BEAM MONITORING IN THE EXTRACTION REGION OF THE NEVIS SYNCHROCYCLOTRON

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Summary

A secondary emission monitor has been designed and tested for use in beam profile measurements of the extracted proton beam of the Nevis Synchrocyclotron. The monitor will provide a non-destructive simultaneous measurement of the vertical and horizontal position distributions, with a resolution of ~ .1 in. A residual gas ionization counter has been also designed. This counter will measure the radial profile of the accelerated beam at the parking radius.

I. Introduction

The extraction system of the modified Nevis Synchrocyclotron consists basically of three magnetic field distortions: The Peeler, the Regenerator and the Time Varying Bump (TVB). We plan to accelerate the beam to full energy (~ 560 MeV) and then turn the accelerating rf voltage off: Allowing the beam to coast at a stable orbit radius (average parking radius ~ 77 in.). During the later stage of the acceleration cycle, the beam is displaced away from the peeler and the regenerator through the action of the TVB. The slow time variation of the TVB then moves the beam particles toward peeler and regenerator where an exponential build up of radial oscillations provides the necessary turn separation for extraction. Three successive magnetic channels will then guide the beam through the fringe field out of the vacuum chamber. The adopted extraction system leads to a duty factor of ≥ 50%. The repetition rate will be 300 Hz: of the 3.3 msec single cycle ~ 1.5 msec will be used for acceleration and ~ 1.8 msec for extraction. (For a detailed description of the extraction system see Ref. 1)

For optimum alignment of all extraction elements it is of importance to monitor the beam at the parking radius and to know the profile of the non-circulating beam.

II. Design Considerations And Construction

The extracted proton beam lies within the main synchrocyclotron vacuum chamber and fringing field. Consequently, the monitoring device must operate in magnetic fields of ~ 20 kG and vacuums on the order of 10^{-6} torr. The presence of a strong magnetic field can reduce the monitor efficiency because of the small radius of curvature of the secondary electrons (energy ≲ 30 eV). Further inefficiency of the counter or distortion of the beam profile is possible due to electron drift along $\vec{E}\times\vec{B}$, where $\vec{E}$ and $\vec{B}$ are the collecting electric field and the magnetic field, respectively. Therefore, a secondary emission device which will operate in a high magnetic field should: (a) have an electric field configuration such that $\vec{E}\times\vec{B}$ drift is minimized and (b) take advantage of the strong $\vec{B}$ field lines. The detector is shown schematically in figure 1. The beam intercepts a 0.25 mil aluminum foil at an angle of incidence of ~ 20°. The emitter is biased negatively with respect to the collectors. Copper strips above and below the beam collect the electrons emitted by the foil. The arrangement shown has the following advantages: (a) simultaneous horizontal and vertical profile measurement, (b) the $\vec{E}\times\vec{B}$ drift is reduced, and (c) the tilt of the foil prevents emitted electrons from being recollected due to spiralling in the field (provided they have an appreciable velocity component toward the collector). A prototype was constructed entirely from radiation-proof materials. The overall capacitance of the device was on the order of a few

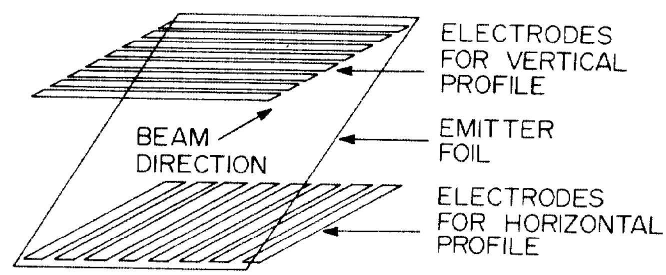

Figure 1 - Electrode configuration of the secondary emission monitor showing the electrodes which provide the vertical and horizontal profiles and the negatively biased emitter. Each strip electrode is connected to an integrator; the integrator outputs are sequentially interrogated yielding the profiles.

picofarads. A readout system was built which allowed the charge collected on each strip to be integrated. It also provided the display of the beam profile on an oscilloscope. The charge could be sampled and held in storage capacitors. This sample-and-hold procedure could be performed for a given number of beam pulses. In the single beam pulse mode, the integration time could be effectively gated to include only the beam-on time.

