DIAGNOSTICS AND COMMISSIONING PROGRESS ON ISIS

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Abstract

Good progress has been made in increasing the intensity and reliability of ISIS, the spallation neutron source sited at the Rutherford Appleton Laboratory. The primary proton beam energy has been increased to 750 MeV, a muon source commissioned and the condensed-matter research programme using neutron scattering is well underway. Recent advances are described, together with some of the diagnostics.

Introduction

ISIS uses a 50 Hz proton synchrotron designed to accelerate 2.3E13 protons per pulse (184 μa mean) to 800 MeV [1]. These strike a U 238 target which is surrounded by moderators, providing thermal and epithermal neutrons used for experiments at up to 25 stations. A large detector (KARMEN) has been built to study neutrinos created from the target, and an intense pulsed source of 28 MeV/c muons of both signs, derived from an intermediate graphite target, has been brought on stream.

In the year ending March 1987, 2E4 μA-hours were delivered to the target at 550 MeV. For the last 12 months the figure is 1.5E5 μA-hours at an energy of 750 MeV. The intensity has increased by a factor of about three, and there has been a great improvement in reliability. The neutron yield has increased as a result of the higher proton energy.

Commissioning Progress

In April 1987, with a new extraction septum magnet in place and all 6 RF cavities operational, the energy was raised to 750 MeV. Neutron flux increases of 50% and 100% were measured from the forward and rear moderators respectively. The former figure agreed well with the (E_p-120) MeV law, and the enhancement in the rear moderator flux is due to the greater proton range in uranium and to the cascade development.

The muon target (2.5 mm of graphite) was moved into the 750 MeV beamline 22 m upstream of the U 238 target, the optics having been altered to give a small (20 x 30 mm) source size, and the beamline successfully tuned [2]. The μSR facility has been operating reliably since that time.

The injection beam bump magnets [3] were found to be overheating at 50 Hz, leading to a large horizontal closed orbit distortion during the injection pulse; cooling is presently being fitted. In addition, an aperture restriction was diagnosed. This was due to an RF shield plate in one of the dipoles which had become distorted, had moved into the beam path and been locally melted as a result. The distortion was probably caused by beam mis-steering.

August 1987 saw 2.6E13 protons injected and circulated in the machine, but fewer than half this number could be captured by the RF. Nevertheless, a record 9.7E12 ppp at 50 Hz (77.6 μA) were taken to the target and ISIS was set up to operate at 60 μA for neutron studies. A revised method of measuring Q-values (see below) was used to observe coherent tune shifts versus beam intensity. Changes of -.012 and -.038 were seen in the horizontal and vertical planes respectively at 1 ms as the intensity was increased to 7E12 ppp.

Longitudinal microwave and vertical transverse resistive wall instabilities have been observed, both in normal operation and in a 70 MeV storage ring mode of operation. Above 1E12 ppp, the coasting beam at injection develops longitudinal density perturbations at 202.5 MHz, which is interpreted as microwave growth of the residue of the linac bunch structure. Above 4E12 ppp, the growth saturates, with the subsequent damping enhanced on increasing the intensity. Observation is made via the analogue output of a spectrum analyser set at 202.5 MHz, with input from a high-frequency beam monitor (supplied by R L Martin, ANL). Microwave signals are also observed throughout acceleration but these are due to the non-equilibrium bunch distributions that arise from the non-adiabatic acceleration.

When used as a storage ring, the vertical resistive wall instability appears at the lowest coasting beam mode, $(4-Q_v).f$, where f is the revolution frequency, with enhanced growth rates as $Q_v \rightarrow 4$. In synchrotron operation, the instability develops too slowly to be observed during injection, but the $(4-Q_v)$ frequency is observed as a resistive wall head-tail mode in the 2 to 4 ms interval of acceleration. It appears with a node at the bunch centre, characteristic of head-tail mode m = 1. The expected mode is m = 2, suggesting a chromaticity lower than the design value (see below). To control the growth, trim quadrupoles are used to adjust the tunes during the cycle; these are set high up to 2 ms to offset space charge effects, but are reduced from 2 to 4 ms to enhance $(4-Q_v).f.$.

