DEVELOPMENT OF THE ISIS SYNCHROTRON DIAGNOSTICS

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Abstract

Developments of the diagnostics system on the 800 MeV High Intensity Proton Synchrotron of ISIS, the Spallation Neutron Source at the Rutherford Appleton Laboratory, are described. Substantial hardware upgrades, including the addition of many fast digitiser channels, improved position monitor amplification, automated signal switching, a DEC Alpha Workstation, improved software for data processing and display, are outlined. The applications of the new system with both normal high intensity beams, and specially configured low intensity 'diagnostic' beams, are also summarised. The new information provided by the system will be a significant aid in set-up and optimisation of the machine.

1 DIAGNOSTICS UPGRADE

1.1 Background and Basic Aims

The ISIS Synchrotron [1] accelerates 2.5×10^{13} protons per pulse at 50 Hz. High intensity beam is established via charge exchange injection over 120 turns. Beam is then bunched and accelerated from 70 to 800 MeV in 10 ms, extracted in a single turn, and transported to the target.

The Synchrotron was built with a comprehensive suite of diagnostic devices, which provide all the information needed to run the machine. However, upgrades to the accelerator control system, and the associated increase in computer power, highlighted the potential for upgrading the diagnostics data acquisition. This upgrade, presently underway, makes fuller use of existing diagnostics, acquiring more detailed information and processing it appropriately. The hardware upgrade is based on the addition of many fast digitiser channels, with software switchable inputs, which can capture most beam derived signals. The dedicated Diagnostics DEC Alpha Workstation, incorporated with the Control System, controls data acquisition, provides power to process and display data, and can control most machine parameters. Automation will promote quick and simple measurements, with high level software providing convenient user interfaces. The increased amount and detail of information will help improve machine control.

1.2 Applications of the Upgrade

The main application for the upgraded system will be acquisition of transverse dynamics information from 20 capacitative position monitors around the ring. The other major application is acquisition of bunch shapes from a capacitative pickup, for studies in the longitudinal plane. Acquiring data from other diagnostics e.g. beam intensity toroids and beam loss monitors, is also planned.

1.3 Low and High Intensity Measurements

The ISIS diagnostics were designed primarily for measurements on high intensity beams, however, these have been complemented recently with the use of specially configured low intensity 'diagnostic' beams [2]. The upgrade will make increased use of these methods. Measurements of low intensity beams, occupying a small fraction of machine acceptances, yield much detailed and accurate information not available from high intensity beams, where interpretation is complicated by averaging and space charge effects. Appropriate diagnostic beams are produced by chopping the normal 200 μs injection pulse to ~100 ns (less than one turn), with an electrostatic kicker. These 'chopped' beams are <1% of normal intensity, which necessitates upgrades to amplification on all position monitors. The low power of chopped beams makes them an ideal 'non-destructive' probe.

1.4 Practicalities

On-line experimentation during operational running is made possible by switching many ring parameters to experimental values for 1 pulse in 128, leaving interleaved 50 Hz pulses unaffected. This is useful for experimentation with high or low intensity beams. In the latter case loss of the experimental pulse has negligible impact on neutron production. Automated experiments, using computer control of machine parameters and data acquisition, will exploit this ability for on-line experimentation.

2 TRANSVERSE MEASUREMENTS

2.1 Basic Method

The new information provided by the system is turn by turn positions at 10 monitors per plane. An example of betatron motion of the beam centroid as observed at a single monitor is shown in Figure 1. Least squares fit analysis [2] of this data provides accurate measurements of Q, betatron amplitude, phase and closed orbits. Data from many monitors on the same pulse are particularly valuable in eliminating pulse to pulse variations and making measurements fast. Most measurements will be possible with either chopped beams or at high intensity.

2.2 Basic Measurements

The turn by turn trajectories have obvious applications for **Q measurement**. High and low intensity values can be measured using the fast betatron kicker or a steering magnet. Low intensity measurements are particularly useful for ensuring the programmable trim quads are tuning the machine Q's correctly. Automated experiments, measuring Q as a function of each trim quad current, give the beta function at 20 locations and detailed checks on operation of hardware.

