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HUMMINGBIRD, AUTOMATIC FILM DIGITIZERS AT THE STANFORD LINEAR ACCELERATOR CENTER *

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I. INTRODUCTION

An IBM 360/50 became available at SLAC through a study agreement for graphic data processing with IBM. The first of two spark chamber film digitizers developed at SLAC was connected on line in July 1966. These devices are completely under control of the computer and are made to look like any other peripheral to the programmer.

II. GENERAL DESCRIPTION

The spot on the face of a cathode ray tube is deflected in a TV-type raster scan mode. The film may be accessed in one or a number of randomly located rectangles. The density of scanlines as well as a threshold setting on the photomultiplier signal are specified by the program. The pattern on the tube face thus produced is imaged onto the film. The presence of dark areas on the otherwise transparent film is sensed by the photomultiplier upon which digitization and subsequent transmittal of the coordinates to the computer take place. Figure 1 is a functional block diagram showing the interaction of the different parts of the system.

III. THE SPOT GENERATOR

A cathode ray tube is used as a spot generator. The electron beam is magnetically focussed and deflected. High resolution cathode ray tubes have a flat faceplate for (optical) depth of field reasons. This produces two effects that are to be corrected if the tube is used in a precision measuring application where high resolution is also of importance.

Firstly, the so-called pincushion distortion, caused by the fact that on the face of a flat-faced tube the deflection is not linearly proportional to the current in the deflection coils, must be corrected. A certain amount of linearization, usually about 0.5%, may be obtained either by circuitry or by the attachment of permanent magnets or electromagnets to the tube. The residual nonlinearities are then removed by calibration.

In the Hummingbird devices no hardware correction is applied; all distortions are corrected for by calibration, although provision is made for partial linearization by means of electromagnets near the tube face if this proves to be of advantage at a later date. It has been shown that the differential in computer time to calibrate partially corrected hardware and hardware with no correction at all is very small indeed.[1] Shown in Fig. 2 is the calibration pattern used, and in Fig. 3 the control panel of Hummingbird I with calibration pattern on monitoring memoscope.

At present, spark chamber film is scanned in a distorted coordinate system in which all local pattern recognition, such as the detection of sparks and fiducials, takes place. Corrections are performed on the spark and fiducial centers after these have been located and before linkage into tracks is made. The required accuracy is obtained by fitting a third-order polynomial.[2] Calibration takes place at approximately two-hour intervals to correct for nonlinearities and size changes, while longitudinal and lateral adjustments (drift and film positioning errors) are made on each frame measured.

Another byproduct of the flat-faced tube is deflection defocussing. It is caused by a variation in the length of the electron beam with deflection. In order to maintain (electrical) focus over the entire screen, a correction current in the focussing coil must be applied. It may be shown that this correction should be of the form .

$$I_{fc} \approx k(I_x^2 + I_y^2).$$

An approximation of the form

$$I_{fc(hb)} = K(|I_x| + |I_y|)$$

is generated in these devices, resulting in a spot size smaller than 25 μm over the total useful area of the tube face.

The deflection coils of magnetically deflected CRT's exhibit a small amount of hysteresis (0.05%). This effect is eliminated by approaching the rectangle to be scanned always via the origin (0,0).

Instead of the commonly used P16, phosphor P24 is used. This results in a better signal-to-noise ratio due to the higher light output; also, the resolution of P24 is notably better than that of P16. The longer persistence, 1 μsec to decay to the 10% point, is said to limit the scan speed. With proper electrical filtering, speeds of up to 80 μm/μsec with reasonable resolution have been obtained with this phosphor.[3]

The use of cathode ray tubes in precision measuring applications implies frequent calibration. The more stable the hardware, the fewer calibrations are necessary. By keeping the CRT deflection hardware to a minimum, but of high quality, a high degree of stability is obtained. The deflection amplifiers are dc-coupled and differential throughout. The drift is less than 50 μV, referred to the input, per °C over an eight-hour period and is non-accumulative.[4]

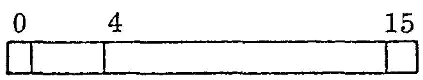
Variations in the accelerating high voltage show as size changes. Since the deflection is proportional to the square root of this voltage, a regulation of 0.01% at 27 kV insures stability of 3.5 μm over a 3×3-square-inch area.

Figure 4 shows the 7-inch CRT and its mounting. Each one of the coils has adjustments for up and down, sideways, and pitch and yaw. Figure 5 gives an overall view of Hummingbird II, which is set up for 70-mm film of the μ-p experiment, the first spark chamber experiment on the SLAC accelerator.

IV. CONTROL AND DATA TRANSFER

At the present time the devices are connected on line to an IBM 360/50. This machine has a word size of 32 bits and has 64K words of core. In addition to the usual array of peripherals, a display oscilloscope with lightpen is available, which has proven extremely valuable for hardware and program debugging as well as for the interpretation and selection of data. The scanner may also be controlled by the operator at set-up time by means of the display and lightpen.[5] The actual connection between the scanners and the selector channel of the 360/50 is made through a 2701 with parallel data adapter. It enables a two-way communication very much like the direct data connection on the IBM 7090 series machines. The transfer of data occurs in 16-bit words. The speed of transfer as determined by the channel is one byte/μsec. Orders to the scanners are given through the execution of write instructions, while data is transferred into the core during the execution of read instructions.

A total of seven orders to the scanners has been implemented. Scanner dataword format:



Device I or II is addressed by the presence or absence of a 1 in bit position 0. Bit positions 1, 2 and 3 have the order code; 4 through 15 contain data.

Orders to the scanner:

CLR (0) Resets all registers internal to the scanner.

YS (1) Loads the first line to be scanned by pre-setting the Y-counter with the contents of bits 4-15.

YF (2) The last line to be scanned, in bits 4-15, is moved into the YF-register. A comparator detects identity, upon which an end of record signal sent to the computer signifies the end of an area or subarea scan.

XS (3) No X-coordinates smaller than the value in bits 4-15 are transmitted.

XF (4) No X-coordinates larger than the value in bits 4-15 are transmitted.

MF (5) Moves film the number of frames (increment) indicated in bits 4-15.

MISC (6) Bit positions 10, 11, and 12 contain scanline density information. Bits 5, 6, 7, and 8 identify one of sixteen threshold settings for the photomultiplier. Bit 15 indicates normal or orthogonal scan direction.

NOOP (7) Not used at present.

