DESCRIPTION AND PERFORMANCE OF THE CERN SPIRAL READER (L.S.D.)

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Introduction

In November 1966 the decision was made to build at CERN a Spiral Reader on the basis of the machine then currently in use at Berkeley[1]. In April 1969 the L.S.D. (short for "Lecteur à Spirale Digitisée") was completely assembled - with the exception of the system for automatic measurement of fiducial marks - and the first events were measured. In November 1969 production could be started with automatic fiducial measurement; at this time the off-line programs were completed and by the end of 1969 about 20,000 events had been measured.

Description

A detailed description can be found in references 2) and 3). We shall limit ourselves here to point out the main differences between the CERN and Berkeley machines.

Figure 1 shows an overall view of the system. The computer is a PDP-9 from Digital Equipment Corporation with 8k-word memory, 2 half-inch magnetic tape units, 1 teletype, 1 paper tape reader and punch and 1 storage oscilloscope display.

Figure 2 gives a general view of the cone-periscope assembly. A significant difference with Berkeley is the vertical position of the periscope. One of the advantages of this position is that it eliminates the influence of gravity in the rotating parts and makes balancing much easier. Furthermore this allows an overall reduction in the machine dimensions. Figure 2 also shows that by using fiber-optic light-guides it has been possible to mount the photomultiplier outside the periscope assembly.

The optical path is shown on figure 3. It should be noticed that the main light beam, i.e. from film to periscope, does not go through any plane-parallel plate, thus ensuring minimum optical distortions. The light goes through plane-parallel plates only on paths where distortions are less important, or may be taken into account by a calibration, e.g. projection on operator's table, on TV camera and on auto-fiducial photo-multiplier slits. The optics is such that it gives a magnification of 200 from the film plane to the TV screen and of 2.8 from the film to a plane perpendicular to the periscope axis at the apex of the cone. This corresponds to a maximum radius of the spiral scan of 53 mm in the film plane, i.e. 72 cm in space for the CERN 2 m HBC. The magnification on the operator's table is about 2/3 life size.

The illumination is obtained by a single 450 W xenon arc lamp. However the light box contains a cold mirror at 45° which eliminates most of the infrared light and prevents the film from being damaged by an excessive temperature rise.

Figures 4 and 5 show the film transport system. It consists of three independent film drives designed to accomodate 300 m spools for 35 or 50 mm unperforated film. Frame counting and accurate film stop are performed by the PDP-9 from the information given by three optical Brenner mark detectors.

Figure 6 shows the X-Y stages. The upper stage moves in the X direction, the lower stage which carries the 45° rollers moves in the Y direction. View changing is obtained by a movement of the Y-stage. From figures 4 and 6 one sees that both stage movements result in a change of the film position in the vacuum boxes. No free loop is required, the film just slides on the air-cushions of the 45° rollers.

Figure 7 shows the operator's table. On the left hand side 10 control buttons initiate different operations required during the measuring sequence (measure a vertex, a fiducial mark, a crutch point, a stopping point, etc...). On the right-hand side a "speed-ball" allows an accurate manual centering of any point on the film under the

TV cross-hair. The teletype provides a convenient operator communication with the control program.

Finally, we should mention the resolution of the different encoders: the X-Y Heidenhain encoders have a least count of 2 microns, the periscope 8 microns (this corresponds to a radial least count of 8/2.8 = 2.85 microns in film plane), the rotary encoder gives 129,600 pulses/revolution corresponding to a resolution of 2.5 μ in the film plane at the maximum scan radius.

The Digitizing System[4)5)6)]

Figure 8 shows spiral scan digitizings for a typical 6-prong event taken from the first production experiment. These digitizings are shown in a cartesian representation of polar coordinates, i.e. angle θ on the horizontal axis and radius R on the vertical axis. These photographed displays have been obtained with a maintenance program which permits different magnifications along the θ axis. A similar display is presented by the oscilloscope on the operator's table for each vertex measurement. This is very helpful to verify that the pulse transfer electronics is working properly.

When the periscope slit (260 x 17 μ^2 in film plane) passes over a track, the photo-multiplier pulse initiates a transfer to the PDP-9 via the data channel as shown on the electronics block diagram (figure 9). If the pulse rises above the discrimination level and if its edges correspond to certain criteria, the pulse analyser generates a "valid pulse" signal to the Channel D electronics which in turn initiates a three 18 bit-word data-channel transfer to the PDP-9. These 3 words contain: radius R (15 bits), angle θ (17 bits), pulse width $\Delta\theta$ (16 bits), pulse height PH (5 bits). During the transfer, which takes 14 μs, no other digitizing can be taken. This implies a "shadow" effect which is not wider than 70 microns, i.e. about 2 track widths, at the outer scan radius.

Procedure for the Automatic Measurement of Fiducial Marks

The procedure for measurement of fiducial marks was originally based on the Berkeley system but in the course of the development at CERN it has been so profoundly modified that it deserves a special description here[7].

At CERN we impose the measurement of 4 fiducial marks per view. These marks have their arms at 45° to the X axis. It was intended to have eight 45° slits (1,000 x 35 μ^2 in film plane) to pick up each arm in a single sweep of the X-stage over a fixed distance. A photo-multiplier delivers a pulse for each arm. Leading edge and trailing edge of this pulse both cause an interrupt to the computer, X-Y coordinates are read at each interrupt and eventually the mark centre is reconstructed under the assumption that both arms make 45° with the X axis.

At several stages, consistency checks are performed on the incoming data: the pulse width must be within the expected width of a fiducial arm, distance between pulses should not exceed the distance between fiducial arms, etc... When the four crosses have been reconstructed a further check is made on the distances between computed fiducial positions.

