New Diagnostic Devices to Monitor Extraction from LEAR

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Abstract

The design, construction and test of two particle detection systems are described. The first one is a "secondary electron device". It presents a homogeneous foil of a few g/cm^2 (~4500 Å) thickness to the beam. This detector can be used in a non-destructive manner to measure the ripple of ultra-slow extraction and monitor the flux. The second device is a "scintillating fibre monitor" to analyse the profile of the extracted beam. This detector can be used as a beam profile monitor with a spatial resolution of 500 µm and also to estimate the intensity of an extracted beam with a flux in the range of 10^3 to 10^6 particles per second. Both detectors work in ultra-high vacuum (10^{-10} Torr).

1. INTRODUCTION

We will describe two particle detection systems. To measure the beam intensity ripple of the ultra-slow extraction from the CERN Low Energy Antiproton Ring—LEAR—and to monitor the flux, a secondary emission monitor has been developed. The second system is a scintillating fibre monitor, that will be used for the beam profile measurement and also to estimate the intensity of an extracted beam.

2. SECONDARY ELECTRON DEVICE

2.1 *Physical mechanism*

The process of secondary electron emission [1] can be regarded as being composed of two essentially independent parts namely: the formation of secondary electrons (secondaries) and their subsequent escape. The energy lost by the primary particles as a result of excitation and ionization processes will be assumed to result in the formation of internal secondary electrons. The secondaries formed are considered to lose their energy in various types of collision processes so that only a small fraction of all those formed are able to reach the surface with sufficient energy to escape from the solid. An important requirement for the detector is to keep the energy loss and the scattering of the passing particles as small as possible.

2.2 *Multiple scattering*

The small-angle multiple scattering of charged particles travelling through thick targets is well understood. In general the Molière theory predicts that a monoenergetic and unidirectional beam will be spread in angle over a quasi-Gaussian distribution. For non-critical applications one can use the Gaussian approximation with the following standard width [2]:

$$\theta_L = \frac{14{,}1}{p\beta} Z_{inc} \sqrt{\frac{L}{L_R}} \left[1 + \frac{1}{9} \lg_{10} \left(\frac{L}{L_R} \right) \right] \qquad (1)$$

where p is the momentum (in MeV/c), β the velocity, and Z_{inc} the charge number of the incident particle and L/L_R is the thickness (in radiation lengths) of the scattering medium. Some values of θ_T, for a proton or antiproton (Z=1) beam passing the foil described below, are given in the table 1. The beam blow up remains acceptable as long as the scattering angle does not exceed a few mrad.

Table 1: RMS scattering angle in the foil used.

P [MeV/c]	θ_T [rad]
61.2	6.28×10^{-3}
105.0	2.13×10^{-3}
200.0	5.96×10^{-4}
300.0	2.72×10^{-4}

2.3 *Description of the detector*

Particles of the beam passing through the thin foil produce secondary electrons. The device to focalize the secondaries onto the electron detector has been designed using the POISSON/EGUN package to simulate the secondary electron trajectories (figure 1.) [3]. The influence of space charge is not taken into account.

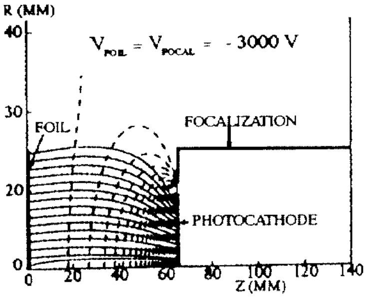

Figure 1. Trajectories of secondary electrons with final energy of 3.0 keV. Cylindrical symmetry is assumed.

A section through the device is shown in figure 2. The foil is inclined under 45° to the direction of the beam. The secondaries produced in the upper layer of the foil are collected by the electron detector: a scintillator-photomultiplier system. Signals from the detector will be used in a feedback channel to correct the ripple of the extracted beam from LEAR.

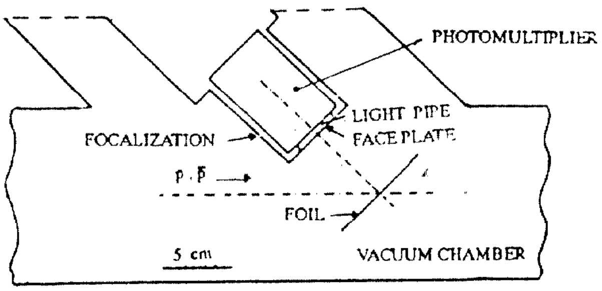

Figure 2. Secondary electron device inside the vacuum chamber.

