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REPORT ON THE DARESBURY SYNCHROTRON RADIATION SOURCE

by
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Summary

The SRS is now substantially complete. The injection system, comprising a 12 MeV linac and 600 MeV synchrotron has been operational for two years, and its performance has been reported elsewhere[1,2].

This report describes the performance of the various systems which make up the storage ring, gives a detailed account of the injection system, and reports accelerator physics observations to date. Also included is a status report on the 5T superconducting wiggler magnet planned for installation later in the year, and an outline of plans to modify the lattice to increase the source brightness.

Introduction

Beam was first circulated in the storage ring in June 1980 only $2^1/_2$ hours inside the target date set the previous year. At that time the storage ring was operated in a very basic state, with only one r.f. accelerating cavity in commission, operating at low power, and with a vacuum pressure of ~ 10^{-7} torr. The storage ring is now essentially complete with only instability suppressing devices and the wiggler magnet installation requiring a break into the vacuum system.

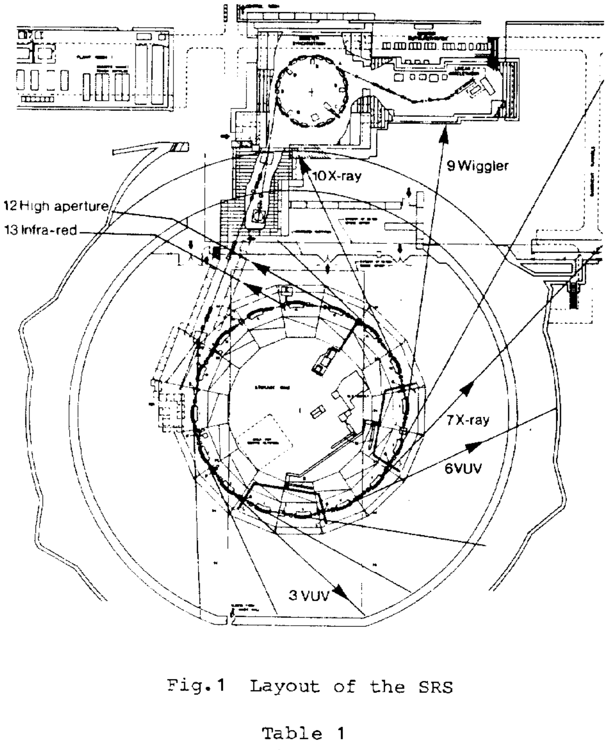

Fig.1 Layout of the SRS

Table 1
Storage Ring Parameters

Energy	0.6 - 2.0 GeV
Current	375 mA at 2 GeV
Circumference	96 m
No. of superperiods	8
Lattice structure	$FOB\bar{O}DOB\bar{O}$
Dipole bending radius	5.559 m
λ_c	3.88 Å at 2 GeV
Nominal tunes Q_R, Q_V	3.15, 2.2
Nominal synchrotron frequency f_s	180 kHz
Orbit frequency	3.123 MHz
Radial emittance	1.3×10^{-6} m-rads

The main features of the storage ring are shown schematically in Fig. 1, and the main parameters are summarised in Table 1.

Since June 1980 effort has been divided between plant commissioning, mainly r.f. and vacuum, the build up of the beam lines and experimental stations, and on accelerator physics. The progress made is reported in the following paragraphs.

Injection

The storage ring injection system employs three fast kicker magnets to produce a localised orbit distortion and a septum magnet to deflect the incoming beam close to the orbit.

The kickers are an arrangement of copper conductors within the vacuum. They are powered by a half sine-wave current pulse, base width 2.25 µs, up to a peak current of 5000 Amps. At this current the kickers produce a deflection of 7.3 mrad. The septum magnet, also situated within the vacuum, has a laminated core, each lamination being 0.1 mm thick Radio Metal. The whole assembly is 0.8 m long, producing the required deflection of 110 mrad at a current of 4800 Amps.