The systematic comparison between manual and automatic measurements, performed during development, has shown that the 45° extrapolations from the arm centres led to a systematic shift in the reconstructed position of the fiducial marks.

This displacement could be traced back to a variation of the film skewness under its clamps, both in the bubble chamber cameras and the Spiral Reader. As was already established on the HPD, this angle could be as large as 30 milli-radians. To eliminate this distorsion, one performs - once the four mark positions have been found with the first sweep - a separate sweep across each mark, ensuring for each sweep that the centre of the slits passes exactly above the cross centre.

Moreover, due to the fact that the film characteristics change along a roll (luminosity,contrast of the fiducial arms, slow variations of the skewness, etc...), the evaluation by the slits of the cross centre is different from the operator's evaluation at the time of auto-fiducial calibration. To eliminate any systematic shift, the auto-fiducial constants are updated with the difference between an automatic and a manual measurement performed every ten events, thus randomizing the effect of the calibration.

This procedure gives satisfactory results. The systematic shift has been entirely eliminated and the precision is almost a factor 2 better than on the manual machines; more precisely, the standard deviation from the title values is $\sigma = 5\ \mu$ for manual measurement and $\sigma = 3\ \mu$ for automatic measurement. The system efficiency is obviously a function of film quality. With the present system it can vary between 30 and 100% depending upon film contrast, presence of spurious tracks in the fiducial area, film skewness, visibility - and sometimes invisibility ! - of a fiducial mark.

Indeed the program includes presently very stringent criteria for acceptance of fiducial data which have been introduced to avoid any risk of getting a spurious cross. Further development of the program might lead to a loosening of these criteria and hence to an improvement of the finding efficiency.

To illustrate the importance of the auto-fiducial system for the overall efficiency of the machine let us mention that the average measuring speed was 20 events/hour before the system was implemented and reached 60 events/hour afterwards.

Current Status

Although the Spiral Reader measured its first events towards April 1969, actual production could only start after the automatic measurement of fiducial marks could be performed at the end of November 1969. Up to this date only 5,000 events had been measured, mostly for the sake of developing the filter program - adapted from Berkeley POOH - and integrating it into a modified version of THRESH (new TRACK-MATCH).

The first experiment performed on the Spiral Reader analysed the film from a 3.9 GeV/c π^- exposure in the CERN 2m HBC. A sample of two- and four-prong events had been selected to study essentially the $\eta\pi$ and 3π decays of the A_2 meson and to analyse other meson resonances. By the end of January 1970 about 25,000 events had been measured, i.e. 17,000 two-prongs, 8,000 four-prongs and 500 six-prongs. After a 2 month shut-down - necessary to increase the reliability of the older parts of the prototype - production has been resumed and it is intended to terminate the 3.9 GeV/c π^- experiment with the further measurement of a series of 16,000 four-prongs and a 2nd series of 100,000 four- and six-prongs.

Presently the effort is being put on training new operators and organizing the measuring team on the one hand, and improving hardware and software on the other hand. The main hardware developments concern the film transport system and the design of a new automatic gain control for the periscope photo-multiplier and the auto-fiducial photo-multipliers. These two latter developments have been made necessary by the poorer illumination quality of the film which will be measured next and the growing interest among the physicists in having the Spiral Reader produce useful ionization measurements.

In December 1969, the machine measuring capability was tested over a 3 week period, on a 5 days/week, 24 hours/day basis. During this period 15,000 events were measured. This represents an average of 60 events/hour of measuring time or an overall average of 45 events/hour, including machine failures, film changing etc... The maximum average speed on a two hour shift peaked at 87 events/hour.

The measuring speed is clearly dependent on beam density. With the present experiment we have very often more than 25 beam tracks per frame. This increases the number of digitizings for the view-vertex and requires from the operator a time-consuming measurement of many "crutch points", and our experience is that most operators take too many of them if the picture is confused.

Acknowledgements

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Figure Captions

Fig. 1 Overall view of Spiral Reader System at CERN.

Fig. 2 Cone-periscope assembly.

Fig. 3 Optical paths.

Fig. 4 Film path for one view (view 2)

Fig. 5 General view of the machine showing the light box, the active side of the film transport (capstans), the X-Y stage and the cone-periscope system with its photo-multiplier.

Fig. 6 Detail of the X-Y stage with the 45° rollers (carried by the Y-stage).

Fig. 7 Operator's table with the control buttons on the left-hand side the "speed-ball", TV screen and teletype on the right-hand side.

Fig. 8 Typical Spiral Reader digitizings for a 6-prong event. The 2 bottom photographs are enlargements along the θ axis of the outgoing tracks region.

Fig. 9 Block diagram of Spiral Reader control electronics; on the right-hand side the pulse analysis system and discrimination logic.

