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A COMPUTER-CONTROLLED FLYING SPOT DIGITISER FOR SPARK CHAMBER PHOTOGRAPHS

P. Scharff-Hansen, T.R. Willitts,
CERN, Geneva, Switzerland

J.-C. Lacotte, C. Victor,
Institut du Radium, Orsay, France

ABSTRACT

A device is described which measures spark chamber pictures automatically at a rate of 1800 per hour, using any small computer of at least 2K memory. It has already been used to measure 500,000 pictures in three experiments.

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INTRODUCTION

A number of devices using a cathode ray tube and a computer are under development for the automatic measurement of spark chamber pictures$^{1-4)}$. The device described here uses a small computer to control a commercial oscilloscope. It was originally designed as a simple solution to the measurement of pictures from a particular experiment. However, the principle of operation is adaptable to any kind of spark chamber pictures.

OPTICAL SYSTEM AND FILM TRANSPORT

A commercial oscilloscope$^{5)}$ is used, with the tube mounted separately from the power supplies and amplifiers (Fig. 1). An image of the spot, with a 1.5 : 1 reduction, is focused onto the film by a lens. The film is clamped against a field lens which ensures uniform light collection by a photomultiplier (150 AVP). A semi-transparent mirror sends a fraction of the light onto another field lens and photomultiplier which is used to modulate the intensity of the cathode ray to obtain a constant brightness of the spot. This reduces the effect of grain in the screen. The output of the principal photomultiplier is fed to a saturating amplifier with an adjustable threshold. This gives essentially two logical output levels with no backlash (Fig. 2). Differentiation is used to ignore slow variations of intensity across the picture.

Unperforated 35 mm film is used, and the frames are positioned by means of a 4 mm square black mark on each, which is detected by a photo-diode.

CONTROL OF SPOT POSITION

The position of the spot is entirely determined by the contents of two scalers (Fig. 1). These are connected to digital-analogue convertors$^{6)}$. The analogue outputs are applied to the deflection amplifiers for the C.R.T. The computer can position the spot by writing coordinates into the scalers. It can then initiate a scan in either of two perpendicular directions by opening a gate to allow one scaler to count a train of pulses from a 500 kc/s oscillator. The computer is then free to continue calculations related to information previously received.

When the spot reaches the beginning of a spark or fiducial mark, the saturated photomultiplier signal opens another gate, allowing a third scaler to start counting. At the end of the spark, both gates are closed (which causes the spot to stop) and an interrupt is sent to the computer (Fig. 2). The scalers now contain the coordinates of the spot (positioned on the trailing edge of the mark just found) and the width of the mark. This information can then be read in by the computer. Since the width is used to find the centre of the mark, the width scaler counts at half speed, and consequently the coordinate of the centre is obtained by a simple subtraction.

There was a troublesome drift due to thermal effects in the deflection amplifiers. After application of a step function, the spot would drift on a few percent, with a time constant of about one second. The built-in compensation circuit of the oscilloscope 5) could not be relied upon to eliminate this entirely, but as there was plenty of gain and bandwidth to spare, overall negative feedback was applied externally and rendered the effect negligible.

For the case where a spark chamber view was not accurately aligned parallel to the other views on the film, provision was made for scanning at a small angle to either axis (not shown in Fig. 1). The computer sets a number N in a register; during a scan in the X direction a pulse is sent into the Y scaler after every N pulses going into the X scaler. This method is clearly not applicable to large angles.

COMPUTER

The device was originally constructed with decimal scalers for use with an IBM 650 computer at the Institut du Radium, Orsay. This computer was very slow (25 sec per picture). It has since been adapted to work with an SDS 920 computer at CERN. Decimal-to-binary and binary-to-decimal conversion routines are used which lose some time. Clearly, binary scalers would be simpler and faster. The IBM 650 computer did not have interrupts and consequently the programme was not foreseen to overlap scanning and calculation. The programme has not yet been re-written to do this.

Since the S.D.S.920 has a speed such that about 50% of the time is spent scanning, careful programming of the interrupts could give a factor two increase in speed.

PROGRAMME

This was written in assembly language for both the IBM 650 and the SDS 920. As the film positioning is relatively poor, the programme first measures the position of the large L-shaped mark (Fig. 3). If this is within the permitted limits, it then transforms the stored expected positions of all other marks according to the coordinates of the L-shaped mark.

