PROGRESS AT ISIS AND POSSIBLE FUTURE DEVELOPMENTS

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Abstract

ISIS has been designed and built as an intense spallation neutron source, based on a rapid cycling 800 MeV proton synchrotron and a depleted Uranium 238 target. The proton beam consists of two 100 ns intense pulses separated by a time gap of 230 ns and repeated every 20 ms. The present operating energy is 750 MeV and the mean proton current is greater than 100 μA. The proton beam is also used to produce pulsed beams of muons and neutrinos, respectively from a small transmission target and the main U 238 target. In this paper recent developments and progress in running at high intensity are discussed. Also outlined are two ISIS related conceptual design studies. One is for a possible future high intensity radioactive ion beam facility and one for a small holding ring to assist with muon catalysed fusion experiments. The future ion facility would use a variable fraction of the ISIS proton beam to produce radioactive ions in a variety of target sources. There would follow an isotope selection system and a series of post accelerators, including the ISIS synchrotron, to achieve an energy of up to 40 MeV per nucleon for the heaviest ions.

Introduction

ISIS now operates with mean proton currents of approximately 100 μA, corresponding to 1.25 10^{13} protons per pulse (ppp) at 50 Hz. Recent developments have been mainly to improve reliability and reduce the beam loss rather than raise the intensity. Areas receiving most attention have been the ion source and column, the synchrotron acceleration and extraction systems and the beamline magnet power supplies. Next for attention is the control system.

The peak intensity achieved has been 1.7 10^{13} ppp, reached after careful adjustments of the closed orbits in the ring and the radio-frequency (rf) feed-forward beam compensation systems. Closed orbits have been corrected using four steering magnets per plane with a scheme that makes allowance for small unknown errors in the beam position monitor signals. The new method for orbit correction is described, as are the developments on the ion source and column, the fast extraction kicker magnets and the control system. Improvements in the feed-forward beam compensation system are described in a companion[1] paper, but discussed here is the importance of reducing the initial inter-cavity phase transients for the six cavities.

Two ISIS related conceptual design studies have recently been undertaken. The first followed a request from the UK nuclear physics community to look at the feasibility of producing radioactive ions at ISIS, as at ISOLDE, CERN, but with a higher intensity and with the provision of post acceleration. Two types of main post accelerator have been studied, a linear accelerator and a fast-cycling synchrotron storage ring. The former has been studied at Daresbury Laboratory, the latter at ISIS, with energies up to 5 and 40 MeV per nucleon respectively for the heaviest ions. The provision of higher energy in the latter case is at the expense of beam brightness. In both cases a detailed design is needed to obtain realistic cost estimates and to confirm the feasibilities.

In this report some features of the synchrotron scheme are given, including the dual use of the ISIS synchrotron.

The second conceptual design study has been of a small holding ring for use with muon catalysed fusion experiments. For these, it is advantageous if the muons are delayed in a small storage ring while the background from the production target decays. A scheme for 40 MeV/c muons at ISIS is described which uses a very small weak focussing isochronous ring to store a 30 ns muon pulse for times up to 1 μs.

Ion Source and HT Column

Recent work has been aimed at reducing the number of trips as each one takes the neutron producing U 238 target through a thermal quench, which reduces its lifetime. The performance of the Penning type H^- ion source has been improved by increasing the available arc voltage and by adding filtering in the control electronics and the arc supply to damp a 15-20 MHz oscillation of the arc current. Efforts continue to increase the lifetime and output of the present source but a separate development is underway for a volume production multi-cusp source. A modification[2] has also been made to the electrodes at the high voltage end of the 665 kV column to give better shielding of the column insulators. The interval between column breakdowns is now about 5 hours, an improvement by at least a factor of three. There is a much greater improvement in the period immediately following an ion source change with the breakdowns at 5 hour intervals whereas previously they occurred every 5 minutes.

