by M W (Mike) Poole

Demand for access to synchrotron radiation sources was burgeoning in the 70's, but was severely restricted by being availability only through parasitic operations on high energy physics rings. This situation led to proposals for new dedicated facilities, but was first realised in a change of usage of TANTALUS, a small accelerator in Wisconsin; however its very modest electron beam energy (240 MeV) could only generate useful spectral output in the longer wavelength regions, with no x-ray capability.

Dedicated sources were christened "second generation" in recognition of a step functional change. At the same time it was realised that any such optimised radiation source should replace the traditional pulsed cycling synchrotron by an electron storage ring, allowing much higher beam currents and also greatly enhanced operational stability. The first (tiny)storage ring called AdA had operated in Frascati a decade earlier and been followed by progressively larger and more powerful examples such as ACO, ADONE, SPEAR and DORIS, all built for particle physics applications. Each of these sources eventually converted to dedicated radiation facilities but it was the design studies and construction of the Daresbury SRS from 1973 to operations in 1981 that were to become the world's first example of a purpose built, second generation solution extending over the full spectral range up to hard x-rays.

Taking full account of User needs the SRS design was refined up to construction approval in 1975 and contained many novel features at that time, whilst also taking advantage of state of art developments elsewhere. An exceptionally high current was specified (1 A), given that the world record at the time was only about 100 mA. In fact the initially installed RF power capacity (a single klystron) would only ever allow up to 370 mA, still an impressive figure. A comprehensive range of instability countermeasures was incorporated, including powerful and flexible correction magnets; a novel type of 12-pole corrector magnet was invented, allowing simultaneous generation of a variety of harmonic fields in a compact solution.

The optimised electron energy of 2 GeV was achieved economically by employing two injector accelerators comprising a low energy linac (12 MeV) and intermediate Booster synchrotron to accumulate storage ring current at 600 MeV. Subsequently the ring energy was ramped to 2 GeV, allowing the whole refilling process to be completed in few minutes. Previous HEP rings had usually employed injection at full energy, a more expensive option successfully avoided on the SRS (although in more recent times the latest generation of sources has reverted to such expensive solutions as a necessity to achieve their specifications). The SRS Booster boasted a number of novel features, one being the adoption of all-metallic vacuum chambers despite its 10 Hz operating frequency, which was much cheaper and more reliable than the alternative ceramic sections traditionally in use elsewhere. Eddy currents were limited to an acceptable level by a very thin wall of 0.25 mm together with a bellows geometry to optimise strength. Similarly the main combined function (bending and focussing) magnets utilised solid copper coils instead of complex and expensive stranded conductor ones.

Although the UHV base vacuum requirements (10-10 torr) had been achieved at other Laboratories the specified radiated power levels of up to 7 kW/m striking the chamber walls around the whole circumference were a new challenge, both for adequate cooling and the control of outgassing induced pressure rises due to stimulated adsorption. The solution was to add a water cooled absorber within the chamber, together with distributed ion pumping and in-situ bake-out up to 300 C. Together with ion clearing electrodes and multiple radiation access ports this defined an interior chamber specification of unprecedented complexity. Not only did it require exceptional engineering control but each chamber also had to be electromagnetically scanned before installation to ensure absence of dangerous impedances that could drive instabilities in the stored beam.

Another unique feature of the SRS, approved in 1977, was to be the inclusion of two superconducting wigglers (5-6 T) to generate higher x-ray energy emission from those two additional sources than was available from the 1.2 T standard ring bending magnets. A few special magnets (insertion devices) had been added to rings elsewhere but never with such a major field perturbation as generated by this powerful technology. Furthermore the performance of the well established FODO lattice chosen for the distribution of magnet focusing around the SRS was severely compromised by the large, localised radiation loss from such a wiggler. As a result a significant correction process had to be established during the commissioning procedure.

First beams were circulated in the SRS in June 1980 and by late July up to 200 mA had been stored, albeit with short life time due to vacuum conditions. Use of the in-situ bake out system was restricted due to the heat impact on vulnerable components. It had always been planned that improved pressure would follow from extensive periods of outgassing induced by the stored electron beams, gradually reducing desorption coefficients. Delays in achieving full energy operation (2 GeV) until April 1981, caused by phasing errors and sparking problems in the four RF accelerating cavities, slowed down this process over the first few months of commissioning. However the first two synchrotron radiation beam lines were successfully brought on stream during 1981 and by early 1982 the full SRS specification (2 GeV, 370 mA) had been routinely achieved.

Even before the commissioning of the SRS it had become apparent that its specification, set in 1975, was no longer at the level to be competitive with newer sources being approved overseas. In particular it had become clear that source brightness, rather than flux alone, would be a critical figure of merit for future facilities. High photon brightness implies similarly high electron beam values and the SRS stored beam emittance (1.5 mm-mrad) was no longer competitive in this respect. The adopted solution was to modify the magnetic lattice by addition of a new set of focussing elements, squeezing the stored electron beam to a much smaller emittance (0.11 mm-mrad). Although already proposed in 1980 and approved by 1983 the scale and cost of this upgrade project delayed its implementation, with User beams not becoming available until mid-1987 after a 7 month shutdown and recommissioning period. In fact the storage ring was almost completely rebuilt during this shutdown (eg 60% new vacuum chambers), sufficient of a change for the facility to be known (internally) as SRS-2 !

