ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-WEPCC18

AN UPGRADED SCANNING WIRE BEAM PROFILE MONITORING SYSTEM FOR THE ISIS HIGH ENERGY DRIFT SPACE

D. M. Harryman*, C. C. Wilcox†, STFC Rutherford Appleton Laboratory, Didcot, UK

Abstract

The ISIS Neutron and Muon Source, based at the Rutherford Appleton Laboratory, begins with an injector line that accelerates an H^- ion beam to 70 MeV. The beam then travels through a High Energy Drift Space (HEDS) before passing through an electron stripping foil upon injection into the proton synchrotron, which provides acceleration up to 800 MeV.

During machine setup, beam profile measurements in the HEDS are taken using scanning wire monitors, which drive a single pair of measuring wires, one per plane, through the beam aperture using an analogue servo motor. Many of these monitors have been in operation since ISIS was commissioned in 1984 and as such are coming to the end of their operational lifetimes, meaning a new suite of monitors is required.

A prototype monitor has been developed along with new electronics and a control system to test the operation of a new drive mechanism based around a stepper motor and resolver, providing increased precision and reliability. This paper discusses the development of a new multi-wire monitor design, and the associated upgrade to the electronics and control system.

INTRODUCTION

The ISIS linac accelerates H^- ions to 70 MeV, producing a 50 Hz pulsed beam with a pulse length of 200 μs. This beam travels through a HEDS before injection into an 800 MeV proton synchrotron. After acceleration, protons are transferred into one of two Extracted Proton Beamlines (EPBs) and delivered to a tungsten target, driving the neutron spallation process.

Measurement of the beam's profile throughout the accelerator is vital during machine setup, whilst also providing valuable information during accelerator studies, and for understanding beam loss mechanisms. Three types of profile monitor are in use around ISIS: wire scanners and wire grid ('harp') monitors, which are both destructive to the beam [1]; and Ionisation Profile Monitors (IPMs), which provide non-destructive measurements. IPMs are used for profile measurements around the synchrotron ring, as any induced beam loss would quickly build to unsustainable levels over multiple orbits. Non-destructive profile monitoring at ISIS is described in further detail in [2] [3].

Destructive profile monitors are installed around the HEDS and EPBs and are crucial during machine setup, providing trusted and reliable measurements of the beam. Profiles are taken by moving conducting wires into the path of the beam and measuring the current generated by secondary electron emission, induced as beam particles pass through the wires. ISIS is operated at a slower rate of 1.6 Hz while these monitors are in use, reducing both the levels of induced beam loss and the risk of damage to the measuring wires.

Harp monitors are installed along both EPBs, consisting of retractable grids of wires which are inserted into the beam aperture using a pneumatic system. The grids contain 24 wires per plane with spacing set to either 6 mm or 10 mm, depending on the beam distribution in each location. Along the HEDS the beam is significantly smaller, with beam widths typically between 10-30 mm. As a result wire scanners are used here instead to allow higher resolution profiles to be measured, in addition to being cheaper to manufacture and causing less beam loss.

A single pair of measuring wires is scanned across the beam aperture by a motor driven linear stage, mounted at 45° to the beam (Fig. 1). As a result, wire displacement in both the horizontal and vertical planes is equal when the wire head is moved, with the distance travelled along each plane inversely proportional to the linear stage motion by a factor of √2. The wires are moved through the beam in horizontal and vertical steps, typically of 4 mm, and a reading is taken at each position to build up a 2D profile measurement over multiple beam pulses.

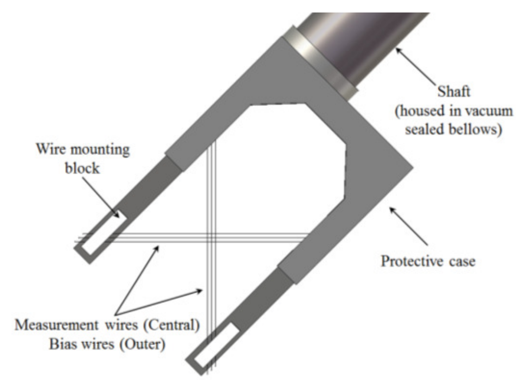

Figure 1: Orientation of a wire scanner head, with a signal wire and pair of bias wires mounted in each plane.

