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SECONDARY EMISSION MONITORS AT THE BEVATRON-BEVALAC*

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I. Summary

Secondary Emission Monitors (SEM) are used for high intensity, high energy beam fluence monitoring of heavy ions. The improved electronics and auto-zeroing of background noise has extended the useful range of the SEM down to the region where the limiting factor is capacitive changes between the chamber foils, from acoustic and mechanical vibration. Usable levels are in the 10^4 particles per pulse range for C^6 ions. The secondary electron yield is proportional to $1/\beta^2$. This gives an increase in yield of about a factor of 25 for injection energies over peak energies at the Bevatron. This enhanced yield has been exploited in designing relative intensity and position monitors that give usable signal levels while intercepting only a small percentage of the injected beam. The detector in this case is a wire grid. The output can be: 1. Sum proportional to the beam intensity or as a time profile; 2. Split grids for a right-left monitor; 3. Single wire scan for a spatial profile. These monitors give usable signals down to a level of 0.01-0.1 μA of injected beam.

II. High Energy Extracted Beam Monitoring

One of the major parts of the 1962 Bevatron improvement program was the installation of the external proton beam. Chambers were installed in the vacuum beam pipe near the exit of the Bevatron to measure beam fluence. The chambers had eleven 0.00025 in. aluminum foils spaced 1/8 in. apart. The chambers were isolated from the vacuum pipe with two 0.10 in. aluminum sheet windows to withstand atmospheric pressure as ion chambers for low intensity beam monitoring, or under vacuum as secondary emission monitors (SEM) to monitor high intensity beams.

Over the years the experimental demands required improvements in beam quality. Materials in the beam lines that could cause scattering or secondary particle contamination were slowly removed. Most experiments required high intensity beams. The ion chamber mode was seldom used. The isolation windows were eventually removed and the chambers were operated only in the SEM mode in the beam line vacuum system.

When the heavy ion program was started at the Bevatron, the experiments were all done in the primary beam rather than in a secondary beam. Nuclear science counting experiments required fluences of 10^4 to 10^6 particles per pulse. Biology experiments used 10^8 to 10^{10} particles per pulse. Low energy runs 100-200 MeV/amu needed minimum material in the beam. Rather than go back to ion chambers and the thick windows, we decided to try to upgrade the SEM system.

In the original system, the chambers were in the beam lines and the electrometers were in the Main Control Room (MCR). The signal cable runs were about 300 ft. There were two basic problems in the system when used at low beam levels—the signal to noise ratio in the cable run and drift in the electrometer.

The first problem was solved by placing a solid state preamplifier current-to-voltage converter near the chamber, so that the signal level in the cables to the electrometer in the MCR was in the one volt range. Without the preamplifier, the signal level from 10^6 carbon ions would be on the order of 2.6×10^{-12} A. Additional cables were installed to provide remote gain-change capability in the preamplifier.

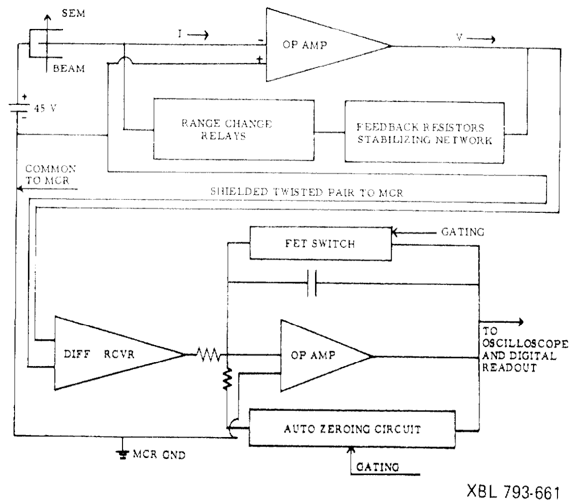

Fig. 1. Block diagram of SEM preamplifier and electrometer circuits.

The second problem, which we have called drift in the electrometer, was really three different problems. First was real drift in the zero of the electrometer in the vacuum tube circuits. Second the integrator had a single-ended input and was susceptible to noise. Third, part of the drift resulted from short-half-life activation of the aluminum foils in the chamber. This was particularly troublesome when changing from a high beam intensity to one of low intensity. When operating at a constant beam level, activation background could be zeroed out by setting the drift in the electrometer to just cancel this background signal, but beam intensity variations made this method unsatisfactory for normal operation.

The new integrator uses solid state electronics for improved stability. Included are a differential receiver to reduce noise effects and automatic zeroing between machine pulses. The latter minimizes zero drift and corrects the DC offsets from background activation. Block diagrams are shown in Fig. 1.

