A VIDICON SYSTEM FOR THE AUTOMATIC RECORDING OF SPARK CHAMBER EVENTS

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Geneva - September 1964

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I. INTRODUCTION

As part of the preparations for a spark chamber experiment on neutral π meson photoproduction by polarized photons at the Lund 1.2 GeV electron synchrotron, a vidicon system operating on-line with a computer has been developed.

The experiment will require knowledge of the energy, direction and polarization of the recoil protons. Those measurements are conveniently made with a carbon plate spark chamber, which subtends a large solid angle, gives a good determination of the particle trajectory and a fair knowledge of the proton energy. The expected asymmetries in the nuclear scattering on carbon which measures the polarization are rather small and a large number of events, of the order of 10^7 , are needed making it imperative to use a filmless method of recording. Wire chambers and acoustic spark chamber techniques become complicated in practice, because it is desirable to accept protons within a fairly wide energy range, and this requires many gaps. The proton tracks are simple and a vidicon system is certainly suitable for the recording. It can store an image long enough for a scan over many lines and has a resolution of typically $1/1000$ of the horizontal sweep. We are fortunate enough to have a small computer, SMIL, nearby so that the data can be transferred on-line, thus eliminating the need of intermediate data storage.

The spark chamber we intend to use in Lund is similar to the one developed for an experiment at CERN by Dr. E. Heer at the University of Geneva, and our vidicon system will first be tested with his chamber and may also be used in his experiment.

From the spark chamber a 90° projection is obtained on one side of the straight view by the use of a 45° mirror. The spark chamber consists of about 60 spark gaps, arranged in groups, with different plate thickness and gap width.

To guide the scanning beam through the gaps, we intend to mount at the beginning and end of each gap illuminated guide strips. Furthermore, empty spaces between the spark chamber sections will be used for mounting fixed calibration points for the reconstruction of the picture (Fig.1).

II. GENERAL PRINCIPLES OF THE SYSTEM

We use a commercial TV camera, Philips EL 8000, where the built-in sweep generators are removed. The sensitive element in a vidicon tube is a photoconducting layer deposited on a transparent conducting surface. Normally the layer has a homogeneous negative charge received from the scanning electron beam and a small dark current flows to the anode surface through the photoconductor resistance. When light strikes the layer, the resistance of the layer drops at the illuminated parts and the inner surface discharges. During the scan the electron beam recharges the layer and the charging current causes a drop in the potential across the anode resistance. The amplified pulses define the image. It may be necessary to erase the picture by one or more additional scans using a defocused electron beam.

As mentioned in the introduction, the left-right asymmetry in nuclear scattering is small. All possible biases of the detector which could affect an asymmetry measurement should therefore be removed. Vidicon systems using the normal sawtooth, horizontal deflection have such a bias since it would not be possible to separate two crossing tracks, which would be interpreted as a scattering always in the same direction. To eliminate this bias we choose to make a triangular sweep.

A preliminary version of the vidicon system has been reported earlier⁽¹⁾. Several modifications have been introduced since, the most important of which is that the vertical deflection is guided directly by video signals, obtained from the above-mentioned guide strips. The beam is deflected until it reaches the edge of the guide strip, which is aligned with the centre of the next gap. The vertical deflection can thus easily be fitted to different spark chamber geometries and non-uniform spacings between the gaps, as shown in Fig. 1. This picture shows a single track (one projection) with two calibration marks in the centre.

The horizontal positions of video signals are digitized by an eleven-bit data scaler counting a 2 Mc/s clock pulse, the output of which is also used to generate the horizontal sweep. This eliminates the need to reset the scaler at the beginning of each sweep.

The video signals due to sparks in the two projections of the spark chamber are selected by a rectangular "frame" signal (Fig. 3(2)) derived from the horizontal sweep voltage. Spark signals in each view instantaneously stop the data scaler and the number in it is dumped into a buffer. This is shortly afterwards read out to the computer.

The system is at present developed for use with the CERN Mercury computer which can only accept data transfers at at least 250 μ s intervals. This limits us to record only the first spark in each view with a horizontal sweep of 1 ms. However, since the sweep is of alternate directions, two tracks in each view can in principle be detected, as described in Ref. 1. SMIL will allow for data transfers every 15 μ s, and should thus, with suitable modifications of the equipment, make the recording of several sparks per gap possible.

