# A SPARK CHAMBER FILM READING SYSTEM

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In preparing a system for the reduction of spark chamber photographs several factors must be kept in mind which would distinguish it from a scanner for bubble chamber photographs. Firstly, spark chamber photographs contain much less information and essentially no background. Secondly, the entire spark chamber format may change from experiment to experiment due to the relatively low cost of spark chambers. These factors in conjunction with the desire to utilize as much existing equipment as possible and to obtain good resolution have led to the construction of the film reading system which will now be described.

This device digitizes the coordinates of all information which is on the film. It records this on magnetic tape which is later processed in an IBM 7094 computer where sparks and tracks are reconstructed and kinematical analysis of the event is made. To match different experiments various spot sizes can be used as well as various spacings of the scanning lines.

## The flying spot scanner

The layout of the optical components of this scanner is shown isometrically in figure 1. The principal difference between this system and the Hough-Powell device for raster generation is that here a fixed illuminated pinhole is demagnified by about a factor of ten onto the film, and the motion of the lens itself produces the scan line of the spot on the film. For this purpose a microscope objective is used which has a large numerical aperture resulting in an intense spot of light. Sixteen such microscope objectives are placed around the circumference of a rotating disk with their optical axes parallel to and 145 mm from the axis of the disk. As long as an objective is passing through the cone of light emanating from the pinhole, it focuses a spot of light onto the film. The success of this system depends on the fact that the lenses used show very small aberrations for off axis rays.

There are three independent optical channels as shown in figure 1. Two provide the normal and orthogonal scans of the film; the third channel focuses onto a transmission grating which provides the X coordinate of the scan by digitizing the azimuthal position of the disk. A high pressure mercury arc lamp is the source for all channels. In each, the light is collected and made parallel by a 210mm f/3.5 camera lens. These are followed by 150 mm f/2.3 lenses which converge the light onto the pinholes and demagnify the 300 micron square arc to about 200 microns which illuminates the largest size pinhole we expect to use.

The two scanning positions are located so that the microscope objective has rotated 45° from the horizontal diameter of the disk when it is passing over the film. This results in the scan lines being at an angle of 45° to the edge of the film and in their being perpendicular to each other at the two positions giving a normal and an orthogonal scan.

Y motion is obtained from a precision stage to which the film is clamped by a vacuum platen. It is digitized by a Ferranti Moiré fringe grating system. The combination of the X and Y motions produces a cycloidal trajectory of the spot on the film; see figure 15. This data is transformed into more convenient rectangular coordinates later in the computer.

Although the azimuthal positioning of the objectives on the disk is not critical, the radial position is. This adjustment is provided by mounting the objectives eccentrically on carriers which can be rotated in their mounting holes in the disk. The objectives have, in practice, been set to the same radius to ± 1.5 micron.

Whereas the X motion is measured using a different objective, the start of digitization for a particular scan must be signalled bythe spot which makes the scan. To do this, just before the spot starts onto the film it is interrupted by a 45° silvered prism which deflects the light through a second ten power microscope objective which remagnifies the spot back up to the original pinhole size. The spot then passes over a slit generating the start of scan pulse. Light intensity is sensed in all channels by ten stage RCA 6199 photomultiplier tubes.

The disk is driven through a belt by a synchronous motor at 520 RPM. This generates one scan line every 7 milliseconds with the spot actually scanning for a period of 4 milliseconds.

The film transport system which is shown schematically in figure 2, handles 35 mm perforated film which is the type used by the fastest cameras suitable for spark chamber work. The supply and take up spools are buffered from the rest of the system by vacuum columns. These spools are driven by continuously running motors which are clutched in and out on signal from pressure switches on the columns. Both spools can be driven only in one direction; the 45 cm long vacuum columns provide adequate buffering for the film motion. Between the columns the film is driven by a sprocketed drive capstan which in turn is driven by a reversible motor through an electrical brake-clutch.

The film motion sequence starts when a frame passes through the projector and registration marks are sensed by a matrix of photodiodes on the screen beyond. At this time metering of film is commenced using the rotary encoder mounted above the drive capstan. The frame is advanced a predetermined distance to the normal window where it is clamped to the stage and the normal scan of the frame is made. When that is done the film is released and advanced to the orthogonal window where it is again clamped and the orthogonal scan is made while the stage returns to its original position. The frame is then returned to the projector and the film is advanced until the next frame is registered and the process is repeated. Since it is intended to scan every frame, normal forward speed is only 20 cm/sec and reverse speed is 43 cm/sec. In the search mode forward speed is also 43 cm/sec.

The format for a typical spark chamber photograph is shown in figure 3. The two squares in the upper right hand corner form the registration mark. The coding at the bottom is the film and frame numbers in the binary coded decimal system. These are read by photodiodes, also located on the projection screen, immediately after the registration marks are sensed.

The circuitry used to sense the frame registration marks is given in figure 4. The relative positions of the photodiodes can be adjusted to match any overall magnification. The registration marks, frame numbering and fiducials are all produced by argon filled photographic flash lamps. This high light intensity is necessary because of the small lens openings and fast cycling cameras used in spark chamber work.

Tests of the film transport and metering system show that film can be stopped repeatedly to within ± 1/4 mm of the expected point. This precision is adequate for the computer analysis where the fiducial marks on the film must be located and recognized unambiguously.

Photographs of the completed film reader are figures 5 through 8.

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The signals directly at the outputs of the various photomultipliers are shown by the oscilloscope traces in figure 9. The parameters of the reader for these traces were as follows: disk speed 520 RPM, all pinholes 55 microns (this yielded a measured spot size of 7.5 microns) and a stage speed which gave a 60 micron line spacing (20,200 and 500 microns are also obtainable). The X grating used had a 17 micron cycle, with the clear and opaque portion approximately equal at 8.5 microns.

The upper left hand oscilloscope pattern is the X grating signal at two different sweep speeds. The upper shows the entire passage of one spot across the grating. The individual crossings of the grating lines are not visible, but their envelope shows a light modulation of about 75%. The shrinkage of light intensity as one moves away to either side of center is caused by vignetting of the light by the microscope lenses and their holders and is not due to defocusing of the light spot. The lower trace is just a portion of the upper one with a sweep speed sufficient to show the individual crossings. The next pattern down is again the X grating but with the scans produced by all sixteen objectives showing. These first two patterns were taken with 85% of the light removed by a uniform neutral density filter placed over the photomultiplier.

To remove the effect of vignetting a nonuniform filter was placed over the photomultiplier to replace the uniform one. This was produced by placing unexposed photographic film over the tube and exposing it to the light from the wheel. With this nonuniform filter in place the X grating signal shown in the lower left of figure 9 was obtained.

In the upper right trace the start of scan pulse is shown just below the X grating pulse. The next pattern down again shows the start of scan pulse and above it the output of the photomultiplier behind the film platen when no film is in place. The last pattern was taken with film in place and contains one data point on that scan.

The data processing unit

The function of this unit is to transform the pulses from the photomultipliers into useful coordinates on magnetic tape. A photograph of the components is shown in figure 8. An abbreviated block diagram of the logic is given in figure 10.

The Moiré fringe system is permitted to start driving the Y scaler when a start of frame signal is picked up from a flasher mounted on the stage. This start signal is used to reset the

Y scaler after a delay of time adequate to complete the frame. As it is now adjusted, one Y count represents 20 microns of stage movement. Similarly the X grating is allowed to drive the X scaler after the start of scan signal has opened a gate. This start signal is also used to reset the X scaler after a time delay sufficient to complete one scan line. Initially one X count corresponds to one cycle of the grating. At present we are doubling this frequency using a time delay and an adder, and this gives a least count of 8.5 microns. The size of the least count can be reduced by at least another factor of two.

An X coordinate is recorded whenever a point is read from the film, but the Y coordinate is recorded only once at the end of these scan lines in which data have been sensed. The data pulse does not appear at the moment the spark is crossed, but instead at some constant distance beyond its center. The method by which the center of the spark is located is explained in figure 11. An independent track centering scaler is used, and when it is full the overflow pulse causes the data point to be read. It is fed at one half the normal frequency while the spot is traversing the spark and at normal frequency thereafter, thus making the distance from spark center to data point independent of spark width. There is, of course, a maximum width which can be so treated as well as a dead time which corresponds to half the width. The capacity of the track centering scaler can be adjusted to match the maximum that is expected. Should a spark width exceed the capacity of the scaler, no data are read.

