AN ELECTRONIC SCANNER FOR NUCLEAR EMULSIONS

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(presented by E. Amaldi)

1. Introduction

The use of emulsions as a tool for research in nuclear physics as well as in other branches of science is often limited by the amount of work and time which is required for scanning them after they have been exposed and processed. Any automatic device which could increase the velocity of scanning by a large factor, would be of great importance. Having this in mind, about a year ago the present authors started the construction of an electronic scanner.

As a first step we considered the problem of counting the number of nearly parallel tracks produced by a homogeneous beam of particles generated by an accelerator.

A similar idea has been followed by Goldsack and Van der Raay who have recently published the description of an automatic scanner working on the same principle as ours, although differing in some aspects.

In this first report on our work we give the details of our apparatus and of the results which we have obtained although we consider them as preliminary.

2. General principle of the method

The following general ideas have been the basis of our work:

1. In order to obtain transient inputs one has to move the image given by the microscope of the events under scanning with respect to the sensitive photocathodes used for their detection. Such a movement, indicated as vision movement will be in general independent and different from the scanning movement necessary to explore the emulsion in all its area and depth.

2. The elementary event to be detected is a single track which can be described as an almost straight black line interrupted by a number of gaps.

3. In counter technique one recognizes the presence of a particle of a given type out of a background of different origin, by means of time coincidences between two or three aligned counters.

The simplest operation that we can ask to be performed by an electronic scanner is the analogue of the detection of a beam of particles by means of a two counter telescope.

This is obtained by placing in the image plane $F_x$ of a projection microscope two little holes or slits which define a direction $x$ parallel to the mean direction of the tracks to be detected. In this simple case the vision movement may be identical with the scanning movement and will simply consist in a displacement with constant velocity $v$ of the object (nuclear plate) in the $y$ direction. Two lenses give images of the two slits lying in the plane $F_x$ on the photocathodes of two photomultipliers whose output are connected to a conventional coincidence circuit.

While in the following we will describe an electronic scanner which is essentially of this type, we call attention to the fact that, at least in principle, by disposing in the plane $F_x$ a suitable number of slits according to a convenient design, and by applying to the outputs of the corresponding photomultipliers the well-known electronic techniques developed in connection with large counter hodoscopes, one can hope to succeed in the future, to construct electronic scanners able to recognize and select rather complicated events, or possibly, capable of delicate measurements as, for instance, gap counting and gap length or scattering determinations.

The above general considerations and the problem of designing electronic scanners capable of increasingly elaborated operations may have also some interest in connection with the problem of vision; the analysis of the more complicated vision operations in a convenient number of elementary steps may be clarified by the planning and construction of electronic models.

3. Details of the experimental apparatus

   Optical and mechanical system.

   a) Fig. 1 shows a schematic diagram of the optical system and fig. 2 a picture of the apparatus.
We have used a type M10 Wild microscope with its standard camera attachment. A slit 35 mm. long of adjustable width parallel to the average direction x of the tracks in the emulsion, was placed in the image plane $F_2$. The slit was divided in three parts by two screens and three lenses $L_1$, $L_2$, $L_3$ made images of these three parts on the photocathodes of three 931 A.

Fig. 1. Schematic diagram of the optical system

A system of 2 or 3 aligned slits can be compared to a two or three counter telescope and therefore we shall call it in the following a microtelescope.

One can define the corresponding angular aperture both in the emulsion plane and in dip.

$b$) In order to obtain an angular aperture adjustable at will in the horizontal plane without reducing the amplitude of the pulses, we have used narrow slits and we have placed in the electric circuit described below univibrators providing square pulses of adjustable time length $T$.

The units perform a function comparable with the so-called persistance of image in the case of animal eyes. If $v$ is the velocity (in the y direction) of the vision movement in the plane of the plate, each slit has an effective width

$$A = vT = MvT$$

($M$ = total linear magnification of the microscope) which can be adjusted at will by changing $T$.

