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ABSTRACT

The performance of the Spiral Reader measuring machine is discussed and the device is compared with other machines that measure bubble chamber film. The methods used to filter out tracks from the measured data are described.

REMARKS ON THE USE OF THE SPIRAL READER

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I. INTRODUCTION

I was asked to talk to you today about the Spiral Reader measuring machine, and to inform you about its capabilities and its progress, so as to aid those of you who are trying to decide upon future plans for bubble-chamber analysis at your institution. The analysis of bubble-chamber film is generally divided into at least three steps: first, the scanning of the film--locating and recording the events of interest; second, the measuring of the events--accurately measuring a few points in two or three views for each track of the event; and last, a highly computerized analysis of these measurements. In most experiments, the measurement stage has been the bottleneck; that is, this stage has limited the number of events processed, and therefore is the costliest stage in processing an event. Understandably, there has long been a motivation to automate the measuring process.

"Conventional" measuring machines, which are digitized projection microscopes (called Franckensteins at Berkeley), measure from 3 to 15 events per hour, depending upon many factors such as the degree of automation and upon the type of event being measured. A number of devices have been or are being developed which can increase this speed. With each of these devices the operator does less of the work and a sophisticated computer program does more. Development of the Spiral Reader, the first of these devices, was started back in 1958, though only in the last two years it has become a successful measuring machine. It has been measuring at the rate of about 100 events/h and has measured more than 350 000 events this year. Another measuring device, also developed at the Lawrence Radiation Laboratory at Berkeley under the direction of Professor Luis Alvarez, is the SMP (scanning-measuring projector), now being used at many laboratories. Though the SMP has proved to be a useful measuring device, its measuring speeds are not comparable with those of the Spiral Reader; the Lawrence Radiation Laboratory has released all of its SMP's and is building more Spiral Readers. Other measuring machines that may be capable of high-speed measurement are the Flying-Spot Digitizer (FSD), sometimes called the Huff-Powell Device (HPD), which has been built at a number of laboratories, and PEPR, about which you will hear more today from Irwin Pless. These devices have one basic thing in common, in contrast to the Spiral Reader. Whereas the Spiral Reader is designed specifically to measure bubble-chamber film, the other measuring machines are more general purpose devices. They can be used to scan or measure other things and in particular, they provide the information with which one could automatically scan bubble-chamber film.

The development of automatic scanning is an intriguing problem which, I'm sure, will be solved some day. But since people are exceedingly good at identifying complex patterns in a short time, I don't expect anyone to develop an automatic scanning system that will compete economically with a human scanner in the next few years. If one is interested in these devices as tools in analyzing bubble-chamber film in the next few years, I believe that they should be compared only as measuring devices.

II. DESCRIPTION OF THE SPIRAL READER

The operator of the Spiral Reader sits at a table as shown in Figs. 1 and 2. He looks at a projected image of the event on the table (Fig. 3) and a magnified image on a TV screen (Fig. 4). His essential task is to center the vertex of the event on the cross-hair on the TV screen and press a button, setting in motion a process that digitizes the event in about 3 sec. Many operations are done automatically under the control of a small computer--a PDP-4 that can be seen in Fig. 1. The six fiducials (two in each view) are measured automatically. The views are changed automatically and the stage is moved automatically to position the film at the approximate location where the scanner recorded the vertex, this information having been read into the PDP-4 on magnetic tape. The film is automatically advanced from frame to frame so that on a routine event all the operator needs to do is to center the vertex.

In the measurement process, an optical-mechanical system in effect moves a narrow, radially oriented slit so that its center follows a spiral pattern as shown in Fig. 5. A point is digitized at every dark spot on the film that cuts out more than about 20 percent of the light passing through the slit. Since the slit is about 10 bubble-diameters long, single bubbles are never digitized but tracks that radiate out from the vertex are almost always digitized. This procedure provides a preliminary filtering of the data in which about 500 to 1000 points are digitized in each view, far less than one gets from less-specialized machines.

The accuracy of the measurements made with the Spiral Reader is comparable with the accuracy of Franckenstein measurements of the same length of track. The length of measured track is limited in two ways on the Spiral Reader. First, because the slit is radial, a track is not digitized after it has turned through from 20 to 40 deg of arc. This imposes a negligible limitation on the accuracy of momentum determination. Second, the present Spiral Reader measures only 40 cm of track and for high-momentum tracks on a large chamber, this significantly limits the precision of momentum determination. The second Spiral Reader, which is almost completed, will measure up to 80 cm of track. As is the case for all machines that measure in the image plane, the Spiral Reader has optical distortions that must be corrected for. This calibration is especially important for the Spiral Reader, because it has two systems of measurement that need to be intercalibrated. Whereas most points on the tracks are measured in a polar-coordinate system that measures the slit position at the time to digitization, the vertex position, the fiducials, and the end points of stopping-tracks are measured with an X-Y stage. Most distortions are understood, and those not yet understood are comparable in magnitude with the distortions in the 72-in. bubble chamber. Since the distortions are quite repeatable, we expect to do a better job of correcting for them in the near future.