A residual gas ionization counter will be used at the parking radius of the proton beam. Assuming a circulation frequency of 20 MHz and a parking time of ~ 1 msec, the beam charge at the parking radius is "enhanced" by a factor of ~ 2×10^4 over that at the extraction channel. This yields usable signals due to residual gas ionization even in the ~ 10^{-6} torr cyclotron vacuum. (For 20 μA time average proton beam a practical detector of 1.5 in. long strips would yield a signal of ~ 10^{-10} Coulomb per burst at 10^{-6} torr vacuum).[3]

The counter is schematically shown in figure 2. It has the advantages: (a) it is absolutely non destructive, (b) it is possible to use the strong $\vec{B}$ field to focus the electrons onto the collecting strips, and (c) there is little profile distortion due to $\vec{E}\times\vec{B}$ drift.

The residual gas ionization counter consists of a series of 24 strips, spaced .25 in. apart, covering an ~ 6 in. region in the radial direction. A conducting plane facing the strips serves as a common negative electrode.

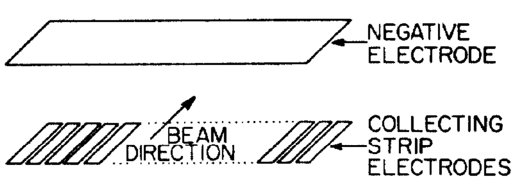

Figure 2 - Electrode configuration of the residual gas ionization monitor measuring the horizontal profile at the parking radius.

In designing the monitors and associated components, it was necessary to use only materials which were resistant to the high background radiation in the cyclotron. In general, this requirement excluded the use of any materials of complex molecular structure. The principal radiation resistant material used in the monitors has the proprietary name of "Mykroy".* This glass-bonded ceramic was used as the insulating material which held the copper electrodes. (see Fig. 1 and Fig. 2) It was also used in the construction of the connectors between the monitors and the external wiring. The external wires themselves were insulated with a commercially available fiberglass insulation. The feedthrough between the cyclotron vacuum chamber and the outside world were of the glass insulated hermetic seal type. Finally, it was convenient to avoid using any kind of cement in constructing the components of the monitors; all structures were secured mechanically.

* T.M. of Mykroy, Inc., 1649 Carboy Road, Arlington Heights, Illinois.

III. Tests And Results

The detectors were tested in the 200 MeV beam of the Brookhaven Linear Accelerator. They were operated at pressures ~ 3 x 10^{-6} torr, in uniform magnetic fields. The $\vec{B}$ field strength was varied from 0 to 10 kG. The detector was illuminated with a 200 MeV Linac beam, which consisted of typically 20 μsec long bursts of 50 mA instantaneous current. The beam spot was of ~ 1 in. diameter.

Figure 3 shows a typical beam profile observed at 1.1 kG and - 100 V bias on the emitter. The shapes of the profiles were in agreement with those obtained from one of the Linac beam monitors located about a yard upstream. Figure 4 shows the dependence of the signals on the emitter bias.

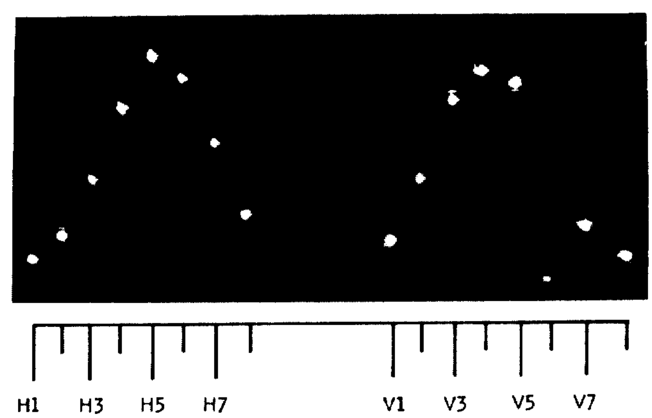

Figure 3 - Horizontal and vertical profiles as measured with an SEM at the Brookhaven 200 MeV Linac beam. The signals from the vertical collection strips are labelled V1-V8 and those from the horizontal strips are labelled H1-H8. (V6 was inoperative during the tests.) For this particular case, the emitter bias was -100 volts and the magnetic field was 1.1 k Gauss.

