PERFORMANCE OF AN IN-AIR SECONDARY EMISSION GRID PROFILE MONITOR AT THE ISIS NEUTRON AND MUON SOURCE

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Abstract

The ISIS neutron and muon source, located in the UK, consists of an H^- linear accelerator, a rapid cycling proton synchrotron and extraction lines to two target stations. A project is currently under way to replace the target assembly of the First Target Station (TS1) in order to secure its continued operation and improve operational flexibility. In addition to a number of other diagnostic tools, a new secondary emission (SEM) grid profile monitor is expected to be located within helium atmosphere of the new target assembly. To investigate the performance of an out of vacuum SEM grid, a prototype monitor was positioned in air between a beam exit window and a beam dump. Profile measurements taken with this monitor are presented, including tests at a range of bias voltages with a fast data acquisition system to investigate secondary signal sources.

INTRODUCTION

The ISIS Synchrotron

The ISIS synchrotron accelerates two bunches with a total of approximately 3×10^{13} protons from 70 MeV to 800 MeV at a repetition rate of 50 Hz delivering a mean beam power of 0.2 MW to two tantalum clad, tungsten targets; 1 in 5 beam pulses are delivered to target station 2 (TS2) and the remaining four to TS1. The target, reflector and moderator assembly (TRAM) of TS1 has been redesigned and will be replaced during the shutdown period from 2020 to 2021 [1].

A Near Target Profile Monitor

The TS1 target intercepts on average 160 kW and is susceptible to damage from over-focusing of the transverse beam size. The condition of the target is therefore monitored with thermocouples in contact with the tungsten plates and cooling water which flows between the plates is also monitored. Target halo monitors measure the approximate transverse beam size and position upstream of the target [2], and have been in use for a number of decades. A new profile monitor located near to the front face of the target would provide more detailed and faster transverse beam information and help to prevent over-focusing and improve positioning.

This near-target profile monitor (NTPM) will intercept four out of five beam pulses during routine operation and be located within the target assembly. The NTPM will be required to operate in the helium atmosphere of the target assembly, which differs from the vacuum environment where these monitors are ordinarily used.

PROFILE MONITOR TESTING IN A GASEOUS ENVIRONMENT

The performance of a wire grid profile monitor in a gaseous environment was tested by positioning a spare monitor in the air between an exit window and a beam dump; Fig. 1 shows the machine components in the vicinity of the dump. The extracted beam travelled through two ordinary in-vacuum profile monitors, EPM1 & 2, before reaching the test in-air profile monitor and then the synchrotron room beam dump (SRBD). Figure 2 shows the layout in front of the SRBD, an air gap of approximately 30 cm separated the beam exit window from the front face of the SRBD.

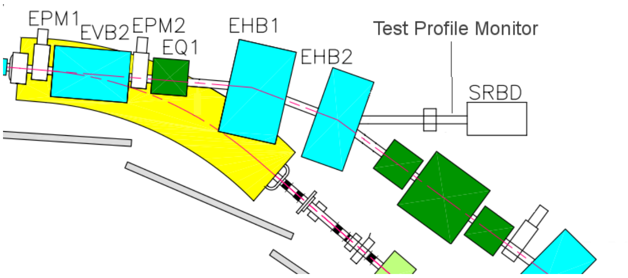

Figure 1: ISIS beam extraction line in the vicinity of the SRBD.

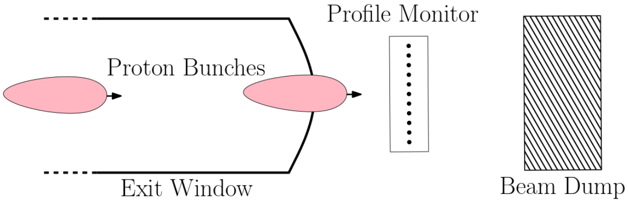

Figure 2: Approximate set-up in-front of the SRBD showing a beam exit window and the in-air profile monitor.

