MULTI-CHANNELTRON BASED PROFILE MONITOR AT THE ISIS PROTON SYNCHROTRON

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Abstract

The gas ionisation beam profile monitor is a well established piece of diagnostic hardware. The use of active devices such as Microchannel Plates (MCPs) and Channeltrons within such a diagnostic can present problems with gain differences between channels. At the Rutherford Appleton Laboratory we have produced a beam profile monitor that uses an array of 40 individually powered Channeltrons; these devices were chosen over the MCP for their robustness and longer lifetimes. These Channeltron devices (like MCPs across their surface) can suffer from large variations in gain at the desired operating voltage. We have successfully shown that an additional in-built calibration system using a single, motorised, Channeltron can overcome these issues. We report on the work to build the calibration system, and the 40 Channeltron array. The PXI (National Instruments) system used to control the motor drive and provide the data acquisition is also covered. Also we report on the new high voltage drift field to reduce space charge effects on the beam profile. Ongoing work on understanding how the drift field as well the beam field affects the measured profile is also discussed.

INTRODUCTION

The ISIS facility at the Rutherford Appleton Laboratory is currently the world's most productive neutron spallation source. The rapid-cycling proton synchrotron operates at 50 Hz and accelerates two proton bunches (total of $\sim 3.5\times 10^{13}$ protons) from 70 MeV to 800 MeV within the 10 ms acceleration period, delivering a total beam power of ~0.24 MW to the target. Accurate determination of the beam profile is important for improving injection and acceleration efficiencies as well as helping to reduce beam loss. Recent major upgrades to ISIS, like the 2nd harmonic system and Target Station 2, have resulted in higher beam currents within the accelerator ring. This increase in beam intensity has placed even more emphasis on the need for faster, more accurate profile monitors. This need has led to our current upgrade programme aimed at improving the ISIS profile monitoring systems.

ISIS RING PROFILE MONITORS

The original, and still used, gas ionisation profile monitors installed in the ISIS accelerator ring employ a single electron multiplier (Channeltron) to measure the +ion current produced from the interactions between the proton beam and the residual gas in the beam pipe. The single Channeltron profile monitor (SCPM) measures the beam profile in one plane only. The Channeltron is either stepped horizontally across the top of the proton beam or moved vertically up one side of the monitor. In each case the Channeltron covers a total distance of 240 mm in 5 mm steps. A high voltage drift field (30 kV) sweeps the +ions into the Channeltron device. At present we have five of these SCPMs, three measuring the horizontal plane and two measuring the vertical plane. Using these devices real-time profiles cannot be obtained because the mechanical system takes several minutes to complete each scan. The desire to obtain real-time profiles for setting up the synchrotron and carrying out machine physics studies of the ISIS beam has prompted the development of a new multi-channel profile monitor. This new monitor has an array of 40 fixed Channeltrons spanning 240 mm across the beam thereby allowing it to simultaneously collect beam profile information.

EVOLUTION OF THE MULTI-CHANNEL PROFILE MONITOR

The Channeltrons are manufactured by the company Photonis [1] (previously Burle Industries) and are their standard 4800 series device. These Channeltrons have a collection aperture of 15.75 mm × 4.5 mm and a gain of $\sim 10^4$ when biased with -1300 V (our normal operating voltage). An example of a 4800 device is shown in Figure 1.

Figure 1: Channeltron on left is the 4800 series of the Channeltron array. On the right is the 4700 series still used in the old SCPM.

The decision to use Channeltrons rather than a Microchannel Plate was influenced by a number of factors. As the existing single-channel profile monitor already used a Channeltron (Photonis type 4700 device, shown in Figure 1) we already had a good working knowledge of this technology. The 4800 series device is small enough to assemble into an array giving a 6 mm centre to centre spacing, which is similar to the 5 mm step size of the existing motorised system. The smaller device also offered the same electrical characteristics as the older 4700 and therefore we could use the same front end electronics as our DAQ system. We also considered the fact that Channeltrons are easier to handle than MCPs, they are more robust and have a greater lifetime, (roughly 10 times). Also, as the beam at ISIS is relatively large where the profile monitor is positioned (~100 mm) this means we have sufficient data points using a Channeltron array (with 6 mm spacing) and do not require the finer resolution that can be achieved using an MCP and custom anode assembly.