The foils (targets) were developed at CERN. They are made from aluminium oxide (Al_2O_3) 2000 Å thick, with a diameter of 60 mm. They are coated with aluminium and cesium iodine to increase the electron yield. Several foil thicknesses were tried and finally the foil, consisting of four succesive layers (Al-Al_2O_3-Al-CsI), having a total thickness of 4500 Å was retained. An extremely uniform thickness is obtained with this method.

2.4 *Experimental arrangement and results*

The beam hits the foil with the CsI layer upstream. The foil forms part of an accelerating and focusing electrode which is held on a negative potential. The ejected electrons are accelerated up to a powder scintillator (P47) deposited over a face-plate, which is optically coupled to a photomultiplier tube (XP2262B). For improved light collection, a thin (slightly transparent) aluminium layer of about 600 Å thickness was evaporated onto the front face of the scintillator. This Al-layer is in contact with the grounded metal case. We have chosen the present technique because it is insensitive to vacuum conditions, and higher accelerating potentials can be used in the primary collection stage, which help to reduce the time spread and to improve the signal to noise ratio. The pulse height in the electron detector is proportional to the number of secondary electrons collected from the foil.

Bake-out tests showed that the maximum temperature that can be supported by the foil is 250° C. The detector works in ultra-high vacuum (10^{-10} Torr). Different tests have been made to optimize the collecting and focalizing fields. As a result, a potential of -3000 V in the foil and the same value in the focalization surface provides for good signals from the photomultiplier tube. It is clear, that if the potential is increased the collection efficiency of secondaries improves, but several insulating and beam deflection problems can occur.

At present, the secondary electron device has been tested with proton and antiproton beams following the ultra-slow extraction process at momenta from 300 to 61.2 MeV/c. The result is that the beam blow up is small and the passage of a particle through the thin foil can be timed very accuretely by detecting secondary electrons (figure 3.).

Further study must be done in electron yield, thin film field emission, beam deflection and radiation damage.

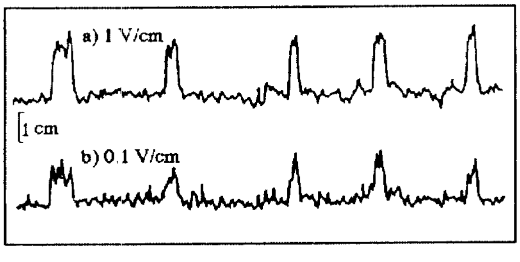

Figure 3. Modulation of the extracted beam due to the Proton Synchrotron super-cycle. Comparison between the response from a scintillator at the end of the LEAR test line (trace a)), and the response from the secondary electron device placed near the injection-extraction point of the LEAR ring (trace b)).

3. SCINTILLATING FIBRE MONITOR

3.1 *Choice of the fibre*

This study is part of the ongoing effort to develop high-precision profile and calorimetry systems based on the scintillating fibre technology. The passage of charged particles is observed by detection of the light emitted in a scintillating medium. The principle behind the fibre approach is that a certain fraction of the light is trapped inside the fibres by total internal reflection and transported to an output face. Among the various scintillating glasses which have been developed, the most attractive ones contain cerium (Ce^{3+}) emitter. These have the most rapid decay time and a good resistance to radiation. This is due to the strong electron affinity of cerium, which inhibits the formation of colour centres by ionizing radiation. After several comparisons [4], especially with regard to light output, we chose to use the glass NE901 [5].

3.2 *Description of the monitor*

A schematic view of the detection system is shown in figure 4.

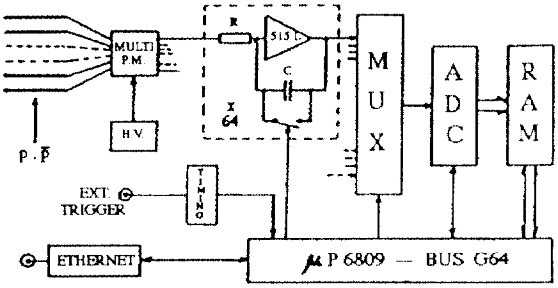

Figure 4. Principle of the "scintillating fibre monitor".

We have constructed a prototype with 32 fibres (each of $\phi = 500$ µm), in the same plane, spaced by 1mm (between two centres). The spatial resolution achieved is 500 µm.The light signals from the detector, placed inside the vacuum chamber, are transmitted to photocathodes of a multi-photomultiplier tube, through a face-plate and a light pipe. The collected current at each dynode, which is proportional to the incident signal, is integrated and amplified. The voltage responses of the integrators, after multiplexing, are digitized by ADCs. These digital values provide the profile of the extracted beam.