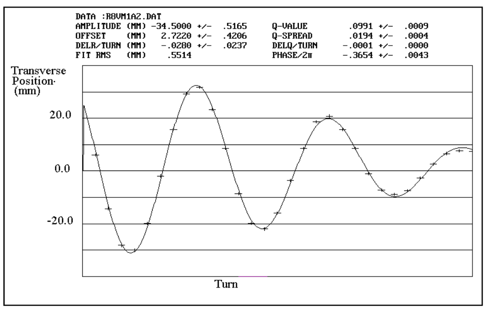

Figure 1: Example of Measured Betatron Motion

The system will allow more comprehensive **closed orbit control**, as well as providing information on turn by turn, and pulse to pulse variations in trajectories. Using automated experiments to scan through currents on all steering magnets, whilst measuring positions at all monitors, gives the 'steering matrices' for correction. Data from these experiments also give lattice information and checks on associated hardware.

Simultaneous measurement of transverse positions of beam centroid at many points around the ring, over ~30 turns, allows measurement of relative beta function at monitors and phase advance between monitors.

2.3 Use of Measurements for Set up

Work reported elsewhere [2] has provided much information on the **injection** process, including direct measurement of 'painting'. However, progress has been limited by the inability to measure closed orbits on AC coupled monitors at injection, when beam is unbunched. Upgraded high gain monitor amplifiers will allow orbit and trajectory measurement with chopped beams. This will give much improved control of injection.

Detailed knowledge of closed orbits and steering matrices will allow thorough **aperture checks** and facilitate the setting up of beam **collectors**, essential for machine protection. Lattice parameters measured all around the ring will improve ability to locate magnet faults and develop lattice models. **Extraction** set up will benefit from orbit control, knowledge of trajectories and improved lattice models.

2.4 Understanding High Intensity Effects

Use of chopped beams to accurately identify best machine set up, perhaps initially optimised empirically at high intensity, will aid systematic optimisation. Complimentary low and high intensity measurements, e.g. Q values, will illuminate high intensity effects. The new system will also allow more detailed studies of fundamental high intensity phenomena, e.g. instabilities.

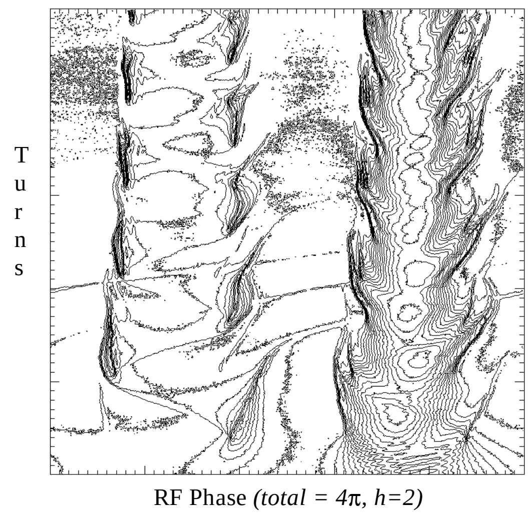

Figure 2: Example of Longitudinal Profile

3 LONGITUDINAL MEASUREMENTS

3.1 Basic Methods

The upgrade allows longitudinal pulse shapes from a monitor to be digitised over thousands of turns at high resolution, quickly providing detailed longitudinal information. Significant computing power is required for processing and display, where development of bunch shapes is calculated as a function of RF phase over many turns. Observation of chopped beams occupying small fractions of RF buckets reveals structure of phase space, e.g. Figure 2, where a bunch is captured unevenly between the two RF buckets.

3.2 Applications

At high intensity, observation of **trapping** and **acceleration** is of considerable interest. The dominant beam loss in the ring is during trapping. This process will now be open to detailed scrutiny, allowing correlation of longitudinal motion with RF loops and data from beam loss monitors. Work is underway to compare measurements with predictions from space charge codes. These studies are important for the proposed dual harmonic RF upgrade to ISIS [3].