A change from a write to a read operation commences the scan. Before the start of a scanline its coordinate is transmitted, followed by the hits or X-values on that scanline. Scanlines are separated by the transmittal of a word containing zeros.

Completion of the scan of a frame or subarea is indicated by an end of record signal. At the end of a roll of film an end of file signal is transmitted. The latter may also be sent manually by an operator to signify an abnormal job ending, thus freeing the channel. The channel is open during the entire scan, but not during the transporting of film. After the film movement has been completed, an attention interrupt is sent which is interpreted by the program as a readiness for the next scan.

V. SCANNING AND DIGITIZATION

The scanner initialized as described previously starts to scan the film when a read instruction is being executed by the program.

A linear sweep moves the spot along a scanline. Concurrently with the sweep, a crystal controlled clock feeds into the X-counter. The contents of this X-counter represent the position of the spot along a scanline at any given time.

The spot, swept over the film, produces signals at the output of the photomultiplier, which are then filtered. Figure 6 shows these signals and a detail before and after filtering. In this case bubble chamber film is scanned. The center of the pulses is determined by means of a delay line track center circuit[6] and a track center pulse is generated. This pulse, after synchronization with the master clock, causes the contents of the X-counter to be jam transferred into the output register, if the X-value lies between XS and XF, for subsequent transmittal.

At the end of a scanline the Y-counter is advanced. Its content is converted into an analog voltage for deflection in the Y-direction. The coordinates from the output register are transmitted directly. This limits the "digital" resolution. A pushdown register is now under development to improve this resolution.

VI. THE FILM TRANSPORT MECHANISM

The film is moved and positioned by a stepping motor on both machines. Two motors on the same axes as the reels are constantly under power, keeping the film taut. Idlers on swinging arms with a spring arrangement provide some buffering. Due to the relatively slow film movement, no vacuum loops or servicing of the idler arms are necessary. One frame of 35-mm sprocketed film is moved in 0.4 second and is positioned to an accuracy of ± 0.1 mm (non-accumulative). Figures 7 and 8 show the transports of machines I and II, respectively. For rewind, the film is taken off the sprockets and put on two idlers external of the normal film path. This arrangement is perfectly satisfactory for spark chamber film that is not pre-scanned and where each frame is to be measured. A faster film transport, having vacuum columns for film buffering, is under construction and will be attached to Hummingbird II.

VII. PERFORMANCE

Although the same basic principles underlie both Hummingbird I and II, some of the more significant differences are shown in Table 1.

The precision of CRT devices is not a function of linearity but of stability, i.e., repeatability. Most of the tests to date have been performed on Hummingbird I, which has a least count of 1 in 4096. In order to gain more knowledge of the behavior of CRT devices on the micron level, a smaller least count is mandatory. In Hummingbird II this is now available. The calibration pattern shown in Fig. 2 has been used extensively in testing the repeatability and hysteresis of the machine. The positions of the two vertical bars near the center are measured repeatedly over long periods of time. Their position in X does not drift more than 0.1 least count/hour. The variations in size have been computed to be smaller than 0.02%/hour.

Repeated accessing of one of the 54 crosses in a random manner produces calculated cross centers that are repeatable to better than 3 μm in both X and Y.

No quantitative measurement of the spot size has been made because no one method of measuring the spot size is generally accepted. To illustrate the resolution, however, an area measuring $\sim 5 \times 10$ mm^2 of BNL 20-inch bubble chamber film is shown in Fig. 9 with the playback from the Hummingbird.

This, along with the evidence of stability, makes the use of Hummingbird devices for the scanning and measuring of bubble chamber film appear promising. A small sample of ten (10) events ($\pi^- p$, 3.4 GeV/c) has been digitized and processed in an experimental way, using the Brookhaven analysis programs.[7] The rate of success at first glance seems small, since only two out of ten came through with flying colors. The reasons for rejection were not catastrophic, however, and may be corrected for on a larger sample in the near future.

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*on leave from CERN, Switzerland

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2. J. L. Brown, GSG 5, Stanford Linear Accelerator Center (unpublished).
3. D. Wiskott, CERN (private communication).
4. J. L. Pellegrin, "High Speed Deflection Amplifier for CRT Flying Spot Scanners," SLAC TN-66-1, Stanford Linear Accelerator Center, Stanford, California (January 1966).
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6. J. van der Lans, BNL BCHP 03-7-A, Brookhaven National Laboratory, Upton, L. I., New York (1963).
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TABLE I

Comparison of Differences Between
Hummingbird I and Hummingbird II

	Hummingbird I	Hummingbird II
Cathode ray tube with P24	5"	7"
Least counts along one scanline	2^{12}	2^{14}
Scanline densities	1024/512	4096/2048/1024
Threshold on photomultiplier	16 levels	16 levels
Normal/orthogonal scan	no	yes
Crystal controlled clock	2 Mc/sec	8 Mc/sec
Time per scanline	$\sim$ 2 msec	$\sim$ 2 msec
Scan speed on CRT	36 μ/μsec	52 μ/μsec
Scan speed on film	18 μ/μsec	52 μ/μsec
Optics	2:1	1:1
Digital resolution (no buffering)	36 μm	104 μm
Film Transport (stepping motor)	$\sim$ .4 sec/frame	.4 sec/104 mm frame
Film size	35 mm	35 and 70 mm

FIGURE CAPTIONS

1. Block diagram
2. Calibration pattern
3. Control panel of Hummingbird I
4. Tube holder and coil mount of 7-inch tube
5. View of Hummingbird II (uncovered)
6. Raw and filtered PM signals of bubble chamber film
7. Film transport mechanism, Hummingbird I
8. Film transport mechanism, Hummingbird II
9. $5 \times 10\ mm^2$ bubble chamber film and playback