This first multi-channel profile monitor (MCPM) was a horizontal plane monitor and the design consisted of 4 Macor (machine-able ceramic) blocks, each housing 10 Channeltrons to form a 40 detector array [2, 3]. The completed monitor can be seen in Figure 2. All 40 Channeltrons were powered from the same 0-2.5 kV power supply. Initial measurements with this design highlighted significant variation in the gains of individual Channeltrons, shown in Figure 3. This meant that the MCPM would need to be calibrated in order to recover the true beam profile.

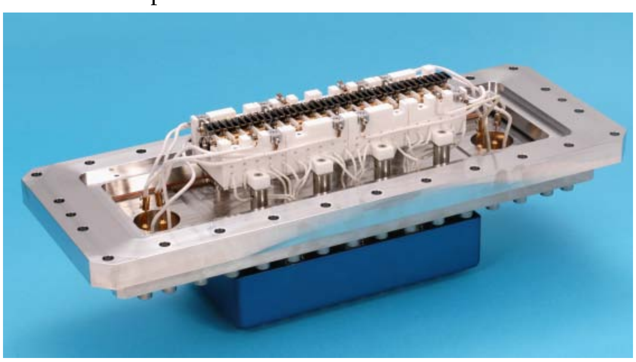

Figure 2: First generation multi-channel profile monitor using a (40) Channeltron array.

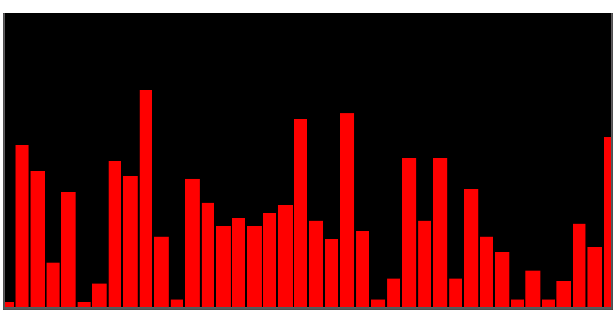

Figure 3: Raw beam profile data.

The calibration of the multi-channel array is achieved using an original motorised profile monitor which is located in the same stainless steel vacuum vessel as the new MCPM. This calibration relies on the fact that the single Channeltron in this system does not suffer from any gain variation during a profile scan. Figure 4 shows beam profile data after calibration.

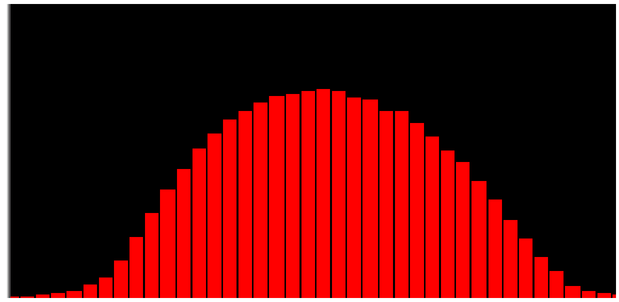

Figure 4: Calibrated beam profile data.

In an attempt to solve the gain variations found in the original MCPM, the second design split the 40 detectors into 10 blocks of 4 Channeltrons. The 4 Channeltrons in each block had been ‘gain matched’ at the Photonis factory and each block was given its own power supply to allow adjustment of gain between blocks. Unfortunately the gain matching of the detectors appeared not to hold within the synchrotron environment and we found that the individual gains of the Channeltron devices were as mismatched as on the first MCPM. Figure 5 shows the ‘improved’ profile monitor in position in the ISIS synchrotron. This monitor measures the beam profile in the vertical plane.

