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TESTS OF SEC STABILITY IN HIGH FLUX PROTON BEAMS*

V. Agoritsas† and R.L. Witkover††

Abstract

The Secondary Emission Chamber (SEC) is used to measure the beam intensity in slow extracted beam channels of proton synchrotrons around the world. With the improvements in machine intensity, these monitors have been exposed to higher flux conditions than in the past. A change in sensitivity of up to 25% has been observed in the region around the beam spot. Using SEC's of special construction, a series of tests was performed at FNAL, BNL-AGS and CERN-PS. The results of these tests and conclusions about the construction of more stable SEC's are presented.

Introduction

The SEC has been the standard intensity monitor in proton external beam lines for many years because of its unique and unmatched characteristics of dc response, linearity over many orders of magnitude and simplicity. Machine improvements resulting in increased beam spot density have lead to changes in the secondary emission coefficient in the area exposed to beam.

In electron machines changes occurring in the first few hours of operation had been observed when aluminum foils were used,[1] but gold plating appeared to prevent this phenomenon.[2] In 1968 Garwin[3] reported a significant long-term change in the coefficient of gold foils in the SLAC beam.

In 1974, Hornstra[4] (FNAL) noted a change of up to 25% in the coefficient of silver plated foils in an external beam line. Observations at BNL (1975) on a similar chamber, but containing aluminum foils, also indicated a 25% change. Measurements at CERN (1977) of the SEC's in the ss 62 beam line showed the secondary emission coefficient of the aluminum foil SEC's went down by 20-30% and the titanium or silver foil SEC's went up by 15-25%. The integrated proton flux per cm^2 was of the order of 2×10^{19}.

Such changes in the secondary emission coefficient are intolerable to the high energy physics experimenters and make accelerator studies, such as slow extraction efficiencies, impossible to interpret. Thus, a series of tests were begun to better understand the problem and determine suitable solutions. The SEC's tested were built at BNL, CERN, FNAL and SLAC using a number of different materials and constructional procedures and were exposed to proton beams at BNL, CERN and FNAL. These experiments and the results will be described.

Tests of Aluminum Foil SEC's

The first observations of SEC beam induced changes made at BNL were on a commercially built unit[5,6] containing 33 aluminum foils in three groups. Constantly decreasing extraction efficiency in the SEB had led to speculation that the C010 SEC coefficient had changed. The unit was moved to the FEB at the conclusion of the SEB run (March-April 1976) so that it could be placed on a moveable table about 3 meters upstream from the target and scanned across the fine FEB beam, using calibrated beam current transformers as reference. The spot produced by the SEB was found. The SEB was then left at a fixed position and scans made at regular intervals. After several weeks, a spot of 25% maximum depth was observed, corresponding to a change of $2\%/10^{18}$ protons/cm^2 (Fig. 1). This unit was opened and the foils inspected. A small raised region was observed on the foils, being more pronounced on those closest to the center.

At the start of the next SEB run a new chamber of the same design was installed. Careful records were kept of circulating proton beam and extracted beam as indicated by the SEC. Periodically the SEC's were checked using Foil Activation Techniques[7] (FAT). The results are shown in Fig. 2, from which a change of $2\%/10^{18}/cm^2$ was also inferred. At this point it was clear that a better design was required and different materials and techniques would have to be investigated.

Multi-Material Test SEC

Because a similar problem existed with the SEC's at FNAL, M. Awschalom and others had several special test units built to their specifications. In a cooperative effort these units were tested in beams at both FNAL and BNL.

One of these units (SSEC-2) contained three groups of 6μM aluminum foils on which was vacuum deposited 500 Å aluminum, 500 Å silver and 500 Å gold. The other unit (SSEC-3) had three groups of 6μM foils with 500 Å silver, but with each group having different inter-foil spacing. The foils were to be made by a subcontractor and transported to the SEC fabricator in an argon atmosphere. The assembly into the pre-baked SEC was also to have been done in an argon tent. There is some question about how carefully these procedures were followed however, since they could not be monitored by FNAL or BNL representatives.

The SEC's were placed in the P-East proton beam line on a moveable table about 10 meters upstream of the target. Data was taken on beam spot size and accumulated flux. The SEC's were scanned across the beam to search for beam induced changes. The detailed procedure and results are described in Ref. 8. The units were exposed to an integrated flux of 6×10^{18} protons/cm^2 at 400 GeV. Study of day-by-day performance of these special chambers show no secondary emission coefficient variations beyond the several percent resolution of the measurements. Because of the low integrated proton flux per cm^2 the tests, although extremely encouraging, could not be considered conclusive, making it necessary to continue the tests at BNL.