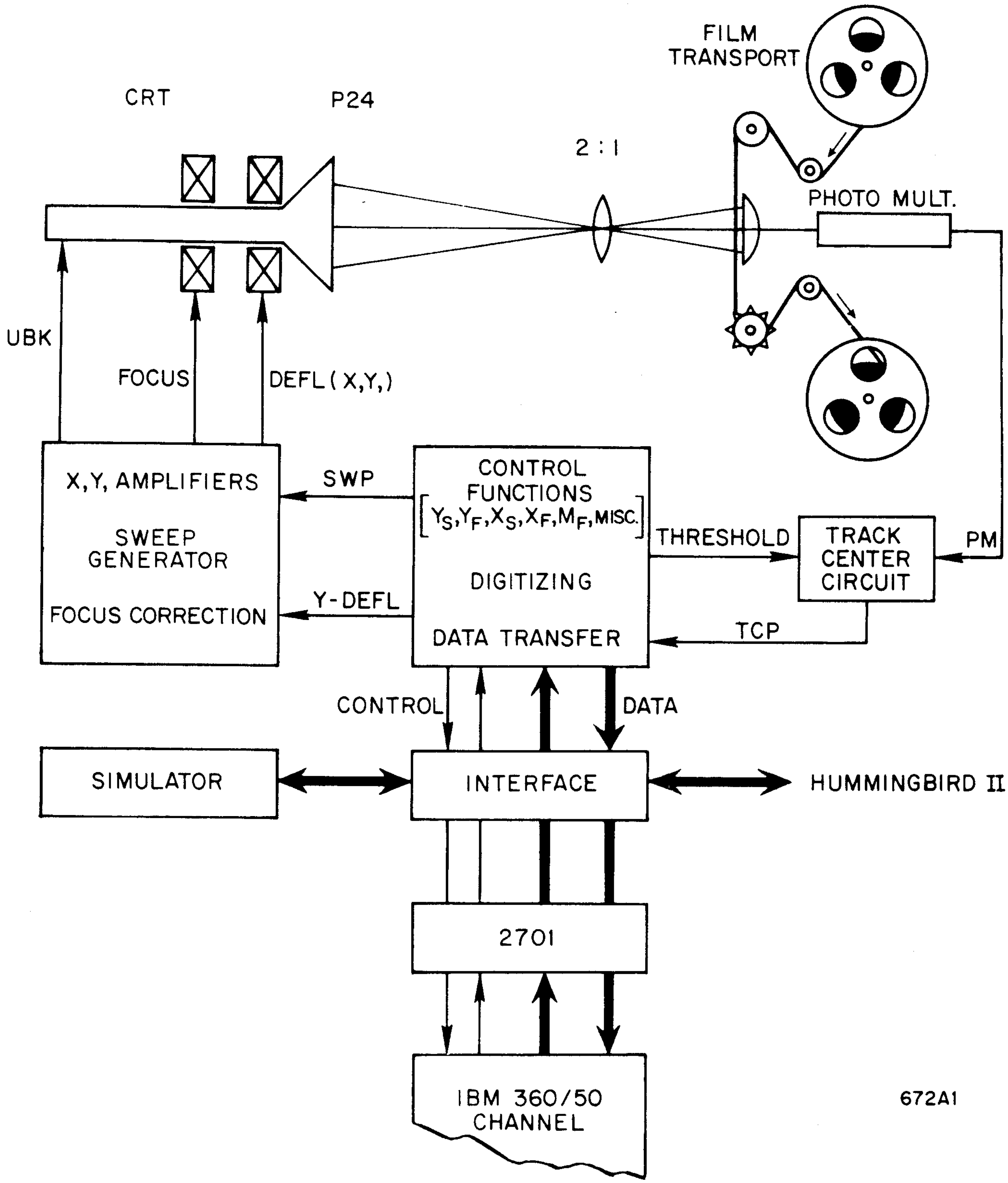
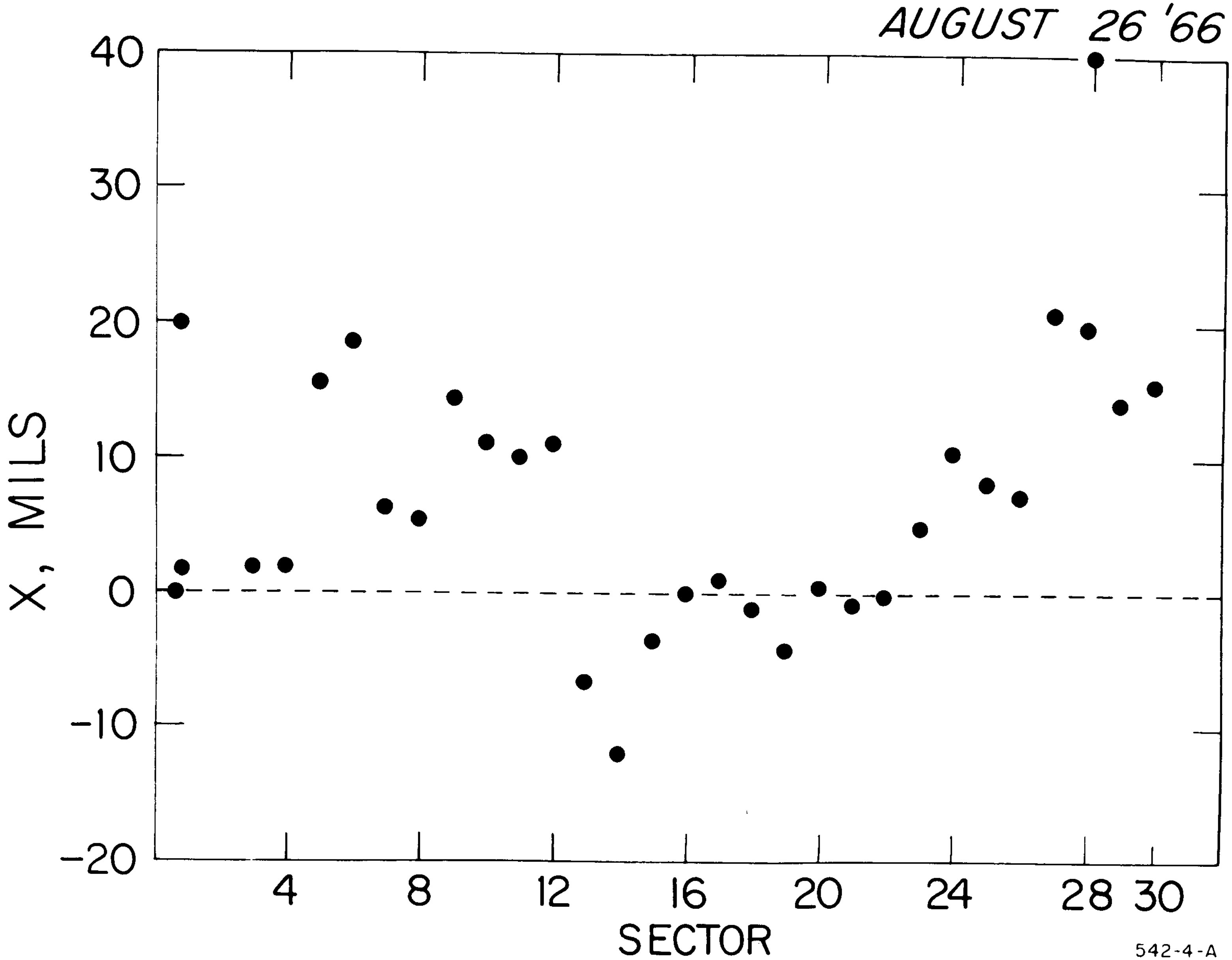