For each view, there is a vertical scan across each of the two horizontal guide lines. This gives the information on the position and angle of the gaps for that view. Then, for each gap, there is a horizontal scan which measures the positions of the two vertical fiducial lines and all sparks in that gap. There are checks to ensure that all marks and sparks have reasonable widths and lie in their expected regions. The spark coordinates are normalised with respect to the two fiducial lines and the reduced coordinates are written onto magnetic tape. A tape can contain some 15,000 events.

Errors (film badly positioned, marks not in expected positions, etc.) are handled in three ways :

a) repeat scan in that region

b) message on typewriter

c) skip to next picture.

The choice of the action to be taken depends on whether the fault is on the film, a noise pulse from the photomultiplier or elsewhere, or a bad adjustment of the device. When initial setting up is complete, only very occasional operator intervention is required.

At present, the measurement of one picture of nine views takes 1.1 second and 1800 pictures per hour are being measured, including time for all adjustments, changing of films and magnetic tapes. The speed could easily be increased by the following procedures:-

a) use binary scalers to avoid binary-decimal conversion and vice-versa.

b) Re-write programme to make efficient use of interrupt, allowing simultaneous scanning and calculation.

c) Increase in scan speed by a factor 10.

d) Improved film transport, taking 100 mS instead of 500 mS.

c) A faster computer with 2 μs basic cycle instead of 8 μs.

It would seem reasonable to aim at a rate of 4 pictures per second.

CORRECTIONS AND ACCURACY

Marks directly mounted on the spark chambers are used to correct for non-linearity. From time to time these are measured by the FSD and the reduced coordinates compared with the actual marks. A polynomial of 2. or 3. order is fitted to the differences by a separate programme and used as a correction in the reconstruction programme. This method corrects for errors of the following kinds:-

a) distortion by mirrors and the camera in the experiment.

b) Non-linearity of the digital-analogue convertors and the CRT deflection system in the FSD.

(Note that dynamical errors due to finite bandwidth and drifts are also corrected since the linearity marks are measured at the same speed as sparks).

c) Distortion by the FSD optical system.

Comparison of measurements on a manual measuring machine (IEP) and on the FSD (Fig. 4) shows that errors due to the mirror optics of the experiment are not negligible compared with those due to the FSD. The largest deviation due to imperfections of the mirror optics was found to be 70 μ on the film; that due to the FSD was 130 μ. Short-term repeated measurements of a given mark gave a distribution whose standard deviation was 15 μ. Long-term variations of 30 μ were found, but are of little importance as they are taken care of by daily measurement of the linearity marks.

The experiments [7, 8] for which the FSD has been used have employed four spark chambers with a magnet to determine particle momentum. Some pictures were taken at invervals with the magnet turned off. Straight lines were fitted to the reconstructed coordinates from these pictures. The maximum systematic devation of a track was 0.4 mm in space. The precision of alignment of the chambers is considered to be 0.25 mm.

The rms random deviation for all chambers was 0.6 mm, which contains a contribution from multiple scattering of 0.5 mm.

The precision attained was entirely satisfactory for the experiments for which the FSD has been used. It is related to the step size of the digital-analogue convertors ($1‰ = 40\ \mu$) though this figure does not represent the actual accuracy attainable. The scalers consist of 4 decades, where the least significant decade is not connected to the convertor. A measure of integration is applied to the analogue output, tending to smooth out the staircase into a ramp. The last decade thus serves to interpolate between steps.

The precision of each step is about 0.2‰ . It would seem feasible to construct binary versions of the convertors with steps of 1 in 4096 or even 1 in 8192.

The spot size (200 μ on the film) limits accuracy since its shape is not constant over the surface of the CRT face. It also caused some problems as it was not possible to resolve two sparks which were close together. The reconstruction programme recognized this situation by comparison with the other view.

Cathode ray tubes are available with 10 times better resolution, which usually require magnetic deflection, but would ease the above problems.