Orbit Correction

Harmonic correction of the closed orbit is chosen over other schemes because of the coherent betatron tune variation with intensity. A new technique has been adopted to obtain this harmonic correction. Four steering magnets and fifteen beam position signals are available for each transverse plane. Each steering magnet set may provide successively one of the following: one phase of a fourth harmonic correction, the orthogonal phase, with both of these introducing no odd harmonic excitation; one phase of a third (or fifth) harmonic, the orthogonal phase, and with both of these introducing no even harmonic excitation. Orbits are measured at three different tune values, eg 3.78, 3.86 and 3.94 for the vertical plane or 4.25, 4.19 and 4.13 for the horizontal plane. Harmonic steering magnet adjustments are made until the closed orbits show the minimum change for the different tunes. At this point it is assumed there is optimum fourth and third (or fifth) harmonic correction and that the residual signals correspond to the unknown monitor errors and the uncorrected orbit harmonics. Faulty monitor signals are rapidly identified and a Fourier analysis of the residual signals gives an indication of the scale of the monitor errors. The ring apertures are large and monitor errors are of the order ± 2 mm. Despite this, it is believed that the new technique allows orbit correction to better than 1 mm peak. Vertical closed orbits are corrected at T = 2 ms and 9.8 ms of the 10 ms acceleration cycle, whereas the horizontal orbit is also corrected at T = 0 ms, as there is some early radial variation of the orbit.

RF Feed-Forward Beam Compensation

Details are given in a companion[1] conference paper, and here is discussed only the effect of inter-cavity phase transients for the 6 rf cavities. The cavities are located in two groups of three on opposite sides of the ring, with diametrically opposite cavities operated in pairs. They operate on harmonic number 2 over a frequency range of 1.3 to 3.1 MHz. During injection, the separate cavities of a pair are powered in anti-phase for zero net voltage. After injection, the voltages are swung into phase within 30 μs, providing 3 kV per turn. Subsequently, after some initial bunching, the voltages are rapidly increased, reaching 70 and 126 kV peak per turn respectively after 1 and 5 ms of acceleration. It has been found that inter-cavity phase transients of a particular form are introduced after the transition from anti- to in-phase operation. The effect of these on the trapping have been studied by a 1-D longitudinal space charge tracking code (CRP). This has shown that, for a debunched injected beam of $1.4\ 10^{13}$ ppp, the trapping loss increases from 3 to 5.5 to 11.7 to 39 % for peak inter-cavity phase exursions of 0, ±5, ±7 and ±10° respectively. Reducing the transients has led to more stable operation, with typically 10 % loss for accelerated beams of $1.4\ 10^{13}$ ppp and 20 % loss for $1.7\ 10^{13}$ ppp. At the higher intensity, the enhanced loss is not understood, but increased beam loading and transverse and longitudinal space charge all play a role. The complexity of the trapping is shown by the computer plot of Figure 1 for the longitudinal distribution of a high intensity beam at T = 1 ms.

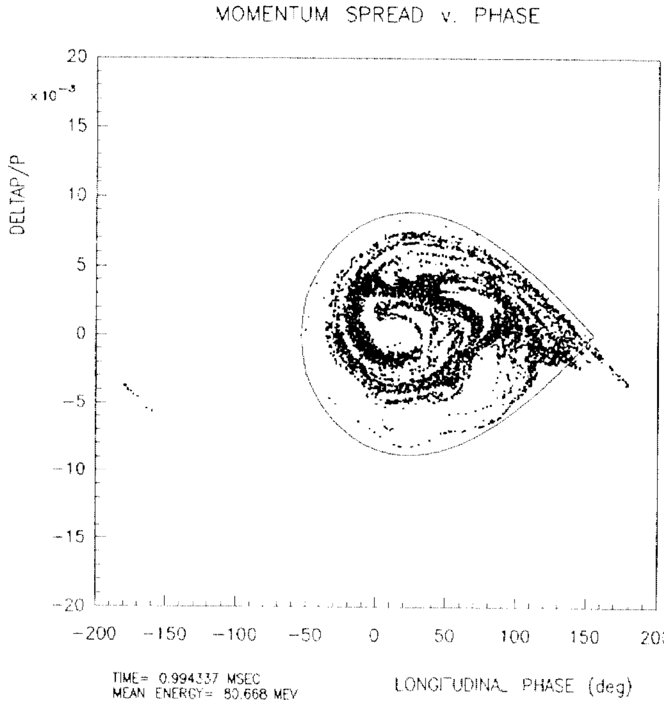
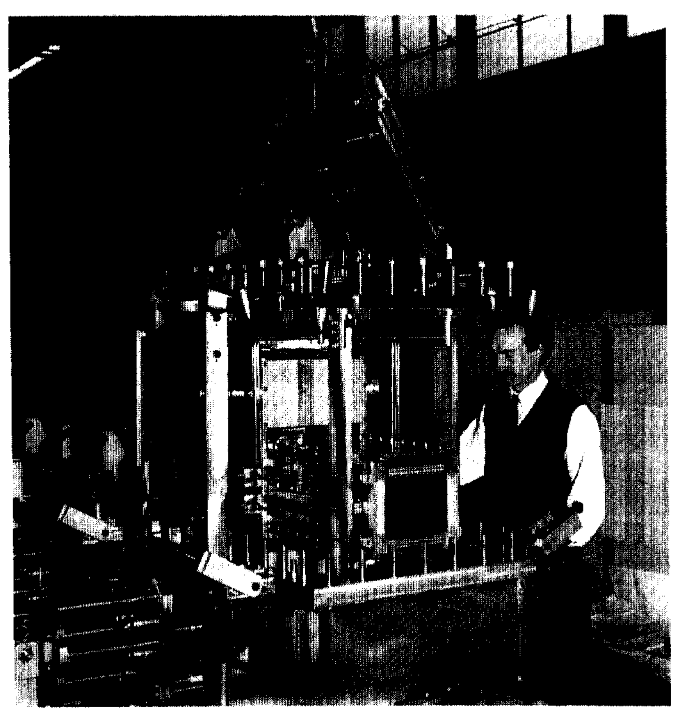


