A SELF CALIBRATING REAL TIME MULTI-CHANNEL PROFILE MONITOR FOR THE ISIS PROTON SYNCHROTRON

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Abstract

A +ion 'multi-channel' (gas ionisation) profile monitor (MCPM) has been developed at the Rutherford Appleton Laboratory to capture 'real time' beam profile data within the accelerating ring of the 800MeV ISIS proton synchrotron. The MCPM uses an array of 40 electron multipliers (Channeltrons), operating at a gain of ~10^4, to measure transverse beam profile data in the horizontal plane. The data obtained is an average of two rotations of the beam bunch, a limitation due solely to the speed of the +ions. Fast electronics and a multi-channel PXI / LabVIEW data acquisition system are used to simultaneously process and display 40 channels of beam profile information. Variations in the channeltron's gain are dealt with using an independent motor driven +ion detector. The beam profiles obtained from this single detector are stored and used as a calibration file to correct data obtained from the new multi-channel profile monitor.

INTRODUCTION

At ISIS the accelerator ring (gas ionisation) profile monitors use a single electron multiplier, a Channeltron [1], to measure the +ion current from the proton beam / residual gas interactions. At ISIS this equates to a +ion flow of around 200pA per sq. cm into the electron multiplier at beam centre. The Channeltron is stepped across the top of the proton beam in 6mm increments and the +ions are swept into the monitor using a high voltage drift field (typ. 30kV). Real time profiles cannot be obtained because the mechanical system takes several minutes to complete each scan. A new multi-channel detector has now been developed which uses an array of 40 fixed Channeltrons, that span 240mm across the beam path, to simultaneously collect beam profile information over a single 10ms ISIS acceleration cycle. The new monitor is located in the same stainless steel vessel as one of the original motorised beam profile monitors. Calibration problems with the multi-detector array have been taken care of by using the single channel profile monitor as a calibration tool. This is possible since the gain of the single detector does not vary during a scan. Data acquisition is achieved using a fast sampling PXI system [2] which can simultaneously sample all 40 channels at 100µs intervals over the 10ms acceleration cycle. Performance of the electronics / PXI systems can be checked using a newly developed computer controlled MCPM simulator. The simulator also allows further development of the complete data acquisition system in the absence of a proton beam.

THE DETECTOR

The new profile monitor has been built using 40 miniature Channeltrons (figures 1 & 2). The Channeltrons are mounted in ceramic blocks, 10 to each block. Each block is powered by its own dedicated power supply. The Channeltron aperture is 15.75mm x 4.5mm and the centre to centre spacing of these electron multipliers is 6mm - giving a total span across the beam of 240mm. In front of the detectors is an earth shield (not shown) that has a slot cut into it and which allows the +ions through to the Channeltrons.

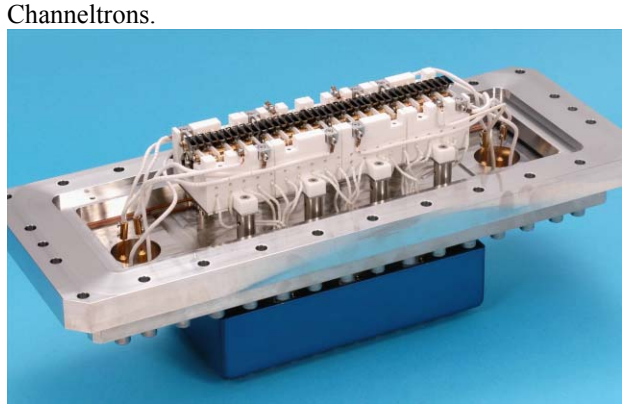


Figure 1. Multi-channel Profile monitor consisting of 40 miniature electron multipliers covering 240mm across the proton beam path.

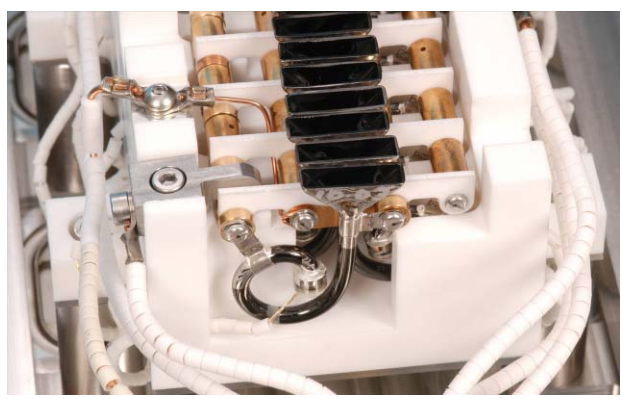


Figure 2 Close up the electron multipliers (Channeltrons)

Individual ceramic blocks were used in order to make construction of the MCPM simpler and provide a means of 'coarse' calibration. The middle two blocks (i.e. the middle 20 Channeltrons) will see more +ion current, since

they cover the centre of the beam, and so their gain will fall off more quickly than that of the outside 20 Channeltrons. This fall in gain over time can be compensated for by adjustments to the individual power supplies. Final calibration is carried out by the MCPM calibration system.