CONCLUSION

The FSD has been used to measure 70,000 pictures with the IBM 650 at Orsay, for one experiment[7], and 400,000 pictures at CERN with the SDS 920 for two other experiments[8, 9]. It has proved quite easy to have 10-20,000 pictures completely analysed in 3 or 4 days after they were taken, in spite of the fact that the SDS 920 was only available during the periods in which the CERN Proton Synchrotron was not operating, it being also used for an on-line experiment.

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9. To be published.

FIGURE CAPTIONS

Figure 1 : Block diagram of optics and logic.

Figure 2 : Waveforms.

Figure 3 : Photographs to be measured.

Figure 4 : Linearity corrections.

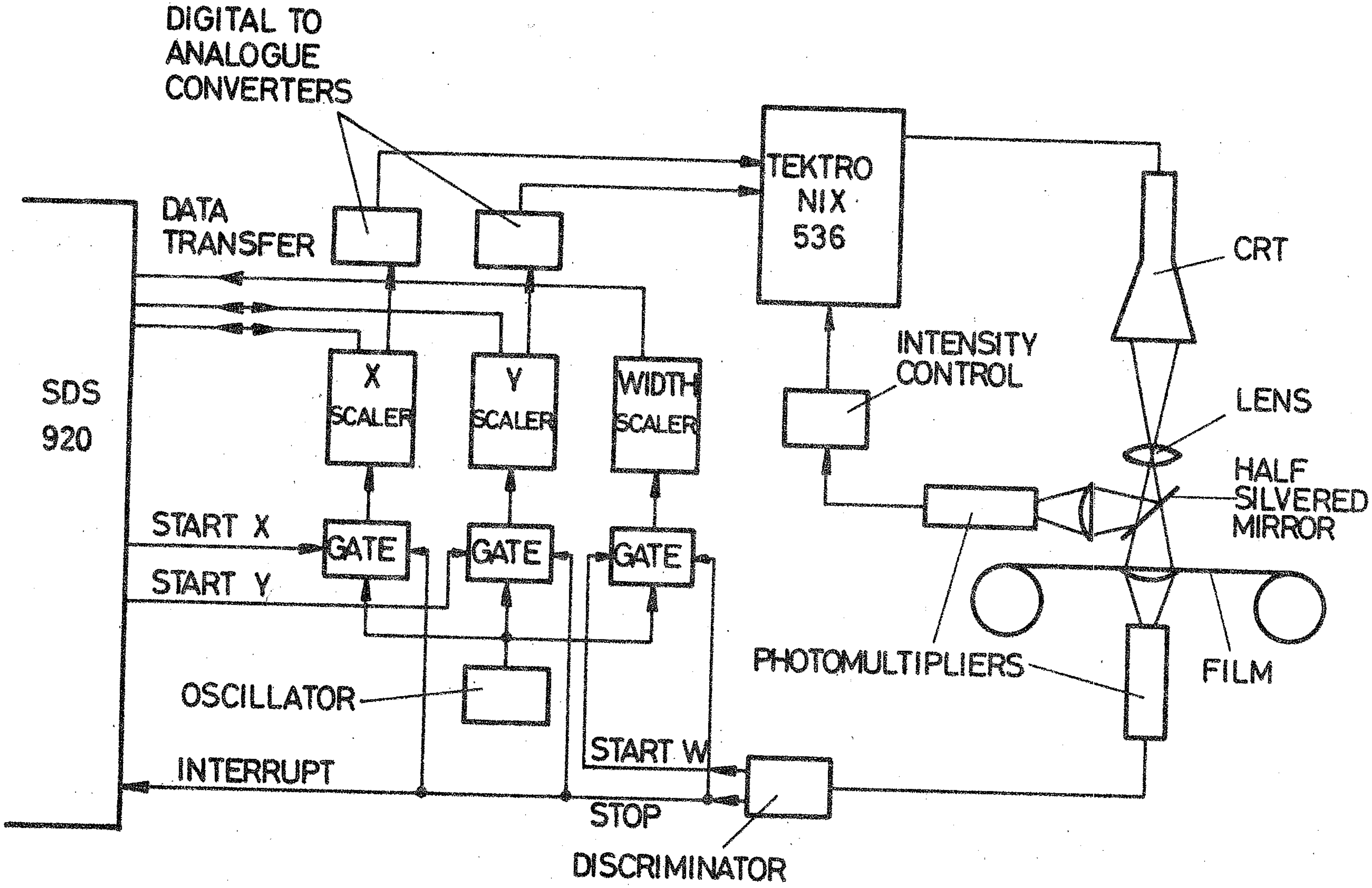
DIGITAL TO ANALOGUE CONVERTERS
DATA TRANSFER
TEKTRO NIX 536
CRT
SDS 920
X SCALER
Y SCALER
WIDTH SCALER
INTENSITY CONTROL
LENS
HALF SILVERED MIRROR
START X
START Y
GATE
GATE
GATE
PHOTOMULTIPLIERS
FILM
OSCILLATOR
START W
INTERRUPT
STOP
DISCRIMINATOR