Under the above conditions, the contents of the X and Y scalers are read into a 256 word core memory. This memory serves as a buffer between flying spot scanner and the tape unit enabling the reading of more closely spaced points on the film. When the memory is half full it dumps 128 words onto tape leaving the other half of the memory to accept data. The interlace network prevents simultaneous reading and writing in the memory. A read request always takes preference, and the write information is held until the reading of the word is completed.

Since each word in the memory contains 18 bits, it must be reduced to three words of 6 bits each for use with the 7094 computer. The tape buffer and ring counter do this and also manufacture parity bits as needed. The tape unit itself records 200 bits/inch at a tape speed of 150 cm/sec.

Figure 12 is the first event we attempted to scan. Only the normal window position was used with the 45° scan line running generally from lower right to upper left. In figure 13 is shown the face of the cathode ray tube on the 7094 which displayed the event after it had been scanned and transformed from the cycloidal system into the rectangular coordinate system.

The computer programs

A program, called STEAM, has been written for the IBM 7094 computer to analyse events in a cylindrical spark chamber. The flow chart for this is shown in figure 14. The times given are for the processing of both the normal and orthogonal scans of one frame, each containing 2,000 data points. This program specifically analyses K + p elastic scatterings to obtain the differential cross section as a function of scattering angle.

One file on the tape, which corresponds to the normal and orthogonal scans of one frame on the film, is read into the core memory of the 7094 computer. The first thing that must be done before these two scans can be superimposed in the same coordinate system is to locate the fiducial crosses on both scans.

Figure 15 shows diagrammatically how this is done. The areas containing the fiducial data are approximately known since the position of the frames on the vacuum platen repeats to within a few tenths of a millimeter. A binary search is made of the memory to locate the data in these areas which are candidates for fiducials. In one of these areas the smallest value of Y is sought along which scan there are two data points, that is X values. The next larger value of Y is sought again having two data points with the requirement that $\Delta X$ for these be less than the $\Delta X$ for the previous scan. Continuing this process, pairs of data points are accepted until the crossover point is reached after which it is required that $\Delta X$ for the two points increase with each succeeding scan line. When all data arising from this selection process have been obtained, those points read by the scanner first on each scan line while $\Delta X$ is decreasing are matched with those read second while $\Delta X$ is increasing. Likewise the points read second before the crossover are matched with those read first after the crossover.

These two groups of data are now transformed from the cycloidal coordinate system of the scanner to rectangular coordinates. With this done, straight line least squares fits are made to the two sets and the intersection of the two lines is the fiducial point. This process is repeated for each of the four fiducial marks in both scans.

The sequence then proceeds into the main program where the data from both the normal and the orthogonal scans are unpacked to give one coordinate per 36 bit word. The data are then transformed from the cycloidal into a rectangular coordinate system. This transformation is performed through a combination of table look up and calculation so as to minimize the time needed. As indicated in the flow chart of figure 14, this transformation requires approximately 0.15 seconds for 2,000 data points.

In the routine TRFØRM the data from the orthogonal scan is translated and rotated so that the fiducial points in both views coincide. It is required that the matrix of this transformation be a simple translation plus a rotation, otherwise one of the scans is stretched or shrunk and the event is rejected. All the data is now known with respect to the center of the spark chamber.

The spark chamber is divided into 128 sectors which, since there are 10 gaps, yield 1280 areas into which the data can be located. This is shown in figure 16. All data that do not lie in these sectors cannot be candidates for sparks. The size of the sectors was chosen so that ordinarily not more than one spark lies in a sector and so that one spark will usually lie entirely within one sector. SØRT classifies each datum according to its gap and sector with the result that an ordered table is obtained having for each segment of area the number of data points in it, the sum of the X and the sum of the Y coordinates of these points in the rectangular system, and the first and last points picked up by the scanner in the area.

Upon entering the TRACK routine a table, SPARK, is set up containing in each grouping, information relating to one spark, such as the first and last points on a spark, the centroid of the spark, and some identification. A spark must be entirely within one or two area segments, and it is assumed that all information in one area belongs to one spark. Assignment of data to specific sparks is shown in figure 16. The first point in one sector must be within some predetermined distance from the last point in the adjacent sector of the same gap for the two sets of data to be assigned to one spark. It is also required that there be between two and fifteen points for a spark.

Now that the SPARK table has been set up, these sparks are assigned to tracks before a least squares fit is made to their centroids to find the equations of the tracks. As this assignment is made, the sparks are ordered in a new table, called A, in the same sequence as they occur along the track.

Starting with some spark, the computer examines the adjacent gap in the same sector and in the two adjoining sectors. For each spark so found the minimum distance, d, between either of its end points and either of the original spark's end points is found. For a spark to be a candidate, d must be less than some preselected value, D. Of the sparks found in the adjacent gap, that one having the smallest d is assigned to the track. A similar search is then made into the third gap, if an acceptable candidate is found the track is started; if not, the computer returns to the second best spark in the second gap and seeks a compatible spark in the third gap.

With the track thus started, the sequence is continued through succeeding gaps, with the modification that the most acceptable next spark is that whose minimum distance, d, is nearest to the d of the preceding spark and not necessarily the minimum. It is also required that changes in sector number along the track be monotonic.

In the event that a gap of the spark chamber has failed to fire, a search is made into the next gap, with the requirement that d now be less than D + g where g is the gap width. Similarly, if two successive gaps fail to fire, d must be less than D + 2g. If more than two successive gaps fail, the track is assumed to have terminated.

With Table A set up, all sparks have been assigned to tracks or have been rejected for assignment. It is now required to that there be six tracks as are obtained from an elastic scattering event. A stray background particle passing through the chamber would yield four more tracks which, although not permitted at present, would not unduly complicate the programming. It is also required that there be at least n sparks in the track, where n is some number between 6 and 10, inclusive.

Straight line least squares fits are now made to the centroids of the assigned sparks resulting in six equations of the form $ax + by + c = 0$.

The direct images are distinguished from the reflected images by the fact that the former must intersect in a common vertex as do the tracks of the scattering particles in real space. The number of combinations of tracks which must be taken to make this identification is reduced by the fact that the reflected images are always located either clockwise or counterclockwise from the direct images. The track of the incoming particle is known from the layout of the experiment.

The equations for the tracks are next fed into the kinematical analysis program for $K + p \longrightarrow K + p$ elastic scattering. Here the two possible identifications of the outgoing tracks are tested and if one combination satisfies the constraints for kaon-nucleon elastic scattering, within an allowable error, the event is accepted and the desired quantities therefrom are printed out.

One notices that throughout the program whenever one criterion is not satisfied, the event is discarded. This is permissible since only one particular type of event is being sought.

The program in its entirely has been tested with hand digitized events from the K + p elastic scattering experiment.

Acknowledgments

Many people at Brookhaven contributed to this work, and it is a pleasure to thank them all; unfortunately space does not permit acknowledging them individually. In particular the contributions of Dr. A.L. Read in the programming problems, G. Schwender in electronics and control systems and J.A.G. Russell in the early phases of the project were essential.

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Figure captions

Fig. 1 Film reader optical system. Relative positions of components have been distorted to show all elements.

Fig. 2 Film transport system. In reality the normal and orthogonal windows are the same size and are 45$^o$ above the horizontal diameter.

Fig. 3 Typical spark chamber event showing coding method. Registration mark is in upper right corner with frame number at the bottom. K meson entering from the top is scattered in liquid hydrogen contained within fiducial crosses. The scattered meson and recoil proton are both visible. A secondary image of each spark located counterclockwise from the original gives depth of spark in chamber. This photograph was made in the ten gap cylindrical chamber made by T.F. Kycia and K.F. Riley at Brookhaven.

Fig. 4 Circuitry for sensing frame registration marks.

Fig. 5 Overall view of flying spot scanner. Mercury lamp housing is to the right, rotating disk is in the center and the film transport system is to the left.

Fig. 6 Close-up of platen area showing microscope objectives mounted in wheel. Pinholes are mounted on three mutually perpendicular slides to the right. 45$^o$ prism for start of scan is mounted on remagnifying lens.