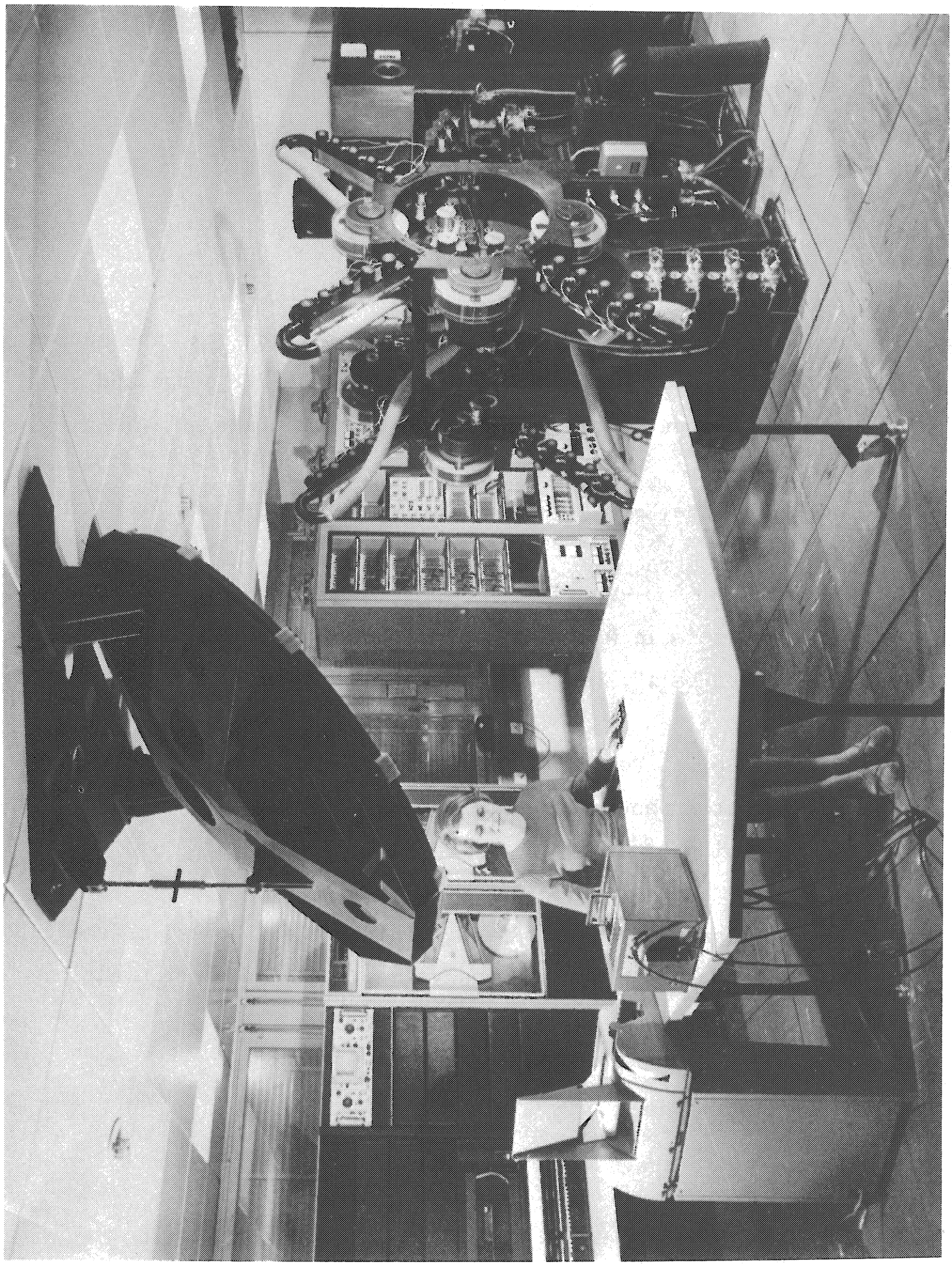


Fig. 1

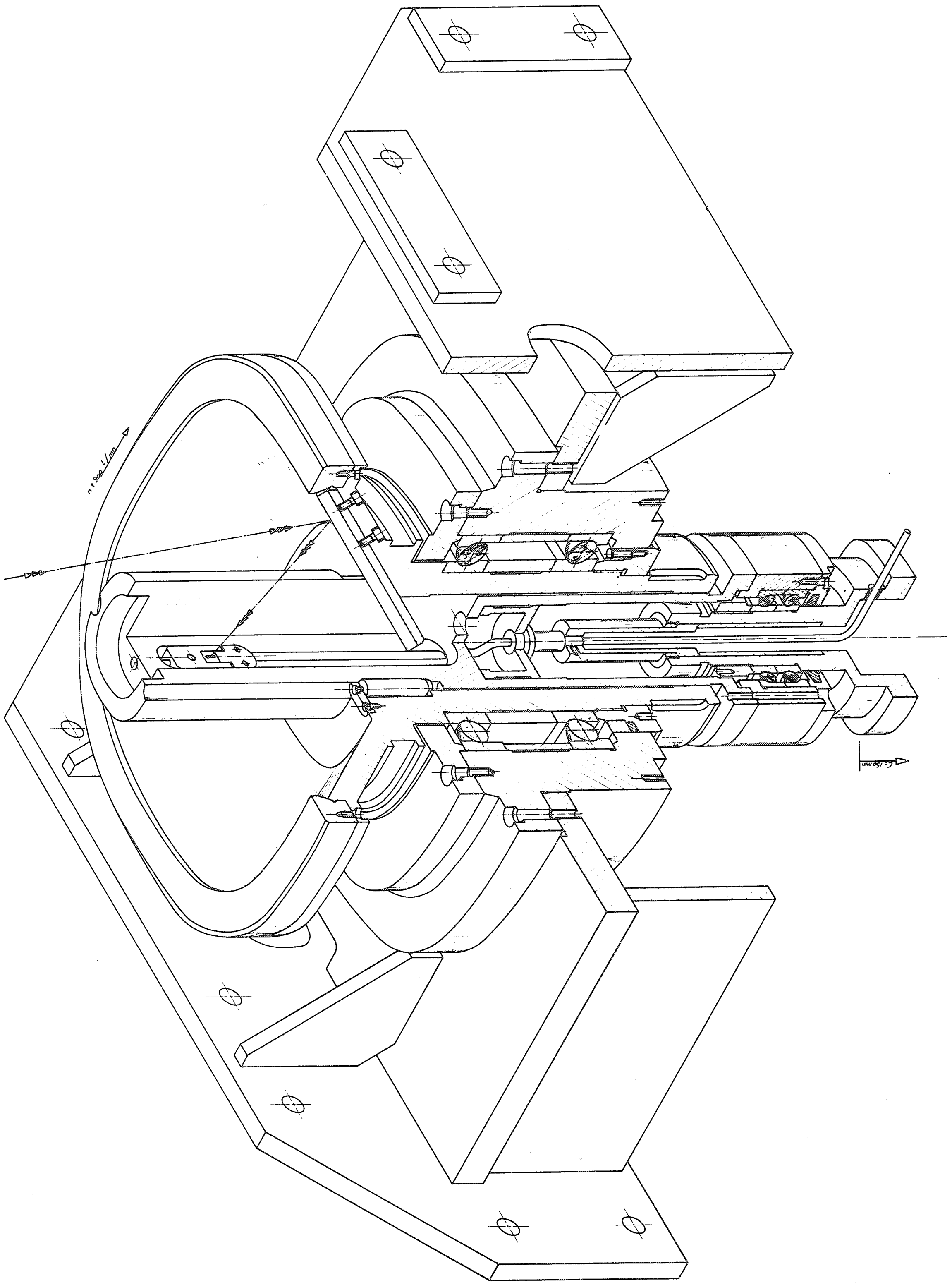


Fig. 2

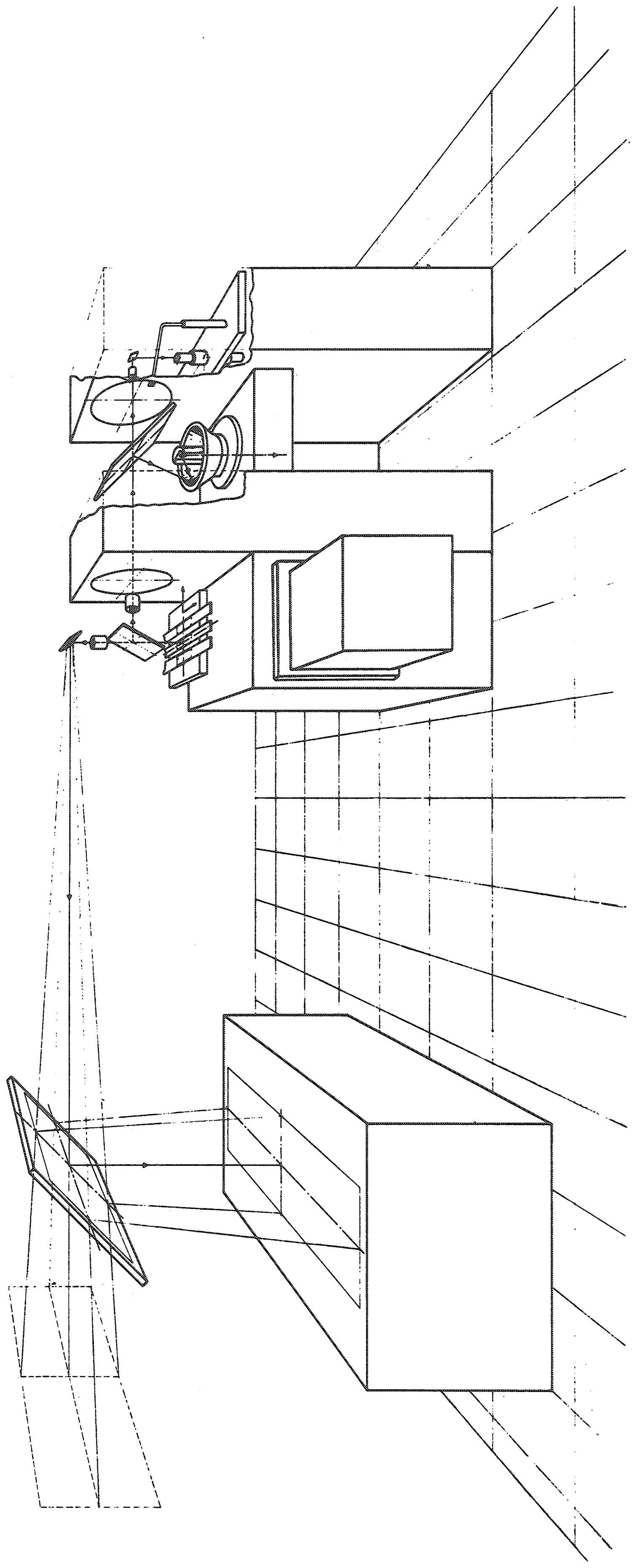


Fig. 3

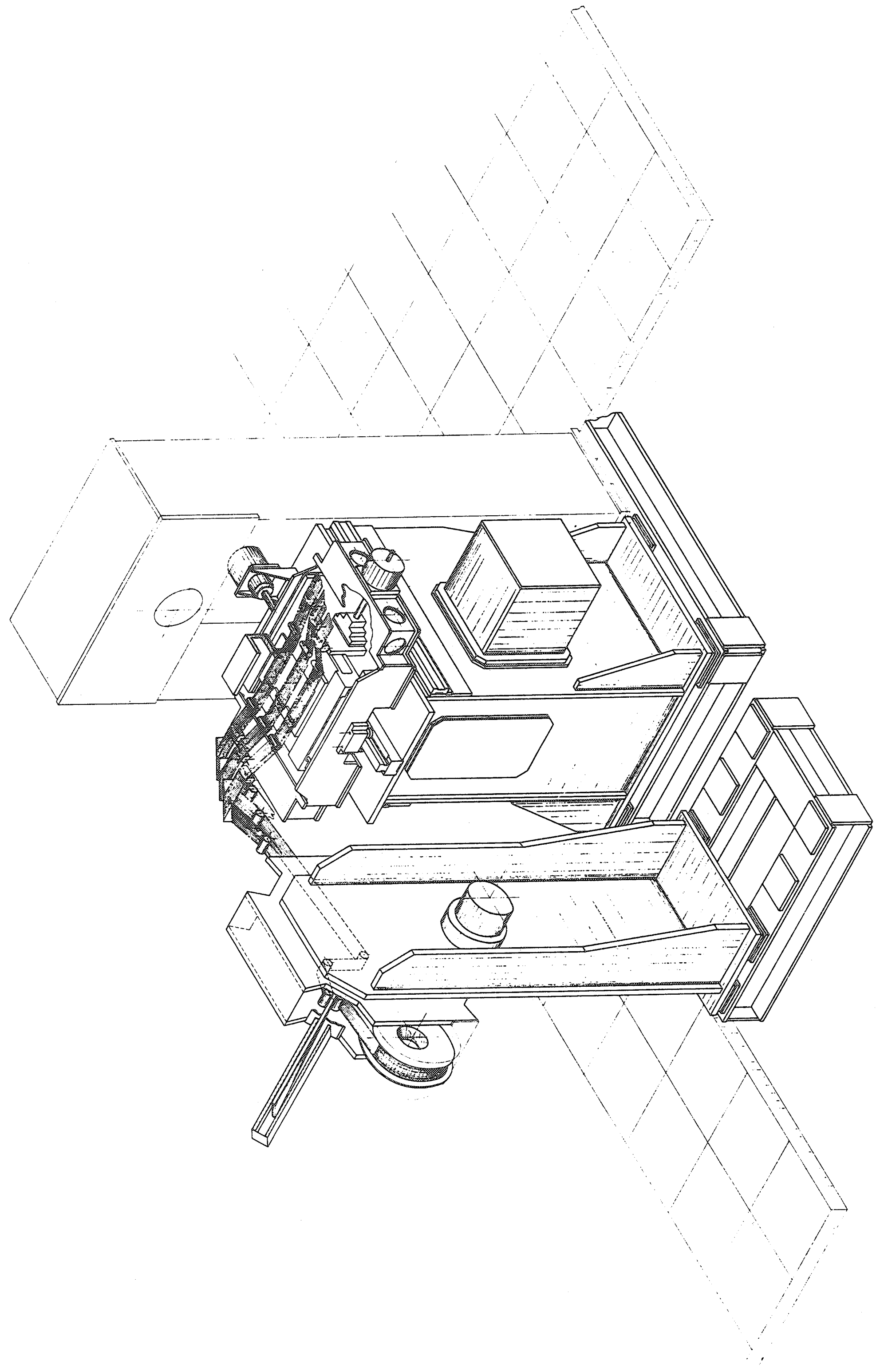


Fig. 4