4 HARDWARE AND SOFTWARE

The ISIS control system [4] consists of a cluster of DEC Alpha Workstations running the Open VMS operating system. These are connected via ETHERNET to CAMAC, MPX and STE interfaces for hardware control. The controls software is based on the VISTA Controls system, with custom written drivers which link VISTA to the various interfaces. Diagnostics data acquisition hardware and software were chosen to be compatible with these systems.

4.1 Outline of Hardware

The synchrotron ring position monitors each require two digitising channels. **Transverse measurements** use 10 position monitors and therefore require 20 digitising channels. The synchrotron revolution frequency ranges from 0.7-1.6 MHz. Sample rates of 100 MS/s with bandwidths of 100 MHz give the required signal resolution, whilst 250 kbyte record lengths allow 1000's of turns to be acquired. Twenty digitising channels are conveniently supplied using 5, four channel digital storage oscilloscopes (DSO's). **Longitudinal measurements** require data from one monitor digitised at 1 GS/s, with record lengths of ≥1 Mbyte per channel. These are also provided using a DSO. The DSO's are remote controlled using GPIB and include flexible customisable set-ups for beam measurements.

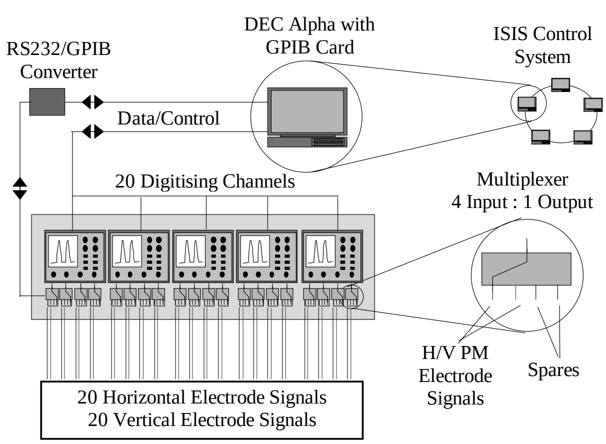

Figure 3 : Schematic of Diagnostics Upgrade

Each position monitor electrode has an amplifier with switchable gain for use with high and low intensity beams. Amplifiers are able to switch between two gain settings within 10 ms, to allow measurement of chopped beams during on-line experimentation.

Signal switching at the input of the digitisers is controlled using twenty, 100 MHz, 1 of 4 way, software controlled switching boxes [5]. These are controlled by GPIB. At present two inputs are used to switch between horizontal and vertical position monitors. Two spare inputs are available for future expansion.

The computer control for these systems is a dedicated DEC Alpha running Open VMS. This provides the necessary processing power for data analysis and display. The workstation is a node member of the cluster and offers full integration with the existing control system over ETHERNET. This allows direct access to synchrotron hardware control. A PCI slot on the DEC Alpha motherboard is used to house a GPIB card. Commercial drivers compatible with FORTRAN provide GPIB card control [6]. Figure 3 outlines the hardware.

4.2 Software

The diagnostics and control software uses two languages, FORTRAN and IDL [7]. Both languages have extensive application libraries and offer calling mechanisms to one another, providing a flexible development environment. Hardware control is driven by FORTRAN application libraries. These have been developed to provide GPIB remote control and data transfer operations for DSO's and switching units. This language is also used for low level calls to the ISIS hardware interfaces for synchrotron control. Graphical user interfaces for measurement control and data visualisation are written in IDL. Data analysis modules called from these interfaces are written in both languages. This choice of software has the additional advantage that it is largely platform independent.

5 STATUS AND CONCLUSIONS

5.1 Status

Most hardware is now installed and development of data processing software and measurements is well underway. Full use of the upgrade is envisaged for detailed beam studies in the years ahead.

5.2 Conclusions

Upgrades to diagnostics data acquisition on the ISIS Synchrotron are making much more detailed information easily available. This will be of great value in running and optimising the machine.

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