EVALUATION OF HIGH STABILITY SECONDARY EMISSION MONITORS

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Summary

A stable, remotely operated low scattering ($\theta = 0.246$ mrad) secondary emission monitor (SEM) which was developed at Argonne National Laboratory (ANL) is described. Experimental results for secondary yield vs. energy of incident protons of 3.6 GeV/c to 12.33 GeV/c indicate that the yield increase is about 0.03%/GeV/c/Al surface. Theoretical yield increase in the same energy range is about 0.02%/GeV/c/Al surface. The overall yield/proton/Al surface as observed at ANL increases from 2.7%/Al surface at 3.6 GeV/c to 2.96%/Al surface at 12.33 GeV/c.

General Description of SEM Systems

Two identical SEM systems were built at ANL and both are being used for quantitative measurements of the proton beam extracted from the Zero Gradient Synchrotron (ZGS). Due to the relatively high radiation level at the location of external beam measurements and also due to a relatively wide dynamic range to be covered, viz., $10^8$ to $10^{13}$ protons/machine cycle, both SEM systems are remotely monitored.

The output signals of both systems are distributed to various experimental and monitoring areas. Both systems are self-contained and easily movable to different locations. Details of the secondary emission chamber (SEC) themselves are shown in Fig. 1. Both chambers have the following technical characteristics, some of which are identical to those described elsewhere:\footnote{Work performed under the auspices of the U. S. Atomic Energy Commission}

1. Each chamber has a total of 15 aluminum electrodes of 15 cm active diameter. Each electrode is $1.25 \times 10^{-3}$ cm thick and has a mass of about 3.34 mg/cm$^2$.

2. Each titanium window of the chamber is $25 \times 10^{-3}$ cm thick and has a mass of about 1.14 mg/cm$^2$.

3. Total divergence angle of the crossing proton beam caused by the sum of all masses (279.44 mg/cm$^2$) is about 0.246 mrad.

4. A permanently secured differential ion pump of 15 liters/second pumping capacity (Ultek Model 22-011) keeps the inside pressure of the chamber at the level of about $2 \times 10^{-8}$ torr.

5. Total capacity of each chamber measured at its external terminals is $755 \text{ pF} \pm 2 \text{ pF}$. The total stray capacities of connectors, cables, etc., add up to $43 \text{ pF} \pm 1 \text{ pF}$. Hence, a total capacity value which appears at the input terminals of the electrometer (Cary 31) used in this system is $798 \text{ pF} \pm 3 \text{ pF}$.

6. Each chamber has a remotely operated range capacitor (see Fig. 7) of about 1900 pF which allows the standard maximum range of the electrometer to be increased from 30 to 100 V.

A general block diagram of the complete SEM system is given in Fig. 2 along with various triggering signals which are obtained from the ZGS Complex.

Although electrical circuit diagrams shown in the attached figures are self-explanatory, some additional comments are in order.

The circuit diagram of Fig. 3 shows on the left side the manual remote control circuit which is located in the main control room of the ZGS; whereas on the right side is shown the SEC with complete control circuitry, which is located at the site of the actual proton beam measurements.

Figures 4, 5, 6, and 7 show details of the remote control circuits which activate range, zero-adjust controls, and electronic input shorting of the electrometer.

In Fig. 8 is shown the general layout of the SEM location behind the shielding wall. In Figs. 9a and 9b a typical schematic timing program for the SEM is shown when the external proton beam is extracted from the ZGS during the first flattop (EPB). As it may be seen from these figures, proton beam extraction in this case occurs when the magnetic field of the ZGS is kept constant at about 8 K. The actual beam extraction time may vary from a few microseconds up to some 300 milliseconds. The remaining circuit blocks indicated in the general block diagram of Fig. 2 \footnote{F. Greeley and G. A. Sprau from ANL replaced original electromagnetic switch by high impedance (-10$^{11}$ ohms) MOSFET 2N3824 transistor, which proved to be very reliable.}
represent standard type units; therefore, they will not be described any further in this paper.

Experimental Results

Calibration of the SEM system was made on the basis of proton beam intensity readings obtained from evaluation of activated gold foils which were located in front of the SEC and their comparisons with the calibration standard of the SEM system. The energy range covered by measurements at ANL was 3.6 GeV/c to 12.33 GeV/c. The accuracy of the activated gold foil measurement is roughly 5%. This accuracy may not be adequate for more precise quantitative beam evaluations; however, due to difficulties in precise measurements of the proton beam in the GeV/c range, this relatively simple method is being extensively taken advantage of at ANL, whenever that accuracy range can be accepted.

