A SCANNING SECONDARY EMISSION PROFILE MONITOR

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Summary

Harp profile monitors have been used in the primary beam lines at TRIUMF. Disadvantages include a fixed, sometimes too coarse, resolution, changes in wire-to-wire efficiency[1] and restrictions on multiple insertion. A secondary emission scanning wire system has been developed. A beam sensor is mounted to each of two parallel linkage systems driven, via a ferrofluidic feedthrough, by a stepping motor controlled cam. This mechanism moves the sensors linearly across the beam and keeps them perpendicular to each other and to the beam pipe axis. The precision is ±0.13 mm over 100 mm sweep. Magnetic sensors provide fiducial indications. Wire sensors are used at ~100 μA; blades 10 mm long by 0.25 mm wide at nA intensities. The sweep frequency is 0.5 Hz, chosen for mechanical stability and to provide a usable profile for a beam modulated at 1 kHz. The spatial resolution requires an electronic bandwidth of greater than 300 Hz. Noise within the monitor was reduced by employing shielded wiring and stationary bias field electrodes. 60 Hz pick up between the monitor and remote electronics was reduced by using balanced cable and a differential amplifier. The overall rms noise level is equivalent to a beam density of 0.1 nA/mm of blade movement.

Introduction

The TRIUMF beam consists of a train of proton bunches 0.5 to 4 ns wide at 23 MHz. Extracted beam of 70 to 500 MeV is available at intensities of 0.1 nA to 200 μA i.e. 26 to 5.3×10^7 protons per bunch. The beam is pulsed at 1:5•4800 of the rf (about 960 Hz) with a duty cycle of 0.1 to 99.2% for diagnostic purposes and intensity control. At present ionization (Ar/CO_2) and secondary emission harp profile monitors are used. The former operate at 0.1 to 30 nA, the latter at up to 10 μA for metal and 50 μA for carbon wires.

Scanning Blade Concept

The SEM coefficient of a blade is increased over that of a foil normal to a beam by the ratio of the length of the blade along the beam axis to the depth of the emitting layer. A 1 cm long aluminum blade intercepting 1/20 of a 500 MeV beam would yield 20 nA of signal per μA of beam. Thin 0.005 in. metal wires with SEM coefficients of ~4% can be used for high current beams. Then 5 nA of signal per μA of beam would be produced by a 1 cm wide beam. Signal collection from the scanning elements rather than from nearby collector electrodes allows simultaneous X and Y profiles and preserves the time structure allowing synchronous sampling with a pulser. The peak current is increased over the average by the reciprocal of the duty cycle, improving signal-to-noise ratio. Spatial resolution depends on sweep rate. At two seconds per sweep over a total of 13 cm, the blade velocity is 9.5 cm/s in the linear region. Samples are then available at 0.1 mm spacings, for a 960 Hz pulsed beam.

Mechanical System

The prototype blade scanner, Fig. 1, was designed to fit into existing 22 cm monitor boxes. A motor and cam operate in air, the blade drive in vacuum. Two interchangeable sensors were used; an aluminum blade 0.010 in. thick by 0.375 in. long and a 0.005 in. diameter gold-plated molybdenum wire. The blade is intended for beams of less than 1 μA. Evaporation of the wire's gold plating can occur for beams of 200 μA/cm^2 or at 40 μA/cm^2 if the monitor stalls. For convenience, the sensors will be referred to as blades. Two blades run simultaneously and orthogonally across the beam to provide X and Y profiles. The blades were tensioned by springs and insulated by vespel blocks. Their motion is out of phase by 5° so that one blade does not shadow the other near the beam line axis. Each blade is swept through the beam by a pair of pantograph arms which keep the blade surfaces parallel to the beam axis. The two orthogonal scanning motions are coupled by a 90° bevel gear mechanism. A rotary ferrofluidic feedthrough on the monitor lid drives the linkages which were anchored by an aluminum frame. A bias ring close to the frame provided a clearing field for secondary electrons. Figure 1 shows a second ring installed after the tests. The signals and bias pass through a single 9-pin ceramic feedthrough.