FILM
TRANSPORT
CRT
P24
2 : 1
PHOTO MULT.
UBK
FOCUS
DEFL (X,Y,)
X,Y, AMPLIFIERS
SWEEP
GENERATOR
FOCUS CORRECTION
SWP
Y-DEFL
CONTROL
FUNCTIONS
[Y_S,Y_F,X_S,X_F,M_F,MISC.]
DIGITIZING
DATA TRANSFER
THRESHOLD
TRACK
CENTER
CIRCUIT
PM
TCP
CONTROL
DATA
SIMULATOR
INTERFACE
HUMMINGBIRD II
2701
IBM 360/50
CHANNEL
672A1

Fig. 1



HORIZONTAL SHIFT SINCE APRIL 20, '66

Fig. 2

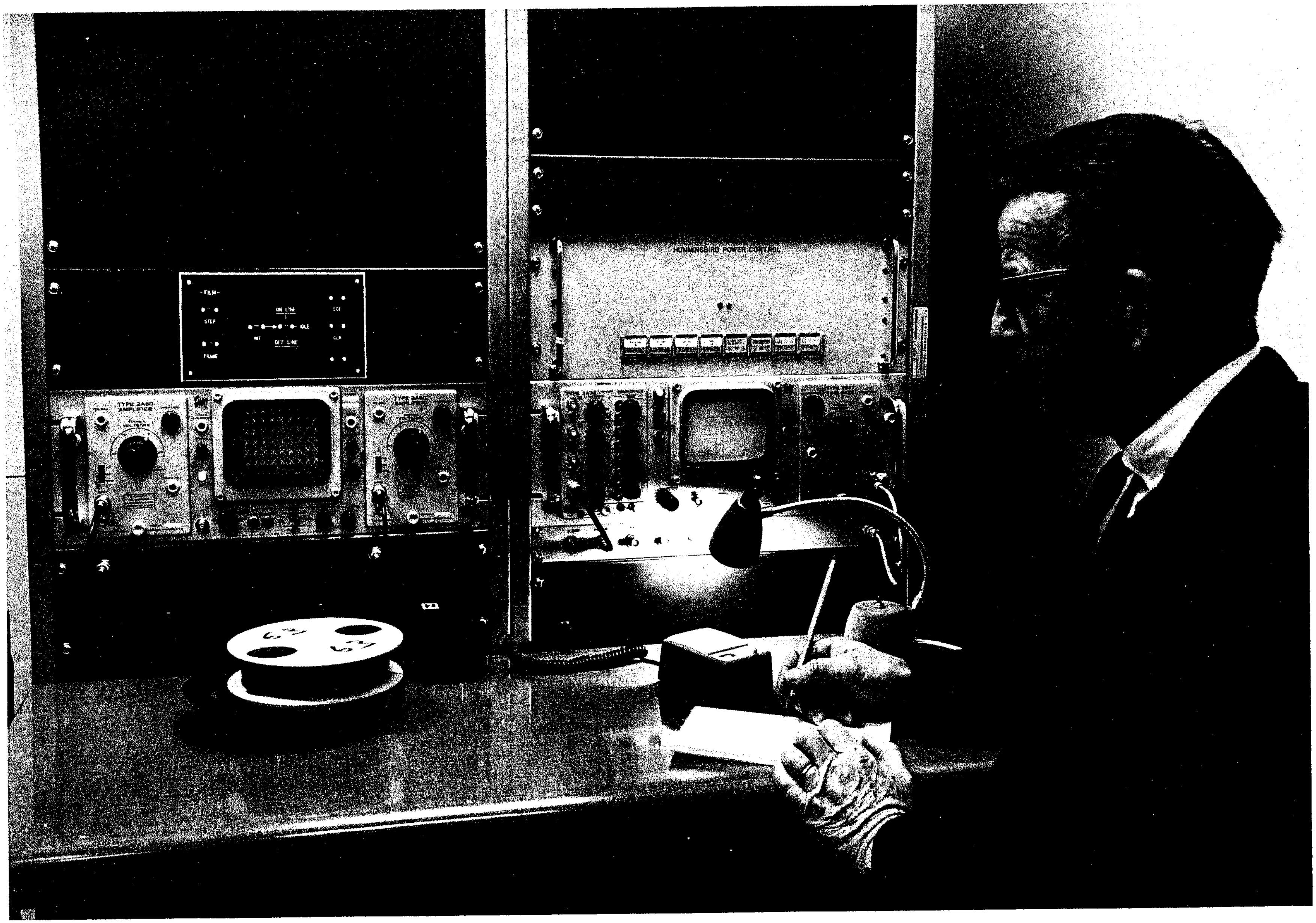

