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THE SRS: PROGRESS REPORT ON THE DEDICATED SYNCHROTRON RADIATION SOURCE AT DARESBURY; AND OPERATION OF A 600 MeV BOOSTER

D.J. Thompson*

Abstract

Design of the 2 GeV Storage Ring is virtually complete and construction will be finished in April 1980. The injector, a 600 MeV 10 Hz synchrotron, has been commissioned and its performance is reported.

Introduction

An artist's impression of the SRS$^{(1)}$ is shown in Fig.1. A 2 GeV electron storage ring is injected from a 600 MeV booster synchrotron with a 12 MeV linear accelerator as pre-injector. The synchrotron radiation has a characteristic wavelength of 4 Å from the 1.2 T bending magnets, and a superconducting 3-pole wiggler magnet is being built with a 5 T field on the orbit. Initially, one 250 kW klystron is being installed to provide r.f. power at 500 MHz. This will support a circulating beam of 370 mA at 2 GeV or higher currents at lower energies. The storage ring can be upgraded by provision of a second klystron and this will provide enough power for 1 A at 2 GeV with two wigglers in operation.

The linear accelerator and booster synchrotron have been commissioned and accelerator studies are in progress. Operation is via the computer control system. Most components for the storage ring have been ordered, prototypes of all major items have been tested, and production units are now arriving. The steelwork to support the shield tunnel has been installed and installation of the ring is scheduled to start in July 1979.

There is provision for 12 beam lines, most of which will feed several experiments. The first two will be installed for first beam and further lines will be added as fast as funds and manpower allow. Though not in the first two, a wiggler line and an infra-red port are planned for early installation.

The Booster Synchrotron

The 600 MeV booster synchrotron (Fig.2) has a mean radius of 5.06 m and uses combined function magnets in a FODO lattice.

Injection from the 12 MeV linac is by means of two kickers and a septum and the injected current is usually 30 mA, modulated at 500 MHz (which is the booster r.f.). The tune at injection is $Q_V = 2.30$, $Q_R = 2.43$ and injection extends over a period of between two and three turns. However, the linac operates at present without a prebuncher and this results in a high emittance and considerable loss at injection. The current in the ring after three turns is 25 mA. The closed orbit at injection seems good and the first turns are not sensitive to steering, which is by backleg windings on the magnets and helmholz coils in the short straights.

The closed orbit remains good throughout acceleration. There is considerable beam loss in the first few tens of microseconds (hundreds of turns), and this is thought to be an r.f. capture problem, which is still being investigated. It is dependent on $\dot{B}$, and when injecting into a d.c. field, 25 mA can be captured and held. No further losses occur after this capture period, although the tune changes considerably. Under some conditions the beam is lost on crossing $Q_V = 2.33$ but this is easily avoided. So far 10 mA has been accelerated to 600 MeV. This is adequate for filling the storage ring, but a larger current would mean a greater safety margin in the event of poor transfer efficiency, and under single bunch conditions.

The 500 MHz r.f. system consists of a single-cell cavity with a shunt impedance (ZT^2) of 4 MΩ powered by a 500 W source. The cavity has adjustable matching and tuning and a voltage feedback loop.

The booster has an all-metal vacuum system, the magnet vessels being corrugated stainless steel 0.3 mm thick. The magnet current waveform is a 10 Hz biassed sinusoid. Calculations indicated that eddy currents would produce a small d.c. offset and a small but not negligible sextupole field. This was too small to measure in the laboratory. Poleface windings providing quadrupole and sextupole fields have been installed, and whereas in the d.c. mode, capture is optimised with zero sextupole correction, there is a clear but flat optimum under a.c. conditions when the sextupoles are set to 0.3 T/m^2. This is reasonably close to the calculations, although the sextupole may be correcting other effects also.

The extraction septum will be installed in March and tested in April. Extraction uses a beam bump, two kickers and a septum, and is a "shaving" process designed to extract over three turns so as to uniformly fill the storage ring, which has a diameter of 30.56 m. The tune can be controlled as the poleface windings are computer programmable. However, as shown in Fig.3, the natural variation of tune goes so close to the 2.33 vertex that good extraction is likely without correction.