There are currently 15 wire scanners installed along the ISIS HEDS, many of which have been operational for over 30 years and have surpassed their design lifetimes. As a result a replacement programme is now underway, and a new monitor design has been developed alongside an upgraded control system and electronics.

MONITOR DESIGN

A prototype monitor of the new design has been built, tested and recently installed in the ISIS HEDS. The monitor offers improved measurement resolution and precision compared with existing monitors, in addition to enhanced reliability. As the motion undergone during measurement

* daniel.harryman@stfc.ac.uk
† christopher.wilcox@stfc.ac.uk

ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-WEPCC18

causes wear in several components, predicted lifetime usage was a key factor during the design phase. All components were selected to ensure a design lifetime of 20 years heavy use, corresponding to 8,000 scanning cycles.

Measuring and Bias Wires

Silicon Carbide (SiC) coated carbon wires with diameters of 142 μm are used for the measuring wires. This material is an ideal choice due to its rigidity and high emissivity, meaning it does not suffer from excess heating whilst intercepting the beam [4].

The wires are left unconstrained at their outermost extent to allow for thermal expansion to occur without causing damage. Instead the wires threaded through small guide holes cut into Macor® mounting blocks to ensure they remain aligned during operation.

Each measuring wire is flanked by a pair of bias wires (Fig. 1), these can be set to a positive bias voltage of up to 200 V to attract electrons emitted from the measuring wire, preventing recombination from affecting the beam-induced signal during measurement.

Motion System

A radiation hardened stepper motor, resolver and brake, manufactured by Empire Magnetics, is used to drive the linear stage and wire head through the beam (Fig. 2) [5]. Stepper motors rotate in small, discrete steps, ensuring highly accurate levels of rotation. Additionally a strong holding torque is generated while these motors are energised and at rest. An electromagnetic brake, released when supplied with current, is connected to prevent shaft movement when the system is not in use, and provides a safeguard in the event of power failure.

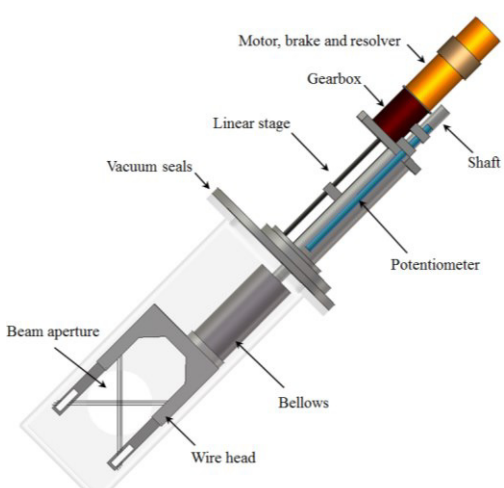

Figure 2: Simplified layout of the profile monitor.

A 5:1 gearbox is connected between the motor and the linear stage, providing extra protection from the compression force generated by the bellows when the wires are withdrawn from the beam aperture. The resolver provides a measurement of the wire positions, producing signals induced by the motor's rotations which are then passed through a resolver to encoder converter for processing in the motor drive unit. The overall system can theoretically measure the position of the wires to a resolution less than 0.1 μm, comfortably exceeding the precision required.

The scanning speed required is set by the reduced rate of 1.6 Hz at which ISIS is operated during measurement. Movement of the wires between each scan position is completed during the time between adjacent beam pulses, ensuring the profile is measured as quickly as possible.

Honeywell 9HM1 microswitches, suitable for use in radiation environments, are used as limit switches and positioned to set the linear stage stroke to 156 mm, 6 mm larger than the beam aperture [6]. When the monitor performs a profile scan, the wires are centred in the beam aperture relative to these switches, meaning precise switch activation positions are vital. During testing the switches demonstrated excellent precision, with the measured shaft positions at each limit undergoing variations of just 40 μm over 2,000 cycles of operation.