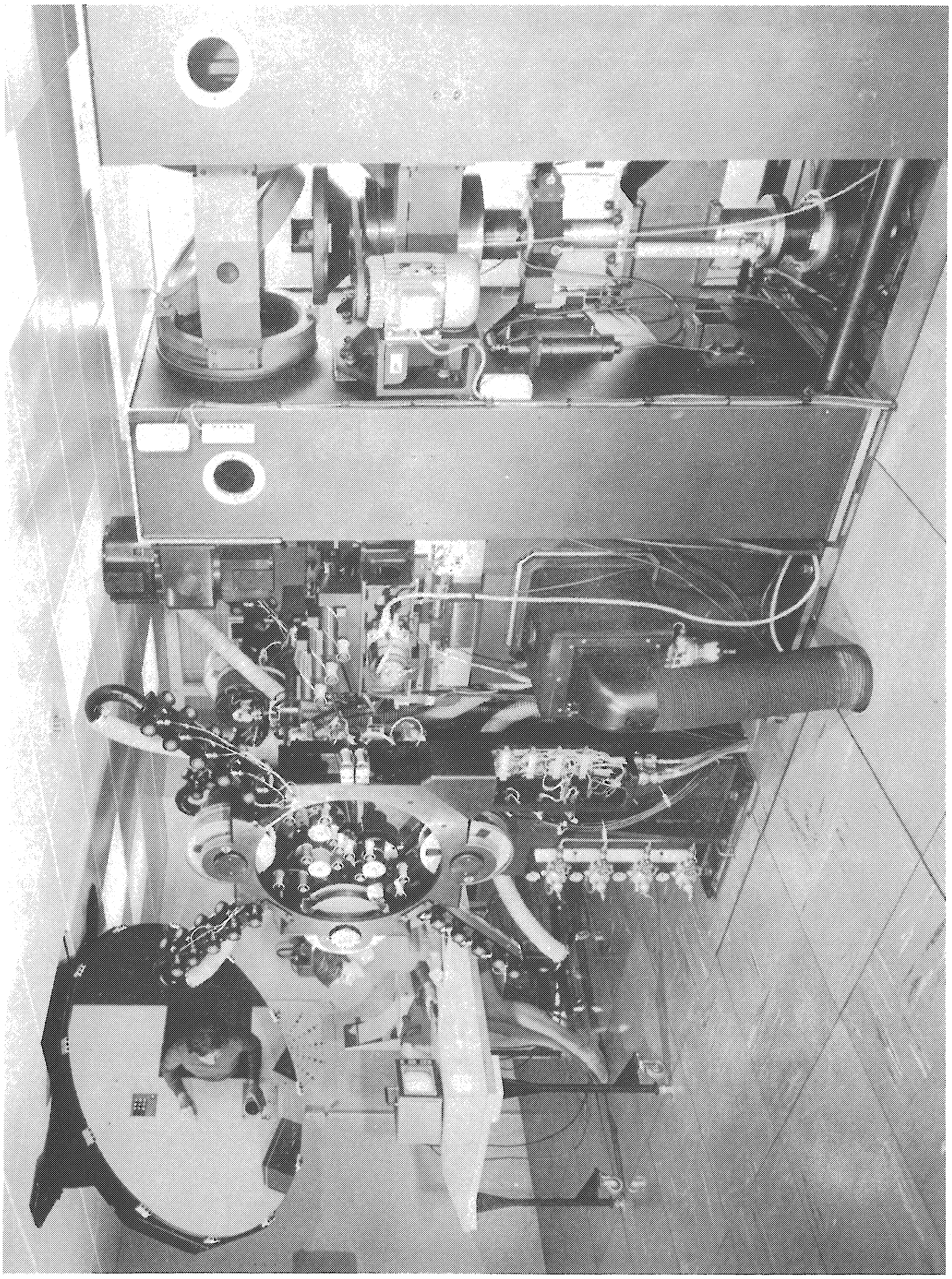


Fig. 5

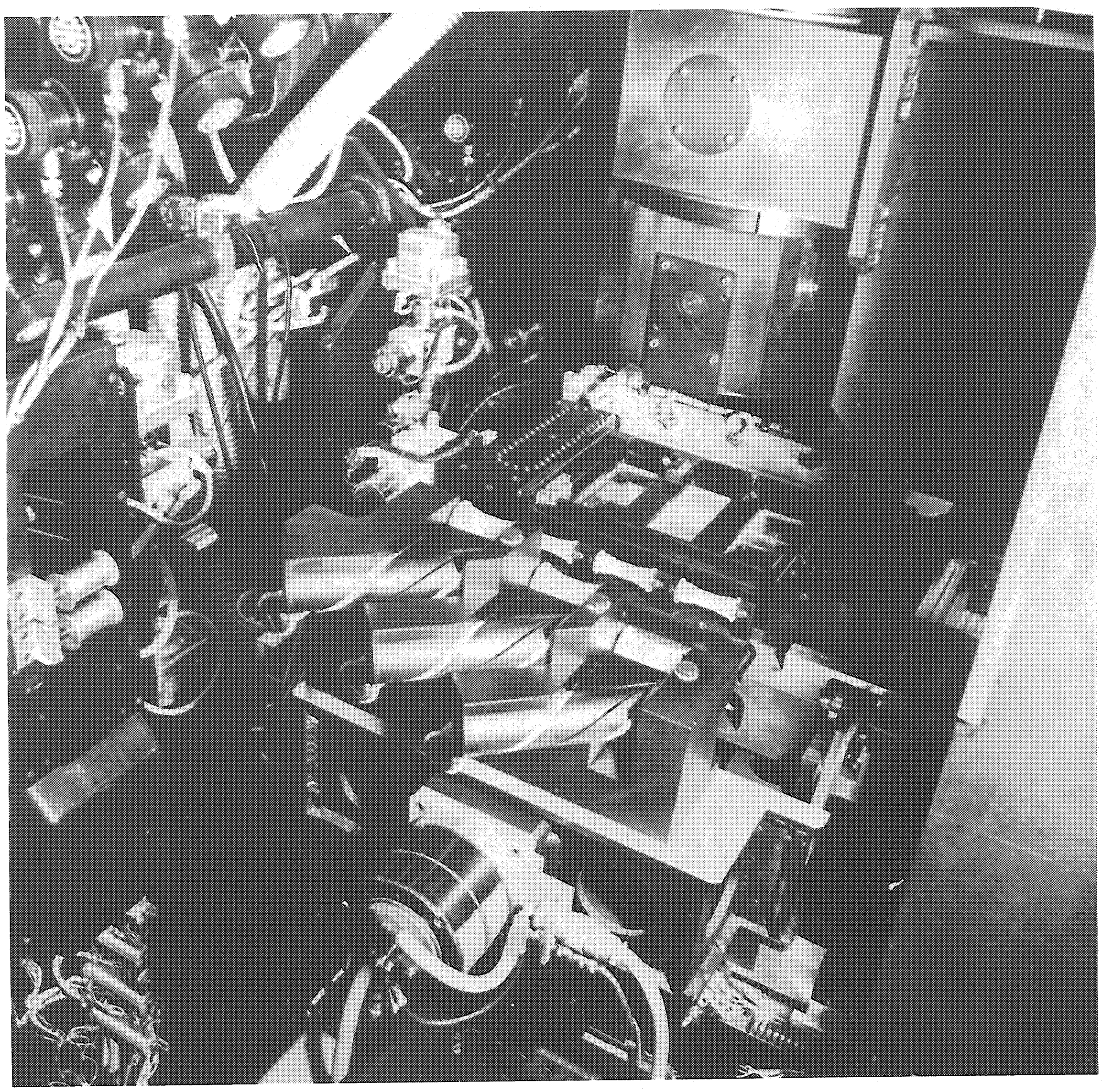


Fig. 6

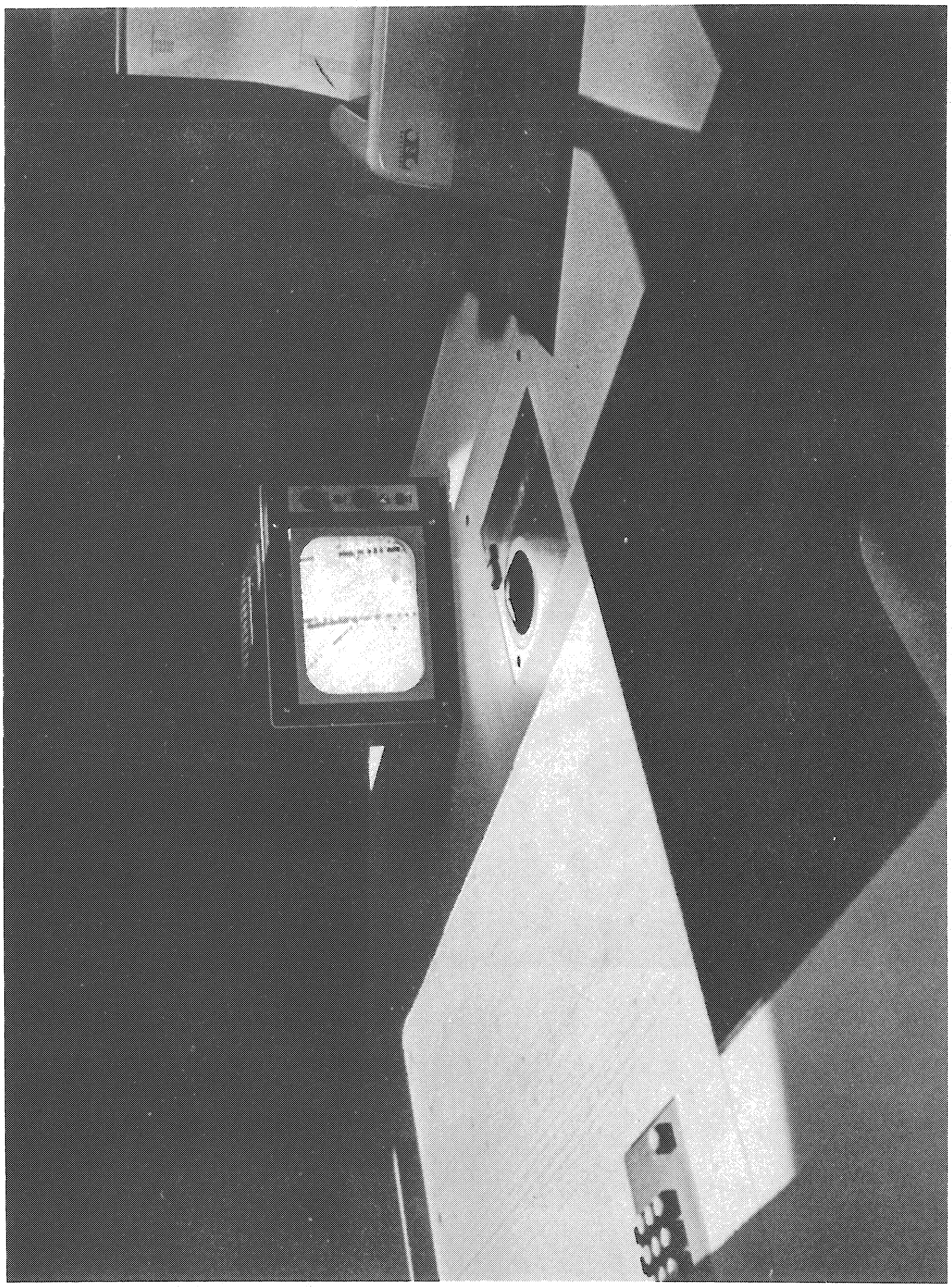


Fig. 7

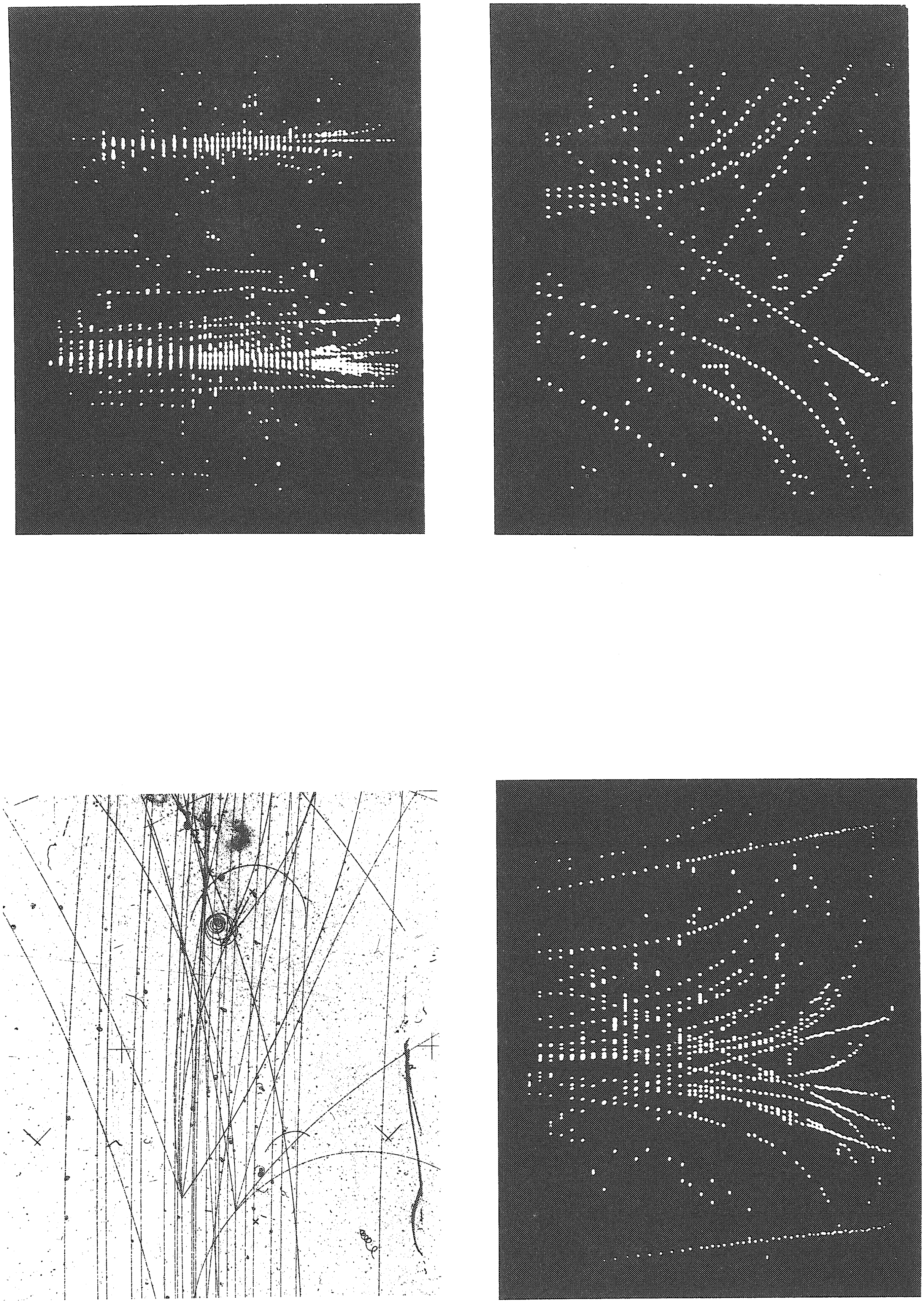