FILM
STEP
FRAME
ON LINE
IDLE
OFF LINE
TYPE 2A60 AMPLIFIER
HUMMINGBIRD POWER CONTROL

Fig. 3

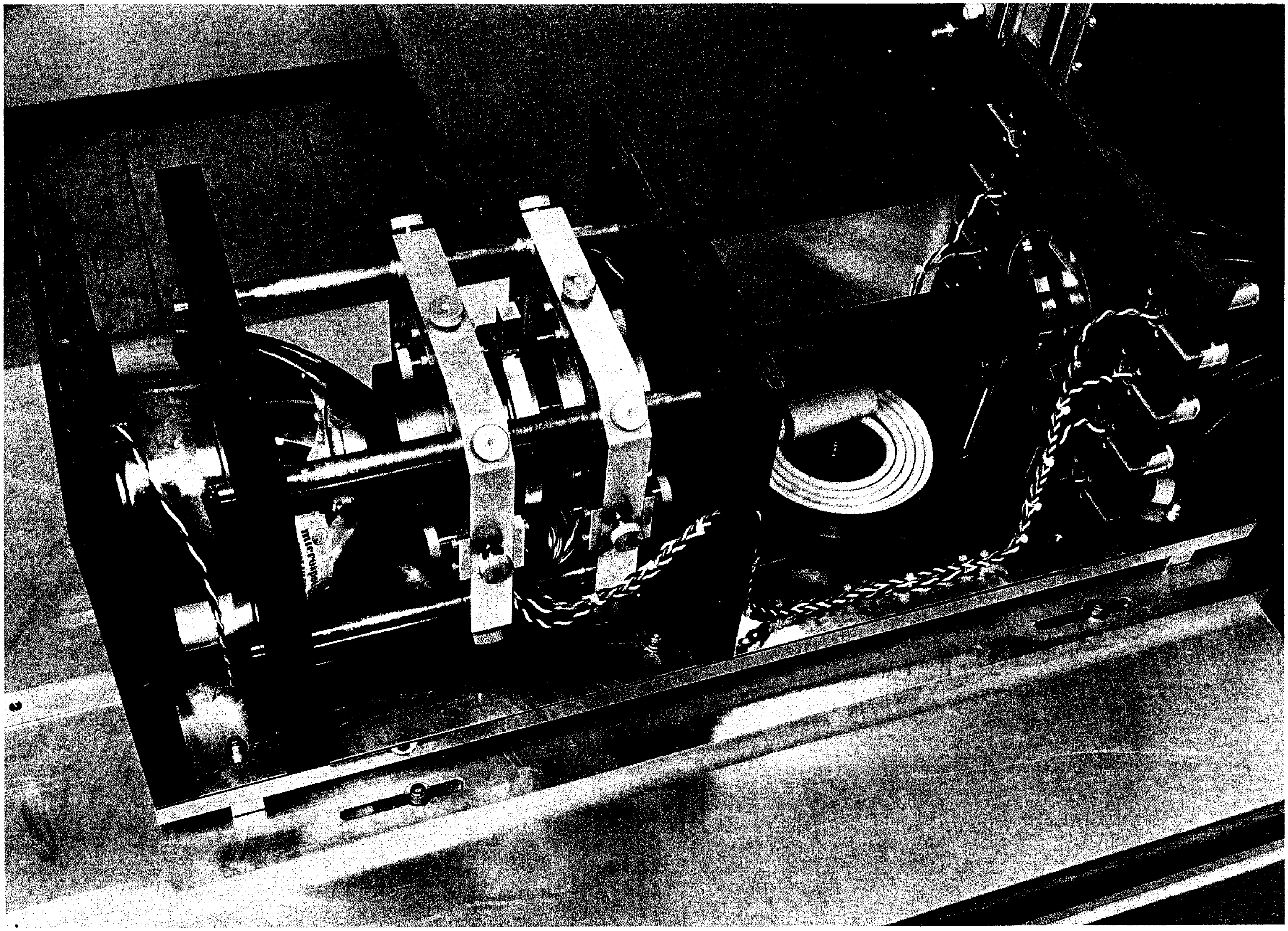


Fig. 4

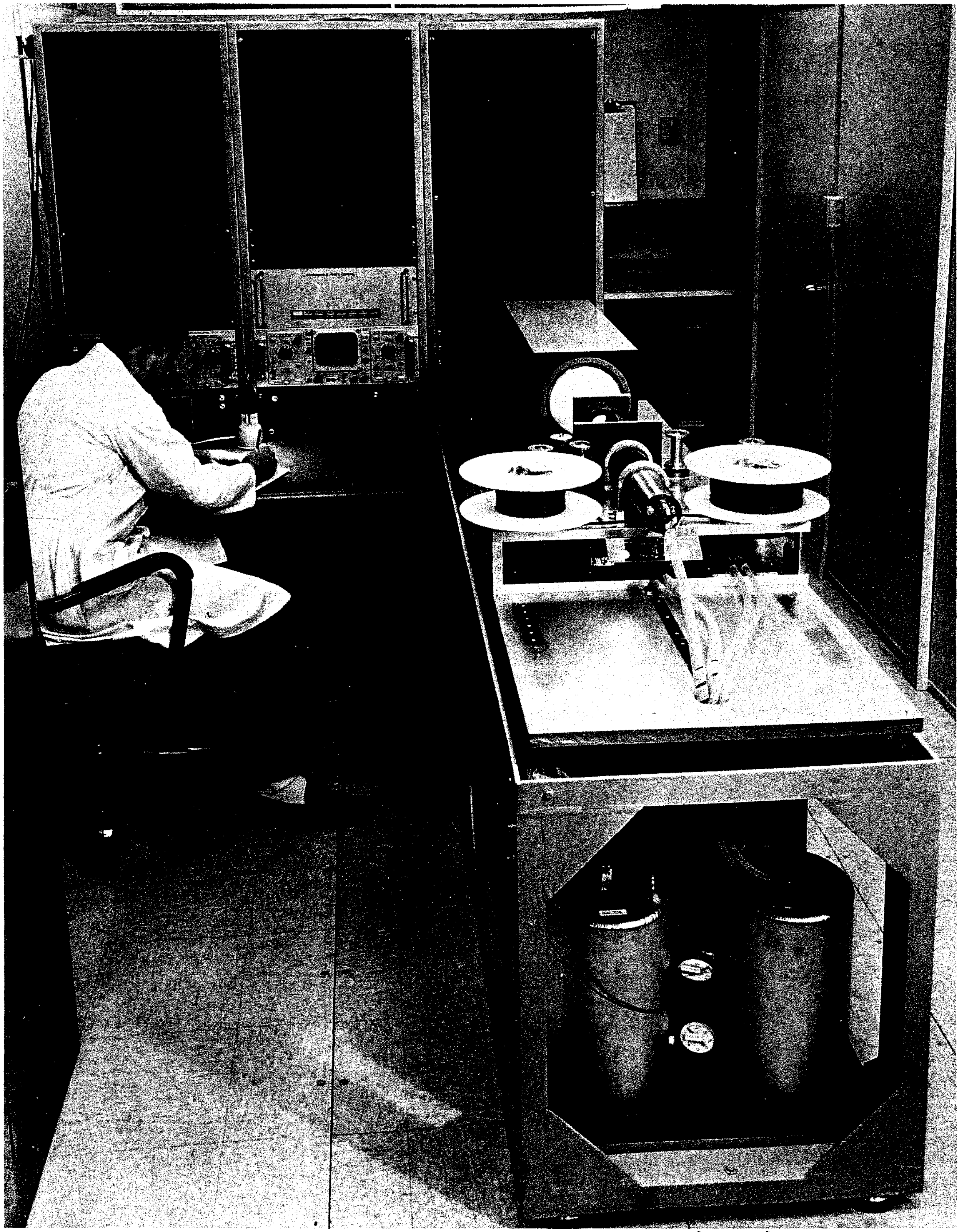