The computer control system works well. The main computer is an Interdata 7/32 with 128 kbyte memory. This controls the plant via 4 mini-computers (Interdata 7/16) and is connected to a central IBM 370/165 for bulk storage and other purposes. High level programmes are written in RTL-2.

The Booster Synchrotron is rapidly settling down to reliable operation; the linear accelerator is somewhat more critical to set up - this should improve when the prebuncher is commissioned.

The Storage Ring

The general status was given in the Introduction and certain specific aspects of interest will now be discussed.

Magnets

The storage ring dipole magnet has an air gap flux density of 1.2 T, but the values of field in the C cored steel yoke approach 1.8 T in certain regions of the pole. It was therefore appreciated during the design of the magnet that non-linear behaviour would be present both in the field amplitude and distribution at high current excitations. When the prototype dipole was measured it was apparent that these non-linearities were greater than had been predicted by computer calculations using programs 'MAGNET' and 'TRIM' and the steel manufacturers measured permeability curves. An unexpected 3% loss of field amplitude was overcome by increasing the current rating by this amount. However, the change in field distribution required more radical consideration. At 1.1 T the prototype magnet displayed an almost perfect dipole field, there being less than 0.02% peak variation over the working aperture of ± 80 mm. At 1.2 T this distribution was degraded by a field reduction of 0.18% at the aperture edge, most of this error being attributable to sextupole and decapole fields. This was more than three times greater than the expected non-linearity in field distribution, and would significantly increase the inherent negative chromaticity of the storage ring. Correction was necessary, but it was thought unwise to change the dipole pole design, as any significant incrase in the correcting shims at the aperture edge would further increase the non-linear behaviour of the dipole, and would distort the field component on the correction multipole magnets, and tests on the prototype multipole show that by increasing the coil water presure in order to enhance the cooling, an excitation increase of greater than 50% is possible without overheating or saturating the multi-

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*Daresbury Laboratory, Warrington WA4 4AD, U.K.

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pole magnet. With such augmented sextupole fields available, it will be possible to tune the storage ring well into the region of positive chromaticity to explore beam behaviour and to improve storage time.

In the case of the quadrupoles and multipoles, which operate at a lower flux density, agreement between measurements and computations is excellent.

R.f. system

The four storage ring accelerating cavities are single cells of a fully optimised shape. They are made from electro-deposited copper and are fed via a 150 mm aperture window from a WR 1800 waveguide feeder. Each cell has a mechanical tuning plunger with an inductive joint to the cavity wall. Each cell is rated to dissipate 45 kW of r.f. power at 499.653 MHz.

All the cavities have now been constructed, and the prototype cavity has been extensively tested at Daresbury. After tuning it was found to have a Q of 30,000 and an accelerating shunt impedance of 7.2 MΩ (0.0072 MeV^2/kW). The tuner gave a useable tuning range of over 2 MHz. The cavity has been powered to its full rated dissipation. The cavity will resonate in a large number of higher order modes. To date all but one of these have been damped using a triple antennae system without significant detriment to the accelerating mode.

The 250 kW power source is a Varian klystron and this has been installed and operated at full power into a dummy load. The crowbar consists of four ignitrons in series.

Vacuum

The vacuum system is an all-metal, bakeable system with a design base pressure better than 10^{-10} torr and an operating pressure with full beam current of 10^{-9} torr. The pumps used are 16 triode ion pumps in the straight sections, 16 distributed diode ion pumps in the dipole magnets, 4 air-bearing turbomolecular pumps, and 16 titanium sublimation pumps. Because of the importance of a good beam lifetime, and hence of a clean reliable vacuum system, a comprehensive pressure measurement system supervised by the computer control system is provided(2). Three overlapping pressure regions have been assigned: low vacuum (760 - 10^{-3} torr), medium-high vacuum (10^{-2} - 10^{-8} torr) and UHV (10^{-7} - 10^{-11} torr). Pressure measurement is by Pirani, Penning, and Bayard-Alpert gauges respectively. In addition facilities for partial pressure analysis will be installed using new generation mini-quadrupole mass spectrometers.