Figure 1. Longitudinal Distribution at T = 1ms

New Fast Kicker Arrangement

The present fast kicker magnets have operated since the start-up of the machine in 1984, despite becoming damaged[3] and activated in 1988. There are 3 push-pull lumped kickers, all located in one straight section of the ring and provided with 6 high current pulser systems. Damage to the upper high current conductor of one kicker unit was discovered in 1988 and a decision to replace the entire straight section was made in 1989. A completely new kicker arrangement is now assembled and is to be installed shortly, to be powered by the existing pulsers. The mechanical re-design has concentrated on improving the arrangement for the input feeder cables and the ease of removal of the individual magnets. Thus, the 6 pulsing systems each have 7, 50 Ω input cables in parallel, feeding into the vertical side walls of the kicker housing via flexible bellow units, while the 3 push-pull kickers are mounted individually via the top of the housing. Kickers and cables may all be removed independently. This is in contrast to the original design which is difficult to disassemble and repair and also highly active. A photograph of the new arrangement is shown.



Photograph of New Fast Kicker Magnets

Computer Control System

This uses 4 GEC 4070 computers with software in an interpretative language GRACES. Programs are called via touch screens, and the system has been extended with 2 IBM AT's which have increased the processing power. A replacement system is now being investigated, however, for there are data transfer problems between the two computer types due to the large number of monitor and alarm scheduled programs on the GEC's and due to the non-availability of certain spares. A commercial Vista Control System product, based on Vax workstations, has been chosen which will be able to re-create 800 of the existing 1000 programs and with ethernet connections, data transfer problems should disappear. The remaining 200 applications programs will be re-written in FORTRAN or C; a GRACES-to-FORTRAN translator may be written to facilitate this.

Future Developments

As funding becomes available it is planned to incorporate the following: an improved or new ion source, a power amplifier for the debuncher cavity in the injection line (which is currently powered from the fourth linac tank), 2 additional steering magnets per transverse plane, improved programming for the trim quadrupole power supplies, additional diagnostics, an increased power capability for the rf system, 6 sextupole and 8 octupole magnets and associated power supplies. These are to provide, respectively, increased injected beams, greater control of the input beam momentum spread, improved closed orbits, harmonic correction for gradient errors, improved input matching, greater control for rf beam loading and chromaticity and transverse instability control.

Radioactive Ions at ISIS

The proposal for radioactive ions at ISIS includes: the transport of 25 or 50 % of the ISIS high energy proton beam to a shielded target region, below ground, in the unused ISIS experimental Hall 1; the development of remotely handled high power target-ion sources; the separation of the extracted isotopes; and the post acceleration of the selected radioactive species. The low ion source platform voltage gives initial ion energies of 0.75 keV per nucleon, though twice this value is also being considered. Charge state 1 is assumed for elements up to mass number $A = 80$, charge state 2 for $81 < A \leq 160$ and charge state 3 for $161 < A \leq 240$. This allows the use of a single RFQ linac for the first stage of acceleration to 50 keV per nucleon. Two options are considered for higher energies; in the one, the RFQ feeds a superconducting linac while in the other, it feeds a synchrotron-storage ring which is used in conjuction with the ISIS synchrotron. The peak energy available with the first option is 5 MeV per nucleon; that for the second is much higher, but with a reduced beam brightness. Here, the second option only is discussed.