III. FILTERING

Often, when I describe the Spiral Reader system and I arrive at this point in the description, my listener thinks he understands the system, except perhaps for a few programming details. This attitude exemplifies the gross underestimation that is often made of the magnitude of the task of filtering the raw data--the job of extracting, from some 1000 points in each view, those points that are on tracks and then matching up these tracks. The development of such a program is not a straightforward task but requires considerable experimentation and many compromises in an effort to perform operations with a logical code that a human would perform on a rather subjective basis.

Everyone who has developed such programs has adopted a procedure of first using a program that relies on some human guidance, with the intention of reducing this guidance as the program becomes more sophisticated. In the case of the Spiral Reader this guidance took the form of measuring a point (a so-called "crutch point") at the end of each track. This crutch point served to make filtering easier and to provide information with which to match the track images in the different views. About 18 months ago we got away from this method and now we measure crutch points on only about 10 to 20 percent of the tracks--those that are short, stopping, or obscured in some way. So the Spiral Reader program "POOH" (as in "Winnie the POOH") operates on a "minimum-guidance" system: it is told only the position of the vertex and the number of tracks to be found.

In some other systems (such as the HPD), guidance has taken the form of predigitization on specially built machines. Such a process is time-consuming, and in some cases comparable in speed with conventional Franckenstein measuring speeds. As long as a system uses such predigitizing methods, the speed of the final measuring device is almost irrelevant. Not until a system can eliminate such a predigitization mode can it compete with the Spiral Reader in efficient use of measuring personnel. This does not mean that minimum guidance is needed for efficient operation. Indeed, the Spiral Reader development is moving toward more guidance rather than less. A system has been developed for measuring crutch points rapidly during the 3-sec dead time during which the data are being digitized.

Figure 6 shows a four-prong event that was measured on the Spiral Reader. Note the potential problems that the program may have in filtering this event. Will the program have trouble with the short track? Will it discriminate against the nearby dark track that does not belong with the event? Will the "coat hanger" that goes along the X-axis through the vertex be called a track? Will the three forward-going tracks be distinguished? Figure 7 shows the points that the Spiral Reader digitized for this event in an $R - \theta$ coordinate system, with the radius R plotted on the ordinate and the azimuth θ plotted along the abscissa. The zero for θ is to the left (what would normally be called $\theta = 180°$) and θ increases in the clock-wise direction. In this coordinate system, tracks through the vertex appear as straight lines whose X-intercept is a measure of the initial direction of the track and whose slope is a measure of the track's curvature; the amount of "hook" at the bottom of the plot measures the distance the track came from the vertex, or more precisely, the distance from the position where the operator centered the stage. In Fig. 7, one can easily identify the beam track, the short track, and the group of outgoing tracks. The cross at the end of the short track indicates a crutch point that was measured by the operator.

Without this crutch point POOH would not have found the short track because POOH requires at least seven points on a track. Such a requirement is necessary to avoid finding a flood of spurious tracks. The nearby dark track shows up on Fig. 7 as two very curved sets of points. The program has no trouble in discriminating against these points; they deviate far too much from a straight line to be called a good track. One can appreciate that the precise measurement of the vertex position is essential to this method of filtering. Often, however, such unwanted tracks are not discriminated against and POOH finds spurious tracks. In this picture the "coat-hanger" was found as a spurious track. Indeed, in some experiments with a high density of tracks, an average of more than one spurious track per view is found. Most of these spurious tracks are of poor quality and could be eliminated by using stricter acceptance criteria for tracks. But in this business, one must be aware of the fact that a four-prong, for example, has 15 track images to be found, and missing any one of them will cause the event to fail. So if the program misses 5 percent of the tracks, it fails more than one-half of the events. One cannot afford to apply very strict criteria. In order to eliminate spurious tracks, POOH uses a MATCH routine that has the job of not only matching those track images that are correct, but of eliminating the wrong ones. This is an approach that I believe any minimum-guidance system will have to adopt. It is hopeless to expect to eliminate spurious tracks adequately on the basis of the information available in one view alone. There is a large class of spurious-track images that are best eliminated by relying upon inter-view correlations rather than by applying strict acceptance criteria in one view.