The units were transported to BNL and installed in the FEB. Unfortunately, the aluminum foil section of unit SSEC-2 and part of the gold group of foils became internally disconnected in transit. Scans made over a two-week period showed little change in the data. It is hard to ascribe a flux to this exposure because of considerable abnormal beam motion on the target. Because of these difficulties, the data taken on these units were also limited but again encouraging. However, the trend of the data did suggest that far less deterioration occurred. Even though the actual fabrication was not documented, there did appear to be an attempt to follow the specified procedures. From this experience it was felt that a stable SEC could be built if the foils were kept from exposure to air.

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†CERN, CH-1211, Geneva 23, Switzerland.

††Brookhaven National Laboratory, Upton, New York 11973.

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The Mesh SEC

In one of the early aluminum SEC's cut open at BNL, the area hit by the beam had developed a "dimple". All units showed heat induced discoloration of the windows. While calculations of the energy deposited per pulse by the beam show this to be small, the mechanisms for heat transfer from the foils are limited and the temperature may rise over a long time. Conduction can take place only through a fine signal wire. Radiation is limited since the emitting foil is close to and looking directly at a similar emitting foil as a sink. Calculations of this complicated geometry are difficult to perform so it was decided to build an SEC which would give the emitting foils a better "view" of the outer chamber. This was done by using only single emitting foils with mesh bias planes. Foils of aluminum, gold and nickel were installed with 90% transparency nickel mesh bias planes. The component parts were ultrasonically cleaned in alcohol and baked after installation at 250°C for 24 hours.

The SLAC SEC

The SLAC chamber was developed by E. Garwin[3] and had been used in the beam at SLAC, where it showed no deterioration. Garwin's studies had indicated that CO was being adsorbed on the clean gold surface of the original SEC's used at SLAC, raising the SE coefficient. He found that silver (without oxide) had a very low CO adsorption and would be most suitable for the foil. The solution he adopted was to clean the foil surface by argon glow discharge at very high current density to remove the oxide layer in-situ, then pump the chamber and seal it.

One of the SLAC chambers was obtained for test at BNL. Unfortunately during installation, the vacuum pump seal was broken and had to be replaced. This required reconditioning of the surfaces, which was done at BNL. During the processing the discharge current was allowed to rise too high and the foils bowed. The current was reduced and the foils relaxed to their original position, however, a wrinkling of the surface was observed. The SEC was installed in the SEB, since insufficient time was available to obtain new foils.

Tests on the Mesh and SLAC SEC's

Both units were installed at the AGS exit to the SEB (C010) from July through November 1977.[9] During this period the Mesh SEC saw a flux of 1.1×10^{19} protons/cm^2 while the SLAC SEC saw 1.4×10^{19}/cm^2. Data was taken on only the SLAC and the gold and nickel foils of the mesh unit, the aluminum wiring apparently having opened during handling. This unfortunately prevented testing of the hypothesis that the problems might be thermally induced. During this period the intensity was measured on a monthly basis using FAT. The results indicated no significant change beyond the 5% resolution of the measurement.

The two units were moved to the FEB where the Mesh unit was installed on a moving table. The SLAC unit was installed downstream, but not monitored at that time. The unit was scanned through the beam and clearly showed a spot produced by the SEB of depth 1-1.5% for the gold and 3.2-3.5% for the nickel. After one week of running in the FEB (3.4×10^{18}/cm^2), a spot appeared of depth approximately 2% for gold and 2.7% for the nickel. After another week (6.0×10^{18}/cm^2) the spot had grown to approximately 3.9% for the gold foil and 4-4.6% for the nickel foil. At this time the FEB was shut down.

During this period the SLAC unit was placed on the scanning table and the Mesh unit installed downstream where monitoring of its signals continued. The scans indicated surface irregularity of ± 2.5% over a 7 cm range. This is most likely due to the wrinkling of the foils observed through the viewing window during glow discharge processing. No spot was observed to change during the course of these scans even after exposure to a flux of 2.0×10^{19}/cm^2.

Data was accumulated by means of a program run in batch on the AGS PDP-10. Every two hours readings were taken of all beam transformers and both SEC's and stored on disk for later processing and display. Figures 3 and 4 show the long-term history of the gold foils (Mesh A), the nickel foils (Mesh B) and the SLAC SEC normalized to the closest transformer (U799) in the FEB. The gold foils show an early decrease of 3.5% for a flux of 4.3×10^{18}/cm^2 and then oscillate around that value even after a flux of 3.9×10^{19}/cm^2. This wiggle corresponds to entries in the operations log which describe problems with slow drift of the beam extraction parameters. The nickel foils exhibited a change of 7-8% in the secondary emission coefficient for this same flux but, while they show a "wiggle" over the same period as the gold foils, the behavior continues downward. The SLAC SEC also has a corresponding wiggle, but shows no change in mean value during the exposure to 2.0×10^{19} protons/cm^2.