Fig. 7 Film transport systen. Drive capstan and metering encoder are mounted just to right of the projector. Photodiode matrices for registration marks and frame numbering are mock in this photograph.

Fig. 8 Racks containing data processing unit. To the left is the tape transport and to the right the bins containing the logic components and the core memory. Controls for the scanning table are to the far right.

Fig. 9 Signals from photomultipliers. See text for descriptions of individual traces.

Fig. 10 Block diagram of data processing unit. For the X count signal from the grating to drive the X scaler a start of scan signal is required. The start of scan signal is also used to reset the X scaler after a delay of time sufficient to complete the scan.

Fig. 11 Method of finding the center of a spark along the scan line.

Fig. 12 Photograph of a K + p scattering in a cylindrical spark chamber.

Fig. 13 Photograph of 7094 cathode ray tube after scanning the above frame. Only the normal scan was made giving a poor fidelity for sparks oriented along the scan line.

Fig. 14 Flow chart for analysis of cylindrical spark chamber photographs. Times given are for a normal and orthogonal scan of 2,000 data points. The name of the programmer of each routine is given. Data tape is normally read on a separate data channel while the final analysis is being executed.

Fig. 15 Reading sequence of fiducial marks.

Fig. 16 Track reconstruction. At the left, data points within area segments are shown with end points that are scanned first and last encircled, and spark centroids shown by crosses. In the center assignment of sparks to tracks is made, and on the right a straight track is fitted to spark centroids.