Altering the tunes as described, together with injection 'painting' of the vertical and horizontal phase planes, and varying the debuncher phase and amplitude and the RF beam loading compensation in the ring, allowed the peak accelerated intensity to be increased to 1.3E13 ppp (equivalent to 103 μA at 50 Hz) for 1.7E13 ppp injected. Following this development, the beam scrapers were adjusted for adequate machine protection and the normal operating current of ISIS was raised to 80 μA (1E13 pp on target at 50 Hz).

The chromaticities were measured at three points on the 10 ms acceleration cycle and found to be in fair agreement with prediction, though with a hint that at low energies, where $\dot{B}/B$ is a maximum, there may be some sextupole field component. A more thorough study of the chromaticity will be undertaken to determine whether correction sextupoles, for which space has been left in the lattice, will be required. Machine studies will also be needed to determine whether octupoles are necessary for full intensity operation.

Throughout the year studies continued on the linac injector, the injection transfer line (HEDS) and the extraction beamline (EPB), none of which is yet fully understood. The reliability of the linac modulators has greatly improved, but when the four tanks are properly phased it is not possible to inject beam efficiently into the machine. Recently the effect of the debuncher has been studied and it is thought that the working energy spread has been too small. In the HEDS there are small errors in the calibrations of the quadrupoles which cause the injected beam to be mis-matched to the synchrotron; accurate computer models of both the HEDS and the EPB are needed for matching purposes and to avoid any additional beam loss at the higher currents expected in the future.

During the year the U 238 target [1] was twice replaced. The failures [4] are thought to be fatigue in the cladding due to the large number of thermal shocks suffered, principally as a result of beam trips. Beam-loss and intensity monitors (see below) were set to trip the beam if a single pulse showed abnormal loss. The interlock system has now been changed to respond to average beam-loss over a predetermined time interval. This has reduced the number of trips by an order of magnitude. In addition, when the beam is restarted its intensity is increased gradually to the working level. No increase in machine induced-activity has been found to result from these procedures.

Diagnostics

665 KeV H^- beam emittance measurement

The system consists of two vacuum boxes spaced one metre apart; the first contains H and V water cooled slit plates (1 mm slits), and the second has two HARPS each having ten 1 mm diameter tungsten wires on a 10 mm pitch. The slits and HARPS can be positioned to an accuracy of ± .015 mm. Actuator control, data acquisition (via a Motorola 6800), data processing and graphics are under the control of a GEC 4070 computer. The system can generate an emittance plot in about 500 seconds at 2pps, and was instrumental (fig 1) in detecting a preinjector misalignment. The correction of this, together with improvements to the ion source, resulted in a doubling of the linac current to 13 mA.

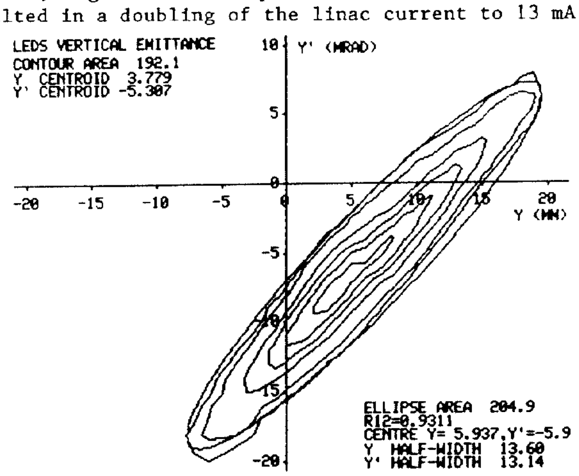

Figure 1

Beam Loss Monitors

The beam loss monitoring system (BLM) is vital to the high-intensity operation of ISIS, in order that 'hands on' maintenance can continue. Long argon-filled ionisation chambers [5], made from lengths of air-spaced coaxial cable, have a uniform, stable loss sensitivity per unit length, a signal risetime of 20 μsec after amplification, and are radiation hard. The system provides a sensitive, fast but qualitative measurement of beam-loss with a spatial resolution superior to that given by the comparison of two intensity monitors.

