INITIAL OPERATION OF THE SNS

David A Gray
Rutherford Appleton Laboratory, Chilton,
Didcot, Oxfordshire, England

The Spallation Neutron Source has been progressively commissioned, culminating in the first neutrons being produced during December 1984 at low repetition rates. Since then sub-systems have been brought up to 50 Hz operation. Start-up for running the science programme is under way. A description of the results of the commissioning runs is given with some comments on equipment development.

Introduction

The SNS project is described in references 1-6. A status report was given at the 1983 Conference (7). A 50 Hz, 800 MeV synchrotron is designed to give 2.3×10^{13} protons per pulse (nearly 200 μA mean) on to a depleted uranium target in the form of zircaloy-clad plates. Cooling of the target (dissipation 200 kW) is by heavy water. Above the target are two ambient temperature water moderators, and below there is a liquid methane moderator at 95K and a super-critical hydrogen moderator at 25K. The target/moderator assembly is surrounded by a reflector of beryllium cooled with heavy water forming approximately a 60 cm cube. The main target enclosure is a 4.3m thickness of steel and concrete. There are 18 holes, 9 on each side through which neutrons pass to the neutron spectrometers either directly or through neutron guides.

Commissioning Highlights

There has been relatively little operating time as building and commissioning of sub-systems has been progressive as determined by availability of resources. A time-table of key achievements is as follows:

- Jan 84 - 1 μs long 70 MeV beam pulses injected into the main ring (with dc excitation of the magnets) and several hundred turns circulated at the first attempt.
- Mar 84 - 0.8 μs, 70 MeV beam pulses successfully circulated with ac + dc excitation of the main ring magnets.
- Apr 84 - 10 μs beam pulses successfully accelerated at the first attempt to 140 MeV using 2 rf cavities. With longer injected beam pulses the maximum accelerated beam intensity was 2.8×10^{12} protons per pulse (ppp) or about 10% of full intensity per pulse.
- Jun 84 - 1.2×10^{12} ppp accelerated, at the first attempt using 4 rf cavities, to an energy of 550 MeV.
- Sep 84 - 1.5×10^{12} ppp successfully extracted into a graphite beam dump, again at the first attempt.
- Dec 84 - Protons at about 5×10^{11} ppp level transported to dump 20m before the main neutron target. Immediately afterwards protons at 2 to 5×10^{11} ppp on to the neutron target for a few hours. Neutron fluxes, spectra and time structure from the 4 moderators measured in 6 neutron beam lines and spectrometers.

All commissioning with beam up to December has been done at roughly 1 or 2 pulses per second in order to minimise activity on machine components.

Injector

The synchrotron injector is a 70 MeV H^- linac with 4 Alvarez tanks which has been converted to work at 50 Hz. A transfer line takes the linac beam over the synchrotron to inject the H^- ions from an inside radius. There is a debuncher powered from the fourth linac tank to give variable energy spread. Arrangements have been made to measure energy spread from the debuncher but some problems in understanding the transfer line beam dynamics have meant that this system has not yet been used effectively.

Since December the linac rf has been run up to 25 Hz after curing of excessive heating in the anode seal of the main drive valves. Some problems with heating remain to be solved before 50 Hz excitation can be used.

The ion source arc discharge has been run at 50 Hz and the beam repetition rate being determined by the 18 kV extract pulse repetition rate. On attempting higher repetition rates the medium gradient accelerating column was found to break down inside the column at regular intervals. It has been established that the breakdown rate is proportional to the column pressure and charge per unit time. It is believed that the glass insulators, from which there is a direct line of sight to the beam axis, are being charged up by scattered particles. On reaching a particular potential the insulator breaks down to the nearest electrode and the column discharges. Following reduction of the column pressure to $3.5\ 10^{-6}$ Torr at the pump end the present situation is that enough beam can be produced to give 2.5×10^{12} ppp at 550 MeV and 15 Hz with a column breakdown every 28 minutes. Electrodes are being made which within weeks will be available to clip inside the present electrodes to minimise the number of particles reaching the insulators. In addition further pumping will be added to the ion source magnet box.

Synchrotron Hardware

The magnet system (6), 10 superperiods each with a combined function dipole, an associated vertically focusing quadrupole and a quadrupole pair has operated without problem to the equivalent of 550 MeV at 50 Hz. The biassed resonant power supply has the make-up from the mains provided by a variable speed dc motor driving a single phase alternator. Feedback speed control allows the frequency of the magnet system to be run at either a fixed frequency or tied to mains (nominal 50 Hz) frequency. The latter has been used for commissioning studies. A stability of better than 0.1% in the 50 Hz current has been achieved with 0.01% in the bias current.