The vertical signal curve is different from the horizontal in shape because the electric field is different for each vertical profile measuring strip and thus each strip reaches its plateau at a different bias voltage. (see Fig. 1) This also causes a change in the vertical profile shape. No

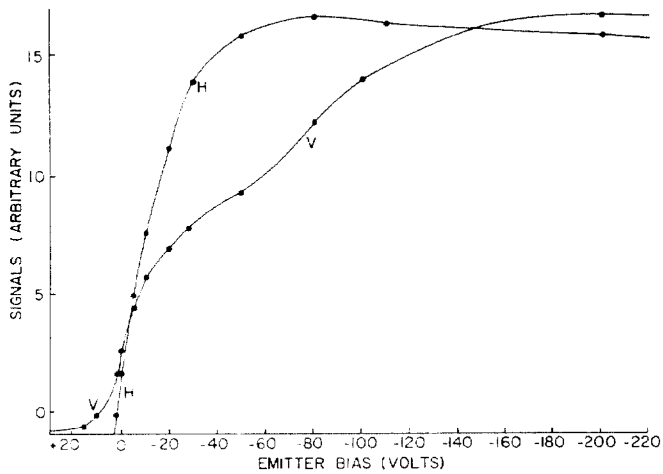

Figure 4 - Dependence of the SEM signals on the emitter bias. The points represent total negative signals as measured by all the horizontal (H) and vertical (V) profile strips. The vertical bias curve is different from the horizontal curve because the electric field varies between adjacent vertical profile strips, and therefore each strip reaches its plateau at a different bias voltage. (see Fig. 1)

change in horizontal profile shape with emitter bias was observed.

The magnetic field dependence of the profiles at -100 V bias voltage was not large. However, at 0 V bias, the horizontal profile "disappeared" entirely at zero field, although the vertical profile merely broadened substantially. A field of ~ 500 G was necessary to regain the horizontal profile. In general, increasing the field sharpened both the horizontal and vertical profiles, and increases the collection efficiency. Above 1 kG, magnetic field increases improved the collection efficiency only by ~ 10%.

The absolute efficiency of the counter, as measured by the positive signal on the emitter, was not precisely determined because there was no accurate beam intensity monitor. Rough estimates of beam intensity indicate an efficiency of 14-28% at -200 V bias due almost entirely to secondary emission. We expect theoretically 15% efficiency for a single foil and 200 MeV protons.[3]

The positive signal from the emitter was observed to be less than the sum of the negative collector signals (by 20-30%) at low bias voltages (less than -40V). This effect disappeared at higher bias voltages. It could be caused by the presence of electron "backgrounds" (produced by beam interactions in the surrounding environment) which are collected by the emitter.

The test of the residual gas ionization counter was difficult in the absence of a circulating beam. A test was nevertheless performed at the Brookhaven Linac beam with a prototype of such a counter and the lower beam current was tentatively compensated for by using a higher gas pressure in the vacuum chamber. This complicates greatly the quantitative analysis of such a test. Although no quantitative conclusions could be drawn from this experiment, it has been established that such a counter is usable in the desired $\vec{E}$-$\vec{B}$ field configuration, at Nevis.

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References

1. R.C. Cohen, E. Martin, K. Ziegler and S. Ohnuma, IEEE, Trans NS-16, No. 3, 434 (1969)

2. See W.H. De Luca, IEEE, Trans. NS-16, No. 3, 813 (1969) for the secondary electron yield as a function of energy.

3. See for example, T. de Parry and L.G. Ratner, IEEE Nucl. Sci. NS-16, No. 3, 923 (1969)