The idea is to build a second fast cycling synchrotron at ISIS, in an extended Hall 1, with the same value of mean radius and peak bending power as in the present ring, R = 26 m and $B\rho$ = 5 Tm. It would operate at 12.5 Hz or less, with the cycle allowing up to 20 ms for injection, 20 ms max for acceleration, 20 ms or more for slow extraction (or for a storage ring mode) and 20 ms max for deceleration. Requirements are: multi-turn charge exchange injection, a low vacuum pressure, a narrow width metallic vacuum chamber, a flexible magnet power supply, a wide frequency rf system and efficient slow extraction. A gas stripper for injection is a key item, requiring an R & D study, as vacuum deterioration limits the ion lifetime due to electron capture or stripping. The ions are injected over 380 turns and must not return through the gas jet. This involves injection painting in both transverse and the longitudinal planes. The gas pressure must be better than 10^{-10} mbar so the chamber must be bakeable; the narrow width is to restrict the eddy currents in the metallic walls.

The new synchrotron may be used singly or together with the ISIS ring. For the former, the energies available are 20, 6 and 2.6 and for the latter, 183, 123 and 40.6 MeV per nucleon respectively for A = 9, 78 and 238. To achieve the higher energies, there is injection and partial acceleration in the new ring, transfer to and and further acceleration in the ISIS ring, and transfer back, stripping and final acceleration in the first ring, which has an appropriate field waveform. Details of the synchrotron based post accelerator are given in reference [4].

Muon Holding Ring for μCF

The ISIS muon beam has a very large emittance and momentum spread and a pulse structure similar to that of the high energy proton beam. For a muon holding ring[5] for μCF studies, therefore, a small circumference is considered, with single turn injection only of one of the two muon pulses per cycle. The smallest practical size is chosen, with a muon revolution time of 40 ns for 40 MeV/c muons, corresponding to a mean radius, R, of 0.6757 m. Assuming an isochronous ring, with fast injection and extraction, using 10 ns fall time electrostatic kickers, there results a 30 ns muon pulse from one of the initial 100 ns pulses. Alternatively, the ring may be enlarged to an R of 1.8582 m to retain the full 100 ns muon flux, and this involves a simple scaling of the proposed design.

Included in the proposed ring are 3 lattice magnets, 2 electrostatic kickers and 2 septum magnets. The 3 lattice magnets are 120° weak focusing sector bending magnets, arranged symmetrically, with their plane of bend vertical. The lattice has $Q_v = 0.77$, $Q_h = 1.208$ and $\gamma_t = 1.1$ for a muon γ value of 1.07. There are 0.35 T fields along the central bending radius of the lattice magnets, and a similar field is proposed for the septum units. Further details are given in reference [5] and a schematic lay out is shown below.

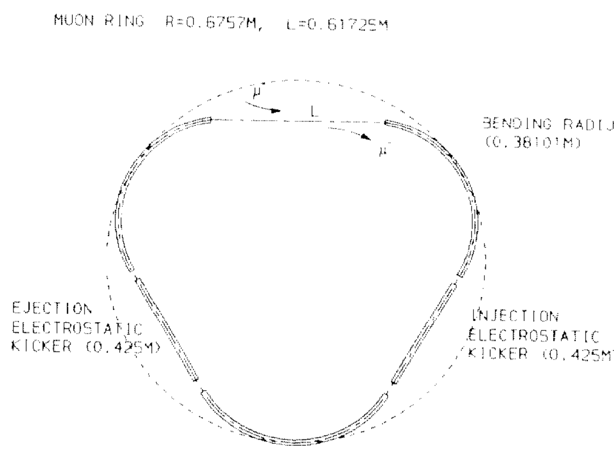


Figure 2. Schematic of Muon Holding Ring.

References

[1] P Barratt et al., "RF System and Beam Loading Compensation on the ISIS Synchrotron," this conference.

[2] M A Clarke-Gayther, ISIS Note/DIAG/N4/90.

[3] I S K Gardner et al., "The Relevance of ISIS Experience to the Design of Future High Intensity Synchrotrons," XIV International Conference on High Energy Accelerators, Japan, 1989.

[4] G H Rees, "A Synchrotron Based Post Accelerator for Radioactive Ions at ISIS," ISIS Note/ϕ/N1/89.

[5] G H Rees, "Design of a Muon Holding Ring for μCF or μSR Experiments," ISIS Note/ϕ/N1/90.