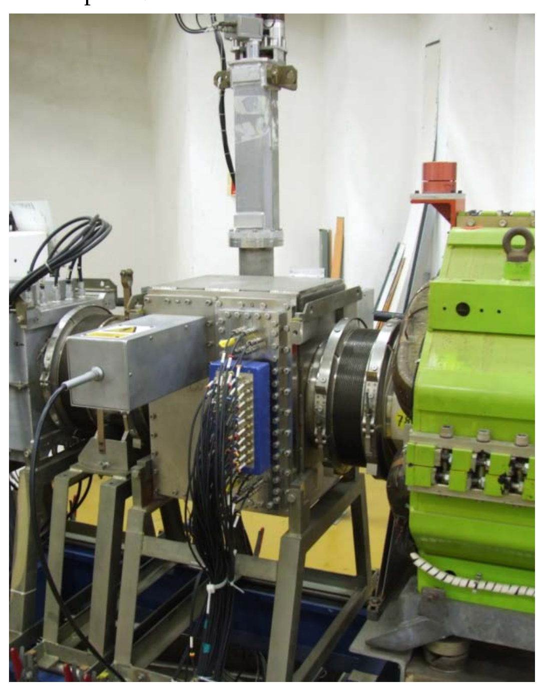

Figure 5: Second generation multi-channel profile monitor installed in the ISIS synchrotron. The motor drive of the SCPM can be seen diagonally opposite.

In a second attempt to reduce the effects of Channeltron gain variation on the system, a third generation design is currently under construction and consists of 40 Channeltrons, still arranged in 10 blocks of 4, but with each Channeltron having its own individual power supply (shown in Figure 6). This design will allow the gains of each Channeltron to be closely matched by varying the individual power supply voltages. This third generation

MCPM is scheduled to be installed in the ISIS synchrotron in the autumn of 2010.

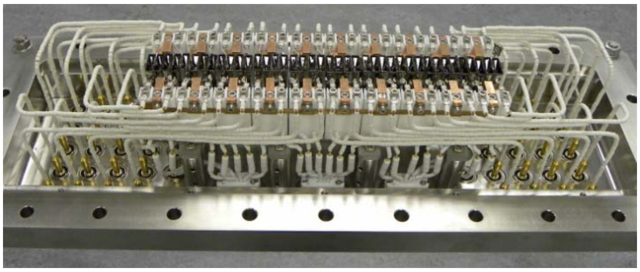

Figure 6: Third generation multi-channel profile monitor.

DATA ACQUISITION AND CALIBRATION

The data acquisition system consists of a National Instruments PXI controller and chassis and five 8-channel analogue input cards which are sampled simultaneously using a timing and synchronisation card [4]. On every 50Hz pulse of ISIS each of the 40 channels are read for 10ms at an interval selected by the user, down to 10us. From the LabVIEW user interface the user can view the profile of the beam at a selected time, view graphs that display the 90% beam widths and centres over the acceleration cycle and view a 3D plot of all the profiles (Figure 7). The user can also choose to subtract background data and save data. The saved data can be loaded and superimposed over the currently selected profile.