Direct Position Measurement

A linear potentiometer is attached to the monitor shaft, providing a secondary reading of the wire positions. This is useful for detecting slipping of the monitor's shaft position, which can occur over a number of years. It also provides a method of position measurement in the event of a power failure causing the motor control unit's encoder to reset. The potentiometer measures at a lower resolution of approximately 1 mm but is more robust and provides an independent safeguard to show if the wire head is positioned inside the beam aperture inadvertently. The voltages measured by the potentiometer range between 1- 4 V, chosen so that should anything happen to the 15 V supply fed to the potentiometer it would be instantly visible to the electronics.

Radiation Protection

The monitor's limit switches and motor systems were selected for their suitability for use in radiation environments, as previously mentioned. However these components are significantly more expensive as a result, and potentially unnecessary as in some monitor locations the expected dose is relatively low. To test these dose levels a TID (Total Ionisation Dosimeter) monitoring system, recently developed at ISIS, will be used to measure radiation levels along the HEDS, to test whether more cost effective components can be used on some of the new monitors [7].

ELECTRONICS

Setup

Two units are used to control the profile monitor: a custom motor control unit, used to control the monitors drive system and provide a live position of the monitor; and a National Instruments cRIO embedded controller, which interfaces with the ISIS accelerator control system and acquires data from the monitor [8].

ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-WEPCC18

Motor Control Unit

Figure 3 shows the main components inside the motor control unit, and how they interface with the embedded controller and profile monitor.

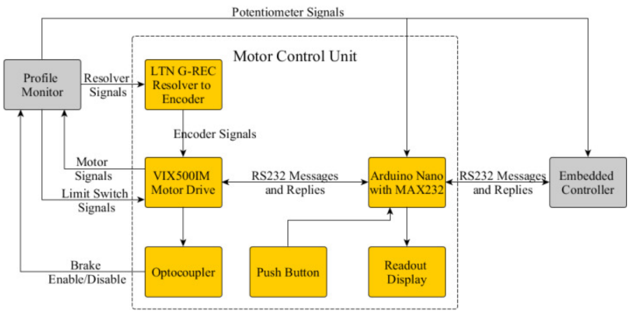

Figure 3: Block diagram of the motor control unit.

RS232 serial commands are sent to the motor control unit from the embedded controller, and are used to control the drive system. Inside the motor control unit is a VIX500IM stepper motor drive from Parker Hannifin. This unit converts the RS232 signals into the electrical signals that control the motor drive [9].

As the profile monitor produces a destructive measurement, it is possible that a failure in the embedded controller or the ISIS control system may result in the wires being inadvertently left in the beam aperture. As such, a requirement for the motor control unit is that the position of the linear stage can be seen on the unit, and that the drive can be used to directly move the measuring wires to a park position, outside the beam aperture, without the use of another system.

To allow for direct motor control, an Arduino Nano mounted on a PCB with a MAX232 IC and associated components are used [10]. The MAX232 is used to convert the messages sent and received from the Arduino and embedded controller from RS232 to UART and vice-versa. Under normal operation, messages sent through the Arduino between the embedded controller and the motor drive are simply passed through. When a push button, located on the motor control unit, is pressed to drive the monitor to the park position, the mode of the Arduino changes and it will ignore communications with the external RS232 port, replying to all messages with a "BUSY" response. The necessary serial commands are then sent to restart the motor drive, send the drive to the park position, engage the brake and turn off the motor.

Figure 4: Motor control unit readout display.

The Arduino is also used to display the position of the drive and other useful information. Figure 4 shows the display and the information shown on it. The displayed position is calculated from the voltage of the potentiometer, giving an absolute position measurement.

