A Scintillator - Photodiode - Beam Intensity Monitor

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Abstract

A detector has been developed for intensity measurements of slowly extracted beams from the heavy ion synchrotron SIS. The MDC (Multi Diode Counter) consists of a plastic scintillator read out by photodiodes in current mode. The linearity of the detector output and its dependence on several beam parameters are investigated.

1 INTRODUCTION

The heavy ion synchrotron SIS accelerates all elements up to energies of about 2 GeV/u. Very low intensities (less than 10^6 particles per second (pps)) are determined by scintillation particle counters read out in pulse mode by photomultipliers[1]. To extend the range of these detectors to higher intensities, an attempt has been made to read out the scintillation light in current mode by photodiodes [2]. One important advantage of photodiodes compared with photomultipliers – besides their size, price, and insensitivity to magnetic and mechanical influences – is their linearity over many orders of magnitude without the need of adjusting a high voltage, when operated in the photovoltaic mode.

In current mode the dependence of the light output on the stopping power of the different ion species and energies becomes important: a linear relation would mean that only one calibration is necessary for all the ion species and the large energy range provided by the heavy ion synchrotron, as the energy loss can be taken from tables.

In earlier investigations especially particles with a high dE/dx showed a non - linear behaviour[3],[4], and attempts were made to describe the scintillator response by taking into account the saturation of a part of the luminescence centers[5],[6]. One can assume that in an inner region around the particle track, the energy loss density is high and saturation can occur, whereas outside this "core", luminescence centers are excited by higher energy delta electrons. In this "halo", the density of deposited energy is much smaller and saturation will not occur. When higher particle energies became available by means of balloon flights and new accelerators, a return to an unsaturated light output as a function of dE/dx was found for relativistic heavy ions[7],[8],[9],[10], a behaviour which fits well with the model of a core which is strongly quenched due to the high charges of the heavy ions and a large halo component produced by energetic delta rays. The only measurement with relativistic (700 MeV/u) ions up to Z = 54 showed indeed a linear response[11].

2 THE DETECTOR

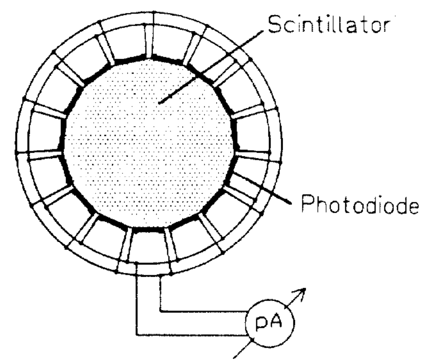

Figure 1: Detector principle and construction

The scintillation material used was NE108 (NE Technology, Ltd.). Its main characteristics is a light output of about 10^4 photons/MeV, peak wavelengths 545 and 570 nm, an attenuation length of 400 cm and a decay constant of 15 ns. The scintillator sheet with a thickness of 2 mm is machined into the shape of a regular 15-sided polygon with an inner diameter of 70 mm, see fig.1. The 15 photodiodes are pressed onto the corresponding surfaces and centered by means of three PVC rings. Silicon grease ensures a good optical transmission.

The SFH100 (SIEMENS) has been chosen as the detector diode, because the shape of its active surface (8.5 x 2.5 mm^2) allows a good optical coupling to the scintillator sheet, and for its relatively high spectral sensitivity in the wave length range of common scintillation materials. As shown in fig.2, the sensitivity of this photodiode is superior to the cathode of a conventional photomultiplier for wavelengths above about 400 nm (before amplification). We chose the orange emitting NE108 which promises to be more efficient with photodiodes, but the detection principle works also with common "blue" scintillators as has been tested in a previous prototype[12].

The 15 photodiodes are wired in parallel and the short circuit current is measured directly by a sensitive current - to frequency converter (10^{-11}A / kHz) without applying any bias. In principle, an operation of this detector in pulse mode should be possible at least for the heavier ions and eventually a thicker scintillator, but has not been investigated yet.

