ISIS Status Report

Ian S K Gardner
Rutherford Appleton Laboratory
Chilton, Didcot , Oxon, England.

Abstract

The recent accelerator development programme leading to increased operational intensity and to improved reliability of the ISIS pulsed neutron source is outlined. The methods used to control, minimise and measure beam loss are described. Some data on induced activity levels are given. The competing effects for accelerator component protection and spallation target survival are discussed.

1. INTRODUCTION

1.1 Facility Description

The ISIS facility is based on a 70 MeV linac, an 800 MeV rapid cycling proton synchrotron and a spallation neutron target. The synchrotron was designed as a high current, low loss accelerator with H^- charge exchange injection. The main use of the proton beam is for pulsed neutron production from the spallation target. The incident beam power on the spallation target is 160 kW, delivered as two 100 ns pulses separated by 200 ns at a repetition rate of 50 Hz. The maximum, operational, mean beam current delivered to date is just over 200 μA, and this corresponds to a circulating ring current of 6.2 A dc.

1.2 *Uses*

The facility is also a powerful source of pulsed muons and neutrinos and in addition supplies a beam of scattered particles from a vibrating internal target for testing particle detectors for the high energy physics instrumentation development at RAL. Irradiation experiments are carried out using both the 70 MeV H^- linac beam and also the neutrons produced from the beam collectors in the synchrotron which are used to collect any beam which is lost during the trapping and acceleration processes.

1.3 *Operational Statistics*

The facility operates from 3500 to 4500 hours per year in 6 week cycles. User runs occupy 4 weeks of the cycle with the remaining 2 weeks being shared by maintenance, machine development and start up. Over 500 neutron scattering experiments were completed in 1993 and the ISIS neutron user community, which is international, is greater than 2000. Some operating statistics are shown in Table 1.

2. NEUTRON INSTRUMENT STATUS

The ISIS neutron instrument suite now numbers 15 and occupies 14 of the 18 available beam holes in the target shielding. The layout of the accelerator and instrument hall is shown in Fig. 1. As can be seen from the user statistics the average neutron experiment takes about 100 hours and scheduling of the large number of experiments requires a highly reliable accelerator, target station and set of neutron instruments, complete with a supply of sample environment equipment, such as cryostats, furnaces, pressure cells and magnets.The experiment programme covers the study of the structure, and the dynamic behaviour, of solids and liquids and includes most of the branches of science.

	1987	1988	1989	1990	1991	1992	1993
Scheduled user time (days)	176	182	178	167	175	145	149
Beam time on target (days)	128	132	131	131	135	122	126
Beam time on target (%)	73	72	73	78	77	84	85
Integrated current mAhrs	120	230	288	302	366	419	510
I_{pk}, 24 hr average (μA)	70	97	107	101	145	174	187
μAhrs per beam trip	6	18	31	61	44	63	75
Targets used	U1,U2	U3,T1	U4,T1	T1,U5	U5,U6,T1	T1,U7	T1
Neutron instruments	7	7	10	12	13	13	14
Neutron experiment reports	168	174	253	330	343	428	~500

Table 1. ISIS operating statistics. U=Uranium target, T=Tantalum target.