Also inside the motor control unit is an optocoupler and relay, used to step up a digital signal from the motor drive from 5 V to 24 V. This signal is used to enable and disable the monitor's electromagnetic brake (Fig. 2). As the VIX500IM expects an encoder signal, a resolver to encoder is also present in the motor control unit, specifically an LTN G-REC convertor [11]. All these components and their associated parts (such as power supplies) are mounted inside a custom 2U chassis. Connections to the embedded controller are made via the front panel and connections to the profile monitor via the back panel (Fig. 5).

Front

Back

Figure 5: Front and back panels of the motor control unit.

Embedded Controller

The embedded controller used for this application is an NI cRIO with a NI 9870 module for RS232 communication, and a NI 9205 module for analogue input measurements. The controller itself features a real-time processor and FPGA that are both programmed using LabVIEW. The analogue input and RS232 signals are routed from the modules into the FPGA; the FPGA then processes this data and sends it to the real time processor that will inter-face with the ISIS control system.

Currently this controller is used to interface between the ISIS control system and the motor control unit. Specifically it's used to control the profile monitors drive and acquire data about the drive from the VIX500IM and the potentiometer. It does not yet take profile measurements, as all fifteen wire scanners at ISIS are connected to a single data acquisition system. Eventually the profile measurements will be acquired by this system as more of the monitors are upgraded.

CONTROL SOFTWARE

Embedded Controller Software Architecture

The software used to program the embedded controller is written using object oriented LabVIEW code. Figure 6 shows how the different software classes interact and the threads that are run on the controller. Three of the threads;

ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-WEPCC18

Webservice, RS232 Serial, and Analogue Input Potentiometer, are run to interface with the different devices and systems used. API classes are then used to interface the Profile Monitor thread to these. The Profile Monitor class and thread is essentially a state machine that decides what action the motor drive should take given the data from the other threads and its current state.

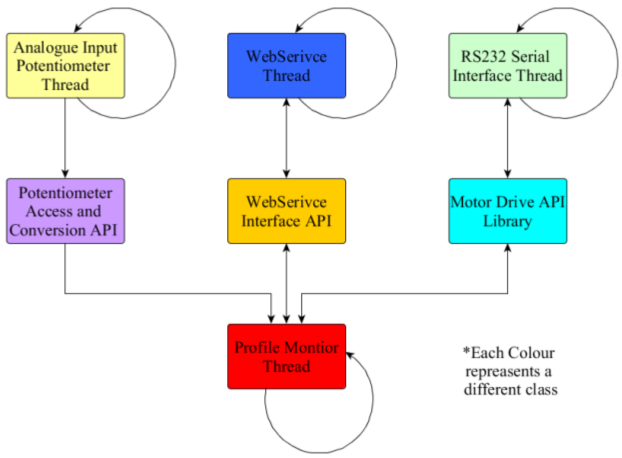

Figure 6: Software Architecture.

The RS232 interface thread manages the communication through the NI 9870 module to the motor control unit; a motor drive API library is then used so that the exact serial commands sent to the drive are abstracted away. The Analogue Input Potentiometer thread will constantly acquire data from the potentiometer, so when the Profile Monitor thread requests information about the potentiometer it will always be the latest value. The Webservice thread is there to host a number of networked variables on the embedded controller that can be interfaced with the ISIS control system. These variables and values are then used to decide the next state for the Profile Monitor state machine.

In its current configuration the software and hardware of the embedded controller can support up to four wire scanner monitors. In software all this would require is for more Profile Monitor threads to be initialised and spawned. More than four monitors are possible, however as the NI 9870 module only supports four serial ports this is its current maximum.

Control System Interface

The main control system used on the ISIS accelerator is Vsystem, from Vista Control System Inc [12]. Vsystem is a commercial SCADA solution that provides communication between many of the different devices and systems used at ISIS. Communication between different devices is made primarily over Ethernet. Databases and channels are stored and hosted by devices that communicate using Vsystem. For newer devices an XML file is hosted on the device that will specify the channels and their data types. HTTP GET and POST requests can then be made from the ISIS control system to update the database and channels hosted on the XML file.