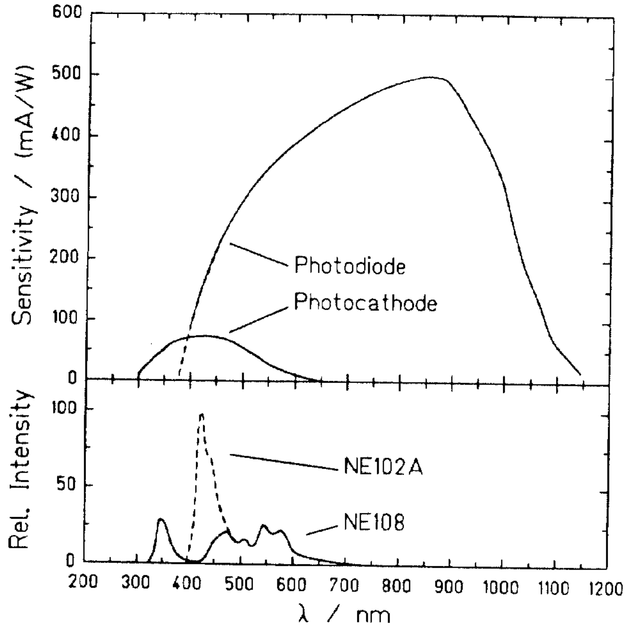

Figure 2: Spectral characteristics. The sensitivity of a photodiode (SFH100) is compared to that of the cathode of a photomultiplier (XP2972) (top). The blue scintillator NE102A and the orange scintillator NE108 have comparable integral light outputs but different emission spectra (bottom).

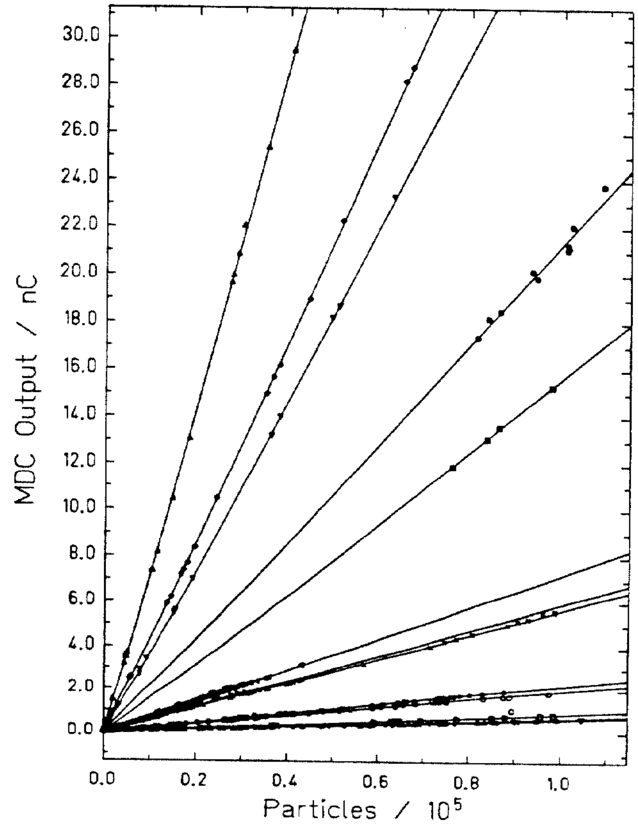

Figure 3: Detector output as a function of the number of ions per spill as determined by a particle counter. From top to bottom (element(energy in MeV/u)): U(300), U(600), U(900), Xe(200), Xe(1095), Kr(300), Kr(500), Kr(800), Ar(800), C(270), Ne(300), Ne(700), Ne(1200), Ne(1800)

3 EXPERIMENTS

For the measurements the detector was installed at the end of a high energy beamline. The beam particles had to pass a thin metallic window, a Multiwire Proportional Counter, a scintillation particle counter and air before entering the detector, in total about 500 mg/cm^2. For each combination of ion species and energy investigated, a series of beam spills with variable intensity was recorded by the MDC and several reference detectors.

The correlation between the MDC output, i.e. the diode current integrated over one spill period, and the number of ions counted by a scintillation particle counter is very good at low intensities, as is shown in fig.3 which summarizes the results taken at different beam times. In these measurements, the sensitivity of the MDC was limited by the resolution of the current measuring device of about 1 pA; the corresponding intensities can be taken from fig.4.

At higher intensities the particle counter starts to saturate; however from the analysis of the ratio of the outputs of the MDC and a secondary electron monitor we know that the linearity continues till the highest intensities available at the test facility up to now (10^8 pps 750 MeV/u ^{12}C). Thus the limits of the linear range are still unknown.

For testing the hypothesis of a linear dependence of the detector response on the energy deposited by the beam particles, the output charge per ion (the slope from fig.3) is plotted as a function of the calculated[13] energy loss in the following figures.

There is a noticeably good linearity within the datapoints of individual elements at different energies, as is shown in fig.4 in a linear scale for Neon from 300 to 1800 MeV/u. Putting together the data of all elements investigated, deviations from the fitted straight line up to a factor 2 are observed, being at least partly due to different systematic errors in different beam times . A dependence on the nuclear charge or mass of the ions can, however, not be excluded, especially at the low dE/dx end of the curve (cf. fig.3 of [7]).

The measured efficiency S of the detector corresponds to the slope of the fitted straight line: $S = 1.3 \cdot 10^{-16}$C/MeV. The expected value, assuming a perfect internal reflection, amounts to $S = 6 \cdot 10^{-16}$C/MeV. This is an indication that reflection losses and losses at the transition from scintillator to photodiode, as well as other effects like escaping delta electrons, are small.