Fig. 5

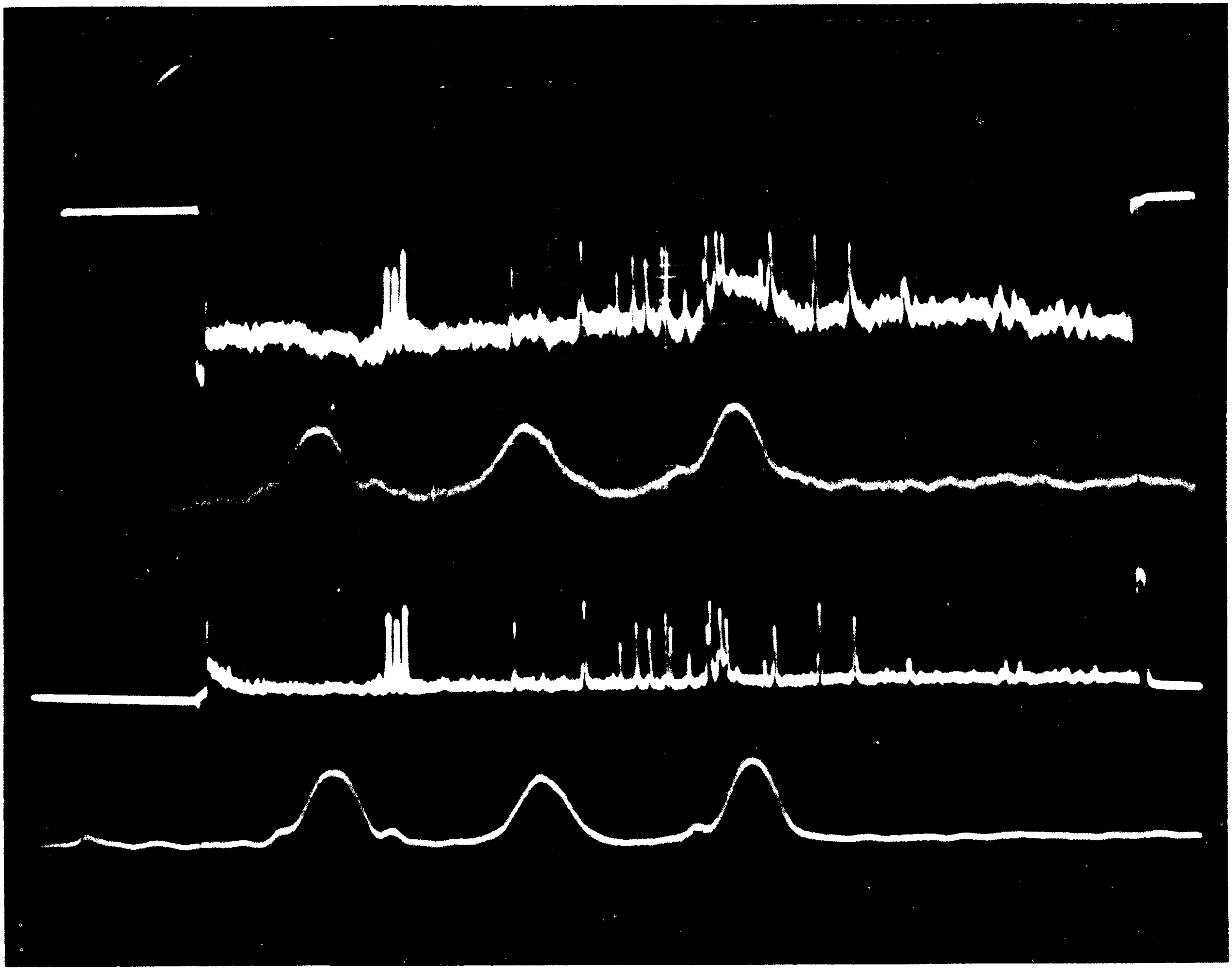


Fig. 6

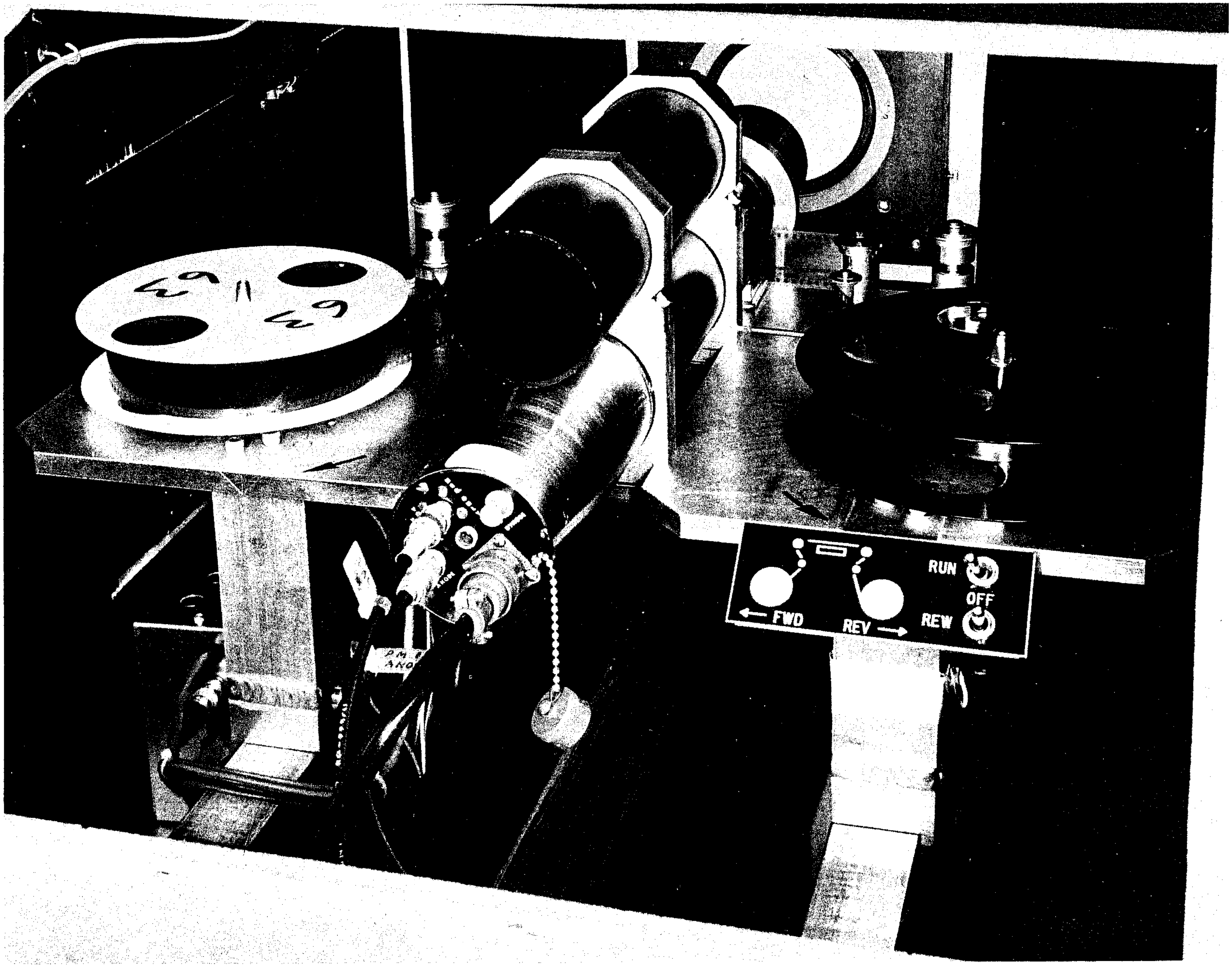


Fig. 7

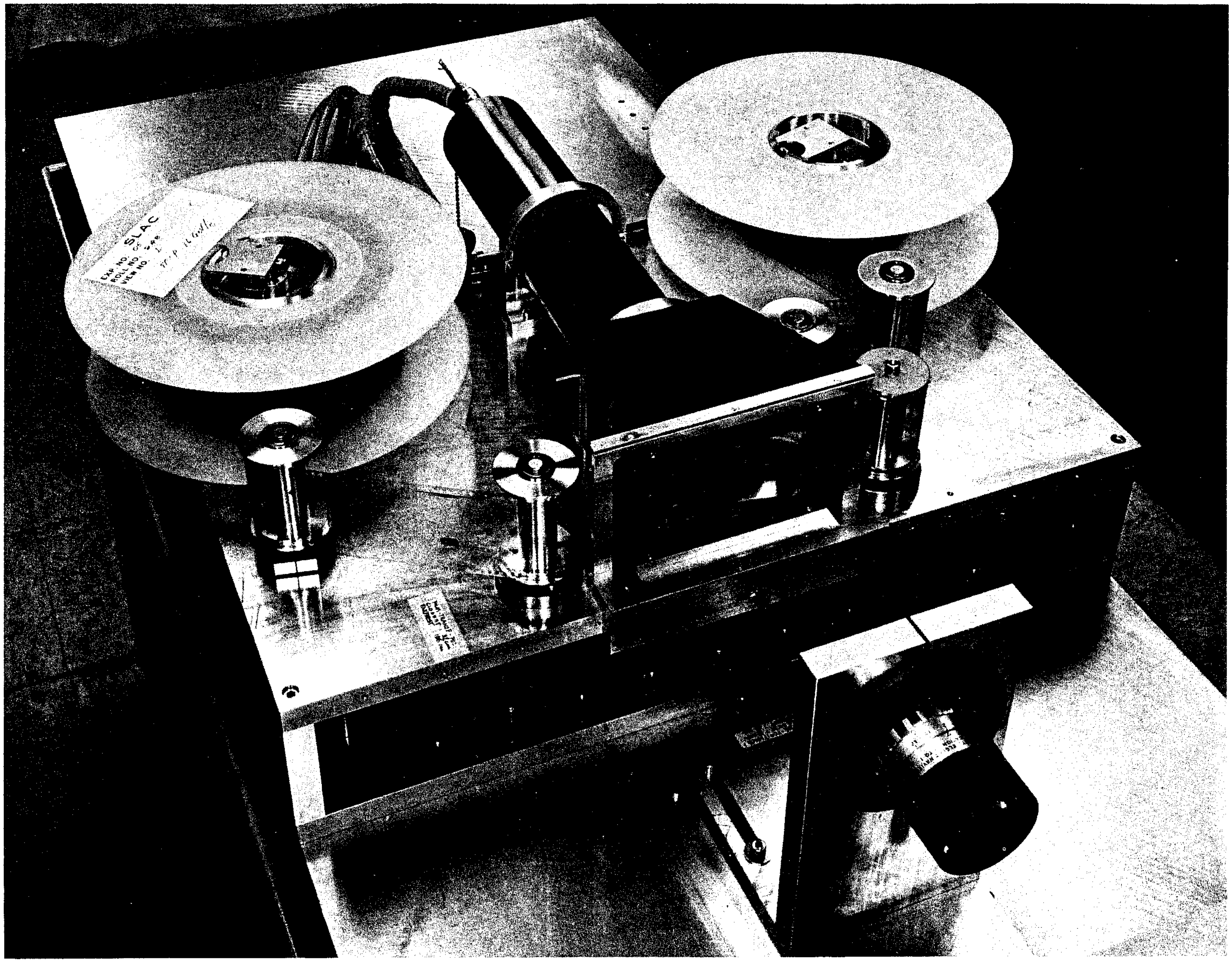
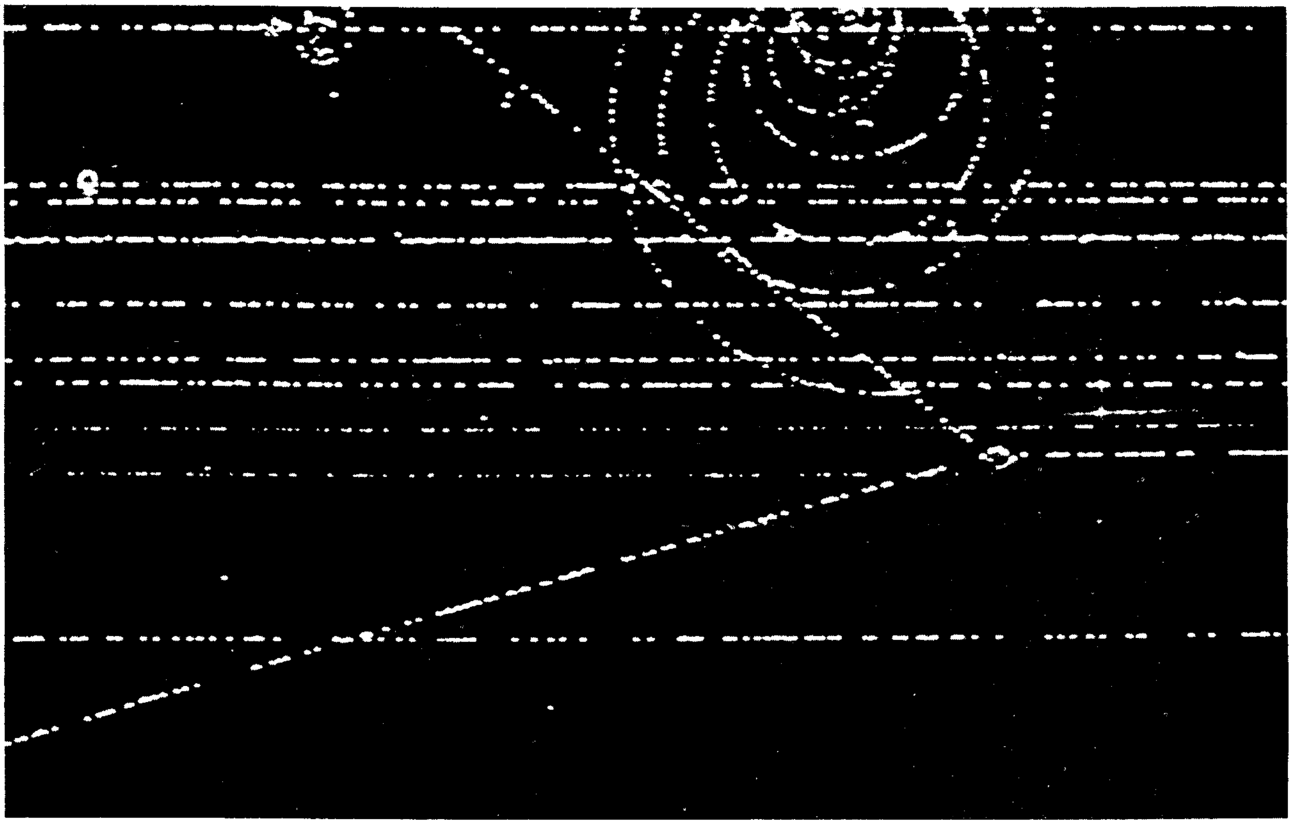