FIG. 1

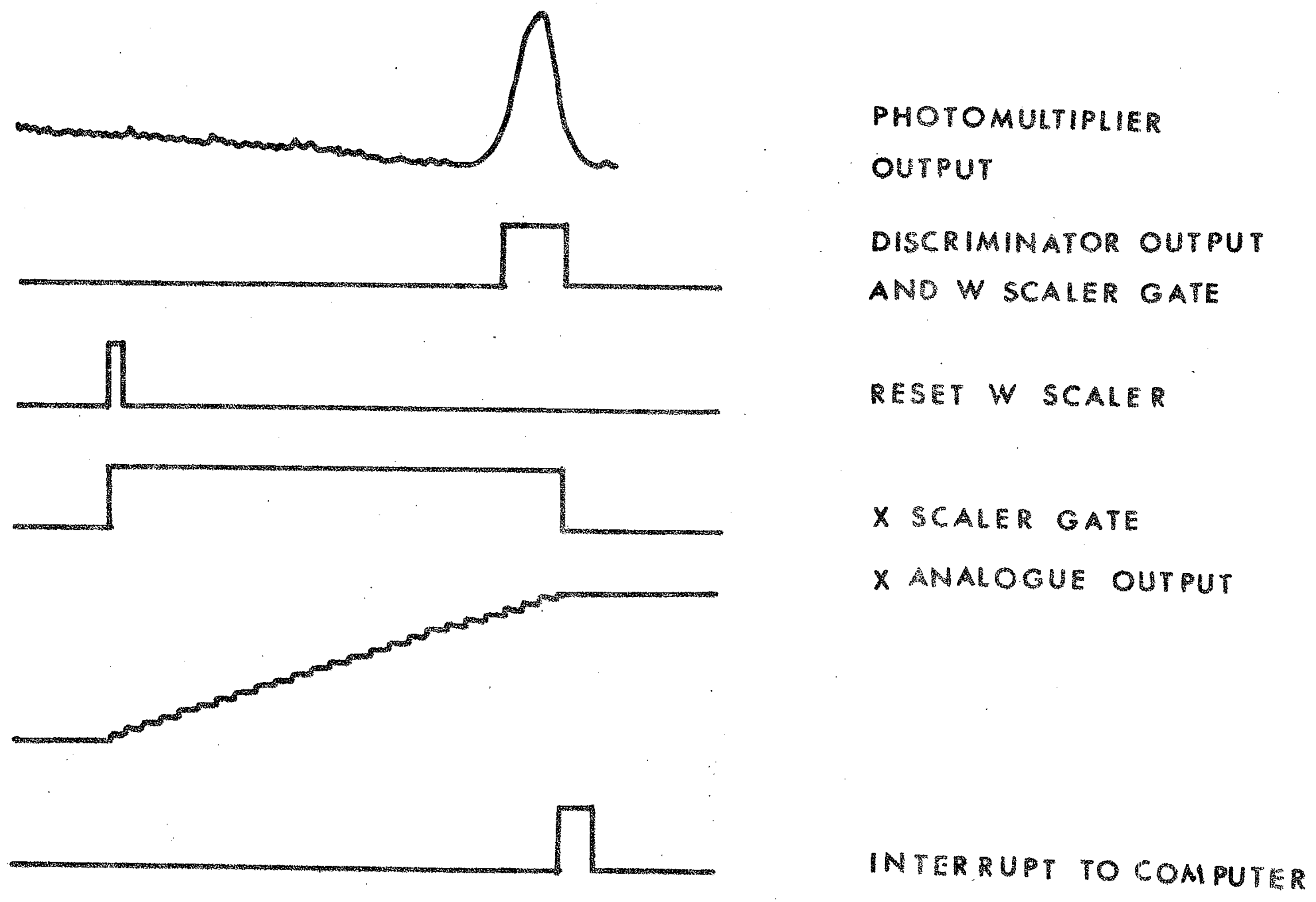
PHOTOMULTIPLIER OUTPUT
DISCRIMINATOR OUTPUT AND W SCALER GATE
RESET W SCALER
X SCALER GATE
X ANALOGUE OUTPUT
INTERRUPT TO COMPUTER