The maximum scanning speed is limited by system backlash and by the inertia of the support arms and mechanism which can overcome the follower return spring torque causing the follower to bounce on the cam. The four-phase stepping motor can generate 70 oz-in. of torque at stall and 26 oz-in. at 15 r/s in the half step mode (400 steps per revolution). It drives the cam through a 3.33:1 reduction using sprockets and a plastic coated chain. The motor turns in one direction only with a constant speed, sweeping the blades through the beam twice before returning them to the park position. A motor controller, capable of supplying 4.7 A per phase, was built using a commercial driver card and power supply. Continuous running and single sweep modes were used. Controlled acceleration allows the motor to

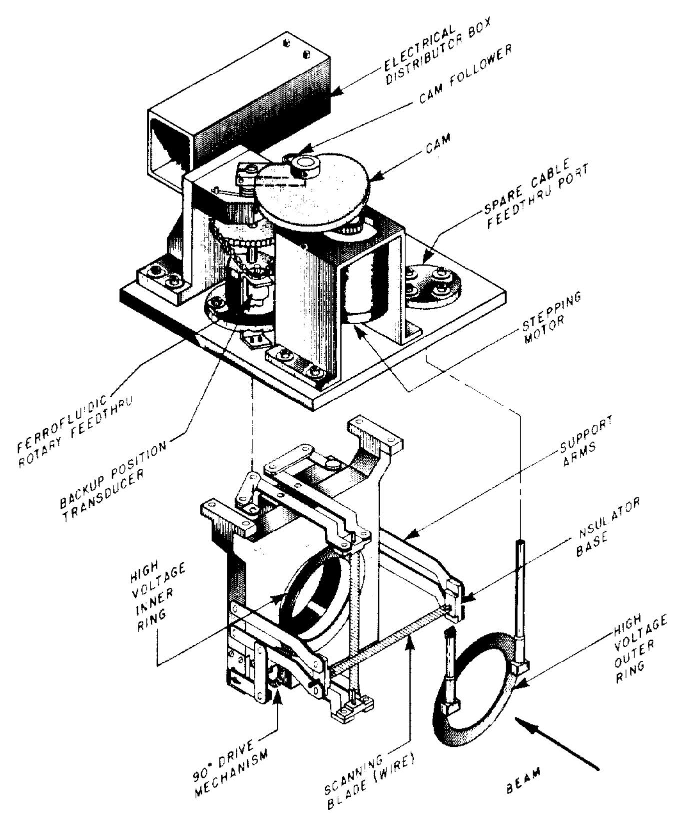

Fig. 1. A mechanical layout of the scanning blade monitor.

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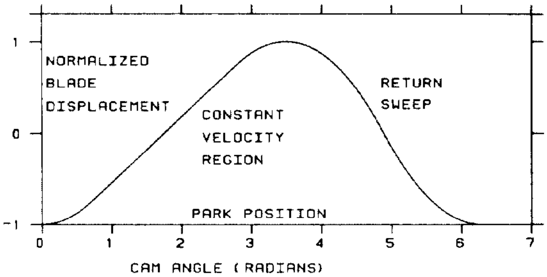

Fig. 2. The cam was shaped to give a region of constant blade velocity across the blade and to minimize acceleration during the rest of the cycle.

start and stop without missing steps. The scanning rate during the tests was 0.25 to 0.5 Hz.

The cam provides a constant transverse blade speed near the beam line axis though they travel in arcs. The specification of the ratio of linear range to maximum range and constant acceleration and deceleration outside of the linear region define the cam shape. The blade motion is shown in Fig. 2 for a ratio of 0.75. The heavy cam and plastic chain drive dampen vibration. The position of the blades is determined by counting motor steps. Re-indexing is done each scan as the blades left the park position, opening a limit switch. A potentiometer also indicated blade position.