Most of the difficult filtering problems arise from interferences between tracks, either interferences with extraneous tracks such as nearby beam tracks, or between two tracks in the same event. The group of forward-going tracks in this event presents such a problem. Figure 8 is a display of this region that is magnified in the θ direction by a factor of 4 and left at the same magnification in R. In this figure the points found by POOH to be on tracks are intensified. In this case, one can see that POOH succeeded in untangling the three tracks. Sometimes, however, it doesn't do so well. Figure 9 shows a display of the same tracks in a different view. In this case only two of the tracks were found. POOH finds tracks by looking first near the origin and then tracking out. If two tracks are not distinguishable for the first one-fifth of the way (8 cm), POOH will not find them without help. Technically, this failure we call an operator failure, because the operators are instructed to put crutch points on the ends of both tracks if they are coincident for such a long distance. But, clearly the information is there--a trained person can see the three tracks easily. A more sophisticated filter program could find all of the tracks, and we are continually making POOH more sophisticated and more reliable. In the past year, failure rates in POOH have, in most experiments, decreased by a factor of 2 or 3, so that on good film the failure rate in POOH on two prongs is about 3 percent and on four prongs is about 8 percent. When tracks are faint or when the beam track density is great, the failure rate may be much larger than this.

One more feature of the Spiral Reader deserves mention. When the Spiral Reader digitizes a point, it records not only the radius and azimuth of the point, but also its pulse height. This pulse height is a fairly reliable measure of the fraction of the light cut out by the track and is useful ionization information. By averaging the pulse-height values for the first 8 cm of track one gets a number that gives about 6 standard deviations of discrimination between a minimum-ionizing track and a black one. Such information is almost essential for some large experiments that are made possible with the Spiral Reader. I have measurements of more than 100 000 K^-p two-prongs, about half of which are kinematically ambiguous. The Spiral Reader ionization measurements make it unnecessary to go back to the scanning table to look at these 50 000 ambiguous events.

IV.. CONCLUSION

One Spiral Reader is in operation. In a couple of months the second one is due to go into operation at Berkeley. Construction of another has been started at SLAC. CERN intends to build one, and a number of other laboratories are seriously considering building them. I am told that it costs $200 000 to build a Spiral Reader, including the PDP-4 computer. This cost is small compared with the operating budget of a laboratory that can process the 1 or 2 thousand events per day that the Spiral Reader can measure, and in the long run the accumulated operating costs of any of these machines are far greater than the initial investment. At present, the operating costs of scanning and measuring with the Spiral Reader at Berkeley amount to about 30 cents per event. The cost is about equally divided between scanning, measuring, and filtering on the CDC 6600. If the filtering were done on an IBM 7094, the filtering cost would be about 2 1/2 times greater, and the cost per event would be about 45 cents, which is still better than the approximately \$1 per event that measuring on the Franckensteins costs.

At present the Spiral Reader is the only fast measuring machine in production that does not require time-consuming predigitization. In the next few years other machines will join the Spiral Reader in this category. I would be the last one to count out other systems because they are not yet performing adequately, for I well remember the time only 2 1/2 years ago when the Spiral Reader was held in such low esteem that those people who made surverys of the field of semi-automatic measuring machines neglected even to mention the Spiral Reader. I see no reason why PEPR, for example, cannot eventually be at least as good a machine as the Spiral Reader, and if PEPR were put on-line to a fast-enough computer, it could ultimately be faster than the Spiral Reader. However, for making economical measurements of bubble-chamber film, I expect that nothing will surpass the Spiral Reader in the next 5 years.

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FIGURE CAPTIONS

Fig. 1. Layout of the Spiral Reader.

Fig. 2. Table at which the operator sits.

Fig. 3. Projected image of a bubble-chamber event as seen on the table by the operator. The circle corresponds to an 8-cm radius in the bubble chamber.

Fig. 4. Magnified image of the vertex as seen by the operator.