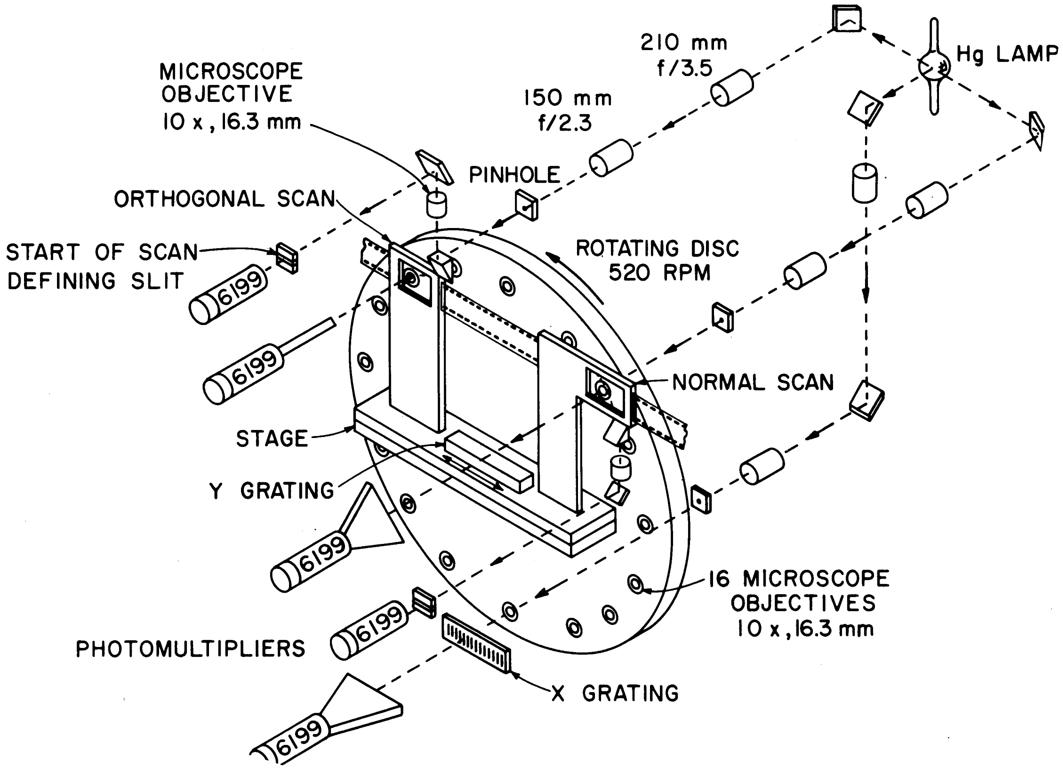



Figure 1

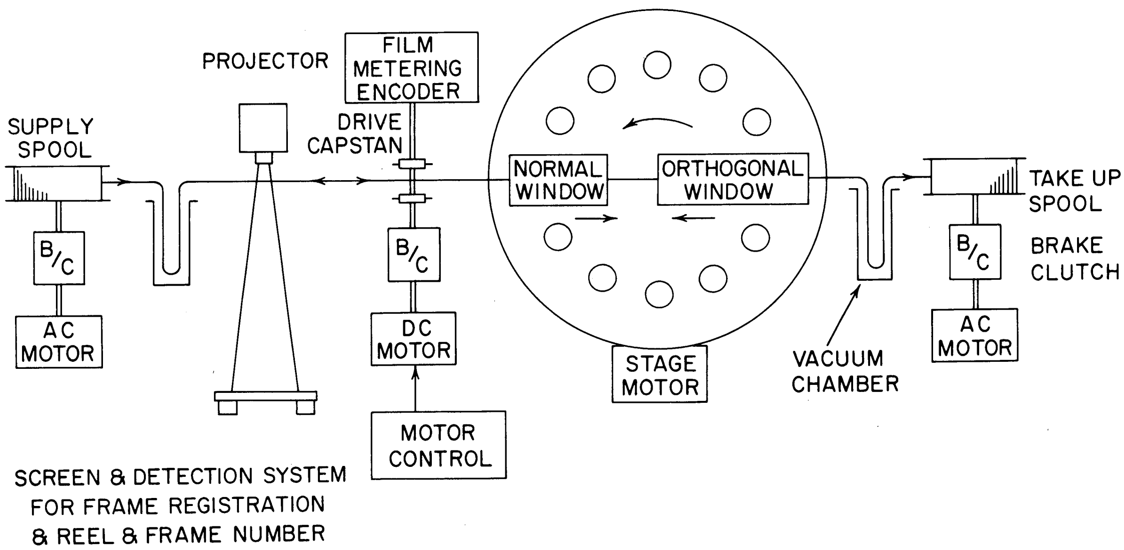



Figure 2

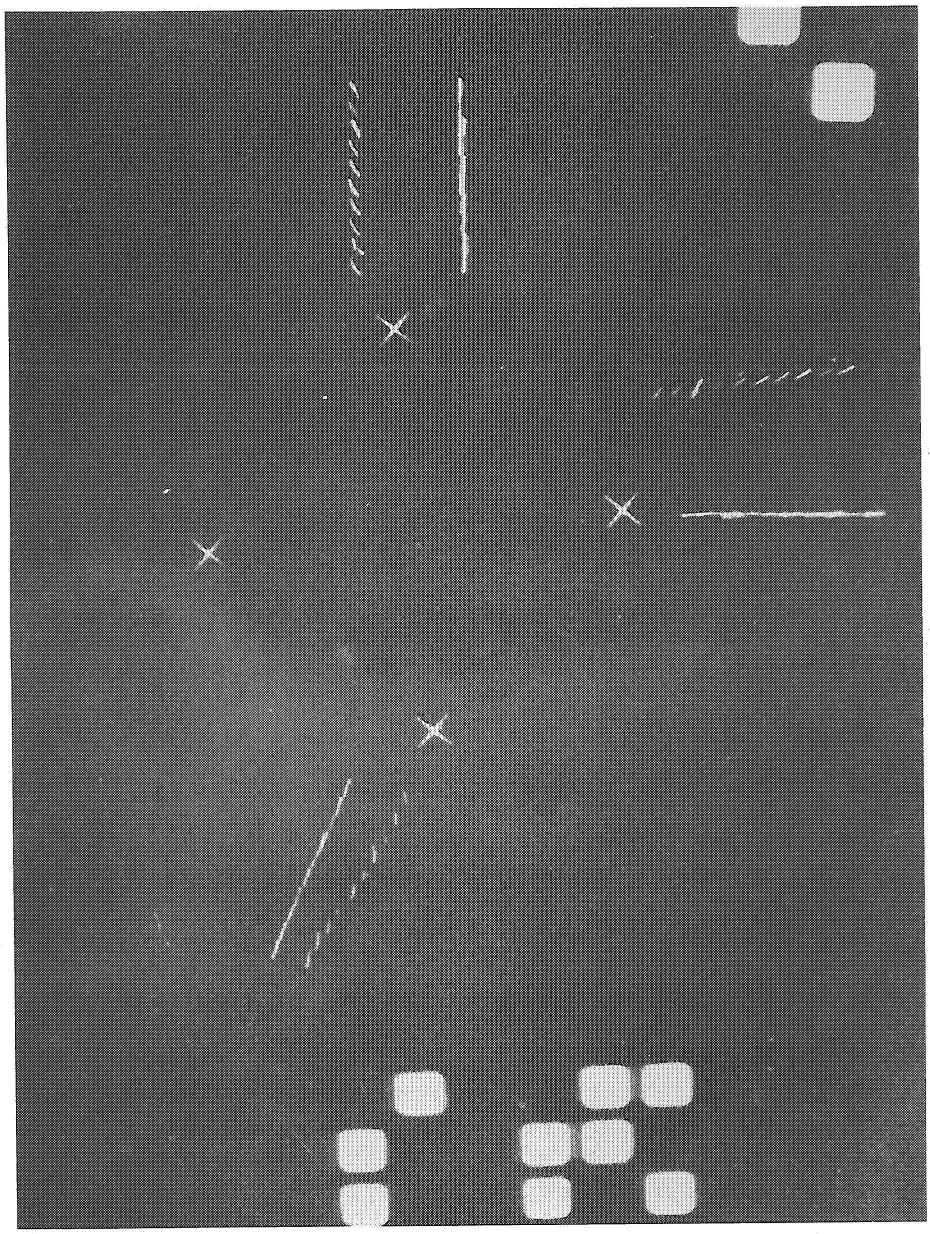


Figure 3