Electrical System

Sampling low duty cycle signals at 1 KHz requires a fast rise time amplifier. 60 Hz noise and its harmonics cannot be removed by filtering as is done with harp type profile monitors. A dual channel, well balanced differential current input amplifier[2] was designed to minimize interference, Fig. 3. Low leakage JFET operational amplifiers and CMOS switches were used. The input impedance was kept low, 3.3 kΩ at dc, to prevent the 1200 pF cable capacitance from degrading the system rise time. The transimpedance of the amplifier can be made large by increasing the value of the feedback resistors in the first stage at the expense of bandwidth or by increasing gain in the later stages at the expense of signal-to-noise ratio. Using LF356 op amps bandwidths of 7, 13 and 20 kHz were achieved for transimpedances of 100, 10 and 1 MΩ, respectively. Amplifier-generated noise at the output was about 15 mV P/P. Provision was made in the circuit for 1:2:5 gain steps, filtering, polarity reversal and 50 Ω line drive capability.

A Kinetic Systems 4022/4050 12-bit 8-channel transient recorder was used to digitize the outputs of the amplifiers. The digitization began as the blades left the park limit. The pulser signal from the cyclotron injection system was passed through a variable delay box before triggering the recorder to store an X and Y sample. The delay from pulser off to sample was generally set to be slightly less than the 412 μs beam transit time through the cyclotron (at 500 MeV). After each scan the recorder's memory was read through the central control CAMAC system by VAX 11/730 FORTRAN programs which made disk files and displayed the profiles. A Tektronix 7D20 sampling scope was also available.

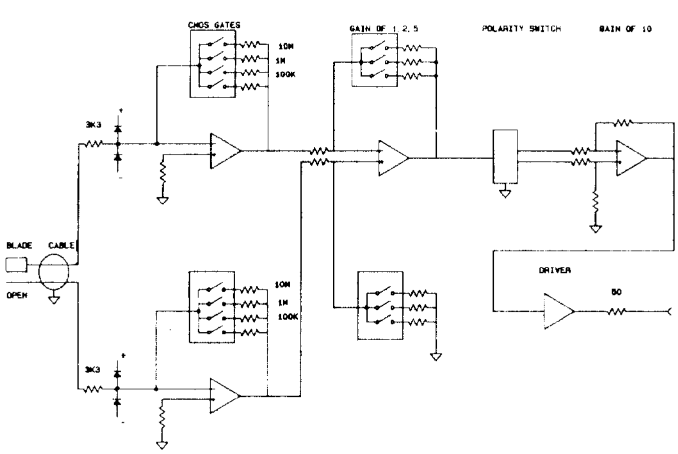

Fig. 3. A block diagram of one channel of the amplifier.

Laboratory and Low Current Tests

The accuracy of positioning was ±0.005 in. At sweep rates of less than 0.1 Hz the blades followed the motor steps. As the speed was increased the system went through various natural modes of vibration, with the maximum amplitude decreasing with increasing speed. Above 0.25 Hz the vibration of the blade was less than 0.005 in. The spring tension in the blades and their low mass combined to raise their natural frequencies above the step frequency, reducing their excitation. The follower began to bounce on the cam at 4 Hz. Beam profiles produced by the blades were confirmed by comparing with a nearby harp monitor. The signal wiring at the top of the monitor had to be shielded from the motor and limit switch wiring. The 100 ft cables from the monitor were grounded only at the amplifier end to prevent noise induced by ground loop currents.