FIG 2

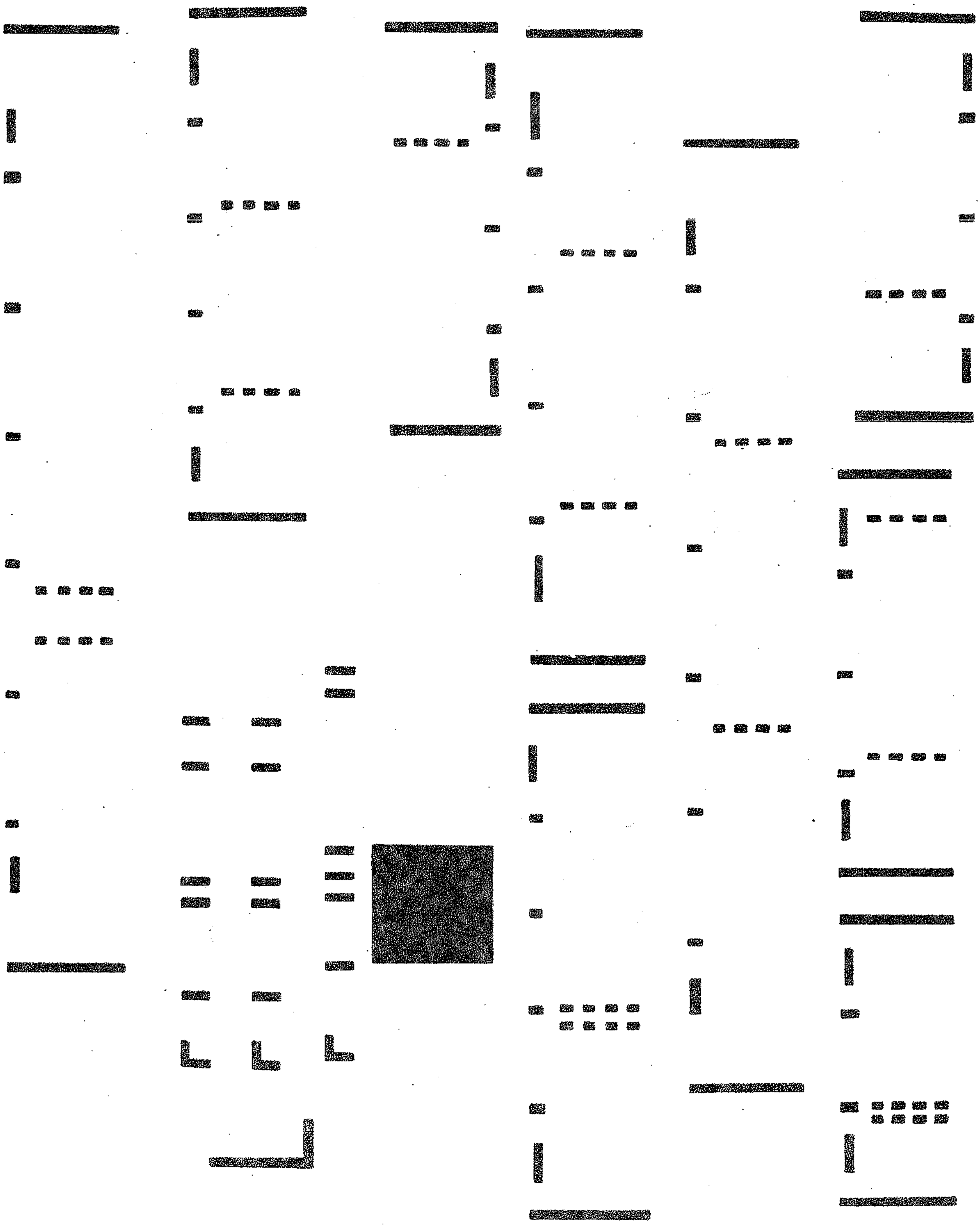

FIG. 3

LINEARITY CORRECTIONS FOR VIEW 4TOP

