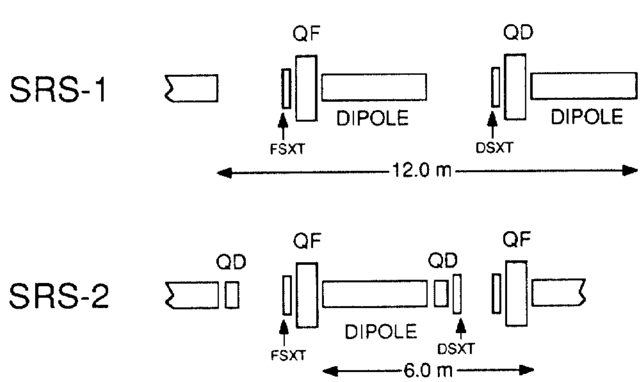

Fig. 1. Comparison between old and new SRS magnet lattices.

Table 1
Lattice parameters

	SRS-1	SRS-2
Circumference m	96.0	96.0
Lattice type	FODO	FODO
Number of cells	8	16
Maximum energy GeV	2.0	2.0
Betatron tune, horizontal	3.18	6.18
Betatron tune, vertical	2.22	3.22
Momentum compaction factor	0.14	0.03
Uncorrected chromaticity, horizontal	-9.0	-10.9
Uncorrected chromaticity, vertical	+0.5	- 4.1
Natural horizontal emittance at 2 GeV mm-mrad	1.5	0.11
Natural bunch length at 2 GeV mm (fwhm)	60	35

Table 2
Brilliance comparison SRS-1 and SRS-2

		SRS-1	SRS-2
Horizontal beam size	(fwhm mm)	14.4	2.6
Vertical beam size	(fwhm mm)	0.57	0.24
Vertical electron divergence	(fwhm mr)	0.19	0.09
Photon emission angle	(fwhm mr)	0.38	0.38
Photon beam divergence	(fwhm mr)	0.42	0.39
Brilliance ratio		1	15

Installation and Recommissioning

Although approval for the lattice modification was given in 1983 it was intentionally delayed until October 1986 in order to complete the scientific programme already in place at the facility. Up to the start of the shutdown which then began, SRS-1 was regularly operating with 300 mA initial stored beam current and beam lifetimes of 10 hours.

The modification programme was planned to take 4½ months from October '86 to mid-February '87. Since over 60% of the vacuum chambers would be replaced, it was possible to have much of the equipment ready as sub-assemblies at the start of the shutdown. However it was still necessary to remove totally the equipment from each of the 16 straights, modify the components such as quadrupoles, sextupoles, kickers, etc., which were to be re-used, and combine them with the new sub-assemblies. The dipole magnets with their vacuum chambers and beam ports were left in place after being let up from vacuum to an atmosphere of dry nitrogen. Due to some unexpected problems in modifying the equipment for re-use the shutdown took two weeks longer than planned and the first commissioning with injected beam started on 1st March 1987.

SRS-2 commissioning took place rapidly despite the fact that major systems had been radically changed.

Within two weeks a beam had been accumulated and ramped to over 1 GeV. By the end of March, 75 mA had been ramped to 2 GeV, the beam orbit had been fully corected and the beam size measured. During April and May one quarter of the vacuum chambers were given an in-situ bake out and the radiation beam lines were brought back into operation. Further beam studies were made and the 5 Tesla superconducting wiggler was re-commissioned. Finally in mid-June the facility came back to routine 24 hrs/day operation for experimental science.

SRS-2 Performance

In the 11 months that the facility has been back in scheduled operation the beam current has increased as understanding of the electron beam behaviour has improved. The increase in average initial beam current at 2 GeV is shown in Fig. 2, where the averaging is made on a monthly basis. At present this current is normally about 200 mA, although it is usually possible to accumulate more, up to about 300 mA, at the injection energy. However as the energy is raised from 600 MeV to 2 GeV, transverse beam instabilities occur intermittently which result in beam loss to about the 200 mA level. These instabilities are presently being studied, see Poole et al.[2]

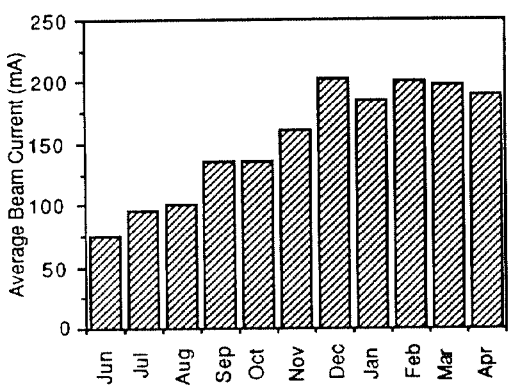

Fig. 2. Improvement in SRS-2 beam current

SRS-2 also operates, according to schedule, in the single bunch mode. This is normally performed with the lattice in a slightly detuned, lower brilliance mode in order to increase the natural bunch volume and reduce the natural chromaticity. In this mode the radial betatron tune is decreased from 6.2 to 4.2, and the emittance increases from $0.11\ 10^{-6}$ to $0.27\ 10^{-6}$ mrad. The maximum current which has been accumulated into a single bunch is approximately 50 mA, but this limit has not been fully explored.[3] At present a limit of about 30 mA is experienced due to the control circuits of the injection kickers receiving interference from the orbit harmonics radiated by the single bunch. This results in the kickers malfunctioning when the single bunch current approaches this value.