Originally, the high voltage bias was applied to thin wires that travelled along with the blades, the beam duty cycle was 99.2%, and the sampling was not synchronized to the pulser. Beam currents of more than 100 nA were necessary for good profiles. The high voltage wires were difficult to tension properly and were subject to vibration which caused random bursts of ringing-like noise. A test of the effect of bias voltage on signal strength is shown in Fig. 4. The curve indicates a plateau at less than -100 V due to high energy scattered electrons and a second plateau above +100 V due to both high and low energy electrons. The total charge collected from each blade divided by the beam charge intercepted during a scan was 5.1 at 200 MeV and 3.1 at 400 MeV. These figures scale as the dE/dX of aluminun. Since no gas fill was used, the coefficients should remain fairly stable. A test at 50% duty cycle, Fig. 5, shows aliasing and ringing of a amplifier filter which was subsequently removed.

Kapton insulated signal wires in the vacuum of the monitor were found to generate noise currents as they rubbed on the grounded metal parts of the monitor during a sweep. This effect is common to many plastics used as insulation, including teflon, irradiated PVC and polyethylene. It was found that most of the noise could be eliminated by replacing the kapton covered

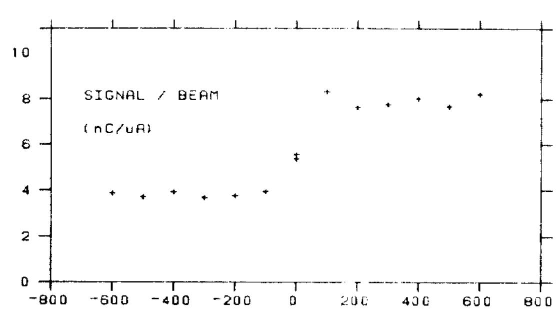

Fig. 4. Varying the bias on the high voltage wires gave two distinct plateaus of signal strength, using about 130 nA of beam.

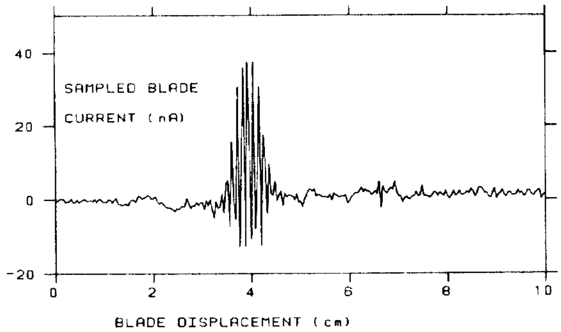

Fig. 5. Asynchronous sampling at 50% duty cycle caused aliasing and ringing in a temporary filter.

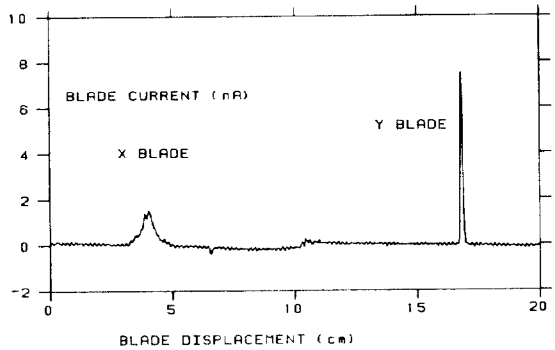

Fig. 6. Eliminating noise sources allowed profile measurement at 15 nA cw.

wire with thin RG174/U coax and grounding the coaxial shield. The high voltage wires were removed and replaced by a fixed aluminum ring a few centimetres from the blades. These changes allowed good profiles of 15 nA, 99.2% beams, Fig. 6. Again, only 100 V was required to reach a plateau region. As the blades sweep, they move away and towards the edges of the high voltage ring and this induces a shift in the signal baseline. The shift was quite small even with 500 V bias and could be reduced further by using two rings to decrease the electrical field gradients.