For a 60 gap chamber, the total data recording time is 60 ms. The time between two events is used to erase the old event from the semi-conducting layer of the vidicon tube. The minimum time interval between two events is thus with one erase cycle 120 ms, as far as the vidicon system is concerned. However, the Mercury computer which has a small input capacity will require about one second for the calculations after each event, and will thus severely limit the rate. While the Mercury is useful for preliminary testing, faster computers such as SMIL must be used in actual experiments. SMIL has also a larger input memory and will allow interrupt operation, i.e. data accumulation of a few events while analysing other events.

III. COMMUNICATIONS WITH THE COMPUTER

At present the vidicon system is adapted to the CERN Mercury computer. The data link allows the transfer of 10 binary digits⁽²⁾. There is one line, the "busy ready" line, (Fig. 3(8,20)), for the communication experimenter-Mercury and one line, the "select" line (Fig. 3(5)), for the reverse direction. When the vidicon system is ready to transfer data, it sets on its line the ready level (-20V) Mercury, within the next computer cycle of 60 μ s, sends back a select pulse (-20V, 10 μ s) telling that the data levels will be read off during the following 10 μ s. On the select pulse the vidicon system responds by giving a busy level (+0V) and the data levels (-20V, +0V) are given as 20 μ s pulses. A programme will tell Mercury how many numbers to read in each picture. It then starts calculations during which no select pulses are returned and the ready level therefore stays on. The assignment of data storage locations in the computer sets the minimum time interval between two transfers to 250 μ s.

IV. THE GENERAL PRINCIPLES OF THE LOGICS

The logic is shown in Figs. 2 and 3. The numbers to be found in the text below refer to Fig. 3.

An event is defined when a charged particle passes through the spark chamber in the proper solid angle defined by a system of scintillation counters. The output pulses of these counters are fed to a coincidence circuit which gives a trigger output as shown in (17). In order to eliminate random coincidences, the output signal from the coincidence circuit is as usual passed through a gate, which is open during the synchrotron beam. The output pulse triggers the spark chamber and is also counted by a scaler, which thus records the event number for future reference. The trigger pulse has to pass another gate which is open during the busy part of the busy-ready signal shown in (8, 20), and which rejects events occurring before the computer has finished the analysis of the previous event.

After passing the busy-ready gate, the pulse triggers a one-shot multivibrator where it is stretched, so that the following flip flops will be blocked about 4 ms. One flip flop, with output signal 15, which controls the vertical sweep generator, has to block the sweep during a time long enough (4 ms) to ensure complete resetting. In order to achieve synchronization between the horizontal and vertical sweeps, the start pulse (16) of the vertical sweep is taken from the continuously running horizontal sweep generator which in turn is driven by the data scaler as mentioned above. Another flip flop, with output 19, is blocked by the 4 ms one-shot multivibrator output in one position and reset by the same horizontal sweep pulse (16) which starts the vertical sweep. Its output is used to read out the event number scaler to a buffer and then into the computer before the scan of the picture has started. The rear part of the read pulse resets the buffer. The output (19) also sets the busy-ready flip flop in ready position in order to inform the computer that the event number should be transferred. The rear part of the output (19) finally flips a flip flop (output signal 18) which is reset by the end of the vertical sweep, and thus defines the first vertical sweep after the trigger pulse, during which the image scan is performed. The following sweeps are used to erase the picture from the semi-conducting surface of the vidicon tube as mentioned earlier.

When the vertical deflection voltage (14) has decreased below a certain value, a discriminator gives a 4 ms pulse to the flip flop (15), which resets the vertical sweep to its starting position. The discriminator level thus determines the vertical sweep length.

The frame signals (2,11) are derived from the triangular horizontal sweep voltage, in a frame generator, with 4 adjustable levels. Video signals due to sparks are recognized in a gate, opened by the frame signal (2). The spark pulse flips a flip flop (output 12). If a video signal is missing in one projection due to the lack of a spark in that particular gap, the flip flop is instead flipped by the frame edge. It is reset by the same edge of the frame signal now delayed by about 8 μ s in a one-shot multivibrator as shown in (12). The output (12) triggers another flip flop which switches the 2 Mc/s clock pulses from the data scaler for a predetermined number of pulses set on a scaler delay unit. The data scaler is thus stopped long enough to read out its contents to the buffer unit

and the recorded number defines the spark position in the gap relative to the start point of the horizontal sweep, where the scaler number is zero. Before it can accept new data, the buffer has to be reset. This is done by the negative going part of the "frame" signal, as indicated by (9). During each horizontal sweep, there will thus be two data outputs, each containing either a spark position, or, in the absence of a spark, the position of the frame.

The data transfer to the computer from the buffer unit takes place when the $8\ \mu\text{s}$ delayed frame pulse during the first vertical sweep sets the flip-flop, which is generating the busy-ready signal, in ready position.