The operation of the injection system is shown schematically in Fig. 2. Multiturn injection is used, stacking in radial betatron phase space to achieve the desired current. The position of the beam within the vacuum chamber, at the septum, is shown in Fig. 3 for a radial Q value of 3.25. This shows that a small loss

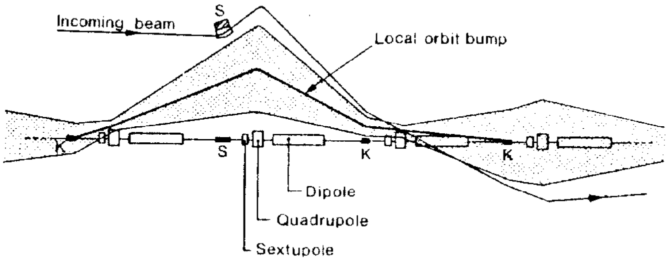

Fig.2 SRS Storage Ring Injection System

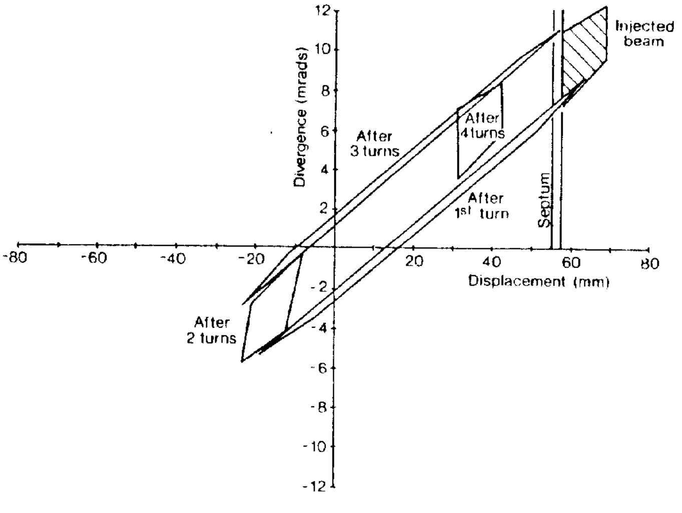

Fig.3 Phase Space Diagram at the Septum showing the Development of the Beam over the First Four Turns

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of ~ 5% occurs after the first turn, with no loss thereafter. At lower Q values there is greater beam loss after the first orbit, but the switch off time of the kickers is less critical. At higher Q values the converse is true.

After the kickers are switched off the effective beam width is ± 55 mms, and this damps down, due to emission of synchrotron radiation, with a time constant of 0.315 s.

When the kickers are fired at the next injection time the circulating beam is brought close to the septum magnet. If the maximum injection rate of 10 Hz is used, a fraction of the last injected pulse engages the septum and is lost, since insufficient time has elapsed to adequately damp the beam. Theoretical estimates put this loss at around 25%. At an injection rate of 5 Hz the last injected pulse should survive the injection process intact.

Injection studies have been carried out in the "synchrotron mode", where the injected pulse is dumped before the next injection time, and in the stacking mode. Repeatability of the input beam trajectory is ensured by targeting the beam on a thin secondary emission finger situated at the entrance to the septum magnet. Setting up the three kickers to produce a localised bump is performed by observing their effect on the stored beam on the synchrotron light monitor. The kicker timings and amplitudes are readily set to give good localisation when the beam image shows no increase in size when they are switched on.

These studies have confirmed the high injection efficiencies which can be achieved with $Q_R \approx 3.25$ (synchrotron mode). Results in the stacking mode have proven more difficult to interpret because sufficient time elapses to allow equipment instabilities to effect the beam, and in particular to effect the stacking rate. However, it is encouraging to report stacking rates of 5 mA/pulse, at 10 Hz with an equivalent injected beam of 7 mA, (21 mA in the booster), which is in good agreement with theory.

Magnets

The storage ring magnet system comprises 16 dipoles, 16 quadrupoles and 16 multipole correction magnets[3,4]. All the magnets were fully measured before installation, using the automated magnet calibration facility developed at the Laboratory[5].