Fig. 8



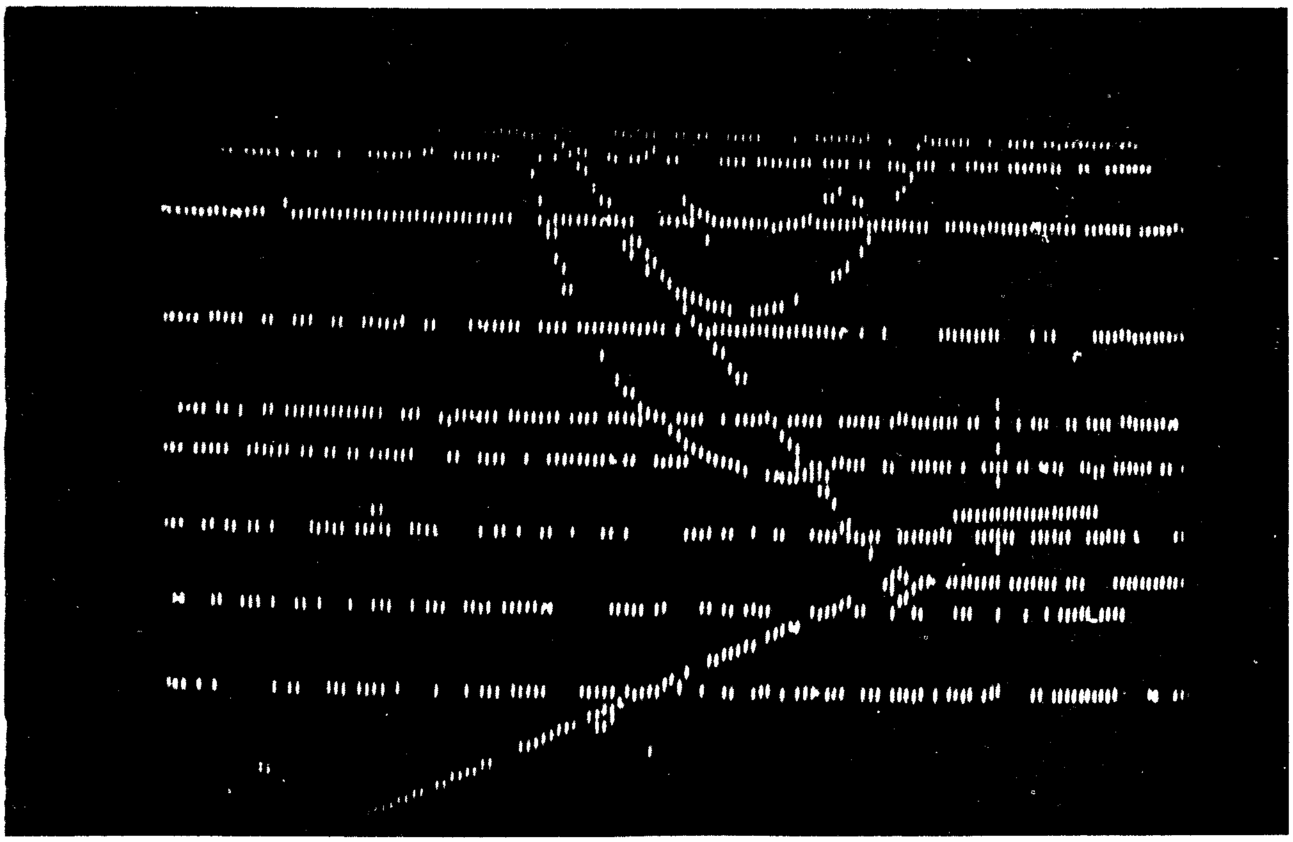


Fig. 9