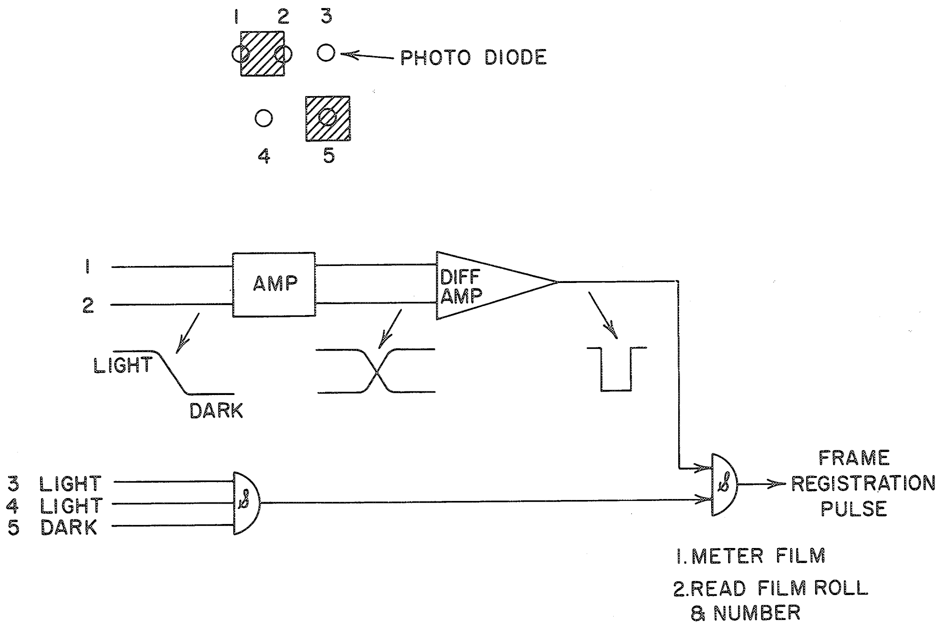



Figure 4

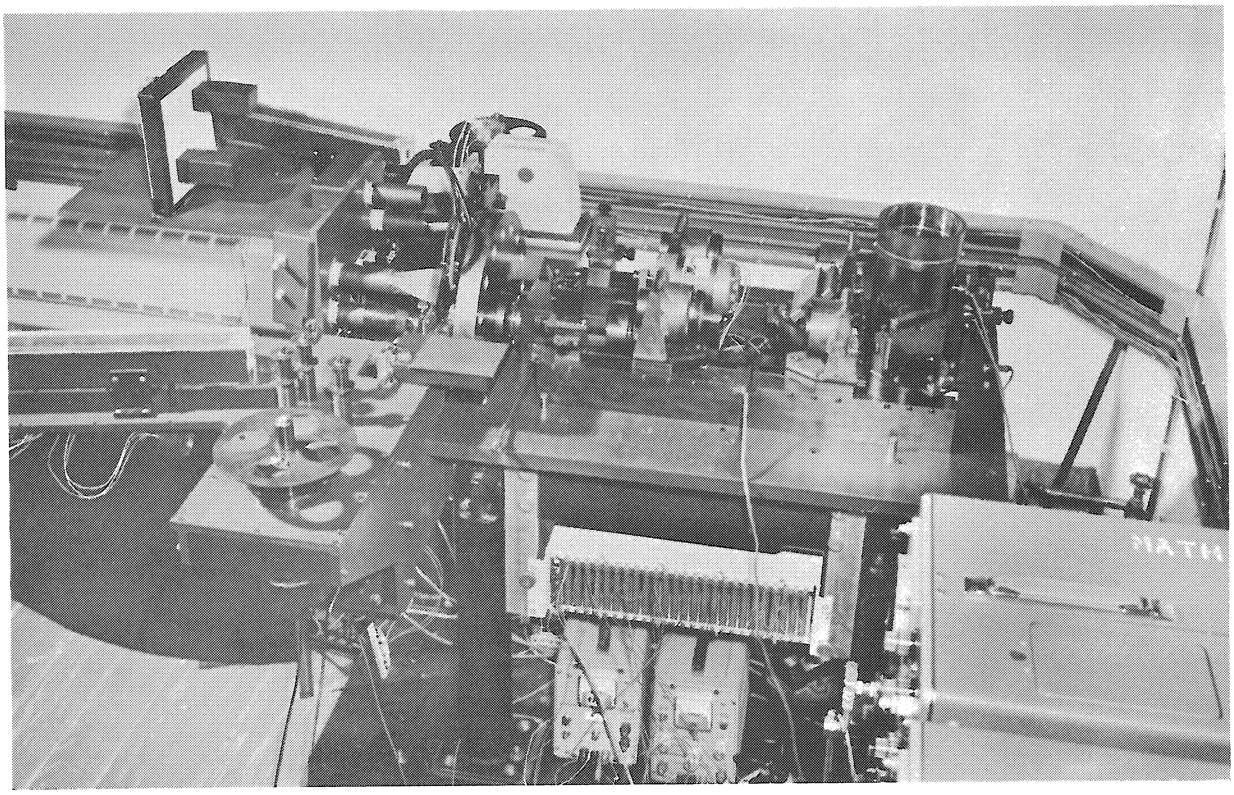



Figure 5

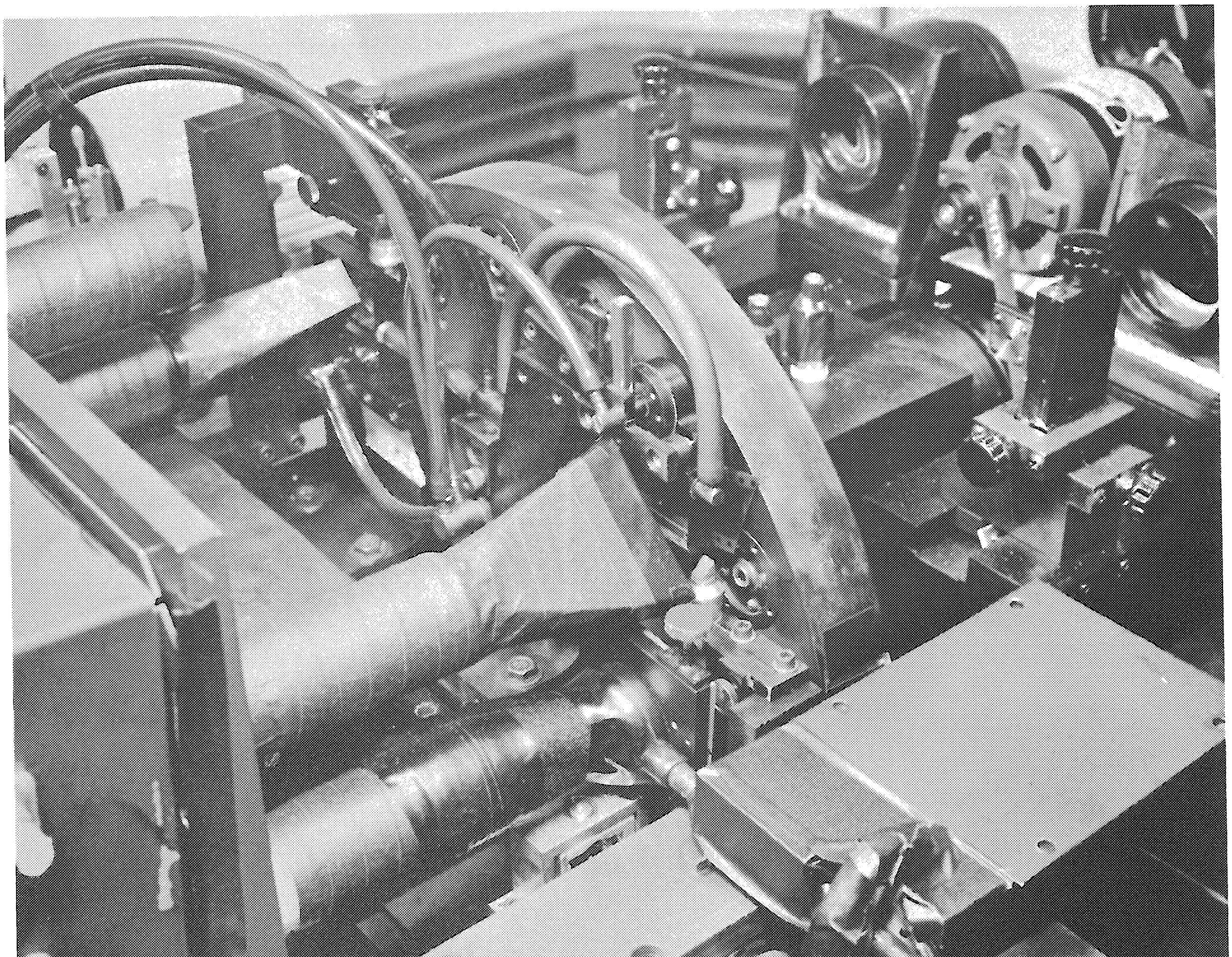


Figure 6

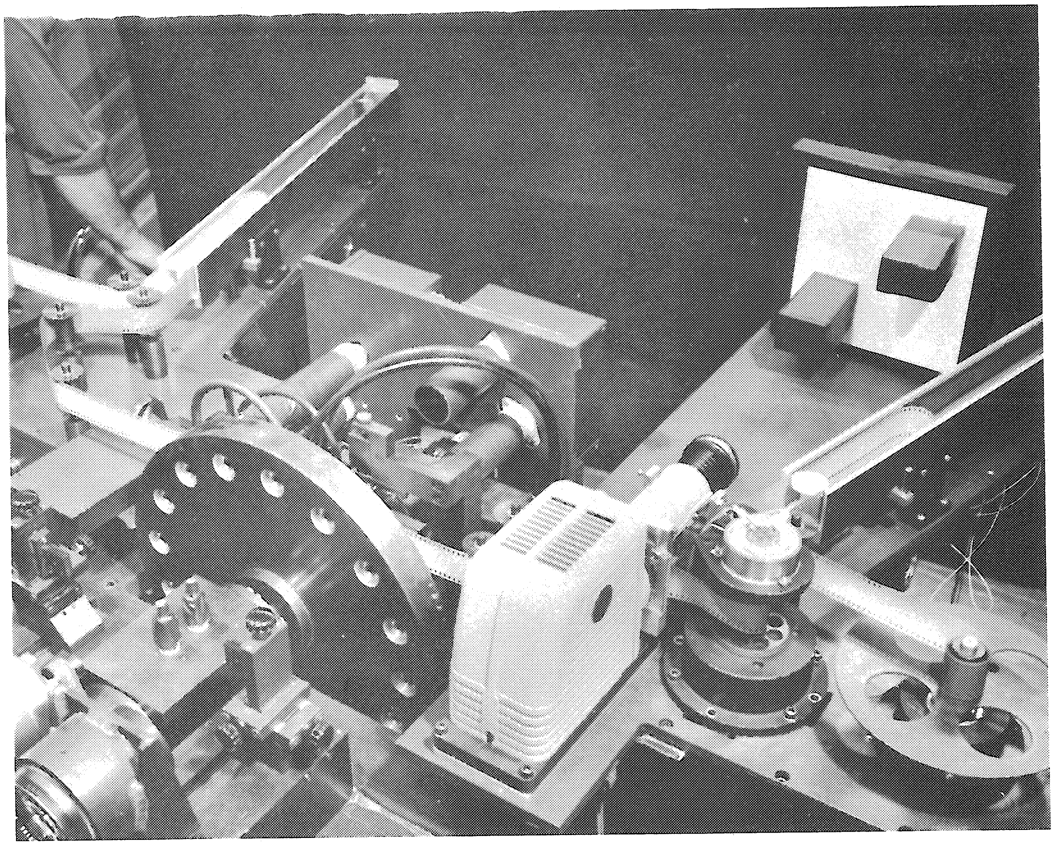