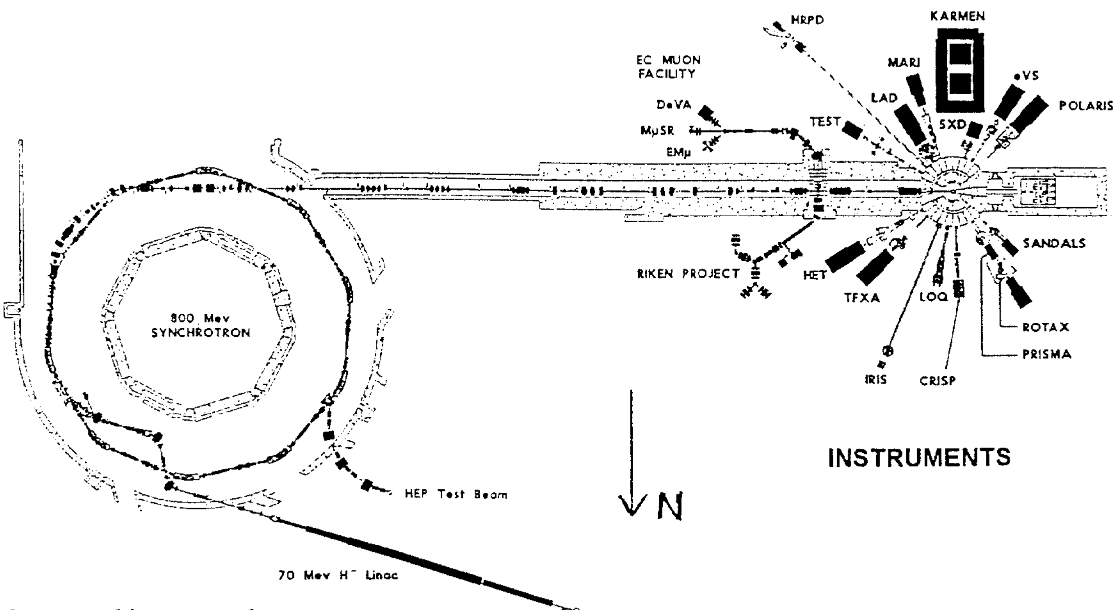

Fig. 1 ISIS accelerator and instrument lay-out.

3. MUON FACILITY STATUS

Muon beams are produced from a thin, water cooled transmission target made from graphite. Various thicknesses from 2.5 mm to 10 mm are used and the beam spot size at the target, which is 20 m upstream of the main neutron target, is about 20 mm diameter. The target provides surface or cloud muons for the EC Muon Facility on the South side of the experimental hall and pions for the decay muon channel on the North side. The EC-sponsored expansion of the original beam line was completed in June 1993, and allowed a 3-way split of the existing channel. Two μ^+SR instruments for condensed matter research are operational.

The muon project on the North side is funded by the Japanese Science and Technology Agency through RIKEN. This consists of a superconducting solenoid and a pulsed magnetic kicker magnet to distribute muons with momenta up to 55 MeV/c to 3 experiment ports. The first muons are expected in October 1994 and the scientific programme will include: μCatalised Fusion, $\mu^{\pm}$SR and muonium spectroscopy.

4. TARGET SUMMARY

Target Station development has continued in parallel with the accelerator development and the performance of the Uranium targets and the one Tanatalum target is summarised in Table 2. The Tantalum target is still operational but there are some measurable changes in its cooling characteristics. It will be replaced in the summer of 1994.

The Uranium targets have failed at the lifetimes indicated in Table 2. It is thought that thermal cycling due to beam trips may effect their lifetime and there is a compromise between minimising the number of gross thermal cycles on the target and turning the accelerator off in order to protect the accelerator components from irradiation due to lost beam. A new Uranium target has been developed with a much smaller grain size than the earlier ones, and it is anticipated that this will give improved performance due to the slower and more random radiation growth in the Zircalloy clad Uranium target plates. This will be installed in the Autumn of 1994.

	Gross Thermal Cycles	Integrated Current mAh	Neutron Production mg
U#1	Not measured	92.4	75
U#2	40000	53.1	52
U#3	10389	174.9	163
U#4	4147	138.8	128
U#5	5074	295.6	273
U#6	2628	126.1	116
U#7	1805	107.2	99
Ta#1	70746	1638.9	970

Table 2. Neutron target operating data. U=Uranium, T=Tantalum

5. ACCELERATOR SUMMARY

5.1 Recent Development Programme

In 1989, an improvement programme was started on the accelerators and beam lines following the signing of a joint funding agreement between the German BMFT and the UK SERC. This was aimed at increasing the operating intensity of the accelerators to the original design value of 200 μA and to increasing the beam availability to 90%. This specification was required for the neutrino experiment KARMEN to achieve good measurement statistics.

The first improvement was the replacement of the 3 pulsed ferrite extraction kicker magnets. The original magnets had been damaged by beam loss and voltage breakdown. The new magnets are designed for higher voltage and ease of maintenance when active. Since installation, they have required very little maintenance and the synchrotron energy has been increased from 750 to 800 MeV.