For example the aperture of a microtelescope composed of 2 slits, each of length B short with respect to their distance $L$, can be defined by making use of the following expression of the probability of detection

$$P_x (x, p) = \frac{1}{z^2} \left\{ \Phi \left( \frac{x_0 + x}{\sqrt{2 \pi} \theta_I} \right) - \Phi \left( \frac{x_0 - x}{\sqrt{2 \pi} \theta_I} \right) \right\}$$

$$+ \text{ if } x_0 \leq x_0$$

$$- \text{ if } x_0 \geq x_0$$

$$\Phi(x) = \frac{2}{\sqrt{2\pi}} \int_0^x e^{-x^2} \, dx$$

where $x$ is the angle of incidence of the considered particles with respect to the axis of the microtelescope; $\theta_I$ the mean angle of scattering of the considered particles of momentum $p$ for a cell of length $l = L/M$.

c) The angular aperture in dip is determined by the focal depth. We have increased it by taking advantage of the field curvature of our optical system. By placing the three slits in different horizontal planes, one could adjust, within wide limits, also the aperture in dip.

d) The illumination needs some consideration especially with thick emulsions because the scattered light reduces the contrast of the tracks and, together with the background due to developed grains of various origin, introduces a limitation on the minimum ionization that a track must have in order to be detected with certainty and selected out of the noise of accidental coincidences.

A reduction of the scattered light was obtained by placing a slit $F_1$ in front of the lamp (30 watt supplied a battery) parallel to the x direction. By adjusting the position of the condenser, the image of $F_1$ was focused in the plane of the tracks to be counted. Under such conditions only a rather narrow band of the microscope field was strongly illuminated.

Electronic circuits

Fig. 3 shows a block diagram of the electronic circuits.

The amplifiers, of a feedback type, have an adjustable bias which can be set to cut away the background of pulses smaller than a given amount.

The emulsions were moved at a velocity $v$ which under typical working conditions was between 0.25-0.4 cm/sec i.e. such as to give a displacement of 1" in times of the order of 1-6 seconds. With a scale of 100 we can count in such a time $10^4-10^5$ tracks; the limitation is mainly determined by the adopted value of the persistency of the image $T$. 
Fig. 2. Photograph of the apparatus.
Fig. 3. Circuit block diagram

PM = photomultiplier
A = amplifier
V = univibrator
T.C. = Threefold coincidences
D.C. = Twofold coincidences among any pair of channels (i.e., (1-2) + (2-3) + (1-3))
N₂, N₃ = mechanical counters, or scaler, or recorder used to mark coordinate y of track satisfying certain assigned conditions (direction and ionization)

In other cases the output of the coincidences was connected to a Brush BL 201 recording oscillograph which writes on a moving strip of paper the coordinates y of the tracks satisfying chosen certain conditions of direction and ionization.

4. Preliminary results

In order to investigate the behaviour of a single channel we have used the following technique. A track of the desired ionization was placed at an angle \( \alpha \) with respect to the x axis and the stage of the microscope was moved in a oscillatory way in the y direction. Under these conditions the pulse due to a track of chosen ionization and orientation was repeated periodically and could be easily measured on the screen of an oscillograph triggered by a synchroscope.

Fig. 4. Pulse amplitude at the output of a single photomultiplier as a function of the focal depth. Used track: \( g/g₀ = 5 \). Objective X100; total magnification 320; slit width 250 \( \mu \)m. Emulsion: G5 400 \( \mu \)m thick

Fig. 5. Background as a function of depth under the same conditions and in the same units as the data of fig. 4

Fig. 4 shows the investigation of the focal depth: the used track had an ionization \( \sim 5 \) minimum and was placed parallel to the x direction (\( \alpha = 0 \)). The total magnification was 320 and the slit had a true width of 250 \( \mu \)m. The emulsion was a G5 400 \( \mu \)m thick and the track was placed roughly at half of the emulsion thickness. The amplitude of the pulse is expressed in volts. Its value however is dependent on the intensity of the used light and on the voltage across the photomultiplier.

Fig. 5 shows the background as a function of depth for the same emulsion.

From fig. 4 one sees that if one sets the discriminator of the amplifier at the position indicated by the horizontal line, the background is eliminated, the pulse amplitude is still of a few volts and the focal depth is about 14-15 \( \mu \)m.