The vacuum system (3,6) including its ceramic chamber has also worked well. Pump-down to operating level of 5×10^{-7} Torr takes about 8 hours. After prolonged pumping and with some known minor leaks, pressures of 10^{-6} have been reached. The rf shield joints (7) have been shown to be mechanically and vacuum sound but the effect on beam dynamics has not been tested.

For the rf system, 4 of the 6 eventual cavities (7) are installed together with their associated class B amplifiers. An unwanted resonant mode at 12 MHz is damped by joining the 2 accelerating gaps by a 30 ohm resistor. An unbalanced situation in the amplifier with the class A valve not installed has led to excess power dissipation in this resistor. The second chain has been installed in the 4 amplifiers since December and should improve this imbalance. Diametrically opposite pairs of cavities are phased to give zero net acceleration voltage during injection and are then brought to the correct phase for trapping and acceleration. Relative phase accuracy during acceleration of better than 5 degrees has been achieved with a sweep in frequency, harmonic number 2, from 1.3 to 3.1 MHz. The voltage-time profile requires a reduction to roughly 5% of peak during the trapping process and then a rise to follow dB/dt. During acceleration studies the beam phase loop servo, switched on at 0.5 ms into acceleration, produced smaller phase oscillations and more stable accelerated beam.

Diagnostics in the synchrotron include intensity monitors, beam position monitors and profile monitors. Beam position has been measured at ± 2 mm. The profile monitors have been used successfully. Fig 1 shows the output during an rf steering experiment to determine available aperture. The vertical steering magnets have been used to produce controllable vertical closed orbit changes. Uncorrected horizontal closed orbit errors amount to 15 mm peak-to-peak. These will need to be corrected to set up the beam collection system to minimise activation of components. Initial tests have been done with beam on the ionisation chamber beam loss monitors spaced along the linac, synchrotron and extracted proton beam.

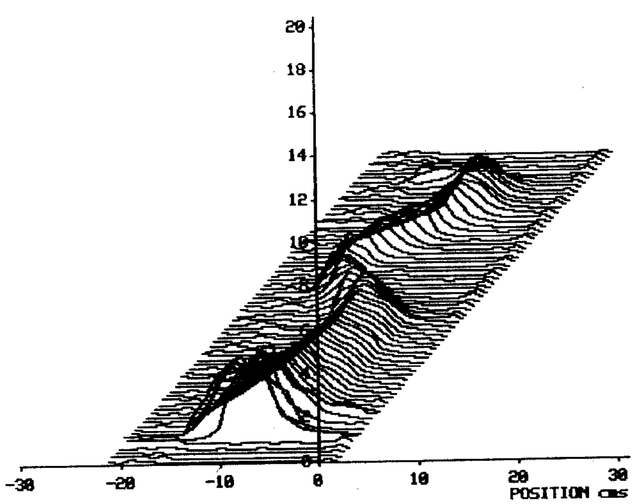


Fig 1: Output of synchrotron profile monitors during steering experiment.

The injection system (2) involves a 0.25 micron H^- stripper foil of 120 mm x 30 mm alumina with four 14,000 A kicker dipoles to control the orbit during the 400-500 μs injection period. As shown by Figure 2, this system has worked well and 10^{13} ppp have been circulated at 70 MeV without signs of saturation.

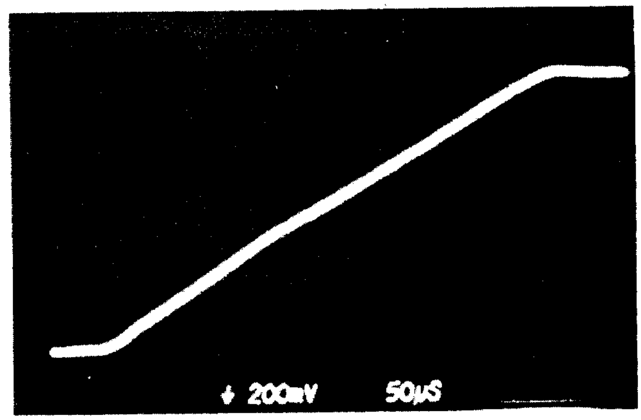


Fig 2: Build up of protons to 10^{13} level during 400 μs injection period

The kicker magnets, which are single turn magnets in series and in the vacuum, have run successfully to 25 Hz and for a short time at 50 Hz. A short from the kicker ceramic-coated conductor through the ferrite core to the rf shield around the ferrite caused heating and melting of the ferrite. A laboratory simulation showed that a 100 mm thick block of the high permeability but low resistivity ferrite (1 ohm.m) would form a runaway conductive path when subjected to a 150 V, 50 Hz, 20A power supply. Extra insulation has now been fitted and individual blocks of ferrite isolated.