The output signal from the SEM chamber is roughly proportional to Z^2/β^2, where Z is the charge of the ion and β is the ratio of the velocity of the particle to the velocity of light. For a 400 MeV/amu fully stripped carbon ion, this would give an increase of 68 over the yield from a 2 Gev proton. This enhanced yield for low energy heavy ions helps extend the useful range of the SEM down to the 10^4 particles per pulse range.

The direct signal from the preamplifier provides a beam shape monitor. This signal compared to the signal from a scintillator and photomultiplier is shown in Fig. 2.

III. Low Energy Injection Beam Monitoring

Low energy beam fluences are normally monitored with a Faraday cup. As this is a destructive monitor, it is desirable to have another means of monitoring

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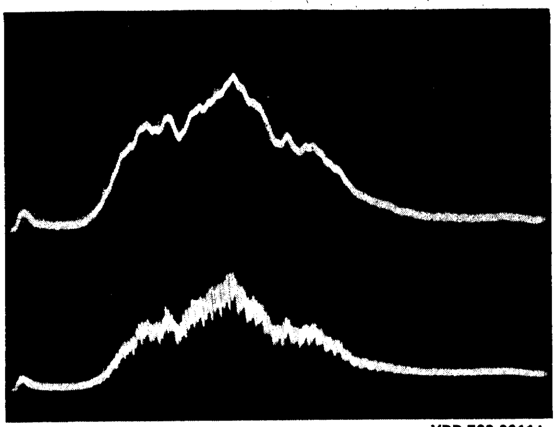

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Fig. 2. Beam 5×10^6 fully stripped ^{12}C ions. Upper trace is the Secondary Emission Monitor (SEM) preamplifier signal. Lower trace is the Photomultiplier (PM) signal, 1 MΩ terminator.

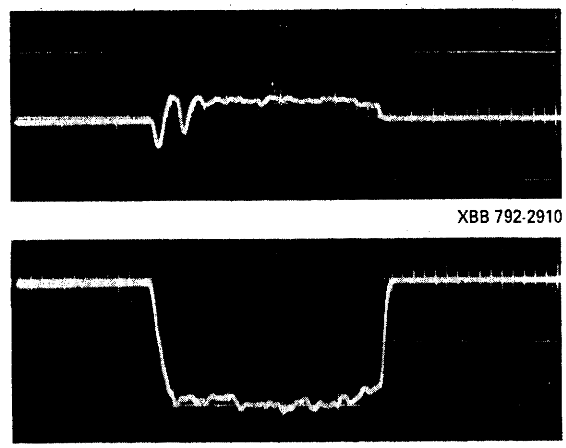

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Fig. 4. Injected beam split-grid signal: upper trace, A-B signal; lower trace, A+B signal.

beam intensity which is non-destructive. With high intensity proton beams this was done with beam transformers. The beam transformers in the Bevatron injection channel require a beam current greater than 0.5 mA to give a usable signal. With heavy ions, injection beam currents are in the range of 1 to 50 μA so some new method of non-destructive beam monitoring was needed. This was solved by using SEM techniques. A tungsten grid of 0.001 in. wires spaced 0.1 in. apart was constructed. This intercepted 1% of the beam. The secondary emission yield is a function of $1/\beta^2$. At injection β of 0.2, the yield is therefore up by a factor of 25 compared to high energy protons ($\beta \approx 1$). This increased yield, plus the higher number of injected particles necessary to make up for capture and extraction losses in the Bevatron, result in signal levels of about the same order of magnitude from the one percent injection grid monitors as from the foil chambers at high energy.

The wire grids are wired for two types of detector. The first type is a split grid. The wires on each side of center are wired in parallel. The two sets are brought out to preamps mounted 12 inches from the grid. The preamps are FET operational amplifiers with resistors in the feedback circuit ranging from 10^4 to 10^8 ohms. Range switching is done by low leakage relays in decade steps. These relays are controlled from the control panel in the injector control room. The control panel also has operational amplifiers that add and subtract incoming signals to provide real time profile or difference signals for right-left monitoring. A block diagram of this is shown in Fig. 3.

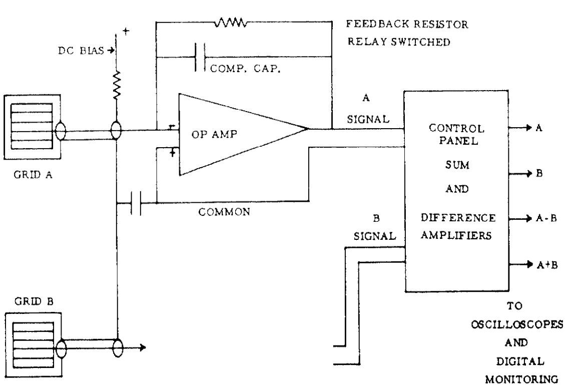

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Fig. 3. Block diagram of split grid detectors in injector beam line.