Operating in this higher brightness mode inevitably increased the ring sensitivity to errors, necessitating more advanced control schemes that rely on feedback systems. Since Users demanded orbit control to 10% of the greatly reduced source size (ie < 10 μm) the position monitoring system had to be upgraded to be state-of-art too, as was also the case of the on-line orbit correction system. Pioneering studies, both theoretical and experimental, were successfully carried out between 1988 and 1992, including minimisation of slow ground-based drifts, thermal effects and vibrations. An advanced 16 bit VME based steering control system, tungsten vane photon position monitors and new electron beam pick-up processing electronics achieved a resolution of 1 μm on both electron and photon beam monitoring systems. Trials of local vertical automatic position control demonstrated that the photon beam had been stabilized to ±5 μm at 15 meters from the source over a 24 h period. Subsequently the installation and commissioning of a new high resolution steering magnet control system and high precision photon monitors on the beam lines led to automatic feedback control of vertical position in routine operational use from 1993. Orbit correction bumps could be set to micron level accuracy which matched the resolution of the tungsten vane photon monitoring system. SRS stabilisation became the equal (or better) of any such system world wide.

From its inception the SRS project embraced the concept of insertion devices to extend its range of operations. A unique feature of the SRS, approved in 1977 for early SRS operations, was the inclusion of a superconducting wiggler providing a 5 T field strength to generate higher x-ray energy emission than was available from the 1.2 T standard ring bending magnets. At this stage a few such special magnets (insertion devices) had been added to rings elsewhere but never with such a large field perturbation as generated by this powerful technology.
Furthermore the performance of the well established FODO lattice chosen for the distribution of magnet focusing around the SRS was severely compromised by both the harmonic fields in the device and the substantial, localised radiation loss. As a result a suitable correction process had to be designed, including a novel high current (100 A) programmable shunt attached to the nearby vertical focussing quadrupole magnet at the end of the straight section. This wiggler was installed in a 6 week shutdown in 1982 and subsequently fed 7 stations simultaneously due to its wide emission angle. One consequence of the later high brightness changes to the SRS was a raised sensitivity to such insertion devices that necessitated enhanced correction to be implemented.

The success of this first wiggler generated demands for another such insertion device and in 1993 a second superconducting magnet was installed, this time with an enhanced 6 T specification, the strongest magnet of its type in the world (wiggler geometries cannot match solenoid field levels). The beam line would feed 5 stations this time. Unfortunately the only suitable remaining space in the storage ring after the higher brightness upgrade required removal of one of the 4 new major nonlinear correctors installed at that time. Extensive studies during 1992 confirmed that all 4 had to be moved in order to maintain their symmetric distribution around the ring, with consequent redesign of other major components. Even after full correction was applied the simultaneous operation of both wigglers implied an emittance increase of around 80 %, highlighting the eventual limitation on all second generation light sources compared with third generation ones (eg Diamond) specifically designed to include many insertion devices.

Another type of insertion device is an undulator, which relies on emission from many poles to generate an interference spectrum, with greatly enhanced output at selected radiation wavelengths. Field strengths and consequential perturbations to the storage ring are much lower than the superconducting wiggler cases. A trial device was built and installed in the SRS in 1983, utilising permanent magnet technology, and in 1984 a soft x-ray beam line was added. Although the SRS was not a bright enough source fully to exploit such a device nevertheless useful flux increases were achieved from it.
Mastering the ‘new’ technology of undulators assisted in the later development of further SRS insertion devices, motivated by the need to remain competitive pending the completion of the new 3rd generation UK source Diamond. A review of the potential availability of any remaining straight sections was undertaken and concluded that three should be possible, although this

implied a major rebuild of 9 of the 16 straights including the relocation of the main accelerating cavities. Most of this work was undertaken in a shutdown late in 1998.

Two multipole wiggler magnets (MPW) were added with field strength 2 T and nine poles, providing a factor 25 flux enhancement in the 10 keV region compared with the standard dipoles. The devices exploited hybrid permanent magnet technology but relied on a minimum vertical gap much smaller than previously allowed (42 mm); after extensive studies a beam-stay-clear of 15 mm was established. However additional space for a vacuum chamber set an overall gap of 20 mm, assuming use of a novel titanium alloy vessel with thin walls. User beams became available on these important new lines during 1999.

The final insertion device to be added to the SRS was a soft x-ray undulator providing variable polarisation. This device adopted a permanent magnet design (APPLE-2) already popular on the new 3rd generation light sources that had emerged during the 1990's. The precision engineering of 4 movable arrays of magnet blocks is quite challenging but was successfully achieved and the new magnet replaced the original undulator in 2004, with circularly polarised photons delivered early in 2005. In this case the relatively high SRS emittance actually gave an advantage inasmuch as it allowed off-axis generated harmonics to extend the operating range of photon energies from the helical undulator geometry. This project was the last in a long and successful series of upgrades of the SRS that were able to maintain its attraction up to the transfer to Diamond that was to follow shortly.

Section to follow

Single bunch