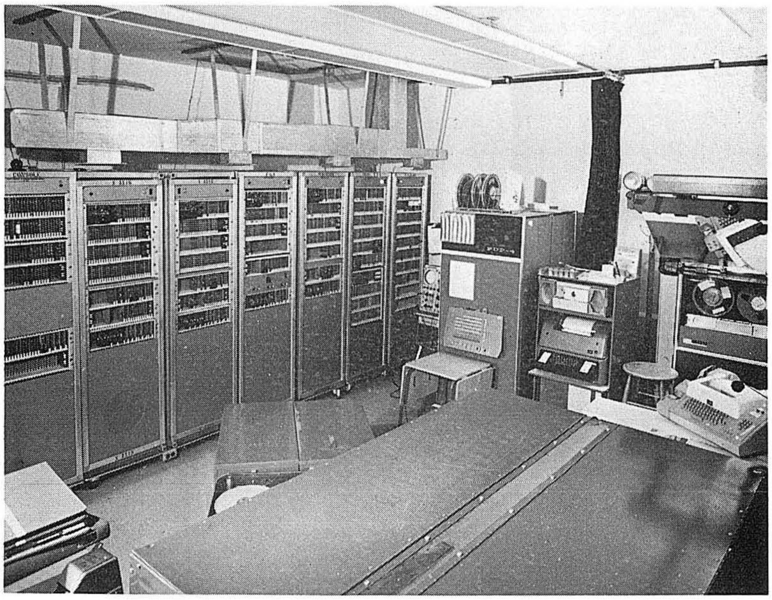
Fig. 5. Spiral pattern swept out by the slit of the Spiral Reader.

Fig. 6. Four-prong event.

Fig. 7. $R - \theta$ plot of the data that was digitized for the four-prong in Fig. 6.

Fig. 8. Magnified plot of the left-hand fourth of Fig. 7 with the points found to be on tracks intensified.

Fig. 9. Plot of the same type as Fig. 8 for a different view of the same event.