High Beam Current Tests

Tests were made using wires instead of blades and with sampling synchronized to the pulser. Profiles were measured at currents of up to 150 μA cw without beam spill trips or wire damage. Consistent profiles were obtained as long as the delay was adjusted to sample within the beam pulse. Outside this delay only a small background was seen. Sampling allowed profile measurement at 0.9% duty cycle with 1 μA of beam (81 μA peak), Fig. 7. Figure 8 compares profiles taken at different biases with a 1.7 μA cw beam. A wide halo appeared on

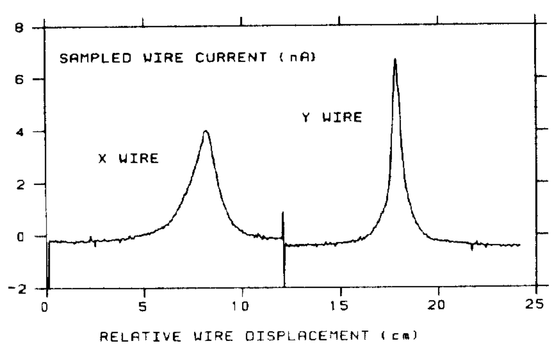

Fig. 7. A profile taken with 0.9% duty cycle beam.

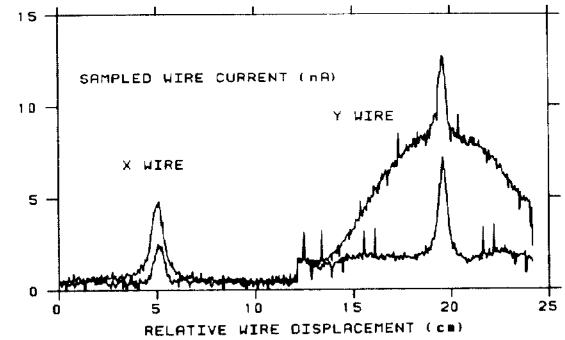

Fig. 8. The halo seen in the vertical profile changed with bias. The lower trace was taken with no bias and the upper trace with +80 V bias.

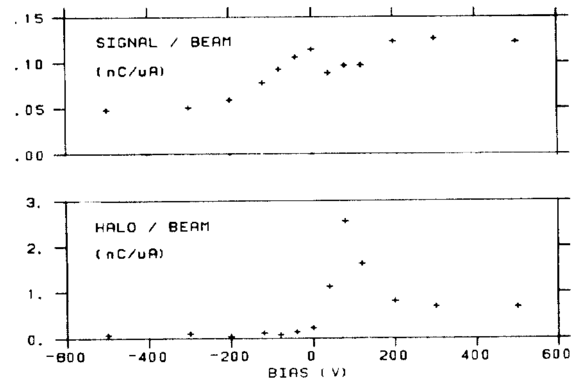

Fig. 9. The background halo was greatest at about +120 V. The SEM coefficient of the wire was 11% at 500 MeV.

the Y profile at biases near +120 V. The dependence of signal and halo on bias are shown in Fig. 9. The halo is thought to have been caused by a cloud of ions surrounding the beam which is electrostatically focused by the bias ring. When an air leak was created in the beam line, the halo effects extended to both wires as shown in Fig. 10.

Acknowledgements

We would like to thank John Stewart and Marty Knoll for their help in the assembly and installation of the apparatus. Dave Morris built the motor controller.

References

[1] G.H. Mackenzie, D. Tse, TRIUMF, TRI-DN-85-22, (1985).

[2] Olin. B. van Dyck and Iverson, LAMPF, private communication (1981).

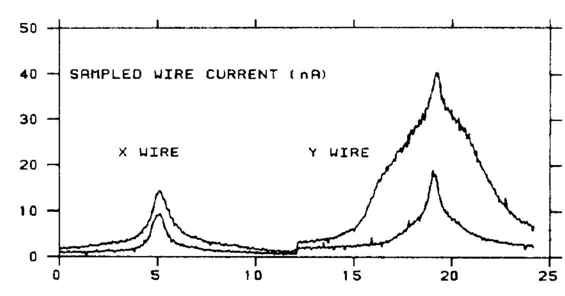

Fig. 10. A gas leak was introduced. The lower trace was taken with +350 V at less than 15 μm Hg, the upper trace with +200 V at 18 μm Hg, 3 μA cw beam.