The ready signal is indicating that scaler data are stored in the buffer unit and the computer acknowledges this by returning a select pulse shown in (5). The select signal sets the busy-ready flip flop to the busy position. It is also stretched to about $20\ \mu\text{s}$ in a one-shot multivibrator (6) to give a sufficiently long read signal (7) to the buffer. The read signal is also gated (18) so it can reach the buffer only during the first vertical sweep (23), in order to avoid interference with the read out of the event number.

While erasing the preceding picture, the vidicon beam is defocused, and is focused by a flip flop triggered by the beam gate pulse, sufficiently in advance of the scanning to allow the current in the focusing coil to adjust itself. The flip flop is reset at the end of the first vertical sweep by the vertical discriminator.

The vidicon system is monitored by a commercial x-y oscilloscope e.g. Tectronics 536 (plug in units type C-A, K, T). We can check all critical pulses in the system simply by setting a switch on a switchboard. The oscilloscope is normally showing the video signals added to the vertical sweep with the horizontal sweep as a time base, (photo 5).

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V. DETAILED DESCRIPTION OF THE ELECTRONICS

The major part of the circuit is built up by standard Philips circuit blocks, essentially as indicated in the block diagram, Fig. 2. Some of the circuits are, however, specially developed.

1. The horizontal deflection generator

The horizontal sweep is normally controlled by the output of the digitizing data scaler, but for testing purposes, a built-in 1 kc/s oscillator is provided. A binary scale unit generates 1 ms long square pulses, which are integrated in a Miller integrator to give a linear triangular sweep (Fig. 4). The symmetrical square wave pulse train is applied through the condenser C_1 . A positive pulse, say, would decrease the amount of current flowing through the amplifying transistor T and its collector potential falls, but not much, because the feedback condenser C_2 tends to compensate the increase in the base potential. A transient equilibrium is maintained every moment causing only a slow fall of the collector potential of T.

The wave form at the collector is almost linear because the condenser C_2 is charged by a nearly constant current flowing through R. It is constant because the change of voltage at the base is very small compared to the 6 volts that we are working with. The output voltage at T, E_{out} , is related to the input voltage, E_{in} , at C_1 as follows:

$$E_{out} = A E_{in} (1 - e^{-t/((1-A)RC_2)})$$

where A is the gain of the transistor T. When expanding the exponential we find if $|A| \gg 1$ that

$$E_{out} = -E_{in} t/R C_2$$

The linearity thus will be better the higher the gain. The diode D coupled to the collector sets the right dc level of the output.

The output of the Miller generator passes through an emitter follower to a npn output transistor with the horizontal deflecting coil in the collector and a variable resistance in the emitter circuit.

2. The vertical deflection generator

The vidicon scan should follow the spark chamber geometry as closely as possible. A staircase sweep is required where the steps are generated by the horizontal flip flop. Some correction is needed to give the steps accurate height. We first tried to use a guiding system, where a photomultiplier watches a cathode ray screen with a mask in front of it⁽¹⁾. The fitting of the mask, however, is a delicate task and we decided on another system using the video signal itself to produce the necessary correction voltage to the vertical deflection.

The signals that generate the staircase sweep are obtained from two basic sources, one giving a preset deflection as a first approximation and the second a correction derived from the video signal itself. The preset deflection system is designed fairly flexible to allow the scanning of complicated spark chamber geometries, consisting of several sections each with a different module, and separated by empty spaces. Each section corresponds to a one-shot multivibrator in a "chain", the first of which is triggered at the beginning of the first scan (Fig.6). The switch from one OS1 to the next one is synchronized with the horizontal sweep. The RC time of each OS1, i.e. the number of gaps in the section, is controlled by an external feedback condenser C_1 and is fine adjusted by a potentiometer inserted in the collector of one of the transistors in the block. Each time an OS1 fires a positive pulse appears on the vertical deflection line 2. Each pulse amplitude is separately adjustable by means of a potentiometer. These pulses serve to give the deflection corresponding to the empty space between sections. The level on vertical deflection pulse 1, also adjustable by means of 5 potentiometers, sets the bias of transistor T_4 in Fig. 5, which controls the amplitude of the synch pulses passing through T_5 and thus the module of each section.

The fine correction to the vertical deflection during the first scan is obtained directly from the video signals. The guide strips shown in Fig. 1 give video pulses, which are standardized and separated from the spark signals by a frame signal (11). They are attenuated in a potentiometer and applied to T_1 in Fig. 5.