As previously reported[1], some of the dipole magnet properties were found to be inferior to the prediction of the computer model due to enhanced steel saturation at the maximum excitation levels. Although this was considered acceptable, the sextupole component at high fields produces a considerable change in the natural machine chromaticity, which must be corrected by the multipoles to avoid the head-tail instability. The distribution of dipoles around the ring was carefully chosen to minimise the contribution to the closed orbit distortion at high energy. It is estimated that the measured spread of 0.3% in field will contribute ± 3 mm to the closed orbit distortion.

The measured variations of magnet properties as a function of excitation level have been incorporated into the control program which tracks appropriate parameters, as the storage ring energy is ramped to 2 GeV. It was found necessary for example to correct for the small variation in dipole end angle, which gives rise to a tune shift of 0.05 during ramping.

A useful facility which was recently commissioned is an NMR magnetometer which is located in a reference magnet connected in series with the main dipoles. Fully automatic control through the computer system provides a continuous check of the dipole field stability, hysteresis and other setting errors. The device is used to calibrate the beam energy and is capable of following this parameter during the ramping operation.

Vacuum

Between June and November 1980 the vacuum system was operated in an unbaked state, using 16 ion pumps and 4 turbo-molecular pumps spaced equally around the ring. After two months continuous pumping this system produced a base pressure of 3×10^{-8} torr. With the beam induced gas loading this rose to 7×10^{-8} torr and resulted in beam lifetimes of 30 minutes under typical beam conditions of 100 mA at 600 MeV.

In November the whole system was baked to a temperature of 200°C. A significant improvement in base pressure to 1×10^{-9} torr was achieved in two of the four vacuum sectors, but unfortunately air leaks were opened up in the other two, leading to an overall base pressure of 5×10^{-9} torr. The increase in gas load under beam conditions was similar to pre-bakeout resulting in lifetimes of 75 minutes. Remedial action later cured the leaks in one sector which rapidly attained the same base pressure as the good sectors. However leaks still remain on the large flanges used on the tanks which house the injection magnets and plans to make good these seals are currently under discussion.

Over the bakeout periods both the distributed ion pumps, contained within the jaws of the dipole magnets, and the titanium sublimation pumps were brought into commission. This extra pumping is not yet in regular use because of the intermittent usage of the dipoles, but when regular operation starts it is anticipated that pressures less than 10^{-9} torr will be readily maintained.

R.F. System

The r.f. power source is a single 250 kW klystron with a solid state drive stage. The storage ring has four resonant cavities which are directly coupled to a waveguide feeder system via ceramic windows. Power splitting and absorbtion of reverse power is by a system of three Magic Tees and water cooled load combinations in the feeder run. Computer controlled phase shifters and adjustable short circuits enable the coupling to the cavities to be varied, on power, up to a factor of 5.

The internal profile of the single cell r.f. cavities was computed to optimise shunt impedance and to minimise higher order modes. To meet the stringent requirements of the computed profile the cavities were constructed by electroforming from copper. Ports to incorporate damping antenae have also been included should it prove necessary to reduce any higher order modes further.

The rated maximum dissipation per cavity is 40 kW. On a number of occasions the system has run satisfactorily at this level, which demands 160 kW from the klystron. Further power demands, upto the maximum available 250 kW, await the effects of significant beam loading.

At present a number of system improvements are under development, notably amplitude and phase feedback. A major development in progress is a microprocessor control system, which will control the auto-tuning, high power phase shifters, and waveguide shorting sections during ramped coupling changes. A valuable extra feature will be to reset the cavity auto-tuning following the loss of a high current stored beam.

Controls

Control and monitoring of the SRS is via a hierarchy of computers. The storage ring has a dedicated minicomputer, an Interdata 7/16, which is linked to 6 local control stations via a CAMAC serial highway 750 m long. The minicomputer is accessed by the operator via an Interdata 7/32 which services two identical control consoles as well as a personnel safety console and a series of computer peripherals. The SRS network is also connected to the site central computer which can be used for large data storage and applications requiring greater processing power.