The hardware is divided into three subsystems covering the injector and HEDS (17 channels), the synchrotron (39 channels), and EPB (10 channels). Signals are processed to provide:-

a) three separate histograms giving a global view of the spatial loss distribution on a pulse by pulse basis. They have a linear horizontal scale (channel number or position) and a logarithmic vertical scale (beam loss). Figure 2 shows a typical synchrotron display, with the loss concentrated in regions where there are beam collectors.
b) a fast beam interrupt facility (injector system) which shuts down the beam when the measured loss exceeds a preset level.
c) an excessive loss warning display (EPB system). This histogram is initiated when the measured loss exceeds a software preset level.
d) a long-term log of beam-loss (EPB system). The system microcomputer integrates loss over 3E4 cycles (10 mins at 50 Hz) and transfers the data to the control computer for long-term storage.
e) wideband analogue waveforms (injector and synchrotron), showing the temporal distribution of loss during acceleration. Fig 3 shows a synchrotron current monitor waveform during acceleration, and (lower) the BLM signal from the extraction area.

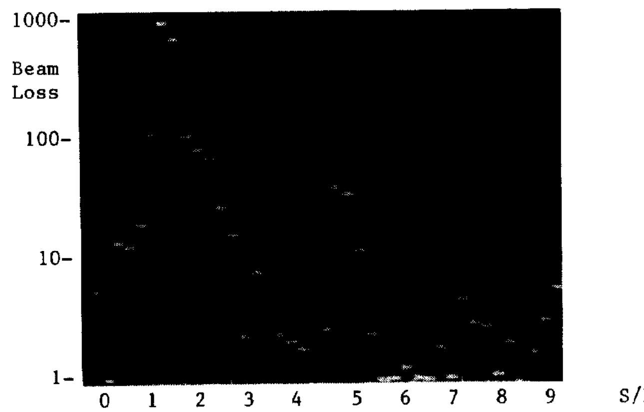

Figure 2

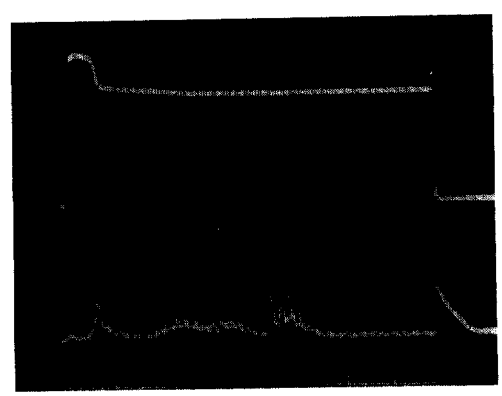

Figure 3

Accelerated Beam Monitors

There are five non-destructive beam profile monitors in the ISIS synchrotron. Two H and two V monitors are near the points of maximum and minimum beta, and a third H is near a point of maximum dispersion.

Electrons created by the accelerated beam ionising the residual gas are driven across the aperture by a transverse electric field of 50 kV/m. They pass through a narrow slit (1 x 30 cm) perpendicular to the beam direction in either the horizontal or vertical plane. A channel electron multiplier which traverses the beam behind the slit is used to measure the ionisation current. For a given position of the detector up to 100 sequential measurements of the current can be made in one 10 ms period of acceleration. These measurements are repeated and stored as the detector traverses the beam aperture in 5 or 10 mm steps. Thus the beam profile and position at any time can be produced from the data. Normalisation is provided by simultaneous measurement of the beam intensity throughout each cycle. The accuracy obtained for intensities up to 1E13 ppp is estimated at ±5 mm for width and better than 5 mm for position.

These devices have been used to check the calibration of the synchrotron beam position monitors. Information on beam width and position is also obtained during beam injection and prior to RF bunching. The onset of a vertical instability is shown in fig 4.