The extraction system with its 3 push-pull ferrite fast kickers has been commissioned successfully to 50 Hz at the 550 MeV level. A small batch of apparently faulty capacitors in the delay lines had to be weeded out in the process. The 200 ns rise time required to match the time between the two proton bunches has been achieved. Figure 3 shows a composite of two bunches in the synchrotron followed by the two bunches in the first part of the extraction line on the occasion of first successful extraction.

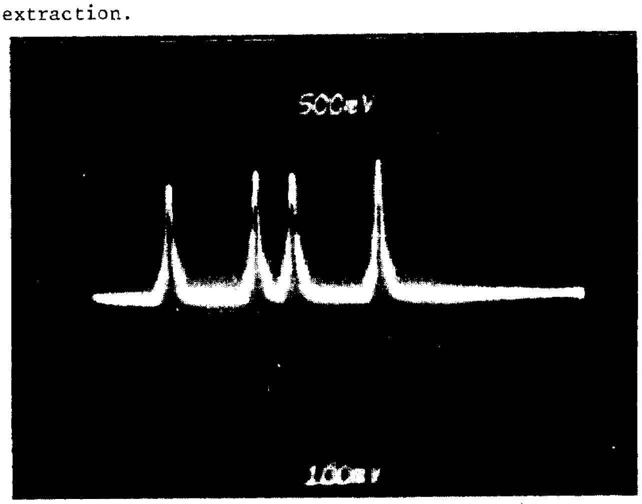


Fig 3: A composite of beam pick-up signals in the synchrotron and the same two bunches at the beginning of the extraction line.

The extracted proton beam line, some 150 m in length and containing 65 magnets, was set to theoretical values for transport tests and the first pulse to be tried was seen on a dump target 20 m before the main neutron target. In the synchrotron room the extraction line takes the beam from above the synchrotron down to the level of the neutron target and there are five horizontal bends totalling approximately 90° also in the synchrotron room. In the tunnel to the target station there are two small bends. Horizontal and vertical correction magnets are provided. Profile monitors are installed along the length of the line. Measurements of beam profile show a good match to theoretical predictions.

Synchrotron Beam Measurements

It has been found that at about 2×10^{12} ppp the signal induced in the rf cavities reduces the accelerating voltage. As mentioned earlier, a second amplifier chain has been installed and this will be powered open loop to cancel out the induced voltage.

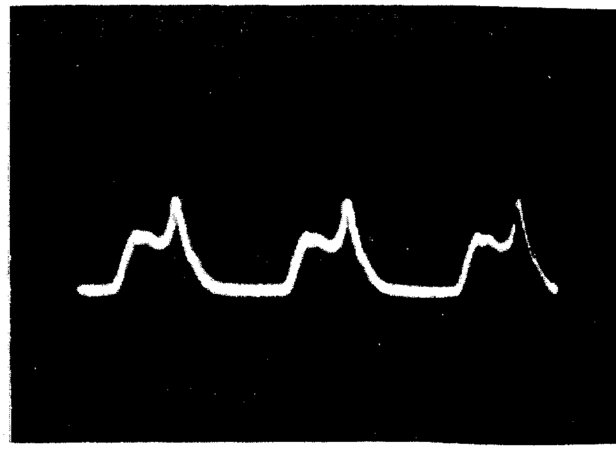
Also at about the 2×10^{12} ppp, longitudinal instabilities are seen within the beam pulses. These are repeatable pulse to pulse. Figure 4 shows the longitudinal structure at various times. Especially noticeable are the very short spikes in Figure 4(b). The initiation of the instability might possibly come from having too small an energy spread from the debuncher. The simulation shown in Figure 5 gives a double-humped pulse 200 μs after rf switch-on for an energy spread of ± 50 keV. For ± 150 keV a single distribution is found. The simulation will be improved by tracking larger numbers of particles and by taking it to 1500 μs.

The debuncher will be tuned to give a larger energy spread.