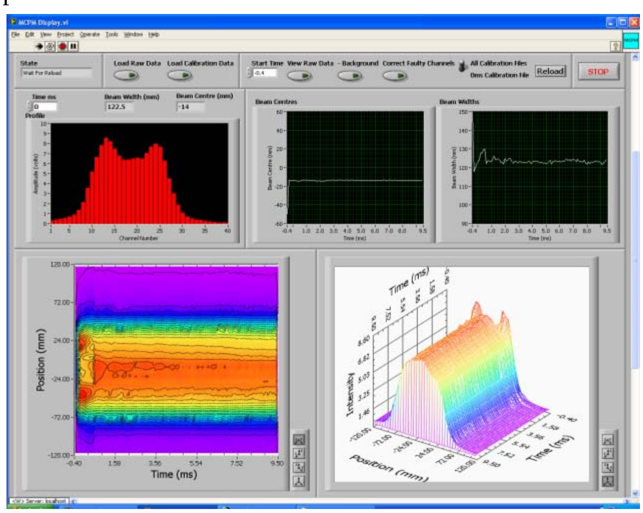

Figure 7: LabVIEW User Interface

During the calibration procedure the SCPM moves across the beam using a step size that aligns it to the transverse positions of the 40 Channeltrons in the MCPM. The data is saved to a database. Using the LabVIEW HTTP server the MCPM program can access the data and use it to create a calibration file which is then applied to the raw data from the MCPM. The PXI system has made the process of simultaneously collecting and analysing large amounts of data from each of the 40 channels relatively simple.

BEAM PROFILE SIMULATION

A beam profile simulator has been developed so that all the electronics and computer hardware and software can be tested in the absence of the ISIS proton beam. The simulator is a microcontroller which can be switched into the circuit using a digital line on a PXI card. Different profiles are preloaded to the microcontroller and selected using a digital I/O card. A signal generator card provides a waveform equivalent to the intensity fall off that occurs during the acceleration cycle. This waveform is applied to potentiometers which adjust the output level of each channel.

SINGLE-CHANNEL UPGRADE

The old motor driven single channel profile monitors (SCPM), have now taken on a new role with the development of the MCPM. Their new function, as a calibration tool for the MCPM has meant that their accuracy, reliability and longevity are vital. To ensure that this is the case, the mechanics of the SCPMs are being re-designed using high quality linear stages with radiation hard motors and wiring.

To ensure accurate calibrations, the new stepper motor driven Channeltron will be pre-aligned with the 40 set locations of the Channeltron array in the MCPM diagnostic. This alignment will be carried out in the lab prior to installation of the monitors. Every new MCPM will have an upgraded SCPM as its calibration system.

FUTURE WORK

The accuracy of the beam profile measurements obtained from a gas ionisation profile monitor are largely dependent on the electric field that drives the +ions and the space charge properties of the proton beam [5]. Both can cause large inaccuracies in the measured profile.

At ISIS, space charge levels are highest during injection into the synchrotron and beam bunching. For the MCPM to provide accurate beam profiles linear ion trajectories between generation point and detection must be assumed. In reality the electric field of the beam itself, which acts radially outwards from the centre of the beam, will deflect the ions and widen the detected beam width.

Measurements on the current system, using drift field voltages from 10 kV to 30 kV have shown a significant change in measured beam width with voltage [6], as shown in Figure 8. Looking at one specific time during the acceleration cycle, in this case 0 ms, Figure 9 shows the measured points fitted to a curve and extrapolated. This highlights the possible increase of accuracy that could be achieved with increasing drift field. The measured beam width at 30 kV is 120 mm, this is reduced to 114 mm at 60 kV and reduced further still to 112 mm at 80 kV. Looking at these results it was decided that a bias field of 60 kV provided a worthwhile increase in accuracy without the cost and technical challenges that would be faced with higher voltages.

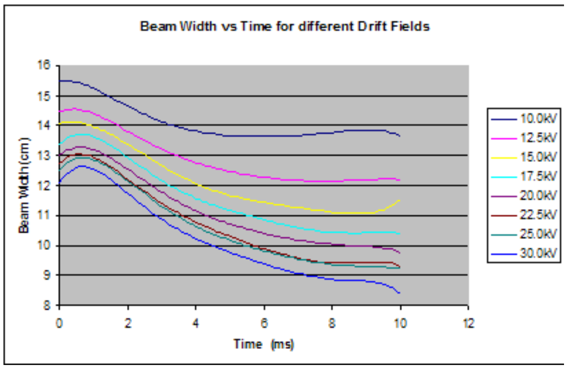

Figure 8: Measured beam width for different drift field voltages over the ISIS acceleration cycle.