Fig. 6 shows the pulse amplitude as a function of the angle \( \alpha \) as it was obtained under the same conditions.

Fig. 6. Pulse amplitude as a function of the angle \( \alpha \) between the mean direction of the track and the axis of the slit
Fig. 7 shows for 3 different values of the width of the slit the pulse amplitude and the continuous current of the photomultiplier as a function of the flux of light in arbitrary units.

This was changed by adjusting a diaphragm placed in front of the lamp.

Fig. 7. Pulse amplitude and photomultiplier current as a function of the flux of the light: \( d \) = diameter of the field diaphragm in millimeters

Fig 8 shows the number of threefold and twofold coincidences as a function of the angle \( \alpha \), and fig. 9 the number of threefold coincidences as a function of \( \alpha \) for two values of the persistency of the image: \( T = 5 \times 10^{-3} \) sec. and \( 1 \times 10^{-3} \) sec., obtained with tracks of \( g/g_0 = 3.5 \).

Part of the emulsions used in this research had been exposed to the Liverpool Synchrocyclotron. We express our thanks to Prof. H. W. B. Skinner.

Fig. 8. Threefold and twofold coincidences as a function of \( \alpha \) obtained with a beam of protons \( (g/g_0 = 3.5) \). \( T = 5 \times 10^{-3} \) s; \( v = 3.3 \) mm/s

Fig. 9. Threefold coincidences as a function of \( \alpha \) obtained with a beam of protons \( (g/g_0 = 3.5) \) for \( T = 5 \times 10^{-3} \) s and \( T = 1 \times 10^{-3} \) s, \( v = 3.3 \) mm/s

LIST OF REFERENCES

DISCUSSION

E. Segrè:
I think you mentioned in some private conversation that with this electronic scanner it is possible to count the absolute number of tracks present in emulsion.
Could you explain the principle of the method?

E. Amaldi:
One of the advantages of an electronic scanner of the type described above, is that it allows, at least in principle, an absolute counting of all tracks (of given ionization and direction) contained in a certain volume of emulsion.

One can for instance imagine to apply a scanning procedure of a thick emulsion of the following type: each one of the two halves (a and b) of a binocular microscope is provided with a microtelescope (for instance a threefold coincidence system) which counts the numbers \( A_i \) and \( B_i \) respectively of tracks belonging to successive intervals in dip according to the geometric scheme shown in fig. 1; in a single sweep across the emulsion one counts simultaneously (table)

\[
\begin{array}{ccc}
A_i & B_{i+1} & C_{i,i+1} \\
\end{array}
\]

where \( C_{i,i+1} \) are the sixfold coincidences between the two microtelescopes \( a \) and \( b \), due to the partial overlapping of their focal depths.

At the next sweep, one of the two microtelescopes, let us say \( b \), is not displaced in dip so that it counts a number of tracks

\[
B'_{i+1} = B_{i+1}
\]

while the other, in this case telescope \( a \), is displaced so to count

\[
A_{i+2}
\]

and the sixfold coincidences give

\[
C_{i+2,i+3}
\]

At the next sweep \( a \) remains focused at the same depth and therefore it counts

\[
A'_{i+2} = A_{i+2}
\]

while \( b \) is displaced so as to count \( B_{i+3} \) and the sixfold coin-

cidences give

\[
C_{i+3,i+4}
\]

One repeats the procedure as many times as necessary to scan all the thickness of the emulsion.

The total number of tracks is given by the expression

\[
A_0 + \frac{1}{2} [B_1 + B'_1 + A_3 + A'_3 + \ldots + A_{2n}] - (C_{01} + C_{21} + C_{23} + \ldots C_{2n,2n-1})
\]

\[
\begin{array}{|c|c|c|}
\hline
\text{Micro-telescope } a & \text{Micro-telescope } b & \text{sixfold coincidences} \\
\hline
\text{First sweep} & A_0 & B_1 & C_{01} \\
\text{Second sweep} & A_2 & B'_1 = B_1 & C_{21} \\
\text{Third sweep} & A'_2 = A_2 & B_3 & C_{22} \\
\hline
\end{array}
\]

Fig. 1