A novel feature of the system is the virtual parameter facility, which permits a single control parameter to cause simultaneous variation of a number of real machine parameters. A trivial, but very useful application of this facility, is the construction of a localised beam bump via three correcting elements, whose values are tied to the current tune value. More complicated applications include the construction of higher order fields in the multipole mgnets, and a program TRACK which uses a software model of the storage ring lattice elements to set up such parameters as the betatron tune, synchrotron frequency and chromaticity. It then changes the relevant parameters according to non-linear formulae, in order to keep the values constant as the energy is ramped from injection to final energy.

With the control system completely commissioned the emphasis has turned to providing a rapid service for inclusion of new plant items and for construction of new programs as demanded by accelerator physics.

Accelerator Physics and Diagnostics

Beam was first stored in the SRS in July 1980 and since then operational periods have been used for commissioning and accelerator study. First beam to experimenters is scheduled for March 1981.

Electrons are injected at 600 MeV with a repetition rate of 10 Hz and accumulation rates of 50 mA/s up to a maximum stored current of 200 mA have been measured. However a more repeatable performance is 20 mA/s to a stored current of 150 mA. During accumulation each burst of electrons from the booster synchrotron takes up only one third of the storage ring circumference. By allowing the booster to free-run at its 10 Hz repetition rate and simply ejecting the beam at peak energy, successive injections in the storage ring are sufficiently random that the circumference is filled reasonably uniformly.

The reasons for the limitation of stored current have not yet been studied, but it is likely that a horizontal beam instability is involved for the following reason. During accumulation the current builds up at an almost constant rate until the limit is abruptly reached. At this point an instability threshold has probably been reached which causes the horizontal beam size to increase and this leads to beam losses on the septum when the injection bump is applied. A constant stored current is reached when the injected beam equals the amount of loss on the septum.

The beam current is measured by two systems. The first is a DC current transformer in which the beam forms a primary loop through a mu-metal toroid. The second system comprises a set of 16 beam position indicators (BPIs) distributed around the ring. Each BPI consists of four pick-up electrodes which are in the form of terminated, quarter wave, transmission lines. From these four signals are derived the beam current and the horizontal and vertical beam positions. There is good agreement between the current transformer and the BPIs.

The signal from the BPIs is essentially at the frequency of the storage ring RF, i.e. 500 MHz, and a high quality oscilloscope is neded to display it. For routine use the 500 MHz signal is heterodyned down to 30 MHz which allows display on, for example, storage scopes.

An image of the beam cross section is formed by reflecting the visible portion of the synchrotron radiation from a water cooled beryllium mirror through a quartz window and focusing it with lenses onto a ground glass screen. This is viewed at the control console by closed circuit TV and experience has shown it to be an extremely important diagnostic device for obtaining a qualitative measure of the behaviour of the beam.

The lifetime of the stored beam agrees roughly with the average vacuum pressure. However reductions in lifetime by a factor of 5 have been observed without significant change to the measured average vacuum pressure. This may be explained by changes in the species present in the residual gas and a system of residual gas analysers which can be read remotely is being installed.

There are no direct indications of instabilities apart from the possible horizontal blow up limiting accummulation at 200 mA. A wideband signal from a pick-up electrode which has a bandwidth of 1.5 GHz has been examined with a high frequency spectrum analyser and no coherent motion is evident, apart from the expected 500 MHz signal and its synchrotron oscillation and orbit frequency sidebands. The pick-up loops in the cavities also show nothing untoward, with small (< 40 dB) contributions from the previously measured higher order modes at 810, 1302 and 1810 MHz.

The betatron tune values are measured by exciting the beam via electrostatic deflection plates whilst simultaneously the signal induced by the beam in a pick-up electrode is fed to a spectrum analyser. A block diagram of the system is shown in Fig. 4 and an example of the spectrum analyser display is given in Fig. 5. This clearly shows the orbit frequency at 3.1228 MHz with two synchrotron oscillation sidebands at 160 kHz spacing on either side. At the extreme left and right are the signals corresponding to the horizontal betatron tune at 2.68 MHz and 3.56 MHz, which imply a tune of 3.14.