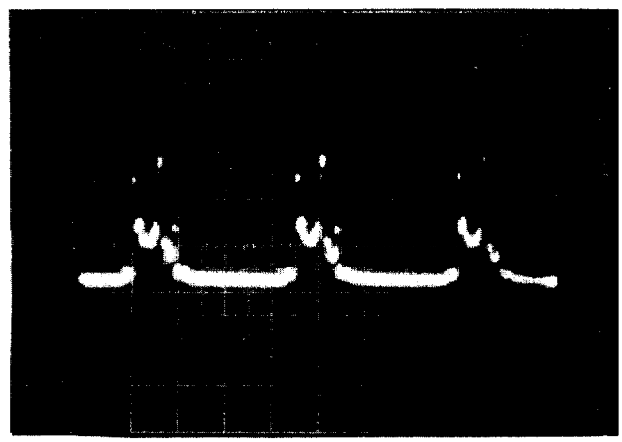
Control System

The control system uses three mini-computers for control of the injector, synchrotron and the target station and one for servicing the control console and signal transmission. The computer system also multiplexes an analogue waveform system. The high level interpretive language GRACES has proved effective in allowing equipment designers to write programs for control of their equipment. The control system has worked well during the commissioning period. Two touch panels were used at the MCR console for interaction with the computers. Tuning of the system still continues and a start has been made on modifying individual programs to provide a set of operations orientated programs.

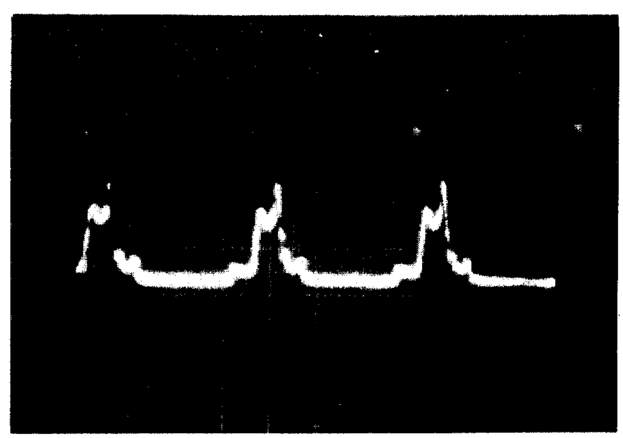
Fig 4: Beam bunch shapes at different times 200 ns/div