Figure 7

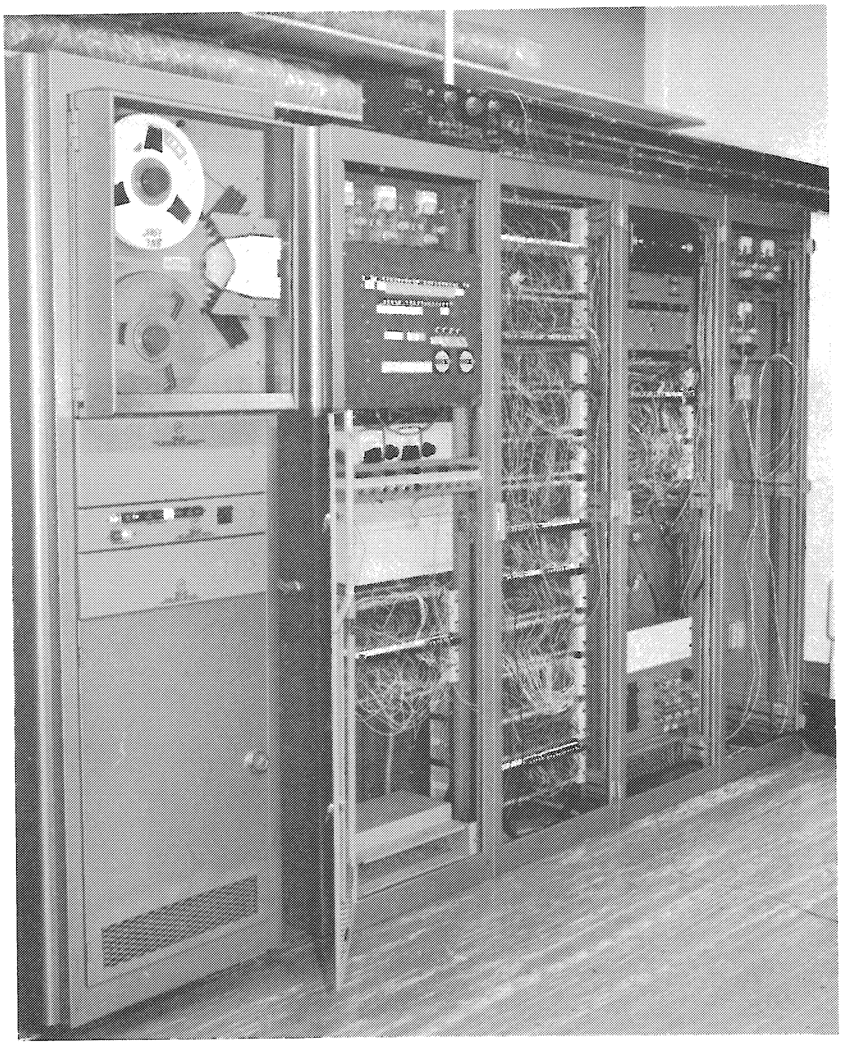


Figure 8

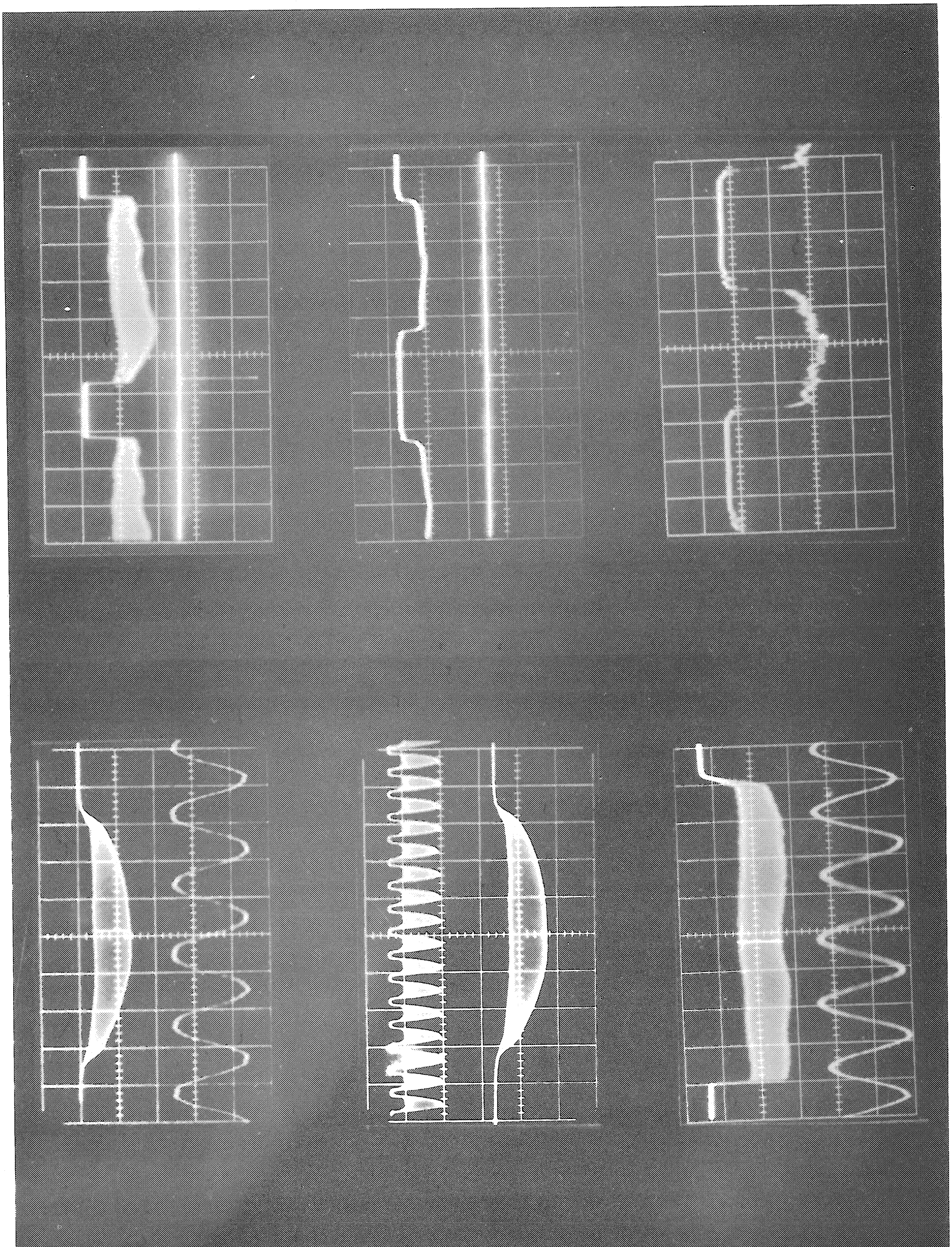


Figure 9

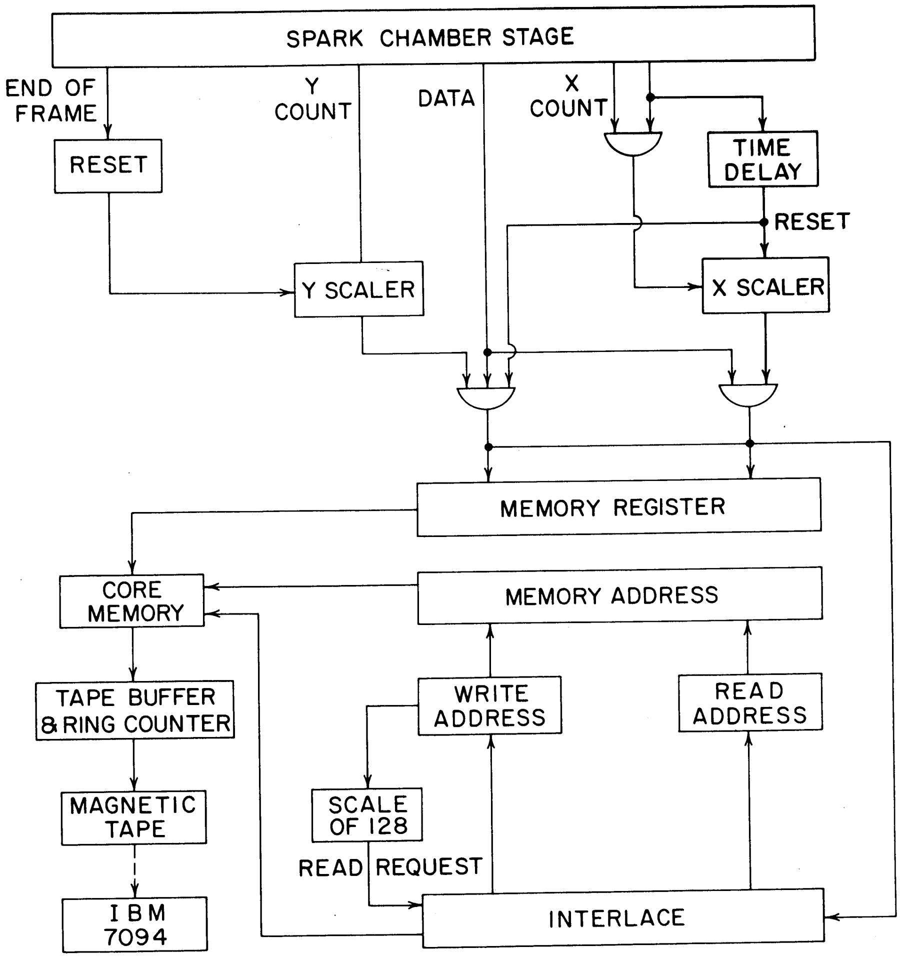



Figure 10