An essential feature of the SRS vacuum system is a very low photoelectron stimulated desorption efficiency The vessels are made from stainless steel with a copper radiation absorber, and detailed experiments have been carried out at Liverpool University(3) to measure the desorption efficiency under realistic conditions and after various surface treatments. The maximum linear power density in the SRS will be 7 kW/m. Results from the Liverpool work showed that for a given surface and electron bombardment current a steady state desorption efficiency is reached, i.e. the lowest value obtainable for that surface under the existing bombardment current and pressure. This result was explained in terms of a balance between desorption of gas by the electrons and adsorption mainly from the gas phase. The role of glow discharge in reducing electron-stimulated desorption (ESD) of surfaces was clearly demonstrated, even after exposure to atmospheric pressure and subsequent bombardment after bakeout but with no further glow discharge. This permanent reduction in ESD by glow discharge is believed to be due to the removal by ion bombardment of surface carbon which is a feature of stainless steel, copper and other metal surfaces.

Therefore on the SRS all the storage ring vaccuum chambers will be cleaned by glow discharge prior to installation, using 90% argon-10% oxygen, and an ion dose of about 1 x 10^{18} ions/cm^2. After this treatment and extrapolating data from the Liverpool work to SRS conditions where the electron bombardment will amount to around 10 mA/cm^2, it can be predicted that after bakeout and several days of "beam conditioning", the desorption efficiency for CO should be near to 10^{-6} molecules/electron, which should then give an adequate beam lifetime of ten hours or so. Other observations on surfaces which had been glow discharged and vacuum baked are, that the desorption efficiency increases as a function of electron energy, generally rapidly up to about 300 eV and there after only slowly, and that the true desorption efficiency is virtually independent of surface temperature.

Wiggler

The design of the wiggler(4) is complete and the coils, made from a Nb-Ti conductor, are now being wound. The wiggler is a three pole magnet, all poles being of equal length but the outer poles having half the number of turns of the centre pole. In all, eight identical coils are used, each comprising an inner and an outer section (Fig.4). If all the coils are energised at the same current dentity, this would need to be 12,000 A/mm^2 to achieve the desired field of 5 T at the orbit and the coils will be opeating at 85% of short sample. However, an alternative is to put 8,000 A/mm^2 in the inner coils, and 18,000 A/m^2 in the outer, which will achieve 5 T at the orbit at 72% and 71% short sample respectively The average field of 5 T is maintained over a bend angle at 2 GeV of 40 mrad.

Detailed computations have shown that the sextupole and decapole components of the field integral are acceptably small, that is, they are less than half the correction available from the adjacent multipole magnet; and that quenches will be safe under all conditions.

Construction of the wiggler will be completed during 1980, and the beam line should be commissioned during 1981.

Shielding

Initially it was planned to build a shield wall round the storage ring and to use a beam scraper to localise the loss area during normal conditions. Following computer studies(5) of loss distribution the shield wall was designed for 1% of total beam lost at any point over about two hours. This leads to a wall thickness of 0.75 m concrete increased to 1.5 m when it is normal to a target (i.e. round a beam line). With this shielding the maximum dose from an accidental dump will be 1 rad.

However, conditions of high loss rate during injection must be considered. Measurements by Dinter and Tesch(6) showed that very high radiation levels can occur at wide angles to the beam direction. To safeguard working areas some distance from the ring during injection a concrete tunnel is now being provided, with 20 cm concrete on the roof and on the inside wall.

Beam lines

The first VUV line and the first x-ray line have been designed in detail. Other lines will follow, including special infra-red, high aperture VUV, and wiggler lines. Differential pumping and fast-acting gate valves are being provided on all normal beam lines.