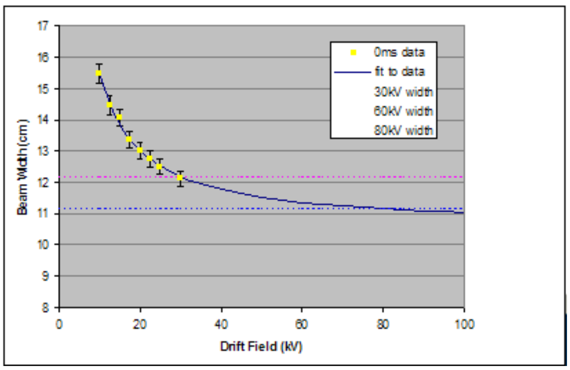

Figure 9: Beam width measurements at 0ms.

This 0-60 kV bias field voltage will allow the opportunity to study the effects of space charge on the profile measurement in greater detail and allow our current space charge models to be checked.

A model of the profile monitor showing electrostatic potential distributions caused by the drift field and space charge effects is currently being developed using the finite element modelling package CST Studio Suite [7]. The potential distributions in the longitudinal plane are shown in Figure 10 and in the transverse plane are shown in Figure 11. It is clear that the curved electric field distribution shown in the transverse plane would have a distorting effect on the beam profile. The distortion is due to the lack of shaping field electrodes within the monitor which were never part of the original design. The CST work will help determine by how much shaping field electrodes could improve the profile monitor data.

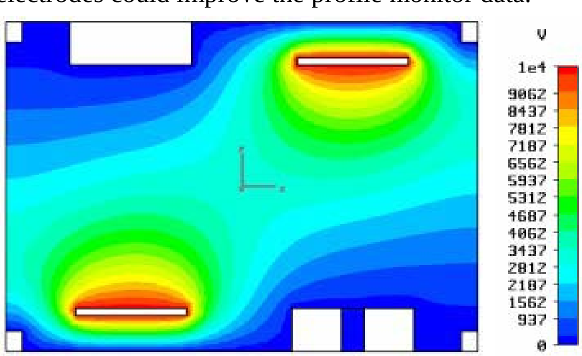

Figure 10: Longitudinal electrostatic potential distributions in the ISIS ring profile monitors.

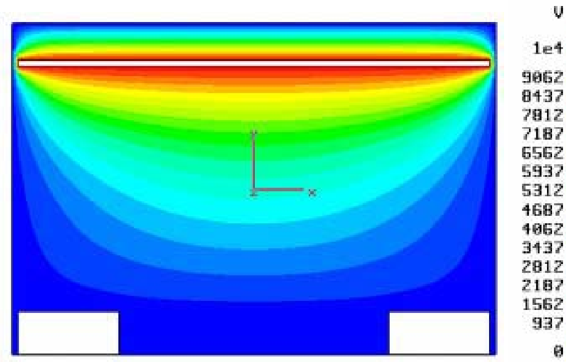

Figure 11: Transverse electrostatic potential distributions in the ISIS ring profile monitors.

SUMMARY

We have shown the effectiveness of the new Channeltron based gas-ionisation profile monitor used in the ISIS accelerator ring. Issues regarding calibration affect profile monitor systems that use active devices like Channeltrons or Microchannel Plates. The use of a separate single Channeltron device that can be driven across the beam to provide calibration for the Channeltron array has proved very effective in our application. Issues regarding space charge effects will be addressed using the new 60 kV variable drift field. Electrostatic simulation work of the drift field, plus work proposed using particle tracking software is being carried out with the aim of improving the profile data. This work might also lead to the installation of shaping field electrodes.

Further research into profile monitor distortions due to the drift field will be carried out in the extracted proton beam line (EPB) to Target Station 1. We are proposing to install an MCPM device in the EPB at a point where there are three harp style wire profile monitors and no quadrupole magnets. Comparison between the harp monitors and the MCPM will yield information on the inaccuracies produced by the high voltage drift field of our present gas ionisation system.

REFERENCES

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[3] S.J.Payne *et.al* ‘Beam Diagnostics at ISIS’ HB2008 conference, Nashville, TN, 2008

[4] For examples of PXI DAQ systems see National Instruments, http://www.ni.com.

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