The tune values have been explored in the range $3.0 < Q_x < 3.5$, $2.0 < Q_x < 2.5$ by storing a beam at an arbitrary point and varying the currents in the lattice quadrupoles. All the betatron resonances shown in Fig. 6 have been identified by beam loss at moderate

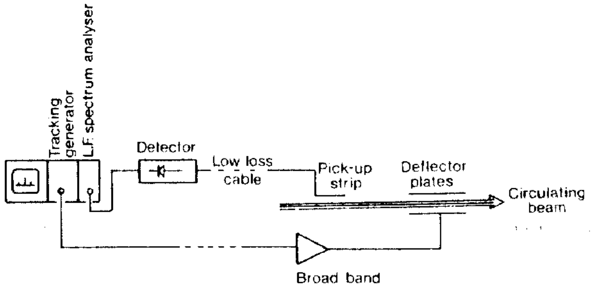

Fig.4 Block Diagram of Spectrum Analyser and Betatron Tune Measuring Equipment

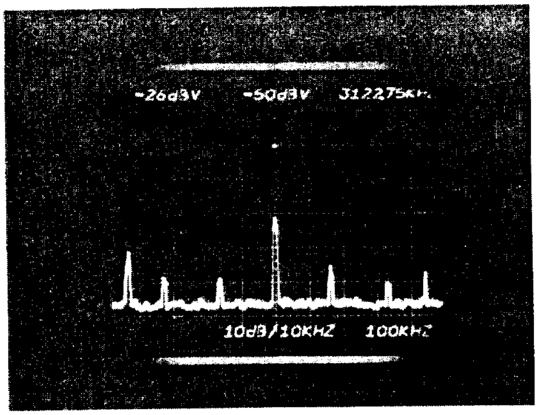

Fig.5 Spectrum Analyser Display

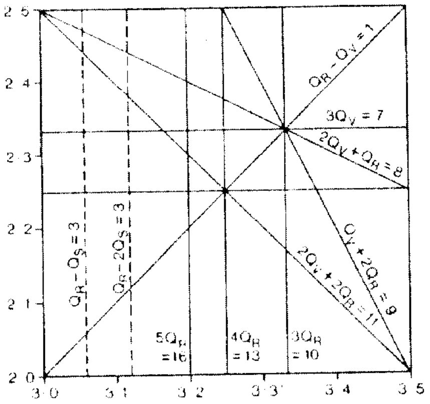

Fig.6 The Working Diagram of the SRS

currents. For small currents, < 10 mA, many are not observed. The two satellite synchro-betatron resonances shown in the diagram are also easily seen when the betatron and synchrotron sidebands on the spectrum analyser merge. These satellite resonances always cause beam loss when crossed.

The tune exploration has been done without energising the lattice sextupoles, the natural chromaticities predicted to be - 5.2 horizontal and - 1.4 vertical. When the natural machine measurements are completed the chromaticity will be corrected to zero or slightly positive.

The electronics for processing the BPI signals has not been commissioned so the sense of the beam displacements are not known. This has meant that the closed orbit cannot be corrected by the usual analysis techniques. The correction elements which are available for steering are 16 horizontal and vertical deflectors in the multipole magnets and a trim winding on each of the 16 dipoles. The operator energises these individually and by judgement is able to reduce the orbit displacements to about ± 5 mm. It is then possible to use a computer program which controls the correction elements in groups of three to generate exactly localised bumps. These are then used to reduce the orbit displacements further, see Fig. 7.