The test profile monitor was a dual plane wire grid with 24 signal wires per plane sandwiched between a series of biasing wires. The wires were SiC coated, carbon fibres with a diameter of 142 µm [3]. Signals from each wire were transported with individual coaxial cables to a data acquisition (DAQ) system in a shielded area. Two DAQ systems were available for this investigation: a slow system which output a voltage based on the integrated signal via a multiplexer, and a fast system which had ten synchronised National Instruments (NI) PXI-5124 scope cards. The fast sys-

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tem had a 200 MSa/s acquisition rate to investigate the signal time structure, but the limited number of channels meant that signals from only 20 out of 24 wires could be acquired at once.

Initial Results

A beam of 2.7×10^{12} protons was extracted to the SRBD at an energy of 700 MeV, and profiles were recorded at the test profile monitor as well as EPM1 and 2; see Fig. 1. Figure 3 shows the horizontal and vertical profiles recorded by the slow data acquisition system overlaid with vertically offset Gaussian fits; the fit standard deviation and uncertainty from the fit are quoted in the legend.

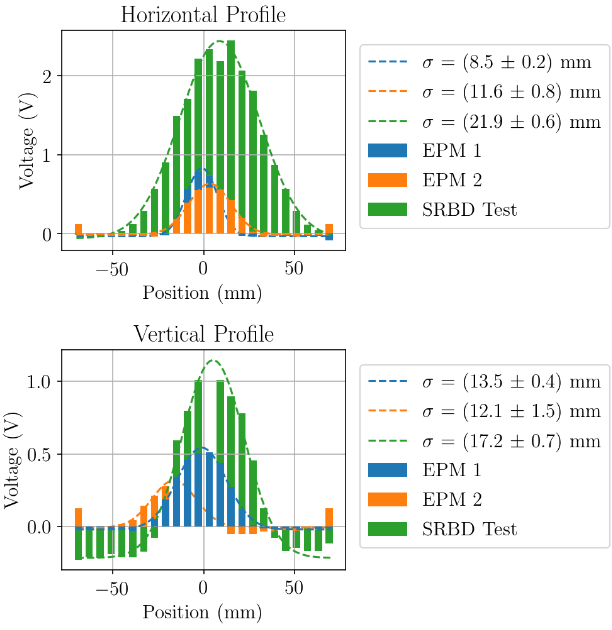

Figure 3: Horizontal (top) and vertical (bottom) profiles measured at EPM1 and 2, and the SRBD test monitor with overlaid Gaussian fits for nominal beam and magnet parameters.

The in-air profile monitor produced larger voltages than those measured in-vacuum, and negative signals were visible on the vertical profile but not the horizontal. Good agreement was observed between measured widths and those predicted by MAD; an overlay of measured vs. simulated widths is shown in Fig. 4, where the emittance was set to match the measured and expected widths at the first profile monitor, EPM1 at $s \approx 1$ m.

Transverse Beam Positioning

The sensitivity of the test profile monitor to changes in transverse position was investigated by varying the current in dipole EHB1 by ±5 A from the nominal (248 A); see Fig. 1. Transverse deflections of ±13 mm were obtained from Gaussian fits to the measured profiles; shown in Fig. 5. MAD simulations of the SRBD line predict an offset of ±10 mm which is considered to be an acceptable discrepancy given the uncertainty in longitudinal positioning of the test profile monitor.

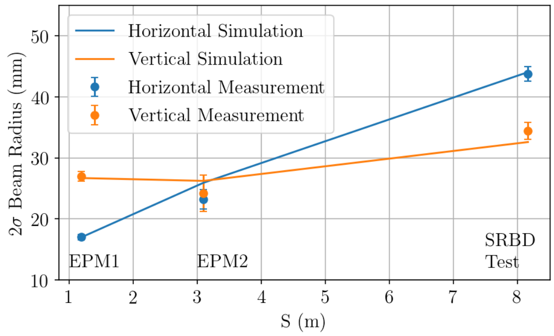

Figure 4: Measured beam widths versus longitudinal position; the points close to $s = 1$, 3 and 8 m are from EPM1, EPM2 and the test profile monitor respectively.