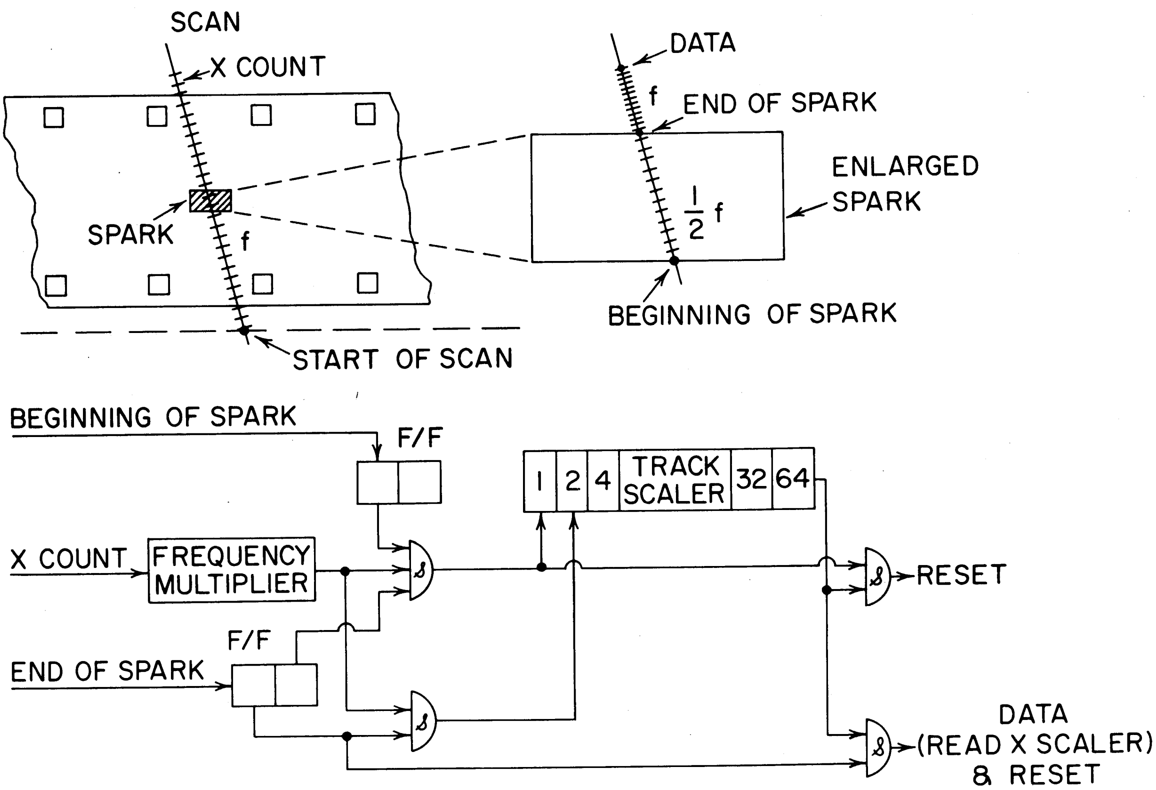



Figure 11

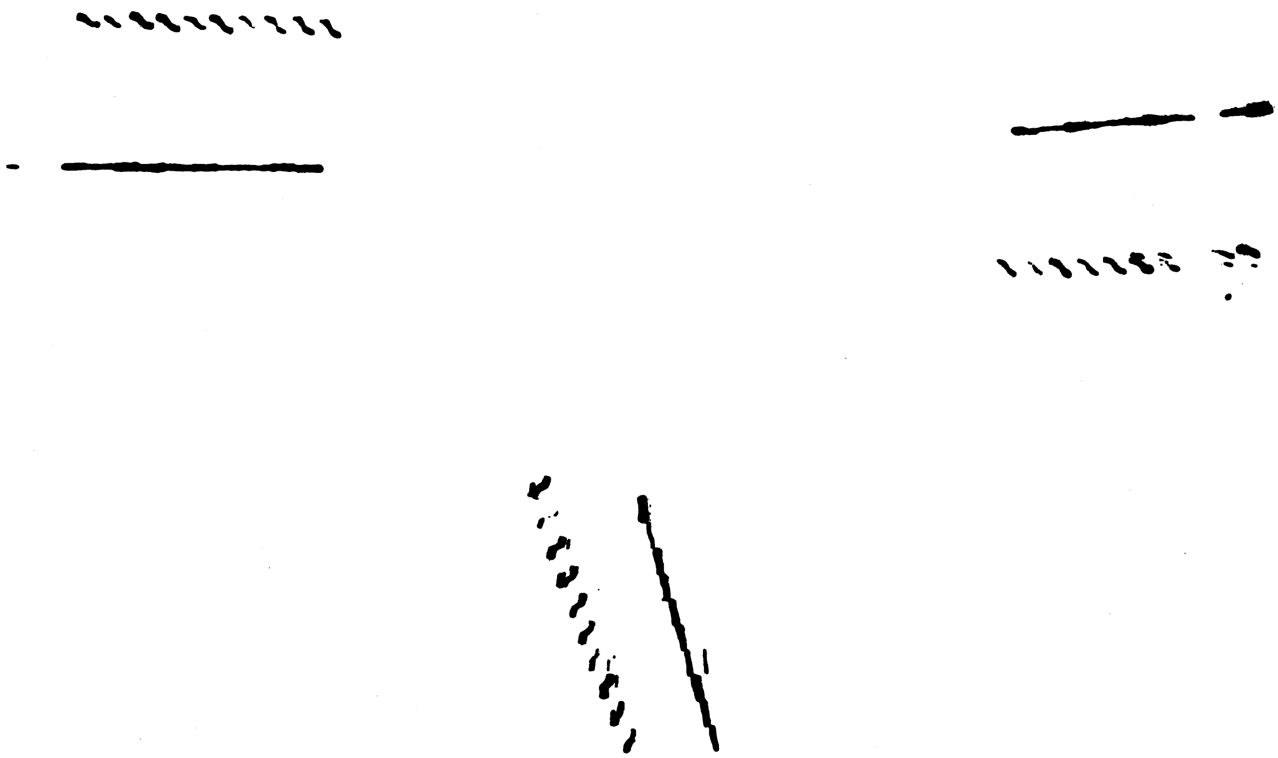


Figure 12

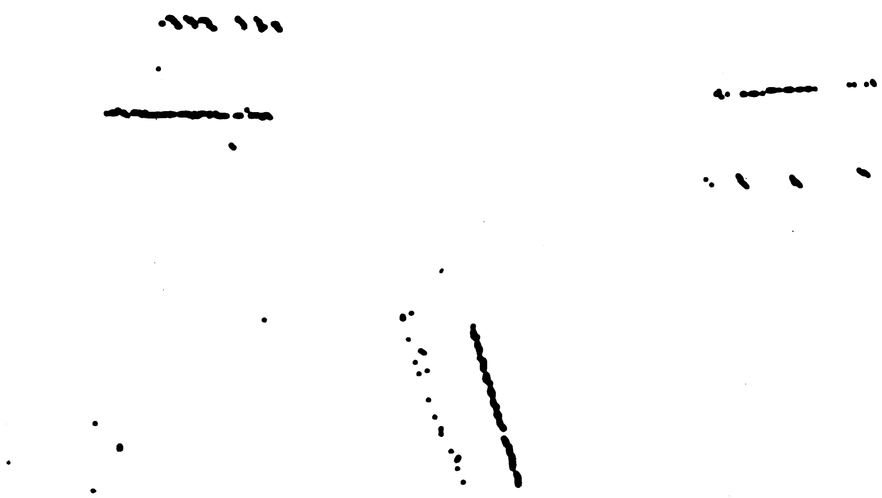
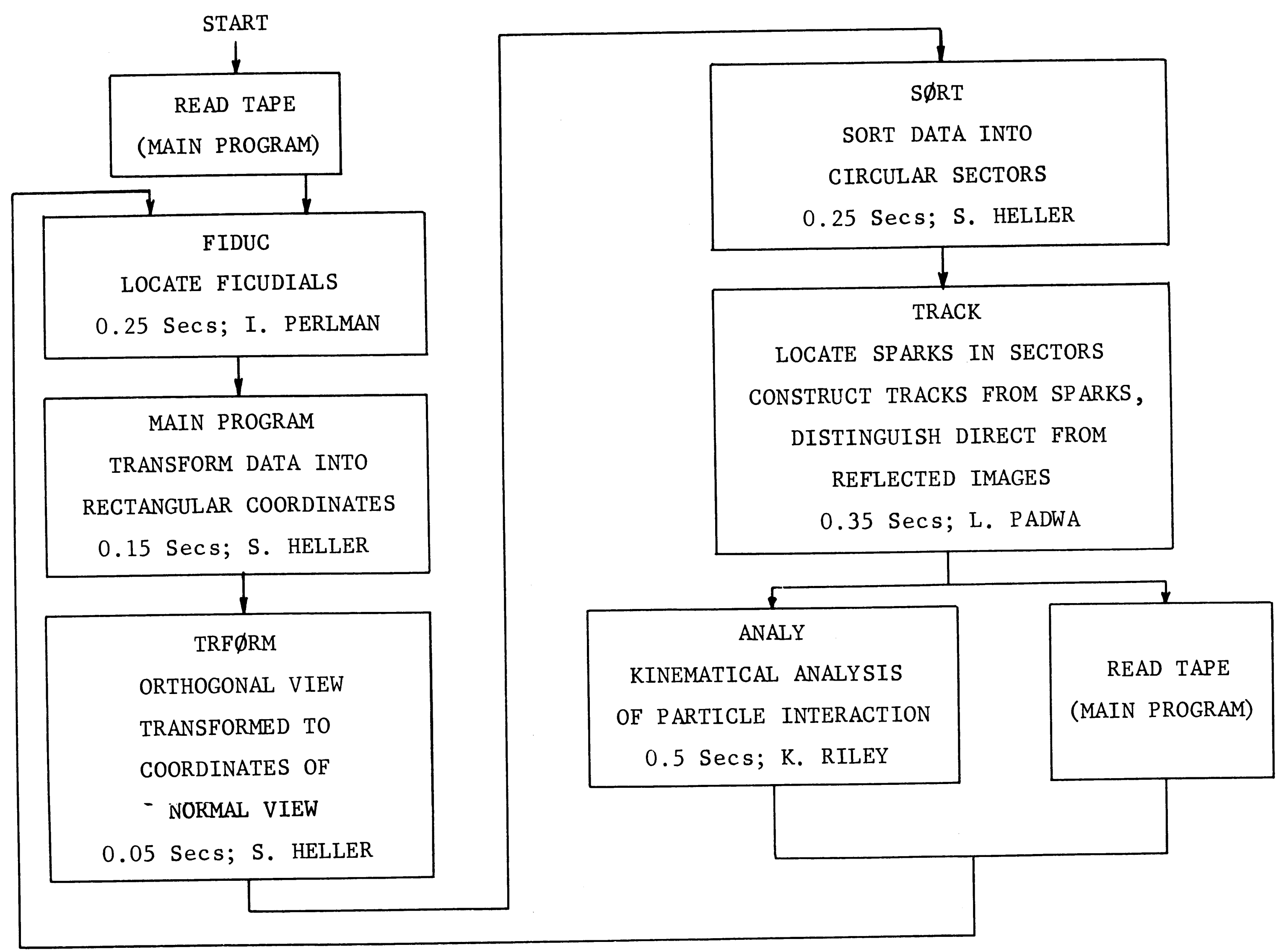