After a satisfactory beam has been accumulated at the 600 MeV injection energy, it is accelerated by increasing the fields in the magnets. This process, referred to as ramping, is performed by a computer control program which ensures that all magnet currents remain within allowed tolerances to keep the betatron tune

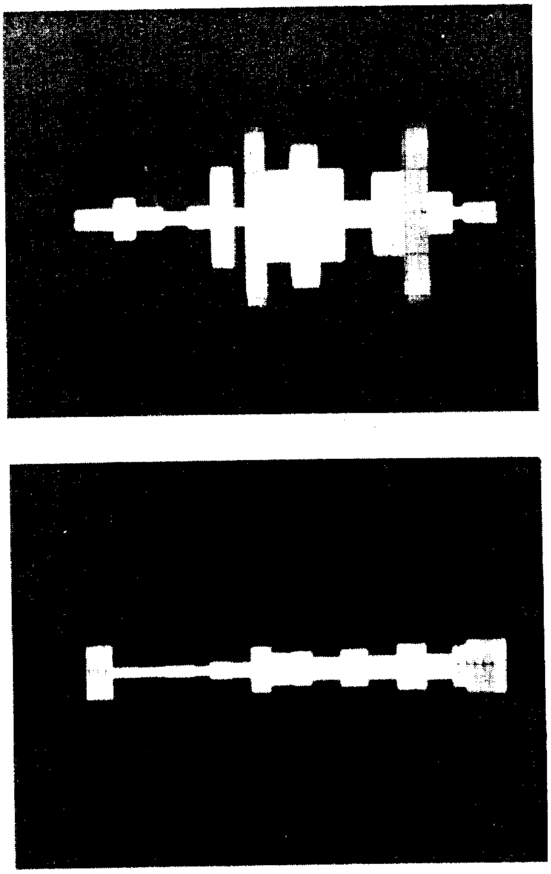

Fig.7 Radial closed orbit before and after correction.
Largest displacement before correction = 12 mm.
Largest displacement after correction = 4 mm.

values constant. It is also possible to control the RF level to maintain a constant synchrotron frequency.

The time taken to complete a ramp is about 5 minutes and the highest energy to which the stored beam has been raised is 1.9 GeV. The main problem encountered is a shift in the betatron tune due to oversimplified specification of the magnet calibrations in the software. Beam loss occurs when the shift takes the beam into a betatron or synchro-betatron resonance. The problem is being solved by applying more accurate calibration data.

Future Plans

Short term

In early 1981 the SRS will start to provide radiation to experimentalists, with two beam lines in commission. The first will provide ultraviolet and soft x-rays to two stations devoted to surface science, whilst the second takes hard x-rays, serving a protein crystalography and an EXAFS station. In the near future this line will be extended to topography and interferometry stations up to 80 m from the source.

Medium term developments are dedicated to increasing the experimental utilisation. Two further ports will soon be installed for users of longer wavelengths, including infrared, and a single bunch facility will be installed in mid-1981. This will use r.f. deflectors between the linac and booster to produce a single 500 MHz bunch. Modifications to the timing system will then ensure that this bunch is transferred to a single tagged bucket in the storage ring.

Towards the end of 1981, a 5T superconducting wiggler magnet will be installed. This has been constructed at the Rutherford Laboratory[6] and has recently achieved 5.5 T on the central pole whilst on test. Further tests will be carried out at Daresbury. With only the centre of the magnet's three poles generating high field, the device is regarded as a wavelength shifter, and when it becomes operational in 1982, it will serve users who require wavelengths shorter than are generated in the standard dipole magnets.

Long Term

A feasibility study is in progress of a modified lattice to improve the source brightness of the SRS by an order of magnitude. This would be achieved by inserting an extra quadrupole at the upstream end of each straight section, thus raising the tune values to $Q_R = 6.25$, $Q_V = 3.25$. The radial emittance is reduced from 1.3×10^{-6} mrad to 0.11×10^{-6} mrad. The practical difficulties of fitting in the extra quadrupoles and moving the multipoles to give chromaticity correction, are not trivial, but probably not insuperable, and much attention is being given to tailoring the new magnets to fit the local environment.

A further advantage of the modified lattice is the reduction in overvoltage required for adequate quantum lifetime at 2 GeV, thus releasing more power for beam loading. If in addition, a higher efficiency klystron were installed then a beam current of 1 Amp at 2 GeV could be attained with existing supplies.

The insertion of undulators in the ring is also being examined.

Acknowledgements

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