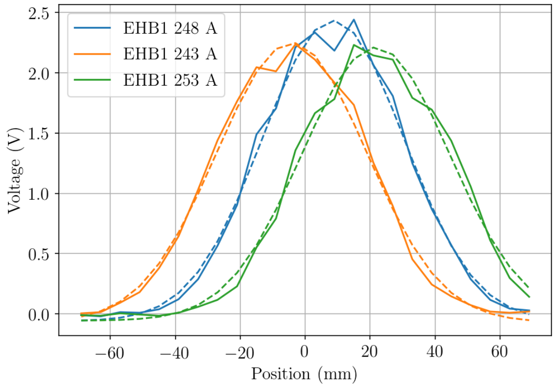

Figure 5: Beam profiles measured at the SRBD test monitor and overlaid Gaussian fits with varying currents to EHB1.

Transverse Beam Dimensions

The sensitivity of the profile monitor to changes in the transverse size of the beam was investigated by changing the current in the horizontally focusing quadrupole EQ1 by ±30 A. The profiles shown in Fig. 6 were compared with MAD simulations using quadrupole strengths from measured magnetic field gradients; Figs. 7 and 8 show a comparison of the simulated and measured beam widths for the horizontally defocusing and focusing measurements respectively. EQ1 is downstream of EPM1 and 2 so their widths are unaffected by the change in current. The measured profiles consistently show the behaviour predicted by MAD, but are generally broader than expected.

Investigation with Fast DAQ

The fast data acquisition system was used to investigate factors which could affect the measured profile, help account for the negative signals and the influence of external ionisation products. Figure 9 shows the signal versus time for a wire close to the beam centre and one at the edge of

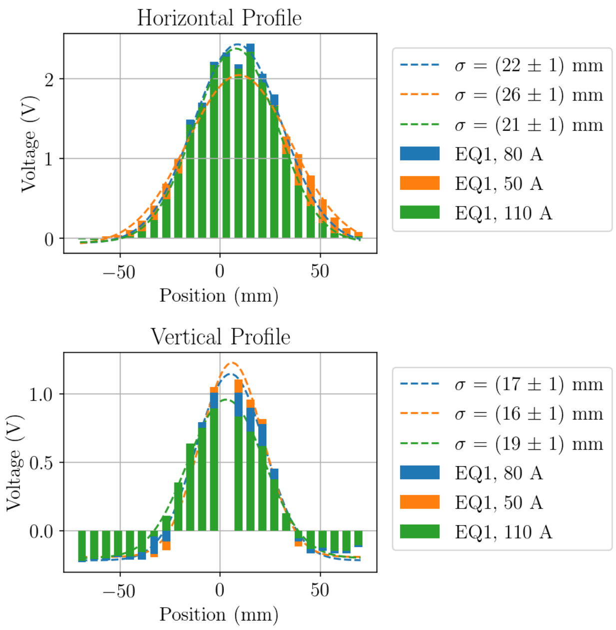

Figure 6: Horizontal (top) and vertical (bottom) measured at the SRBD test profile monitor with varying current to EQ1.

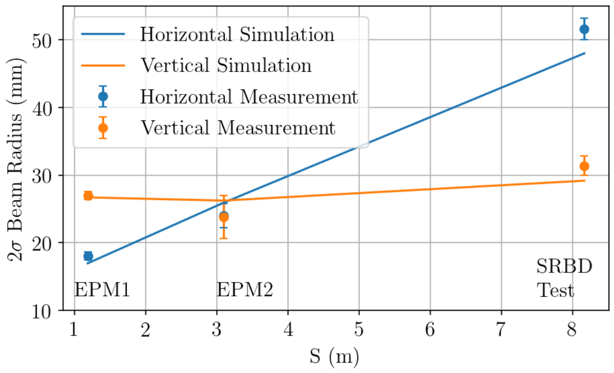

Figure 7: Horizontal defocusing result with 50 A in EQ1.