The experimental yield/proton of the SEM may be obtained by using the following equation.

\[ y = \frac{Q}{C} \text{volts} \text{,} \frac{\text{volts}}{\text{proton}} \]  

where

- \( Q = y \times N \times 1.6 \times 10^{-19} \)
- \( C = 798 \text{pF} \) (capacity of SEC)
- \( y = \text{yield} \) (secondary electrons)
- \( N = \text{number of protons/burst} \)

Then

\[ y = \frac{V \times C}{N \times 1.6 \times 10^{-19}} \]  

Using experimental results which were obtained from SEM displays and from activated gold foil readings for various beam energies, the resultant secondary yields indicated in Table I and Fig. 10 were obtained.

<table>
<thead>
<tr>
<th>GeV/c</th>
<th>SEM y/Proton/C</th>
<th>No. of Gold Foil Activations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.6</td>
<td>75.80</td>
<td>2.70%</td>
</tr>
<tr>
<td>4.4</td>
<td>75.80</td>
<td>2.70%</td>
</tr>
<tr>
<td>4.7</td>
<td>76.63</td>
<td>2.73%</td>
</tr>
<tr>
<td>6.4</td>
<td>77.45</td>
<td>2.76%</td>
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<td>7.1</td>
<td>78.28</td>
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<td>7.6</td>
<td>80.75</td>
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<td>8.45</td>
<td>79.51</td>
<td>2.83%</td>
</tr>
<tr>
<td>9.00</td>
<td>81.41</td>
<td>2.90%</td>
</tr>
<tr>
<td>12.33</td>
<td>83.30</td>
<td>2.96%</td>
</tr>
</tbody>
</table>

All experiment results shown in Table I were recorded during a two-month period of time preceded by several months of operation of the SEM system.

As may be seen from Table I and Fig. 10, the yield of this unit shows an energy dependence of about 0.03%/GeV/c/Al surface/proton for the experimental energy range of 3.6 GeV/c to 12.33 GeV/c. The same energy dependence for a unit of similar construction was observed at CERN.5

Applying the theory which was developed by T. L. Aggson3 for incident electron beam to our case of proton beam, one gets the following relationship for secondary yield/emitting surface/proton.

\[ Y = \text{Const} \left\{ \frac{2mc^2\beta^2}{I} \right\} \left[ \left( 1 - \beta^2 + \frac{\hbar c}{m} \right) \left( 1 - \beta^2 + \beta^2 + \frac{4\pi nZ^2e^2}{2} \right) \right] \]

where

- \( \text{Const} = 2\pi Z^2 r_{\text{vac}} \Delta \)
- \( nZ = 7.826 \times 10^{-23} \text{cm}^3 \) (number of electrons/cm³ for Al),
- \( r_0 = a^2/cm^2 = 2.813 \times 10^{-13} \text{cm} \),
- \( z = \text{number of charges/incident particle} \) (for protons, \( z = 1 \)),
- \( \Delta = 1 \AA \) (computed equivalent active layer of Al surface),
- \( \eta = 10^4 \text{eV} \) (assumed average energy transferred to secondary electrons),
- \( I = 163 \text{eV} \) (average ionization potential for Al),
- \( \hbar = 6.58 \times 10^{-16} \text{eV} \),
- \( c = 3 \times 10^8 \text{cm/s} \),
- \( t = 0.6 \text{cm} \) (distance between Al plates),
- \( \beta = \frac{v}{c} \).

In this expression, equivalent active surface layer \( \Delta = 1 \AA \) has been introduced in order to equate experimental and theoretical results.

Substituting the above indicated values into Eq. (3) yields a curve shown in Fig. 11 covering the energy range 5.0 MeV to 100 GeV/c.

Comparing theoretical and experimental results observed at ANL and at CERN over the energy range 3.6 GeV/c to 16.7 GeV/c, one finds that the experimental energy dependence/GeV/c/Al surface/proton seems to be about 25% lower. Pertinent details of these theoretical and
experimental results are shown in Fig. 10. Due to the fact that the calibration of SEM systems in both cases was only made on the basis of activated gold foils, which have an accuracy of about 5%, this difference between theoretical and experimental results should be regarded with due reservation until more accurate measurements, eventually covering a wider energy range, can be performed.

References

Fig. 5. Schematic Diagram of Electromechanical Servo Drives.

Fig. 6. Remote Control Circuit of the Main Control Station.

Fig. 7. Schematic Presentation of the Control Loops at the Input of the Electrometer.

Fig. 8. General Layout of SEM Location at ANL for ejected Proton Beam Measurements.

Fig. 9A. Typical Cycle of Magnetic Field vs Time in ZPS for a Single Extraction of Proton Beam (EPB).

Fig. 9B. Timing Program for SEM When Extraction of Proton Beam (EPB) takes place during the Time b–c Indicated in Figure 9A.

Figure 10.

Figure 11.