The beam lifetime, averaged over each beam fill and over each month, has shown a steady improvement as indicated in Fig. 3. The two instances where the general trend for improvement was reversed happened when some of the distributed ion pumps were out of operation. The importance of these pumps in achieving good lifetime is demonstrated by the comparison between February and March. In March all pumps were active whilst in February, two distributed pumps representing 13% of the available distributed pumps and only 4% of the total pumping speed, were out of action and yet the beam lifetime decreased by 30%. Further informtion on the performance of the vacuum system is given by Reid.[3]

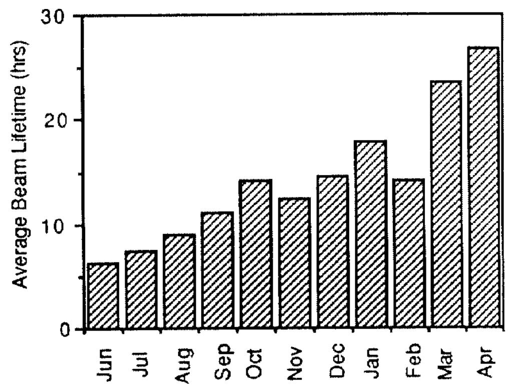

Fig. 3. Improvement in SRS-2 beam lifetime.

The bunch length achieved in SRS-2 is of great interest because of the information it can provide on the vacuum chamber impedance and any instability processes which are taking place, particularly at high bunch currents when operated in single bunch mode. Comprehensive bunch legnth measurements have been made as a function of bunch current, rf voltage and energy. The results are reported in detail by Poole[2] so that it is sufficient merely to report here that compared with SRS-1, SRS-2 no longer shows the clear signature of turbulent bunch lengthening. Nevertheless, the bunch length is longer than the natural value, especially at low energy. For example, at 600 MeV the low current bunch length has been measured as ranging between 55 ps and 65 ps depending on the rf voltage. This is to be compared with the corresponding natural values of 11 ps and 20 ps. However at 2 GeV the measured length of 68 ps agrees with the natural value.

For a synchrotron radiation source such as SRS the measurement of the electron beam size is of prime importance and has received much attention. The first rough measurements were made from a focused image of the beam using the visible component of the synchrotron radiation. This was viewed with a TV camera and Figs. 4 and 5 show the comparison between SRS-1 and SRS-2 made with the same focusing system but with different screens. The small divisions in each case are millimetres and it is apparent immediately that in SRS-2 the horizontal beam size has been reduced by about 5 times, as predicted.

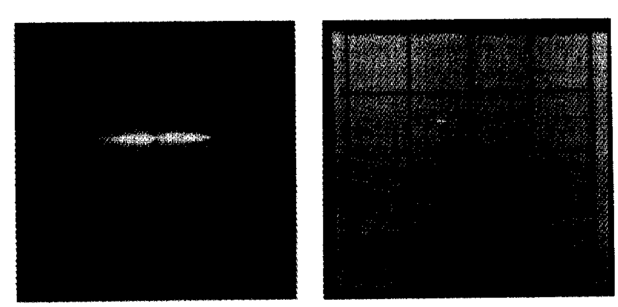

Fig. 4 (left) and Fig. 5 (right). Focused synchrotron light images of the beam in SRS-1 and SRS-2.

Precise measurements of the size of the focused image have been made using photo diode arrays as described by Mackay.[4] At 2 GeV the horizontal beam size agrees with that expected from the natural emittance to within the experimental uncertainty of ±5%, and the vertical beam size corresponds to a horizontal vertical emittance coupling ratio of 3%, although this latter figure depends on the specific choice of betatron tunes. At 600 MeV the beam size is generally larger than the natural beam size to an extent depending on the beam current. This is illustrated in Fig. 6 which shows typical examples of beam sizes measured with the photo diode arrays as the beam energy is increased from injection to 2 GeV. The effect of instabilities and changes in the betatron tunes may be seen.