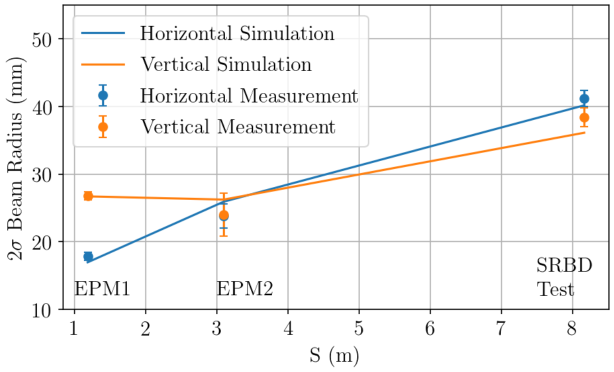

Figure 8: Horizontal focusing result with 110 A in EQ1.

the monitor. On the central wire two large pulses are observed with around 300 ns spacing which is the expected bunch structure. Smaller peaks arrive around 0.2 µs after each bunch and have a similar amplitude and duration on both the central and edge wires; their origin has not been identified. The signal on the edge wire differs in sign to that of the central wire, but coincides with the arrival time of the beam.

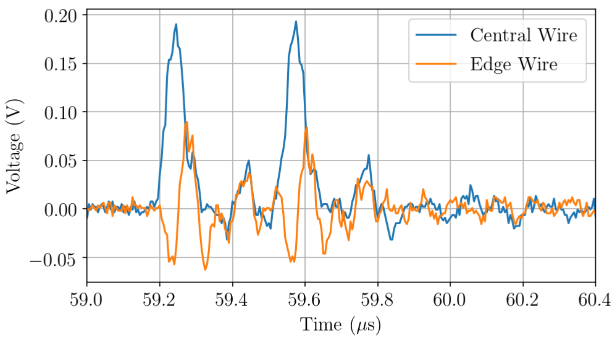

Figure 9: Voltage over a 50 Ω load versus time on a wire close to the beam centre and a wire at the edge of the monitor away from the beam centre.

FLUKA [4] simulations of the set-up have been performed to investigate the transverse distribution of particles generated in the beam dump. These revealed that secondary electrons would be produced with a very broad transverse profile in front of the dump; it's possible that these are also producing a measurable signal.

Effect of Bias Voltage

A voltage was applied between the signal wires and the adjacent grounded biasing wire grid; a negative bias was expected to repel liberated electrons and increase the measured signal, a positive bias was expected to achieve the opposite [5]. As can be seen in Fig. 10, a larger negative bias increased the amplitude of the measured signal, but also of the signals which follow the beam. Profiles were constructed by finding the average voltage for a time window, results for three different bias settings are shown in Fig. 11. The negative bias increases the beam signal but also affected the profile offset.

Signals were also acquired with positively biased wires; for small biases of ≈ 40 V the measured profile had a negative offset but was flat, however for larger biases a broader inverted profile was observed which is thought to originate from secondary particles generated in the surrounding environment.

NEAR TARGET PROFILE MONITOR DESIGN

The monitor will consist of cross planes of 18 silicon carbide detecting wires, this material was chosen because of its thermal characteristics and stiffness. Each plane of detecting wires will be sandwiched between a second grid of grounded bias wires; a DC bias will be applied to the detecting wires. The detecting wires are isolated from the monitors body and each other with ceramic components,

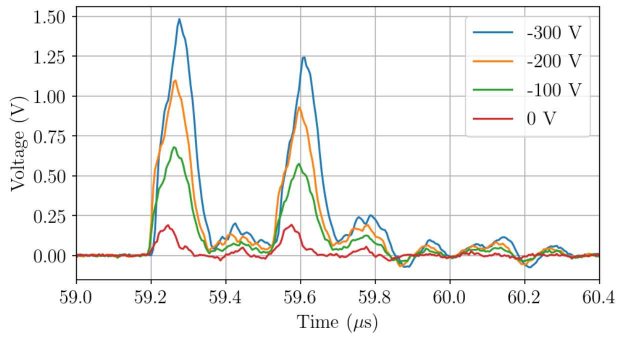

Figure 10: Time domain signal for the current induced on a wire close to the beam centre with different applied bias voltages.