The number of programmable dipole correction magnets was increased from 4 to 6 for the horizontal plane and from 4 to 7 for the vertical plane. These allow the measured closed orbit distortion to be less than 3 mm rms throughout the acceleration cycle. In setting up the synchrotron, the orbit distortion is first minimised and then further small adjustments are made to ensure that the untrapped beam is all picked up on the six beam collectors situated in super periods 1 and 2. Figure 2 and 3 show a plot of the beam intensity and the beam loss [1] during the acceleration cycle.

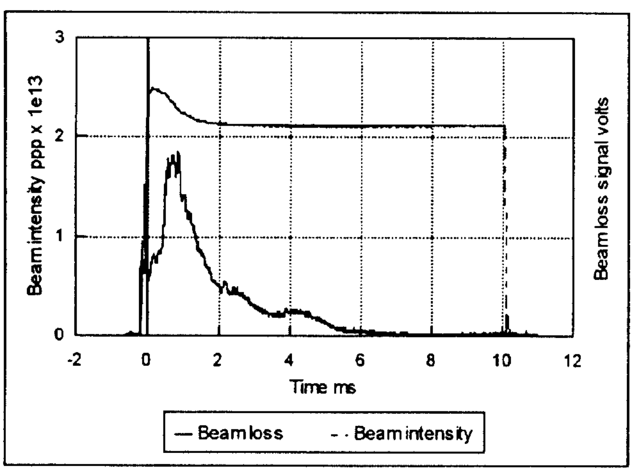

Fig. 2. Beam intensity and beam loss monitors sum signal during acceleration.

Although the original synchrotron design envisaged that the Q-values would only be altered during the multi-turn beam injection period, with minor adjustments for the rest of the cycle, it has been found beneficial to programme the Q-values throughout the full cycle. In addition 7^{th} and 8^{th} harmonic modulations of the 20 programmable quadrupoles

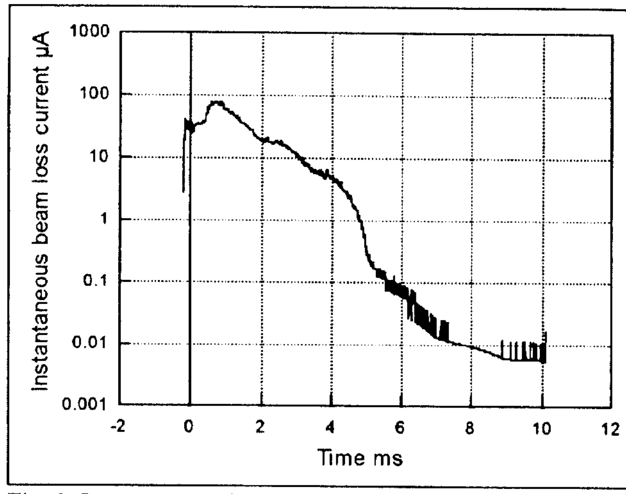

Fig. 3. Instantaneous beam loss current with time.

are used to minimise the beam loss during acceleration. The Q-value variation with time is shown in Figure 3 along with the calculated Q-values allowing for the maximum incoherent tune shift due to space charge. As can be seen the Q_h=4.0 resonance is crossed by some particles very soon after trapping. Small deviations from the Q-value locus shown result in large beam loss, as do increased closed orbit errors; the increase in betatron motion due to crossing the integer resonance for a closed orbit error has been estimated [2].

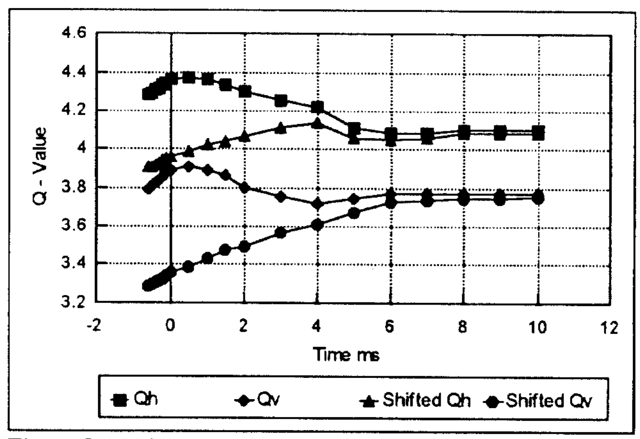

Fig 4. Q - value variation with time for low intensity beam and maximum incoherent tune shift due to space charge.