Figure 13


START
READ TAPE
(MAIN PROGRAM)
FIDUC
LOCATE FICUDIALS
0.25 Secs; I. PERLMAN
MAIN PROGRAM
TRANSFORM DATA INTO
RECTANGULAR COORDINATES
0.15 Secs; S. HELLER
TRFØRM
ORTHOGONAL VIEW
TRANSFORMED TO
COORDINATES OF
NORMAL VIEW
0.05 Secs; S. HELLER
SØRT
SORT DATA INTO
CIRCULAR SECTORS
0.25 Secs; S. HELLER
TRACK
LOCATE SPARKS IN SECTORS
CONSTRUCT TRACKS FROM SPARKS,
DISTINGUISH DIRECT FROM
REFLECTED IMAGES
0.35 Secs; L. PADWA
ANALY
KINEMATICAL ANALYSIS
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0.5 Secs; K. RILEY
READ TAPE
(MAIN PROGRAM)

Figure 14

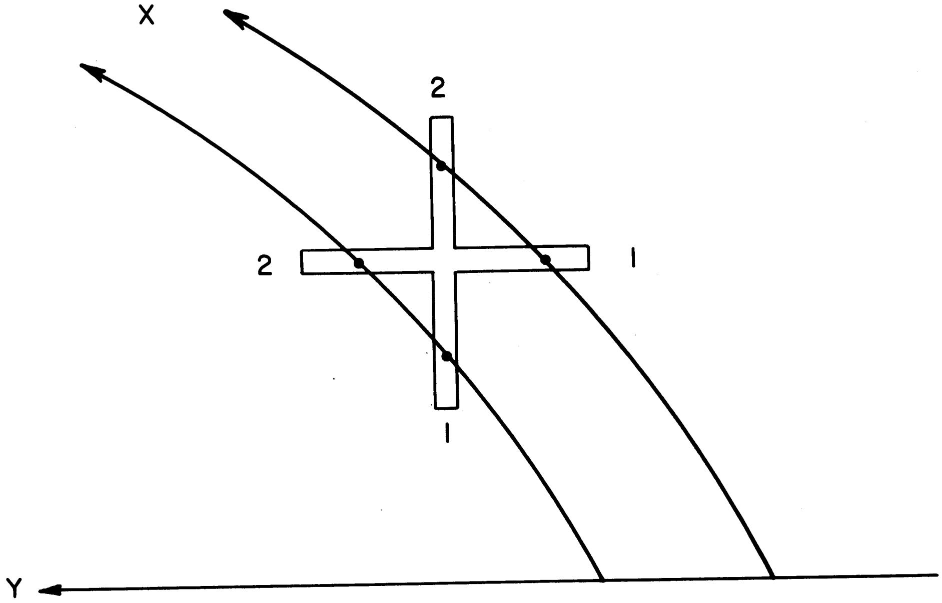


Figure 15

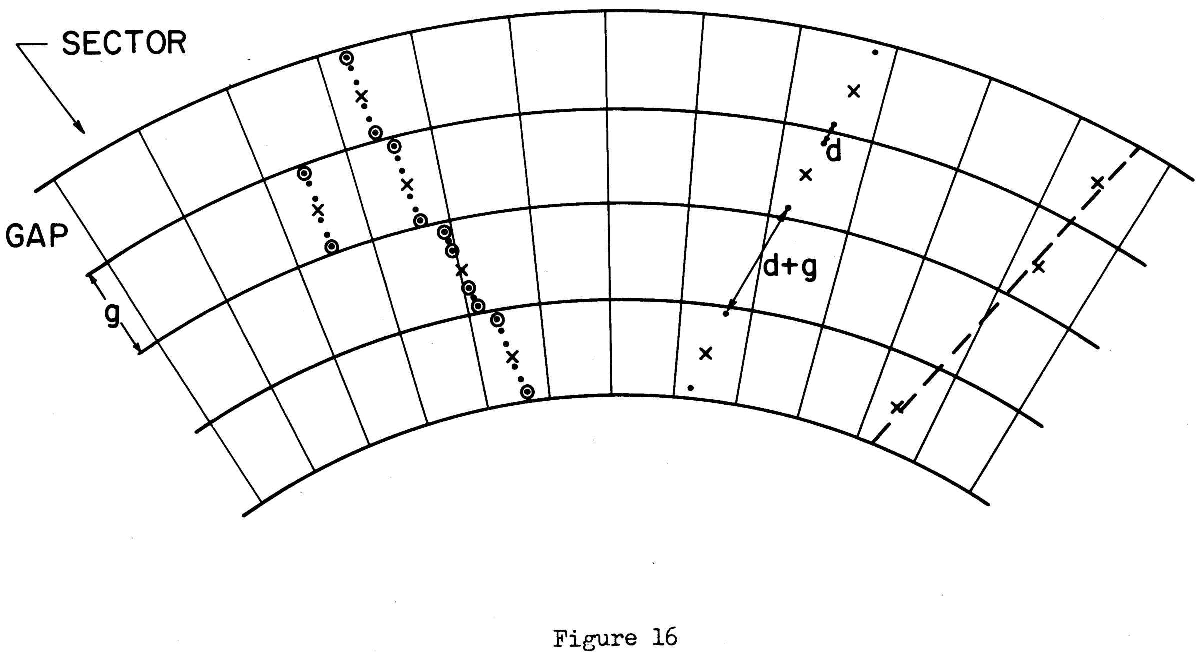


Figure 16

## DISCUSSION

BLOCH: We were wondering whether such a device could be used for bubble chamber work where the precision requirements are much greater. Could you repeat the parameters of your wheel and especially what is the precision of alignment of the microscope objectives. Do you have any trouble due to centrifugal forces ?

BAKER: The rotating disk contains 16 microscope objectives mounted on a circle of 14.5 cm radius. Focusing and radial alignment tests were made with the disk at operating speed. Radial alignment was made possible by mounting the objectives eccentrically in carriers which could be rotated in their mounting holes in the disk. With 75$\mu$ eccentricity in the carriers, alignment was possible to $\pm$ 1.5$\mu$. The force on the objectives is less than twice gravity.

We are using an X grating with 17$\mu$ pitch. Earlier tests with a larger pitch grating gave essentially 100% modulation.

LEBOY: Could you speed up the measuring process by doing the orthogonal scan on a successive view instead of going back and forth on the film transport ? You have to measure the fiducials for each scan anyway.

BAKER: Yes, but this requires some sort of memory of which frame is where.

LEBOY: You put it on tape anyway.

BAKER: Then you would have to sense the frame number at the platens.