DATA ACQUISTION SYSTEM

The data acquisition system consists of the electronic hardware, a PXI (PC based DAQ system) running LabVIEW and a Vsystem Vista Control System [3]. The output current of the Channeltrons, under normal beam conditions, varies from tens of nA near the beam edge to 2.5µA at beam centre. The electronics front end of the MCPM system consists of a set of 40 pre-amplifiers which convert the Channeltron current into a voltage (0 – 10V dc). The output of the pre-amplifiers is sampled 100 times (at 100us intervals) over the 10ms ISIS acceleration cycle. Any of the 100 profile samples can be selected and sent to a multiplexer which will display the 'raw' profile on an oscilloscope. The complete set of 100 sampled profiles is sent to the PXI controller via a set of five, 8 channel, 14 bit analogue to digital PXI-6133 cards.

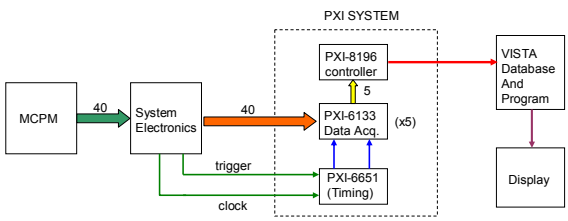


Figure 3 Layout of data acquisition system (see [2] for PXI module details)

The PXI system will display any selected profile and will also give the beam position and beam width numerically, for a single profile at a selected time, and graphically for data representing full 10ms acceleration cycle. The PXI places the results into a system database which can be accessed by the Vista Control System computer. This computer provides the main beam profile display.

When the operator presses the run button on the Vista Control screen (figure 4) the PXI reads the beam profile data, carries out the calibration, and stores the results in a database. The PXI also calculates the beam centre and 90% beam width of each profile and stores it in the database. In figure 4 the data is displayed as a single profile at a user selected time, 1ms in this case (top left); the whole 100 samples over the 10ms acceleration cycle (top right); the beam position, over 10ms (bottom left) and the beam width, over 10ms (bottom right). The Vista screen includes controls to manage the voltage of the Channeltron power supplies, the high voltage drift field, and provides a means of averaging the profile data over *n* beam pulses if required.

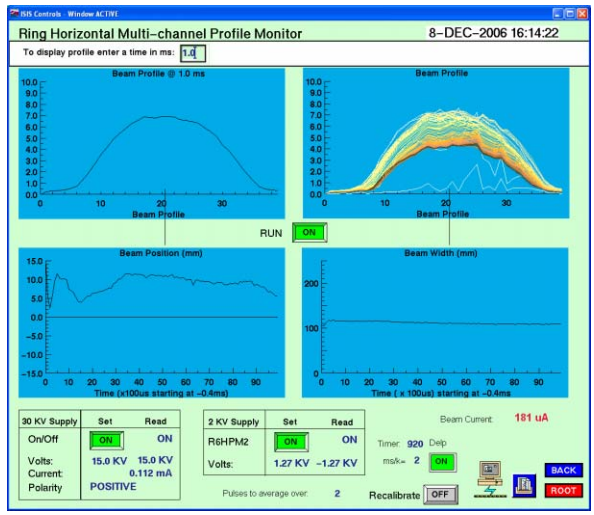


Figure 4. VISTA display

MCPM CALIBRATION

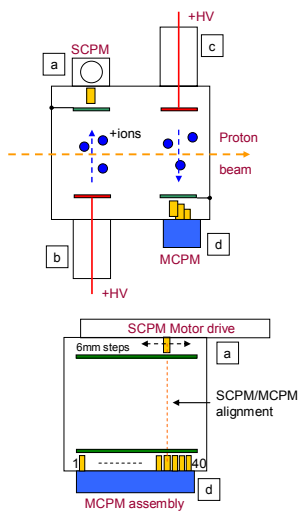


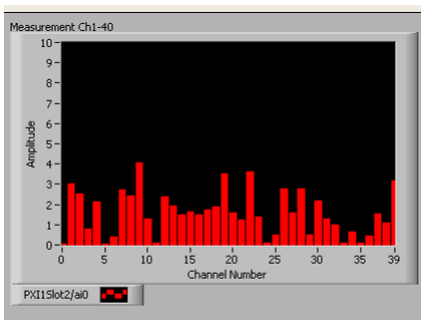
Figure 5. Calibration schematic

The motorised profile monitor, shown schematically in figure 5, produces a beam profile by moving a single Channeltron across the top of the beam in 40 equal steps of 6mm. Each stepping point is in exact alignment with one of the 40 fixed Channeltrons in the MCPM. The outputs from every fixed and moving Channeltron 'pair' are sampled and recorded. The ratio of these results is then stored as calibration data. All MCPM data can then be software corrected to produce an accurate beam profile.