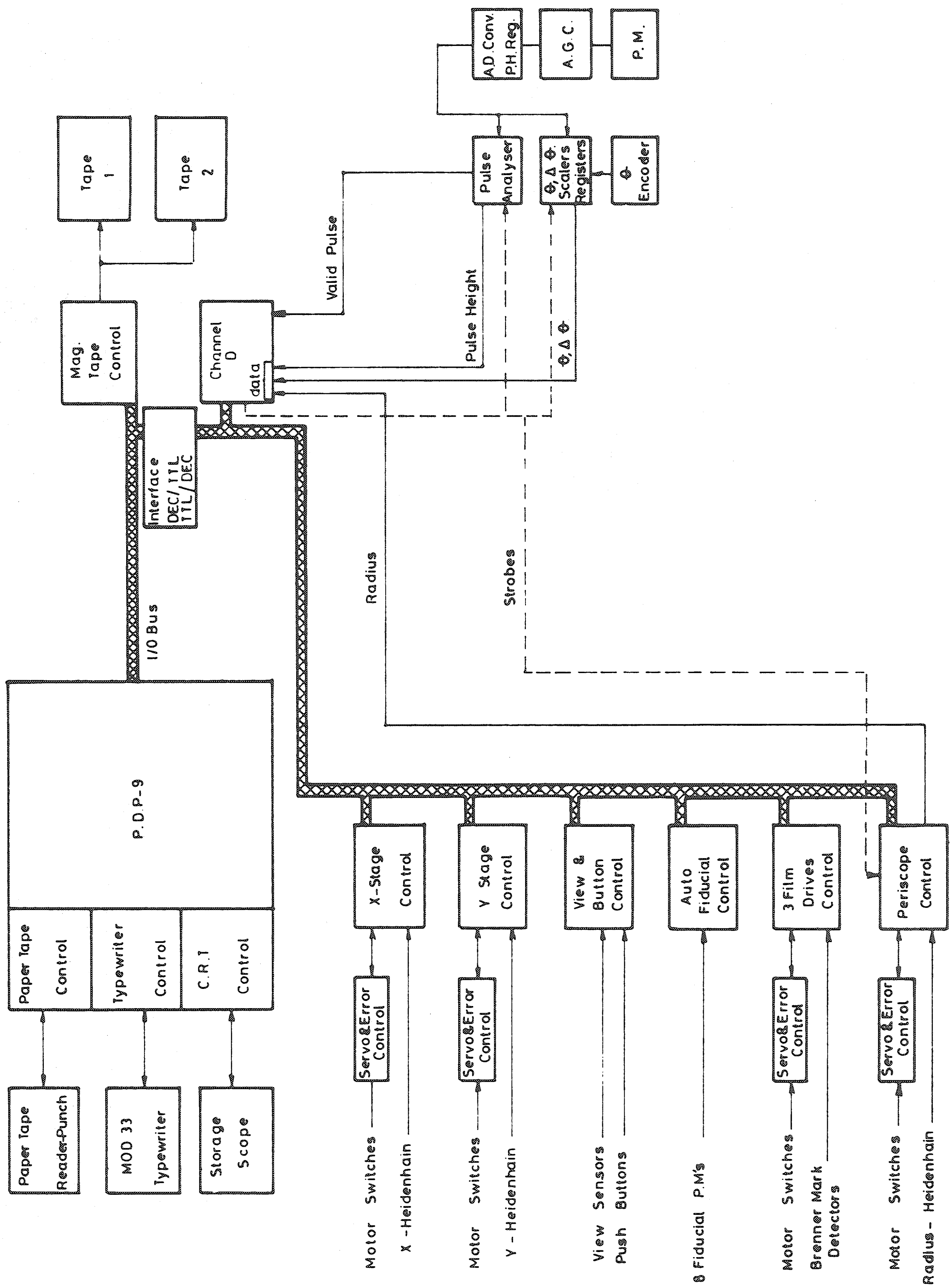


Fig. 8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Tape 2
Mag. Tape Control
Channel D
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Pulse Height
θ, Δ θ
A.D.Conv. P.H.Reg.
A.G.C.
P.M.
Pulse Analyser
θ, Δ θ Scalers Registers
θ Encoder
Interface DEC/TTL TTL/DEC
I/O Bus
Radius
Strobes
P.D.P-9
Paper Tape Control
Typewriter Control
C.R.T Control
Paper Tape Reader-Punch
MOD 33 Typewriter
Storage Scope
X-Stage Control
Y Stage Control
View & Button Control
Auto Fiducial Control
3 Film Drives Control
Periscope Control
Servo&Error Control
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Motor Switches
Y - Heidenhain
View Sensors
Push Buttons
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Motor Switches
Brenner Mark Detectors
Motor Switches
Radius - Heidenhain

Fig. 9