Two further factors dominate the maximum achievable beam intensity and these are the distribution of the horizontal and vertical betatron amplitudes of the beam during injection and the momentum distribution of the injected beam. A beam diagnostic system for measuring these parameters has now been completed to an initial stage. It makes use of a beam chopper in the 70 MeV H^- linac to ring beam transport line [3]. This selects a beam pulse of a fraction of a turn (200 ns) at any time in the injector pulse . Use is made of position monitors and a digital storage oscilloscope to track the beam pulse on many turns. The betatron amplitudes in each plane can be measured along with many other parameters of the synchrotron. In addition by measuring the rate at which the beam debunches then the momentum spread can be deconvoluted. Typical outputs from the system are shown in Fig 5, 6 and 7. The required variation of vertical betatron amplitude is produced by a programmable magnet in the 70 MeV beam transport line.

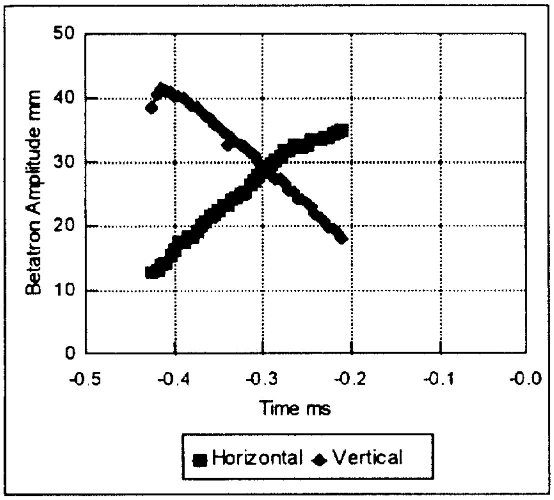

Fig. 5. Horizontal and Vertical betatron amplitudes during injection.

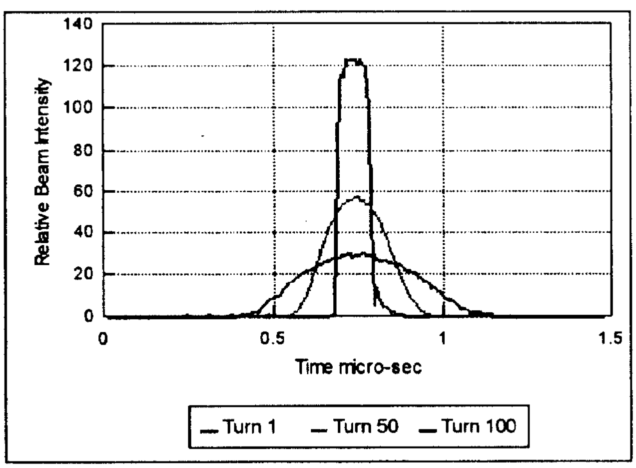

Fig. 6. Chopped beam pulse debunching over 100 turns.

The 6 RF accelerating systems in the synchrotron continue to work well following the change to the double 500 kW valve configuration. The feed forward beam loading compensation system [4] requires only occasional adjustment and copes easily with beam intensities of 2.5 10^{13} ppp. Beam phase and radial control loops are used to maintain stable operation.