The output of one diode depends on its distance to the particle track. This effect should be eliminated for the

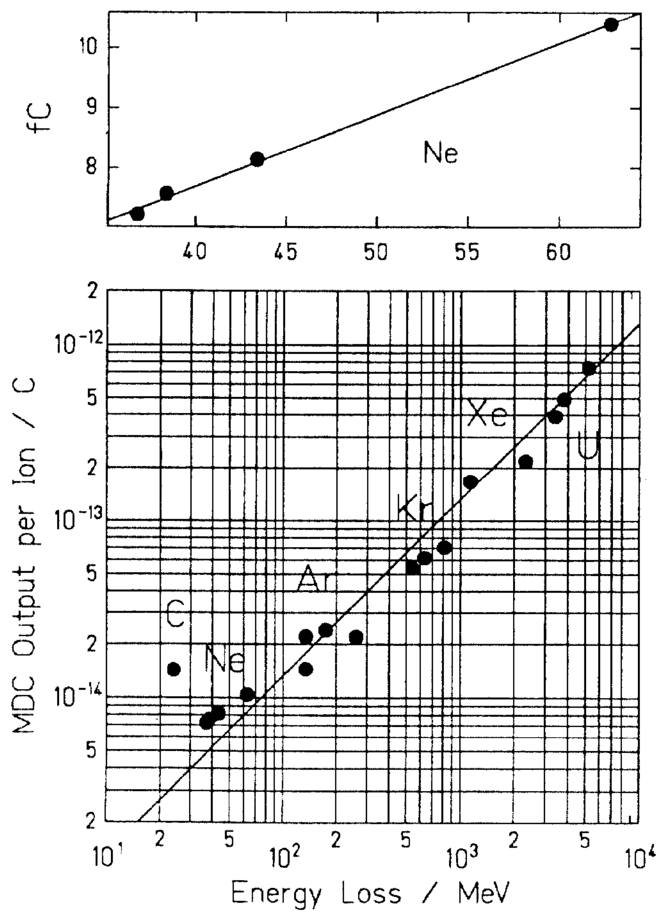

Figure 4: Detector output as a function of the energy loss. Top: only for Neon in a linear scale. Bottom: in a logarithmic scale with a straight line fit through zero.

most part by the summing up of all diode currents. The remaining position dependence is due to reflection losses and bulk attenuation and, near the edge, to the fact that each side surface is covered only to 57% by the active surface of the corresponding diode. The efficiency as a function of the position has been determined quantitatively by scanning the surface by means of a collimated beta source, fig.5. Clearly a spot of low efficiency can be seen. This region has probably been damaged when a high intensity beam stayed unintentionally too long at this position. This is the only sign of radiation damage after the detector had been installed for about one year at a place which is not only used for detector tests but also for regular beam diagnostics at intensities up to 10^9 pps. When checked regularly, radiation damage can surely be controlled. A homogeneity of the efficiency of about 2% should be possible within a diameter of 50 mm. Previous investigations had shown that in this configuration the photodiodes are less endangered by radiation damage than the scintillator material[12].

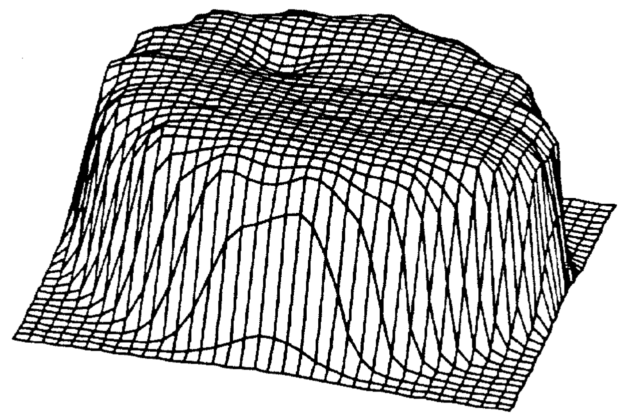

Figure 5: Position sensitivity of the detector when scanned with a beta - source in steps of 2 mm. Note the spot with reduced sensitivity due to radiation damage.

4 CONCLUSION

The results of the present investigations can be summarized as follows:

The upper intensity limit has not been reached yet; for 750 MeV/u ^{12}C it is beyond 10^8 pps. By means of energy loss tables, the calibration factor can be determined in advance with a precision of 50%. Relative (or, when calibrated by means of a particle counter, absolute) intensities can be determined within a few percent. When operated at high intensities, the detector should be checked regularly for radiation damage.

The few datapoints taken are not sufficient for an investigation of the light output as a function of other parameters, like the nuclear charge and the mass of the beam particles, which would be interesting from a more theoretical point of view. We can say, however, that this undemanding, inexpensive scintillator - photodiode - monitor is a useful beam diagnostic device for intensity ranges which are difficult to measure with other detector types.

5 REFERENCES

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