Figure 5 shows the vertical deflection unit. The vertical staircase deflection is introduced by charging up a condenser C_1 by positive current pulses of the four different sources mentioned above, each via a diode pump. C_1 is the integrating condenser of a Miller circuit, which involves an amplifier T_1 and an emitter follower. In order to ensure a flat top for the steps, the base current leakage of T_1 must be small, that is, the collector resistance of T_1 must be large. An electronic switch T_2 resets the vertical sweep. When a negative pulse is applied to the base of T_2 , C_1 is discharged and the base of T_1 returns to ground potential. In order to shorten the resetting time, a diode D is introduced to increase the current flowing to C_1 . The diode will transmit current only as long as there exists a potential drop across it and the last part of the discharge of C_1 will have a time constant determined by RC_1 . It is important that the resetting is complete before introducing a new sweep, otherwise the scan will not return to its assigned starting position. Therefore, the block pulses going to the dc input of the reset controlling flip flop (1) must be long enough. The PS1 discriminator determines the length of the vertical sweep. It triggers at a given negative voltage level (set by the potentiometer R_2) and the pulse duration is determined by the condenser C_2 and the base current of T_3 . The flip flop (1) is blocked in reset position as long as the positive pulse from the discriminator lasts and is flipped back by the next synchronization pulse from the horizontal flip flop. Similarly the trigger pulse is stretched in a one-shot multivibrator so that it will block the flip flop (1) long enough for the vertical reset to be complete.

3. The spark discriminator

The video signals from sparks are handled by two different discriminators (Fig.7). One has the threshold so adjusted that it excludes noise from the video amplifier. The other contains a differentiating network. The risetimes of the video signal are around $4 \mu s$ (photo 12) and the differentiating time constant is $1 \mu s$. The amplifier threshold of the discriminator is set very low, so that the second part of the differentiated pulse triggers near the zero cross (also background from noise is accepted). The output of the two discriminators are fed to a triple coincidence circuit, where the third pulse is the spark frame.

4. The frame generator

For the separation of the spark and the sweep correction pulses a frame is needed. The frame generator is shown in Fig. 8. The triangular sweep triggers a series of standard discriminators, the output of which are combined in "and" circuits to give the desired frames (2,11). The 30 V supply is introduced to make the setting of the potentiometers more independent of one another. A synch pulse is needed to compensate for hysteresis in the PS1.

5. Vertical deflection for erasing

During the erase procedure, the correcting circuits are inoperative and there are also no pulses on vertical deflection line 2. The control voltage on vertical deflection line 1 is provided by flip flop (2) in Fig. 5 with the output (18), via a potentiometer R_3 , which will cause a uniform staircase sweep voltage to develop. To ensure complete erasure of the picture, the beam is also defocused to a width larger than the step size (see above).

6. Other parts of the electronics

The "busy-ready" unit is shown in Fig. 9 and needs no further comment.

The scaler and buffer units shown in Fig. 10 are conventional flip flops with a frequency limit around 10 Mc/s. The transfer unit is designed to drive a long 75 Ω matched coaxial cable with pulses of 20 V.

VI. DATA PROCESSING

A preliminary programme handling the analysis of vidicon data in a polarization experiment has been written by Mr. S. Henriksson for the CERN Mercury computer. The spark chamber is assumed to contain four basic units. Section one and three are assumed to consist of thin aluminium plates and define the direction of the incoming and scattered particles. Section two contains carbon plates, in which the nuclear scattering will occur. In section four, which has thick aluminium plates, the particle range as well as its final direction is determined.

Starting with section one and three, the programme calculates the coefficients of eight straight lines, four of which define the incoming and scattered particle trajectories in the two projections and in scans from the left to the right and the other four from sweeps of opposite direction. The lines are combined to see if we have one track or two tracks (in which case the event is rejected) and the final output is the coefficients of four lines defining one broken trajectory. This information together with the end point of the track is stored and analysed later by a programme that meets the experimental requirements giving scattering angle, particle energy, and so on. The main difficulty is to write a programme which is fast enough considering the limitations of a small computer memory.

Principles of analysis

First the event number is transferred. It is followed by a given number of data pairs of 10 bits each. The data can represent either a spark or a frame edge defining the region in each view within which sparks must be located. The computer keeps track of the gap number. The data is digested by the computer which gives a signal to the vidicon logic when it is ready, causing one additional but irrelevant data transfer.