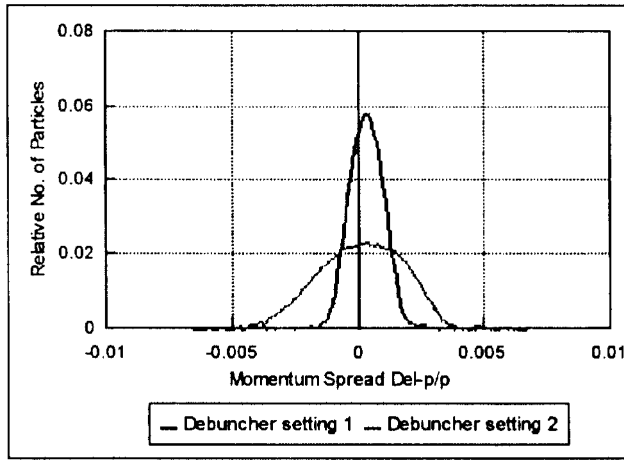

Fig. 7. Injected beam momentum spread for two different debuncher settings.

5.2 Induced Activity Levels and Beam Collection

The induced activity levels on the synchrotron and 800 MeV transport line have remained at the same level for some years now as the allowed rate of beam loss has been maintained at the same level although the operating beam intensity has increased. The sum of the radiation levels from 12 fixed monitor points on the synchrotron survey pillars, subsequent to beam turn off, are shown in Table 3. The beam loss protection system will turn the beam off following beam loss in one of five possible modes. These modes operate in different time periods with the shortest being 60 ms and the longest 500 ms. The system also detects the loss of beam other than on a beam collector, and if this is above a pre-set level this will initiate a beam trip.

Day 2 Radiation level μSv/hr	Day 20 Radiation level μSv/hr	Day 40 Radiation level μSv/hr	Day 60 Radiation level μSv/hr
353	194	150	116

Table 3. The sum of the radiation levels at the mechanical survey pillars following synchrotron shut-down.

6. NEW DEVELOPMENTS

6.1 Potential Developments

There are several potential developments of the ISIS accelerator and target that could enhance the facility and make it available to a larger number of concurrent users than at present. Such developments include a second target station operating at a repitition rate of about 10 Hz, and a radioactive ion beam source 10 or 100 times more powerful than any presently in existence. However, to introduce these facilities without reducing the performance of the present neutron, muon and neutrino fluxes, requires the intensity of ISIS to be increased.

Recent theoretical studies of the synchrotron [5] have shown that the addition of a second RF system working at twice the frequency would increase the intensity from 200 to 300 μA. Implementation of this system would require an increase in the linac current and this may be possible following the development of an RFQ pre-injector. Operation at 300 μA with 200 μA being delivered to the present target station as 2 out of every 3 beam pulses allows two 50 μA proton beams at 8.33 Hz for additional facilities such as a second target station and a radioactive ion beam facility.

6.2. RFQ Development

The RFQ development comprises an H^- ion source injecting into a Radio Frequency Quadrupole linear accelerator and is being designed to replace the present 665 keV High Voltage DC Accelerator, Low Energy Beam Transport and Bunching system. The present high voltage power supply is very old and it is becoming increasingly difficult to obtain spares for the system. The system also suffers from spark downs that discharge the accelerating column. The effects of these on integrated current have been reduced, but the basic problem remains. The high space charge forces, beam loading and the optical aberrations within the column also produce a deterioration in beam quality. The ion source, which fits inside the input end of the column, is not easily accessible.

The RFQ is designed to both bunch the beam and accelerate it to 665 keV at a transmission efficiency of greater than 90% (c.f. 60% with the present system). It should also be possible to obtain better optical matching and alignment into the Drift-Tube linac(DTL). The accelerating voltage for injection into the RFQ is only 35 keV and it will allow ion sources to be changed more quickly. The RF power drive for the RFQ will be identical to part of the existing amplifier chain powering the accelerating cavities of the DTL. Such a pre-injector system should remove the high voltage breakdown problem and improve the transmission efficiency and beam quality into the downstream accelerators.

6.3. Radioactive Ion Beam Source Development

The aim of this programme is to build a test bed facility for use on ISIS, to develop the technology to generate radioactive nuclei in a suitable target using a 100 μA, 800 MeV proton beam, and to produce ionised beams of selected species. The programme is part of a European and world-wide effort to produce a proposal for a radioactive ion beam accelerator. The test bed is being built off line and will be installed in the ISIS target station in 1996 for tests with the proton beam.

7. AKNOWLEDGEMENTS

This paper summarises some of the work of the staff of the ISIS facility.

8. REFERENCES

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