3.3 *Calculation of an integrator-amplifier channel*

An integrator-amplifier channel corresponds to one fibre in the detector and a photocathode in the multi-photomultiplier tube. The multi-photomultiplier, as a current source, determines the characteristics of the integrator as a function of physical parameters. In this study, we will consider a particle beam in y-direction and the profile monitor placed in the transversal plane (x,z). The beam profile measurement in the x-direction (z-direction) is done by placing the fibres parallel to the z-direction (x-direction). The charge depends indirectly on the shape and the dimensions of the beam. The integrated charge corresponding to channel (x_m) is:

$$Q_T(x_m) = (dN_E / dt) \cdot \Phi(x_m) \cdot \delta \cdot T \cdot \Gamma_0(p) \cdot G \cdot e \quad (2)$$

where (dN_E / dt) is the total number of ejected particles per second, $\Phi(x_m)$ the particle density distribution function in x-direction averaged over T, δ the fibre diameter, T the duration of particle ejection, $\Gamma_0(p)$ an optical calibration parameter, G the photomultiplier gain and e is the electron charge. Aiming at an output $V_{out} = 5$ V in the integrator, and taking typical values of the different variables in (2), we get the value of the integrator capacity: C = 2.5 nF. (For the construction of detector we have taken the standard value C=2.7 nF).

3.4 Measurement and results

The value of each ADC is digitized with a resolution of 8 bits ($L_{sb} = 5/2^8 = 19.5$ mV). The signals are displayed in a 32-channel histogram which is our beam profile representation. To compensate sensitivity differences between channels a fitting must be done. To do this, two steps have been considered: the first one, to equalize the responses of all the photocathodes and the corresponding electronics we have used a LED, and the differences have been compensated using potentiometers; second, to know the differences between fibres an Am-241 calibrated source has been used, and in this way the correction is possible. It tourned out that the values of the ADC outputs depend only on the high voltage of the multi-photomultiplier, the integration time and the type and energy of particles. Tests in resistance to radiation and stability of the system are in progress.

3.4.1 Profile Measurements

Several tests have been done in the laboratory with calibrated radioactive sources [6]. Figure 5 shows the profile of a circular-source (ϕ = 10 mm) of Am-241 (500 kBq).

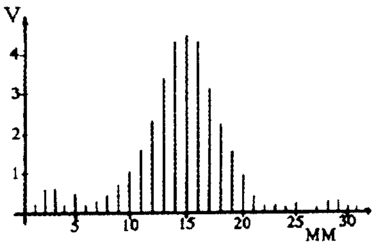

Figure 5. Profile obtained with Am-241.

Different tests to analyze the vertical profile of a proton beam at 61.2 MeV/c have been carried out (figure 6.) [6].

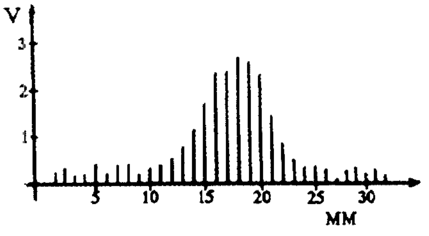

Figure 6. Vertical profile of a proton beam at 61.2 MeV/c.

3.4.2 Estimation of Intensity of an Extracted Beam.

The signal amplitude of each channel is proportional to the number of particles hitting the corresponding fibre. A realistic estimation of the intensity of an extracted beam "F" can be expressed as follows:

$$F = I / (G \cdot T \cdot K) \qquad (3)$$

where: I is the integral of the spatial distribution, G the multi-photomultiplier gain, T the integration time and K is a parameter depending on type and energy of particles. To know the value of "K" for each type of particle (p, $\bar{p}$ and ions) a calibration is necessary. For Am-241 (α emitter at 5.48 MeV), this value is $K_\alpha = 1.32\ 10^{-9}$ V/α. For a proton or antiproton beam K_p will be determined in future machine tests. Tests done with different intensity Americium sources guarantee that the flux can be correctly estimated in the range of 10^3 to 10^6 particles per second.

4. CONCLUSION

The wide range of energies and intensities used in LEAR required the development of two new detection systems. For ripple measurement of the ultra-slow extraction process we have designed and constructed a "secondary electron device", which consists of a thin foil, an accelerating field for secondary electrons and a scintillator-photomultiplier system to detect the electrons. This detector can operate in a non-destructive manner in spite of the low beam energies in LEAR. The second device is a "scintillating fibre monitor", which can be used as a beam profile monitor with a spatial resolution of 500 µm, and also, after calibration, to estimate the intensity of an extracted beam with a flux in the range of 10^3 to 10^6 particles per second. The use of these detectors will greatly facilitate the operation of LEAR.

5. ACNOWLEDGEMENTS

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6. REFERENCES

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