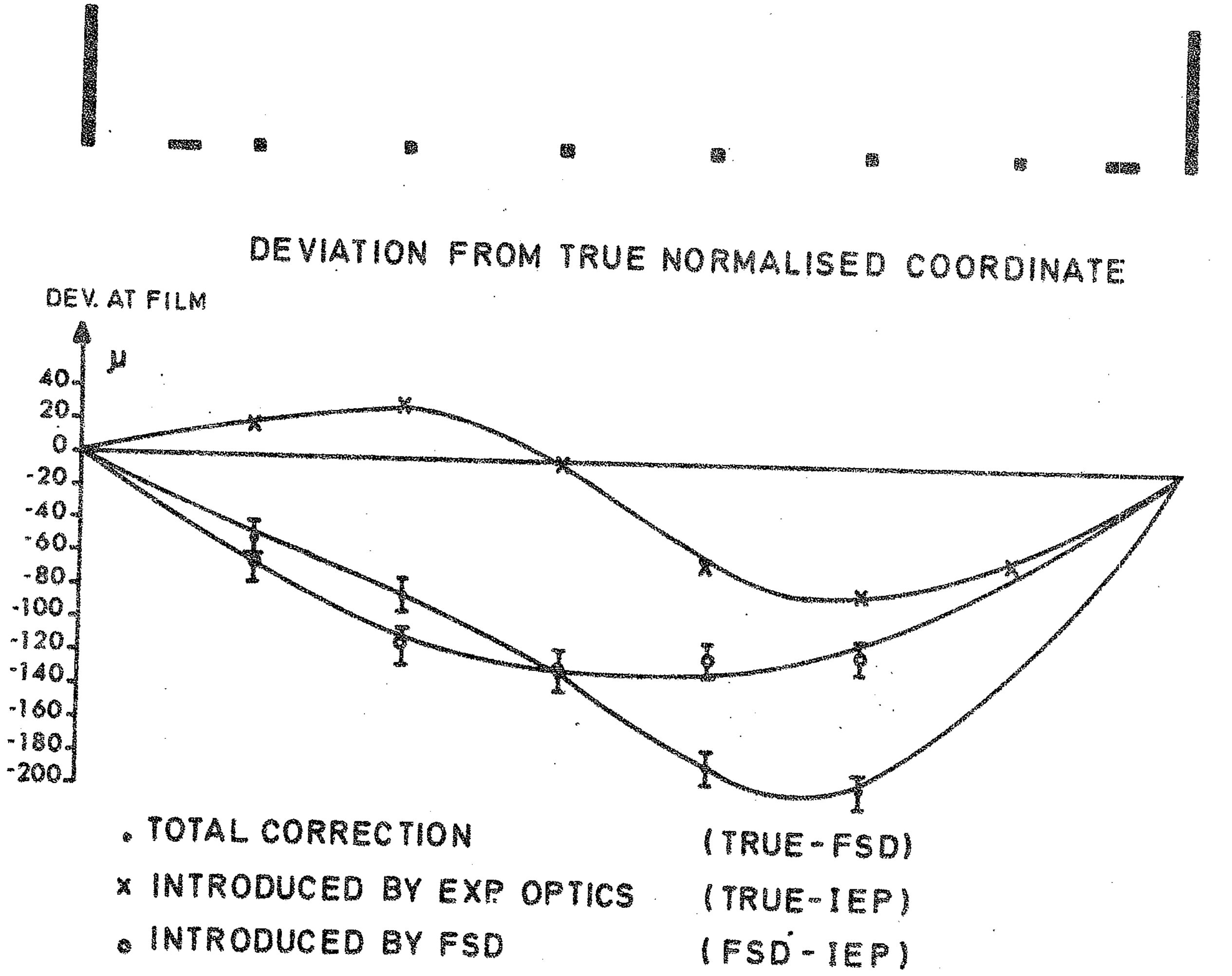
DEVIATION FROM TRUE NORMALISED COORDINATE

FIG. 4