a) At ½ of first synchrotron oscillation

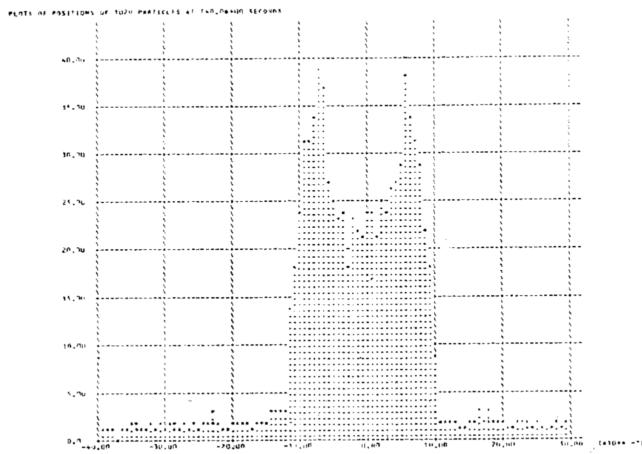


b) 1 ms after rf on

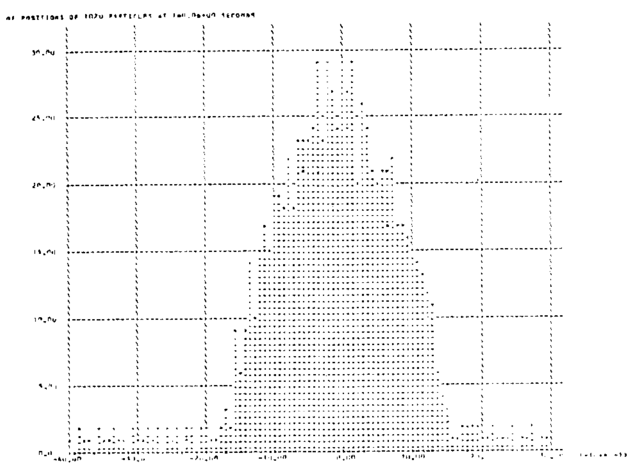


c) 2 ms after rf on

Fig 5: Tracking of particles.
Bunches 200 μs after rf on



a) ± 50 keV input energy spread



b) ± 150 keV input energy spread

Target Station

The target consists of plates of depleted uranium clad with zircaloy. For the December run the target was filled with static heavy water. Above the target are two poisoned water ambient temperature moderators. For the December run these were filled with static water. Below the target are two cryogenic moderators, one filled with supercritical hydrogen at 100K and the other with liquid methane at 25K. For the December run both refrigerator systems feeding these moderators were working successfully. Surrounding the target and moderators are reflector tanks containing beryllium rods and heavy water which, for the December run, was static. The target/moderator/reflector assembly is cantilevered from the door which closes up the back of the stainless steel target void vessel which is 3.2 m diameter and 3.8 m high. The void vessel contains helium gas as an inert atmosphere for the cryogenic moderators and to provide minimum neutron absorption. For the December run the assembly therefore provided the design neutronic arrangement. The bulk shielding of the target station is a 4.3 m thickness of steel and concrete. Six of the 18 2m thick and 4.4m high beam shutters supported within the bulk shield were in the open position.

The target/moderator/reflector assembly with the 90 ton door completing the target shield are on rails so that the assembly can be withdrawn into a remote handling cell fitted with two zinc bromide windows. Four remote manipulators allow assembly and removal of the target module. Also on the same rails is a door closing up the remote handling cell and two services trolleys in the shielded services area. One contains the methane refrigerator and hydrogen cold box for the cryogenic moderators, the other carries the heavy water cooling and circulating equipment and ambient moderator services. Breaking of circuits of radioactive coolant is done only in the remote handling cell. Since the December run further controls have been fitted to the cryogenic services to allow more automatic control of the systems. The coolant systems have been completed, tested and control set up through the target station computer. Ventilation systems have been installed for the remote handling cell and the services area.

The bulk shielding has been completed including the installation of a beam pipe which will allow samples to be placed in a position close to the target where there is a good yield of fast neutrons.

Controlled collimation of the neutron lines comes right to the surface of the target void vessel windows through the shutters and through removable shielding in the insert boxes. In one case a neutron guide goes right through the shielding. For one neutron line a chopper is installed within the bulk shielding.

Neutronic Measurements

The results of the neutron measurements made using six experimental sets of equipment during the December run are being reported fully (8). Fluxes for all moderators and time structure for the two ambient moderators and for the methane moderator were exactly as computed. The pulse length from the hydrogen moderator showed some cross-coupling giving a slightly extended pulse. A decoupler has now been fitted to cure this effect. The transmission of the 95 m and 30 m neutron guides were as expected. The detector systems all worked as expected and the data acquisition was working to provide first results minutes after first protons on to the target.

Running Plans

The procedure for starting up again was initiated on 7 May with the aim of putting the beam on to the target on about 20 May. Routine scheduling has been arranged until the end of the year. Part of the run-up will involve the correction of horizontal closed orbit using steering magnets to allow the beam scraper system to be set up to collect protons lost between 70 and 100 MeV. Also the beam loss monitors will be set up.

Five engineered spectrometers will be available to be followed shortly by a sixth and also three development instruments.

Acknowledgement

This paper reports an important step in the development of the SNS. A large number of people at RAL, especially in SNS Division, have put a lot of effort into the project and it is a pleasure to acknowledge this.

References

(1) G H Rees et al, A Pulsed Spallation Source for Neutron Scattering Research, IEE Trans Nucl Sci, Vol NS-24, No 3, June 1977, p989.

(2) V C Kempson, C W Planner & V T Pugh, Injection Dynamics and Multiturn Charge Exchange Injection into the Fast Cycling Synchrotron for the SNS, IEEE Trans Nucl Sci, Vol NS-28, No 3, June 1981, p3085.

(3) J R J Bennett & R J Elsey, Glass Jointed Alumina Vacuum Chamber, IEEE Trans Nucl Sci, Vol NS-28, No 3, June 1981, p3336.

(4) G H Rees, Features of the Beam Dynamics for the SNS Synchrotron, IEEE Trans Nucl Sci, Vol NS-28, No 3, June 1981, p2125.

(5) R T Elliott, J A Lidbury & M R Harold, Synchrotron Magnets for the SNS, IEEE Trans Nucl Sci, Vol NS-26, No 3, June 1979, p3922.

(6) B Boardman et al, Spallation Neutron Source: Description of Accelerator and Target, RL Report RL-82-006, March 1982.

(7) G H Rees, Status of the SNS, IEEE Trans Nucl Sci, Vol NS30, No 4, Aug 1983, p3044.

(8) A J Leadbetter et al. First neutron results from SNS. Report RAL 85-030.