The profile monitor hosts a number of channels to control its operation. At the start of each set of measurements a Boolean channel is set to True, starting a routine that will drive the motor into the reverse limit switch, edge off of it, and zero the encoder. This is done so that all measurements are taken relative to a known position. Other channels are used to enable movement of the drive, or set a desired position for it to move to. The encoder and potentiometer position as well as the limit switches are all read using these channels.

The data acquisition system for all of the wire scanners at ISIS hosts its own channels used to acquire the beam profiles. During operation, a Vsystem program is run, moving the monitors to the correct position and acquiring the beam profile, all via databases and channels.

FUTURE WORK

Following testing of the prototype monitor, the design has been revised to incorporate some additional improvements, and to address difficulties encountered during the process. This revised design will serve as the template for the rest of the monitor replacement programme.

The most substantial change is an increase to 18 measuring wires, nine per plane, to allow for significantly increased measurement speed over fewer beam pulses. By placing the wires 3 mm apart, the full beam profile can be measured with a single pulse, due to the small beam sizes in the HEDS. Finer resolution measurements will also be feasible, requiring far fewer beam pulses than the current system. To maximise the number of measuring wires available, the bias wires will not be included in the revised design. Testing has found these to have an insignificant effect on the existing monitors [13].

The monitor’s layout has also been rearranged to take advantage of the larger bellows that are required for the additional wires. The result is that it will be possible to remove the wire head whilst leaving the vacuum vessel and remaining monitor components in place. This will allow easier access for inspection and/or replacement of the wire head in the event of damage to the measuring wires, something that has been recently observed in some of the currently installed monitors.

Due to the changes planned for the profile monitors design, the electronics and software will be updated accordingly. To take profile measurements with the new style of monitor the channel count will need to be higher due to the larger number of measurement wires.

REFERENCES

[1] P. Strehl, *Beam Instrumentation and Diagnostics*, Springer, 2006, p. 105.

[2] C. C. Wilcox, B. Jones, A. Pertica, R.E Williamson “An Investigation into the Behaviour of Residual Gas Ionisation Profile Monitors in the ISIS Extracted Beamline,” in Proc. IBIC2016, Barcelona, 2016. pp. 807-810.

[3] P. G. Barnes, *et al,* “A Micro-Channel Plate Based Gas

ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-WEPCC18

Ionisation Profile Monitor with Shaping Field Electrodes for the ISIS H- Injector," in *Proc. IPAC2011*, San Sebastián, 2011. pp. 1371-1373.

[4] D. W. P. d. Boer, A. Pertica, "Thermal Simulations of Wire Profile Monitors in ISIS Extracted Proton Beamline 1," in *IBIC2016*, Barcelona, 2016. pp. 785-787.

[5] Empire Magnetics Inc. [Online]. Available: http://www.empiremagnetics.com/

[6] Honeywell, "9HM1" [Online]. Available: https://sensing.honeywell.com/9HM1-sealed-basic-switches. [Accessed 14 08 2017].

[7] D. M. Harryman, A. Pertica, "Online Total Ionisation Dosimeter (TID) Monitoring Using Semicondustor Based Radiation Sensors in the ISIS Proton Synchrotron," in *IBIC2016*, Barcelona, 2016. pp. 379-382.

[8] National Instruments, "The CampactRIO Platform," [Online]. Available: http://www.ni.com/compactrio/. [Accessed 09 08 2017].

[9] Parker Hannifin, "ViX250IM VIX500IM Stepper Drives User Guide," 2004.

[10] Texas Instruments, "MAX232x Dual EIA-232 Drivers/ Receivers," Feb. 1989. [Revised Nov 2014].

[11] LTN, "G-REC Resolver to Encoder Converter," Jun. 2016.

[12] B. Mannix, T. Gray "Vista Controls Vsystem at the ISIS pulsed neutron facility," presented at ICALEPCS 2007, Knoxville TN, Oct. 2007. unpublished.

[13] T. Kershaw, *Private Communication.* Aug. 2017.