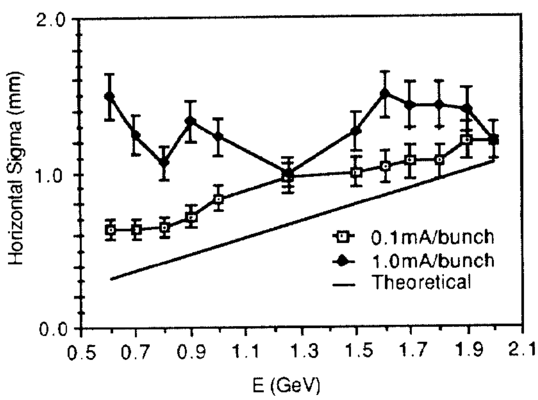

Fig. 6. Horizontal beam size measured by a photo diode array during the energy ramp, at 0.1 and 1.0 mA per bunch.

An independent check on these measurements has been obtained using a simple x-ray pinhole camera on a diagnostic x-ray beam line at another location on the storage ring. Although it can be used only at higher beam energies where there are enough x-rays, this camera has the advantage of producing a 4 times magnified image of the electron beam which is particularly useful in measuring the very small vertical beam size. The pinhole confirms that at 2 GeV the horizontal beam size agrees to within 10% with the predicted natural size and that the vertical emittance coupling is 3%.

Equally important for a radiation source is the position and angle of the electron beam at the origins of the beam lines. The beam orbit in SRS-2 is measured with a set of button pick-ups which are multiplexed on demand through the computer control system. This then displays a set of 16 horizontal and 16 vertical beam positions which are fully corrected for pick-up calibrations and surveyed offsets. Over the range 20-200 mA these monitors have demonstrated accuracies of ±0.25 mm in the horizontal and ±0.15 mm in the vertical.

The beam orbit can be corrected to zero or any other desired position by running a control program which accesses the monitor data and computes the optimum corrector settings using a theoretical model of the lattice. Not only is this a very useful operational aid but it is also a powerful diagnostic facility for locating equipment faults. There have been occasions when corrector faults, stray fields, and shorted turns have been rapidly located using this program.

The operation of the orbit program in correcting the horizontal and vertical orbits is illustrated in Fig. 7. In 5 iterations the vertical orbit is reduced from ±6 mm to within a standard deviation of 0.05 mm about zero, and in the horizontal from ±10 mm

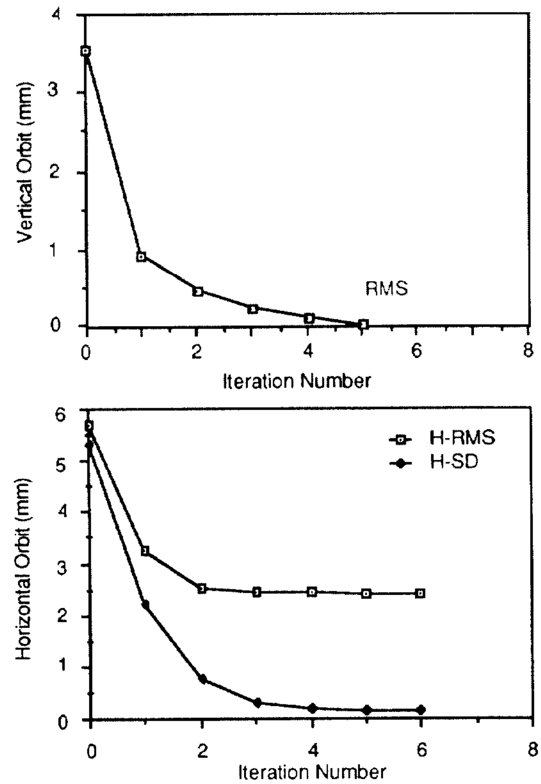

Fig. 7. Correction of the vertical and horizontal orbits, showing the average horizontal offset.

to a standard deviation of 0.2 mm about a constant offset of 2.4 mm. This offset is a real orbit effect due to the fringe fields of the dipole magnets penetrating into the straight sections. It has not been corrected, for example by adjusting the rf frequency, to avoid disturbance to the alignment of the radiation beams.

Conclusions

The lattice change from SRS-1 into SRS-2 represents one of the most major transformations inflicted on an operational accelerator. The change has been completely successful with the main design goals having been achieved or surpassed. It is probable that the present level of performance will be improved further in terms of beam current and beam stability. A continuing programme of studies will attempt to understand the various beam instabilities which are experienced and useful comparisons will be drawn between the behaviour of SRS-1 and SRS-2.

References

[1] G. Saxon, IEEE Trans. Nuc. Sci. Vol. NS-30 No.4 p3136-3138 August 1983.

[2] M.W. Poole et al, 'Beam Instability Characteristics of the Daresbury SRS' - these proceedings.

[3] R. Reid, 'Vacuum System Design and Performance for the Upgraded Daresbury SRS' - these proceedings.

[4] J.S. Mackay, 'Electron Beam Profile Position End Emittance Measurements on the Daresbury SRS' - these proceedings.