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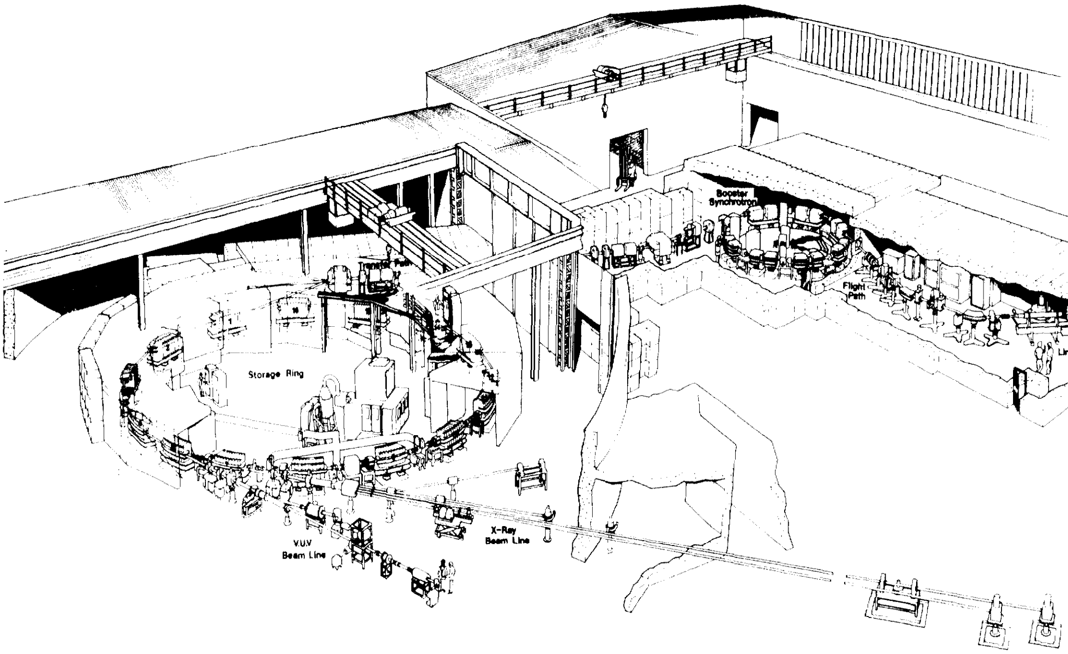
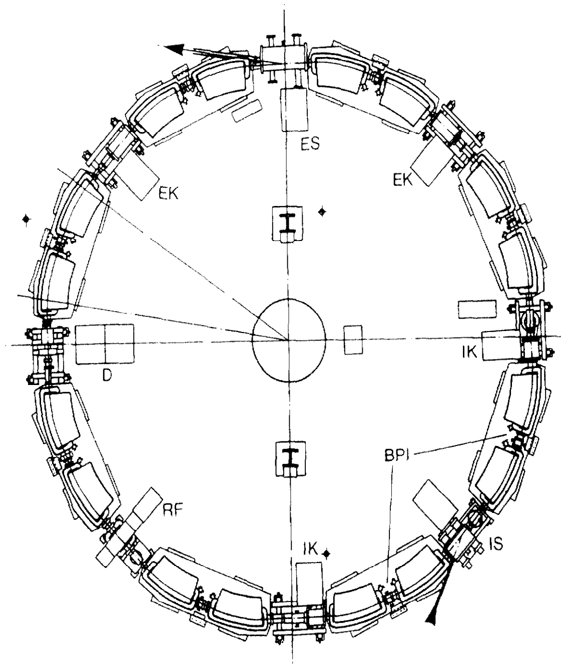


Fig.1 Daresbury Synchrotron Radiation Source



IS	Injection septum
ES	Extraction septum
IK	Injection kicker
EK	Extraction kicker
D	Diagnostic
RF	R.f. cavity
BPI	Beam monitors (8)

Fig.2 Arrangement of Booster Synchrotron

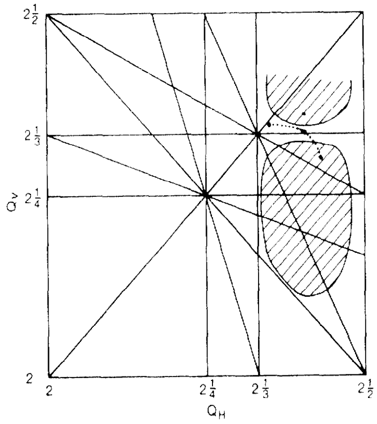


Fig.3 Booster tune-variation during acceleration

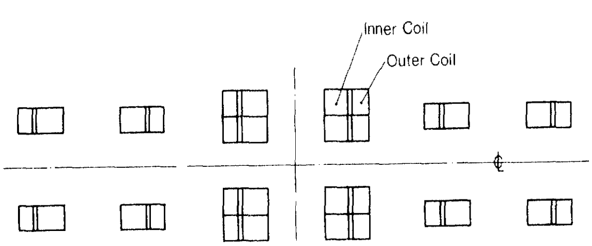


Fig.4 Wiggler coil arrangement