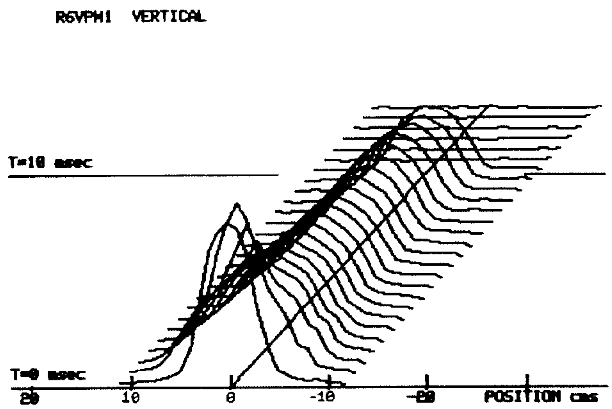

Figure 4

Beam orbit simulation

Beam orbit simulation programmes have been written to analyse the measured closed orbit distortions in terms of angular deflections and their azimuthal positions around the ring. Orbit displacements can be analysed for a best fit of up to 10 angular deflections at any specified locations. Measured data and the computed track for a horizontal correction magnet are shown in fig 5. The programme runs on an IBM PC/AT which can exchange data with the GEC 4070 control computers via an IEEE interface.

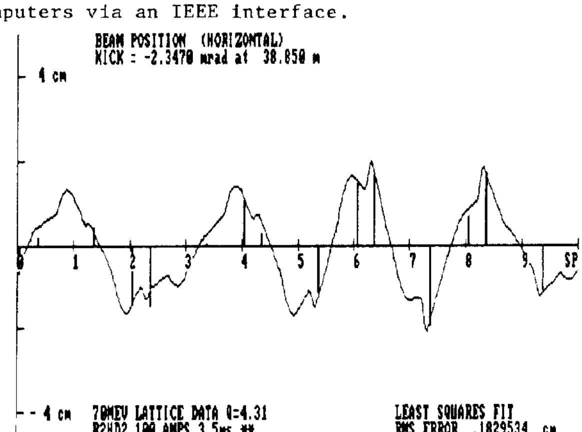

Figure 5

Q-measurements

Q-measurements can be made using a horizontal or vertical kicker to perturb the beam at any time during the acceleration cycle. The subsequent motion is detected using a BPM signal fed through a lowpass filter. The output of the filter is a signal of frequency (n-Q).f, where n is an integer. This output frequency ranges from a few kHz to 500 kHz, depending on the values of Q and f. The signal is sampled at 3.125 MHz and an FFT programme of up to 1024 points is used to determine the frequency spectrum. The software selects the highest amplitude frequency and this, together with the rotational frequency at the time of the kick, is used to compute the two possible values of Q. At present no allowance is made for the change in f during the sampling period, which is typically about 100 betatron cycles.

Beam Alignment

The linac beam alignment is not, in the medium term, completely stable, and it has been found convenient to automate four steering magnets (2 H, 2 V) which are interposed between the linac and the first triplet in the HEDS. The beam position and angle in both planes is read from two scanning-wire profile monitors upstream of the triplet, and correction currents for the steering magnets calculated from previously obtained steering matrices. Usually this results in the beam being aligned to better than 1 mm.

The EPB contains 7 H and 4 V bending magnets and 2 H and 2 V steering dipoles just before the muon target. Using signals from position monitors these are adjusted automatically to obtain a well-aligned beam in about 6 minutes, compared with the 30-60 minutes that used to be required for alignment. We plan to provide the same facility for the HEDS.

Future Plans

In the next two years it is expected that the available funds will allow the current in ISIS to be increased from 80 µA to 100 µA for routine operation, the aim being to achieve at least 90% reliability. One of the priorities during this period will be to modernise the controllers of the 100-odd beamline power supplies, most of which are over 20 years old.

It has not been possible to accelerate more than 1.3E13 ppp, even though 2.6E13 protons can be circulated at injection. This could be partly due to the closed orbit error, caused by the injection bump dipoles, which should be eliminated shortly. The installed RF power is thought to be sufficient to accelerate 180 µA, so the main expense of advancing to the design current may well be the cost of buying sets of multipoles and their power supplies.

Regarding the exploitation of ISIS, ten neutron scattering instruments are currently scheduled and the number is expected to grow at the rate of about one a year; plans for the expansion of the pulsed µSR facility are well advanced and have a good chance of being funded, largely from abroad.

Acknowledgements

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