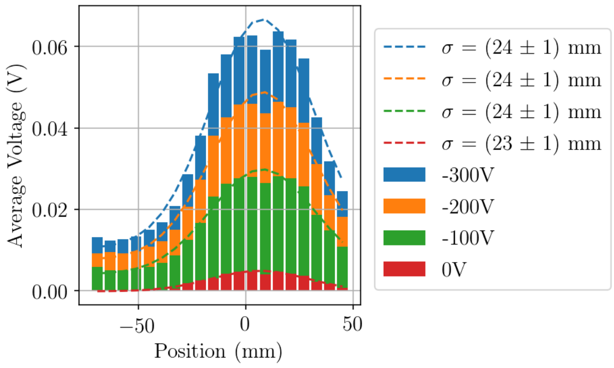

Figure 11: Profiles with different bias settings obtained from the average voltage for a window of the time domain results.

but the monitor is primarily composed of aluminium due to its neutron transparency [6].

The harsh surrounding environment will prevent access to the monitor, so it has been designed with a remote handling gripper and appropriate supporting brackets to allow it to be disconnected and remotely removed by an operator if necessary; see Fig. 12. A radiation resistant umbilical cable will be used, however it is still possible that this will become brittle or be damaged over time and has also been designed to be independently removable by means of a screw connector; see Fig. 13. A 37-pin D-sub feedthrough has been positioned at the bottom of the monitor, and two 19-pin ceramic sockets have been used for the void vessel feedthrough.

CONCLUSION

A wire grid profile monitor has been operated in the gaseous environment surrounding a beam dump. After obtaining a beam profile for a standard set-up the monitor was used to verify behaviour with changes to transverse beam position and size. Measured profiles were consistently broader than predicted by MAD simulations but generally behaved as expected. Profiles at higher beam intensities were significantly broader than expected without considering space charge, but also exhibited the correct general behaviour.

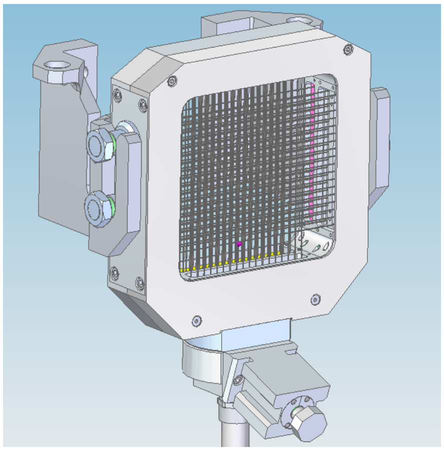

Figure 12: NTPM design with remote handling gripper and screw connector at the base.

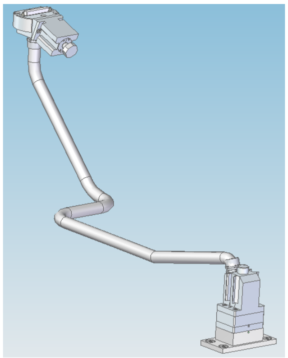

Figure 13: Umbilical cable with the remote handling gripper.

A fast data acquisition system showed signals arriving after each bunch on wires close to the beam centre and at the edge of the monitor, indicating the presence of a broad secondary signal source. Subsequent FLUKA simulations suggest that electrons from the dump would have a broad transverse profile and these are currently thought to be responsible for the signals; simulations are ongoing.

Applying a negative bias increased the beam induced signal as expected, but also the increased the observed offset. A small positive bias was able to produce an offset, flat profile while a large positive bias revealed a broad inverted profile which is thought to originate from secondary particles.

Further simulation work is planned to investigate the impact of these secondary sources on the profile measured at TS1 and the expected longevity of the NTPM wires.

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