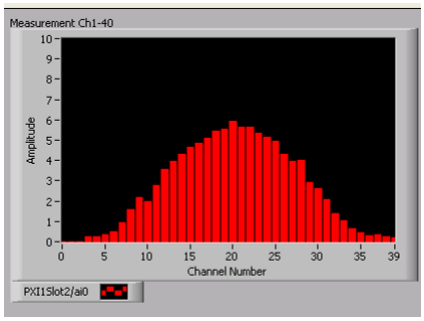
Figures 6a and 6b show the effect of calibration. In figure 6a the raw data is displayed. It can be seen that

there is no real discernable profile. This is due to the relatively large variations in the Channeltron gains. In figure 6b the profile is recovered using the calibration file.

A second profile monitor has been built (for the vertical plane) using 40 Channeltron electron multipliers mounted in 10 blocks of 4 . Each set of 4 Channeltrons have been factory matched (BURLE Industries www.burle.com) so this problem with the raw data should be much reduced. This option of having the matched electron multipliers was not available first time around.



(6a)



(6b)

Figure 6 – raw (a) and calibrated (b) beam profile data

MCPM SIMULATOR

The MCPM project involved developing, from the ground up, the detector and all electronics and computer hardware and software. Since no part of the system was proven, a MCPM simulator was constructed to produce exactly the current outputs (over the 40 channels) that would be expected from the real monitor. This meant that all electronics and computer hardware and software could be proven prior to the commissioning of the MCPM.

The simulator is a PIC based microprocessor that can provide authentic beam profiles of any width and beam position. It can be switched into circuit should a problem arise with the profile monitor system so as to ascertain whether the fault is with the MCPM or the electronics / PXI or computer systems. Development of the electronics and software can also be carried out during times when the synchrotron is shut down by switching in the MCPM simulator.

Creation of the beam profiles is achieved using a spreadsheet (Microsoft Excel). The user enters an initial (symmetrical) profile and then edits the width and position of the profile as required. The output profile data files are uploaded into the microcontroller. To generate the required output profile digital potentiometers have been used to adjust the output level of each channel as required (figure 7). The 40 potentiometers (one for each channel) have been daisy-chained together and are all programmed by the microcontroller.

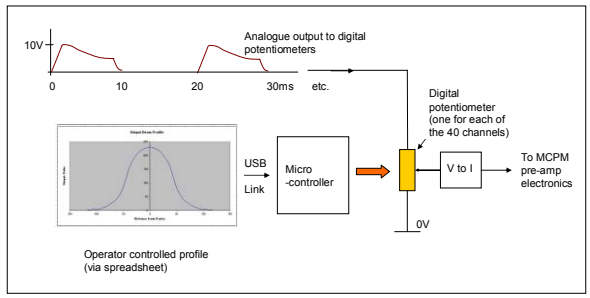


Figure 7 MCPM Simulator channel control

In order to simulate the real multi-channel profile monitor as much as possible an analogue input (from a programmable signal generator) is used to provide the source for the profile outputs. This means the simulator can mimic the +ion intensity fall off that occurs, with increasing beam energy, during the 10ms acceleration cycle. The voltages across the potentiometers are buffered before being passed through a V-I converter to provide an accurate simulated input to the MCPM electronics.

SUMMARY

The MCPM has shown the ability to capture real time beam profile data in the ISIS proton synchrotron. The use of a single channeltron profile monitor as a calibration tool means that the MCPM can easily be kept fully calibrated regardless of the aging of the channeltrons. Further multi-channel profile monitors are being constructed, the first being a vertical monitor a few meters downstream of the horizontal beam profile monitor reported here. A faster profile monitor measuring electrons is being considered for the future to capture turn by turn beam profile data. The detector will be essentially the same; the use of magnetic fields and shaping electrodes for the electric field would be the main differences.

REFERENCES

1) See ‘Channeltron Electron Multiplier handbook’, BURLE industries, www.burle.com
2) See National Instruments www.ni.com
3) Vista Control Systems, 176 Central Park Square, Los Alamos, NM 87544 USA www.vista-control.com