The New CERN SEC's

Based on the observations by Garwin, Agoritsas built new SEC's at CERN using 5μM aluminum foils with 250 Å silver vacuum deposited on each side. After many attempts at obtaining a uniform argon glow discharge on all foils, a different approach was tried. On the basis of the tests of the FNAL special SEC's, a set of silver plated foils were carefully prepared and kept in a strictly maintained argon atmosphere. They were assembled into the SEC in an argon filled glove box and baked at 400°C for 24 hours, after which the units were sealed and pumped to hard vacuum. Six units built in this way were installed in the CERN ss 62 line. One unit was located near a beam current transformer in the primary branch of this line, which can be used for both fast and slow extraction. The transformer was used to check the SEC during fast extraction. After accumulating a flux of 8×10^{19} protons/cm^2 no deterioration of this SEC has been observed.

Summary

A number of SEC's have been tested in high flux proton beams to determine a solution to the problem of beam induced changes in the secondary emission coefficient. It appears that silver plated foils which have either been glow discharge cleaned in-situ, or prepared and assembled into the chamber without exposure to air can provide a stable secondary emission coefficient, even up to the limit where beam induced changes in the crystalline structure of the metal due to nuclear interactions might be expected (10^{20} protons/cm^2). It was beyond the scope of this program to study what surface phenomena take place to produce the change in secondary emission coefficient; however, it has been shown that methods of avoiding this problem do exist.

Acknowledgments

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We are particularly indebted to M. Awschalom of FNAL who gave us the two special secondary emission chambers and, in fact, suggested and supported the long-term stability tests with these chambers at FNAL.

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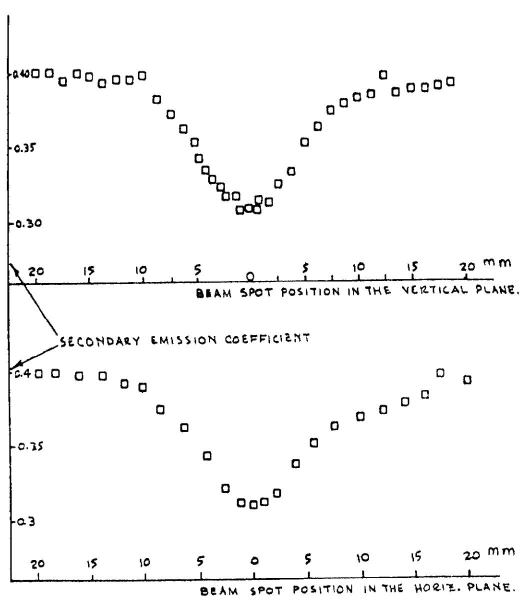

Fig. 1. Scan of BNL aluminum foil SEC.

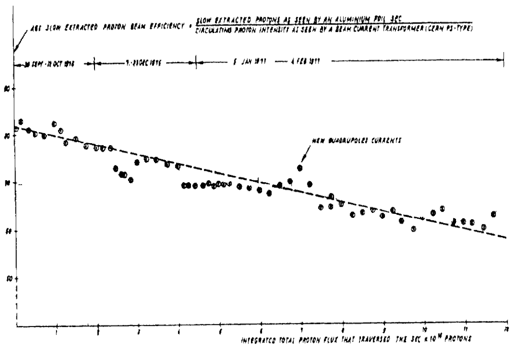

Fig. 2. History of extraction efficiency normalized to circulating beam for BNL aluminum foil SEC.

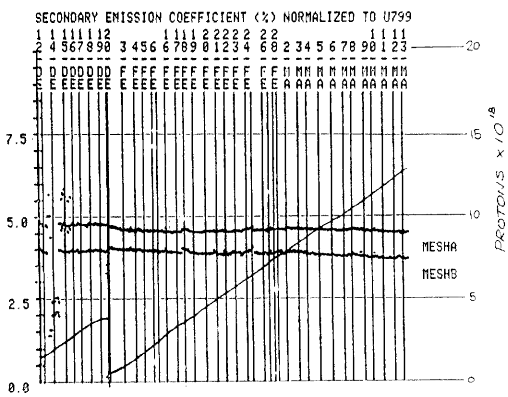

Fig. 3. History of gold foil (MESHA) and nickle foil (MESHB) in the BNL FEB.

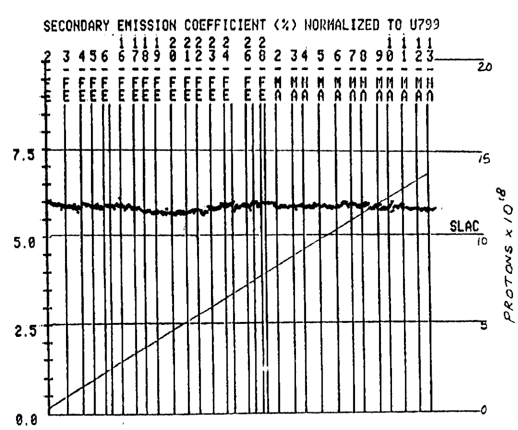

Fig. 4. History of the SLAC SEC in the BNL FEB.