In some sweeps, two calibration marks rather than sparks are measured. The calibration gaps are grouped in pairs in order to give information which allows the picture to be reconstructed. The analysis goes as follows. The spark data are checked to see whether they are in an

allowed zone or not. The good sparks in section one and three are fitted to a line by a least square method. The following system of equations is solved and a normalized line is found.

$$\begin{aligned}w_q t_1 + x_q t_2 &= y_q \\x_q t_1 + z_q t_2 &= \pi_q\end{aligned}$$

where

$$\begin{aligned}w_q &= \sum x_i^0 \\x_q &= \sum x_i \\y_q &= \sum y_i \\z_q &= \sum x_i^2 \\\pi_q &= \sum x_i y_i\end{aligned}$$

The spark with the largest deviation from the line is found. If the misfit is worse than a certain tolerance, the spark will be excluded from both projections. The line is recalculated using the remaining sparks and the procedure is repeated until all remaining sparks are within the tolerance. We then check if there still are enough sparks to define the event. A control is made of the angle between the incoming and the scattered particle trajectories to exclude unscattered proton events. The location of the nuclear scattering is calculated. At this point, sparks in section two and four are included and fitted to the lines in a way similar to that described above. Finally the end point of the track is determined. A computer output telling "event o.k. " together with possible indications of ruled out sparks is obtained and the coefficients of the lines and the end point, are stored on magnetic tape.

Another programme will, at certain intervals, process the accumulated data, merging the lines in the two projections to a reconstruction in space, and computes the required information on the production and scattering angles, checks with the kinematics of the process and makes a statistical analysis. Outputs of this analysis are periodically given to the experimenter.

ACKNOWLEDGEMENTS

We are grateful to Mr. Sten Henriksson, Department of Numerical Analysis, Lund University, Lund, who wrote the programme for the Mercury computer and to Dr. H.J. Slettenhaar, CERN, Geneva for helping in programming and on-line connection to the Mercury computer.

* * *

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PHOTO CAPTIONS

Photo 1 : The horizontal deflection sweep and the spark selection frame.
One sweep is approximately 1 ms.

Photo 2 : Clock pulses fed to the data scaler and scaler stop pulses.
The stop pulse is initiated either by a spark signal or by a frame edge and terminated by a delayed frame edge. The scaler stop is in this case 16 μ s.

Photo 3 : The vertical deflection sweep and trigger pulse. When a trigger pulse is at hand, the sweep immediately resets to the starting position.

Photo 4 : Busy-ready signals and the first vertical sweep selector pulse.
The first ready pulse causes the transfer of the event number, the others cause the transfer of data.

Photo 5 : Video signals added to the vertical sweep with the horizontal sweep as time base. The photo is the image of the test picture.

Photo 6 : Isolated video pulses generating the vertical deflection.

Photo 7 : Isolated video pulses representing sparks.

Photo 8 : Pulses triggering the scaler stopping flip flop. Either a spark or a frame edge can set the flip flop.

Photo 9 : Output signal of the previous flip flop.

Photo 10: Read scaler pulses.

Photo 11: Select pulses received from the Mercury computer.

Photo 12: Video signals of artificial sparks. Time scale 20 μ s/div.

FIGURE CAPTIONS

Fig.1 : Spark chamber scanning sequence.

Fig.2 : Block diagram of vidicon circuits. The numbers in the diagram refer to pulse shapes given in Fig.3.

Fig.3 : Pulse shapes at various points in the block diagram. Note the change in the time scale at the centre of the diagram. The pulses should be compared with the photos.

Fig. 4 : The horizontal deflection unit.

Fig. 5 : The vertical deflection unit and associated electronics.

Fig. 6 : The circuit generating the vertical deflection pulses.

Fig. 7 : The video signal discriminator and the pulse selection circuit.

Fig. 8 : The frame generator and the monitor.

Fig. 9 : The busy-ready circuit.

Fig.10 : The scaler, buffer and transfer units.

* * *

Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

Photo 8

Photo 9

Photo 10

Photo 11

Photo 12

FIG. 2

FIG. 3

DIODES OA 200

GROUND

+6V

-6V

FIG 4

FIG. 5

[illegible]

$\sigma^2 = 0.0009$

(

[illegible]

DIODES OA 200
 T GROUND ∇ +6V ∇ -6V

FIG. 6

DIODES OA 220

GROUND, $\uparrow +6V$, $\downarrow -6V$

FIG. 7

DIODES OA 200

GROUND, $\nabla +6V, \nabla -6V$

FIG. 8

TRANSISTORS ASY 27

DIODES OA 200

GROUND

+6V

-6V

FIG. 9

TRANSFER UNIT
x 10

BUFFER UNIT
x 10

SCALER UNIT
x 10

FIG. 10