If the signals are displayed on an oscilloscope for tuning, the signals can be added together for a time profile or run A-B for a right-left time profile. A typical signal is shown in Fig. 4. In addition, the time signal is integrated and used as a digital monitor of the injected pulse. This digital readout is remoted to the Main Control Room (MCR) and to the Biomed Control Room.

Comparing the beam currents in a Faraday cup to currents from the grids we got the following results. For 19.2 MeV protons we measured 3500 μA in the Faraday cup to 70 μA from the grid. This gives a ratio of grid current to Faraday (beam) current of 1/50 or 2%. That is, a grid intersecting 1% of the beam gives a current reading equal to 2% of the beam current for protons. For 5 MeV/amu fully stripped carbon ions, this ratio goes to about 19% grid current to beam current for a 1% beam intercept. For higher charge ions we get a proportionally higher yield. The grids give usable signals down to about 0.01 μA of beam current.

The above yields are not inconsistent with calculations using Z^2/β^2. However the 5 MeV/amu carbon ions have a range of about 0.75 mil in tungsten so that the calculation is rather involved. Some ions stop in the wire and others pass through with different values of secondary electron production because of different values of β at exit. Secondary production is also a function of the angle of incidence of the primary ion. For this application of the grids there was no need for a detailed study of secondary electron yields, since we are concerned only with a relative measurement.

In the second type of detector, signals from the individual grid wires are brought out to produce a spatial profile. This unit consists of two 16-wire grids of 0.010 in. tungsten wire spaced 0.10 in. apart. The grids are spaced at intervals of several inches, positioned at 90^0 to one another. A biased ring is mounted between the grids to collect stray charges. The signals from the grids go ten feet to a 32-channel current-to-voltage converter; this employs FET operational amplifiers with resistors in the feedback circuit. There are three decade ranges with resistors of

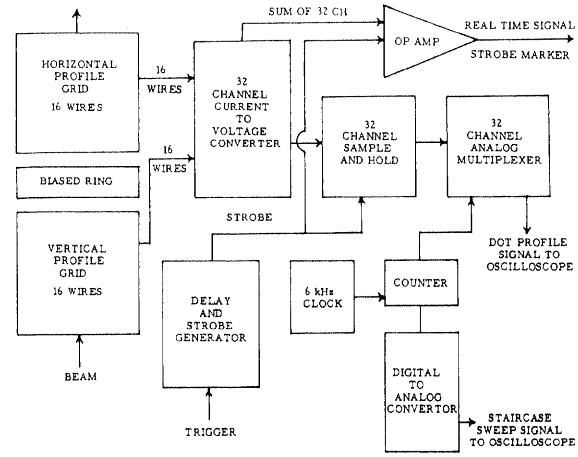

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Fig. 5. Block diagram of beam profile monitor in injector beam line.

10^3, 10^4 and 10^5 ohms. Also, the sample and hold and multiplexers are at the same location. Strobe timing is adjustable to any part of the beam pulse. Repetition rates are between 1 and 2 pulses per second. Sampled values are held and displayed repetitively on a CRT at a 200 Hz rate. A block diagram is shown in Fig. 5. Typical signals are shown in Fig. 6.

IV. Conclusions

In the above presentation, we have taken the secondary electron production as a function of $1/\beta^2$. This is satisfactory for rough approximations. Our basic calibration on the SEMS used in the EPB system is the C^{11} activation using 5.2 GeV protons. The yields for

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Fig. 6. Spatial profile monitor signal: horizontal profile is at left of photo and vertical profile is at right.

heavy ions are then calculated using the calculations of de Parry and Ratner[1] normalized to the β of the C^{11} activation runs.

The excellent response of the SEM at low fluence levels of particles puts us in the region where we can get an overlap between a photomultiplier scaler beam count and the SEM reading. It is planned at a future date to compare fluence measured with a scaler to fluence measured in the SEM for various ions and energies. We can then compare the results given by the above calculation.

The grids in the injection line have provided a rather simple mechanical detector in the beam line that gives very good relative monitoring of injected beam currents. The grid signals can be calibrated to a Faraday cup reading and then used as a non-destructive beam monitor on a pulse to pulse basis.

1. T. de Parry and L.G. Ratner, Evaluation of High Stability Secondary Emission Monitors, Trans. Nuc. Sci. Vol. NS-16, No. 3 June 1969, Pg. 923-926.