BBH 674-115

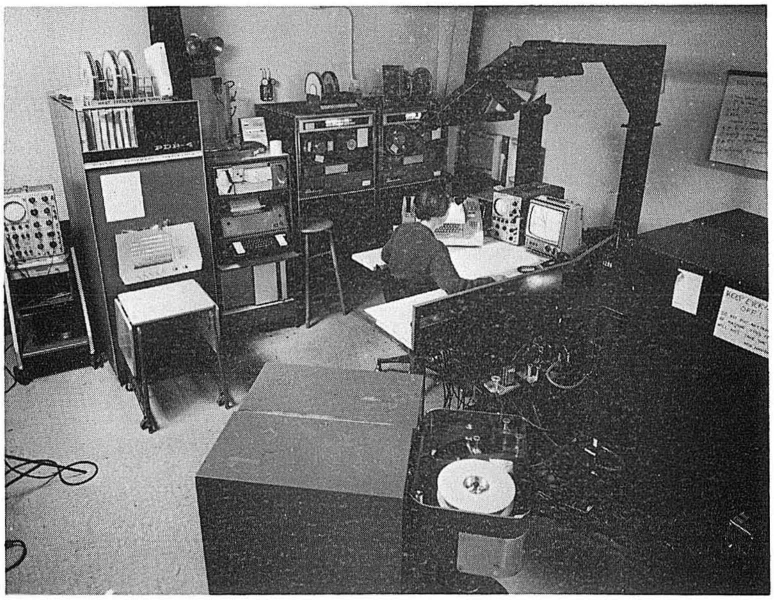


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Fig. 1a and b

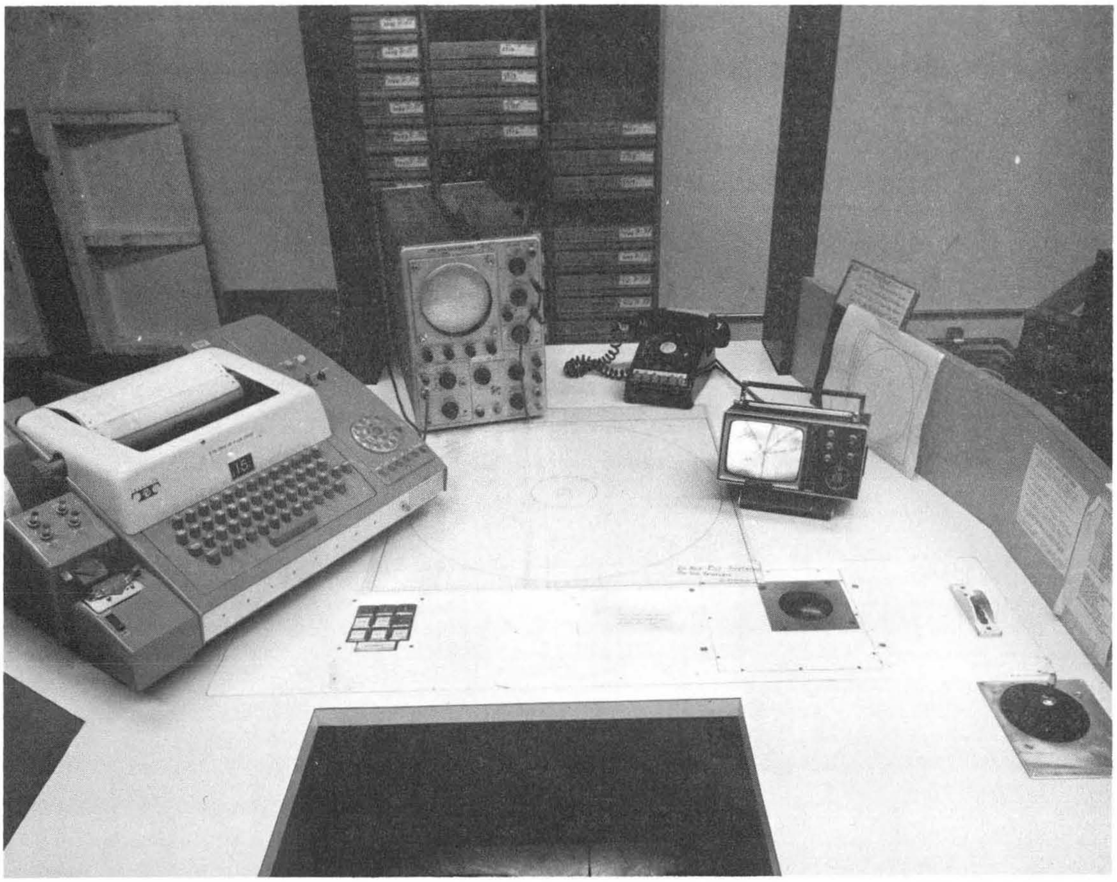

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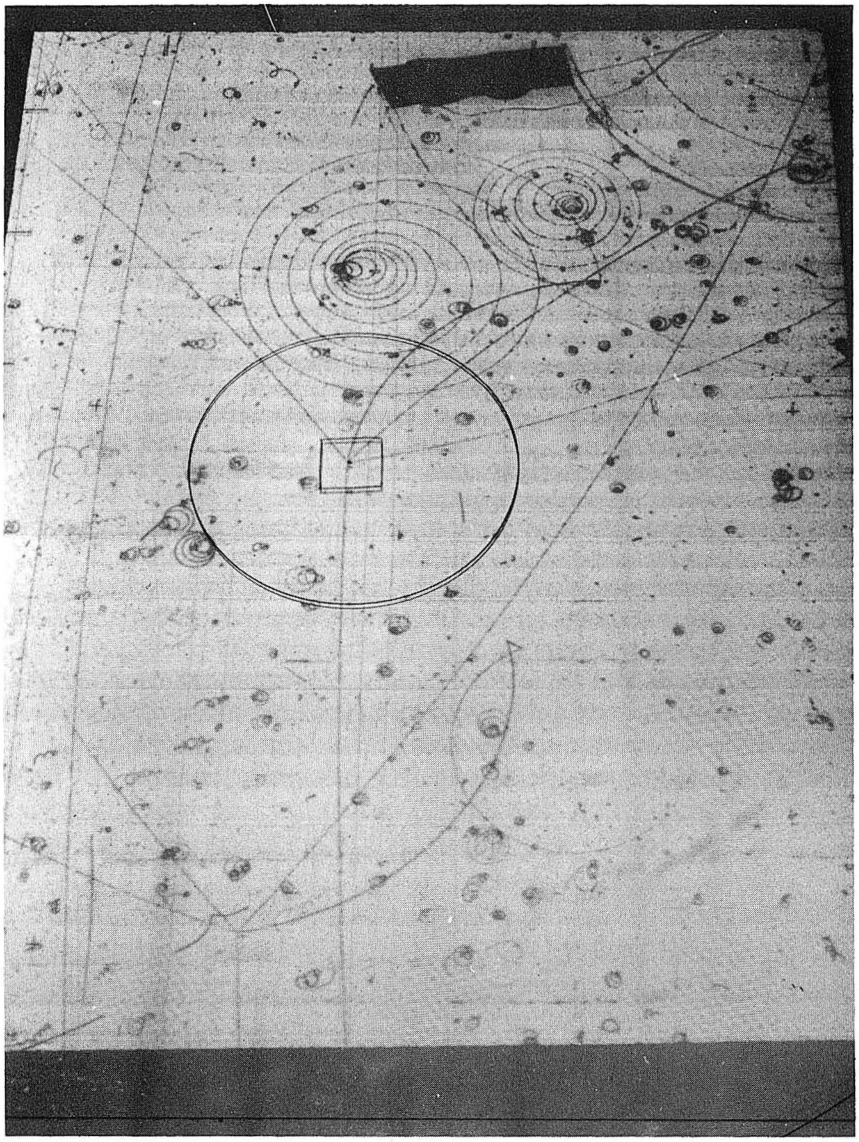
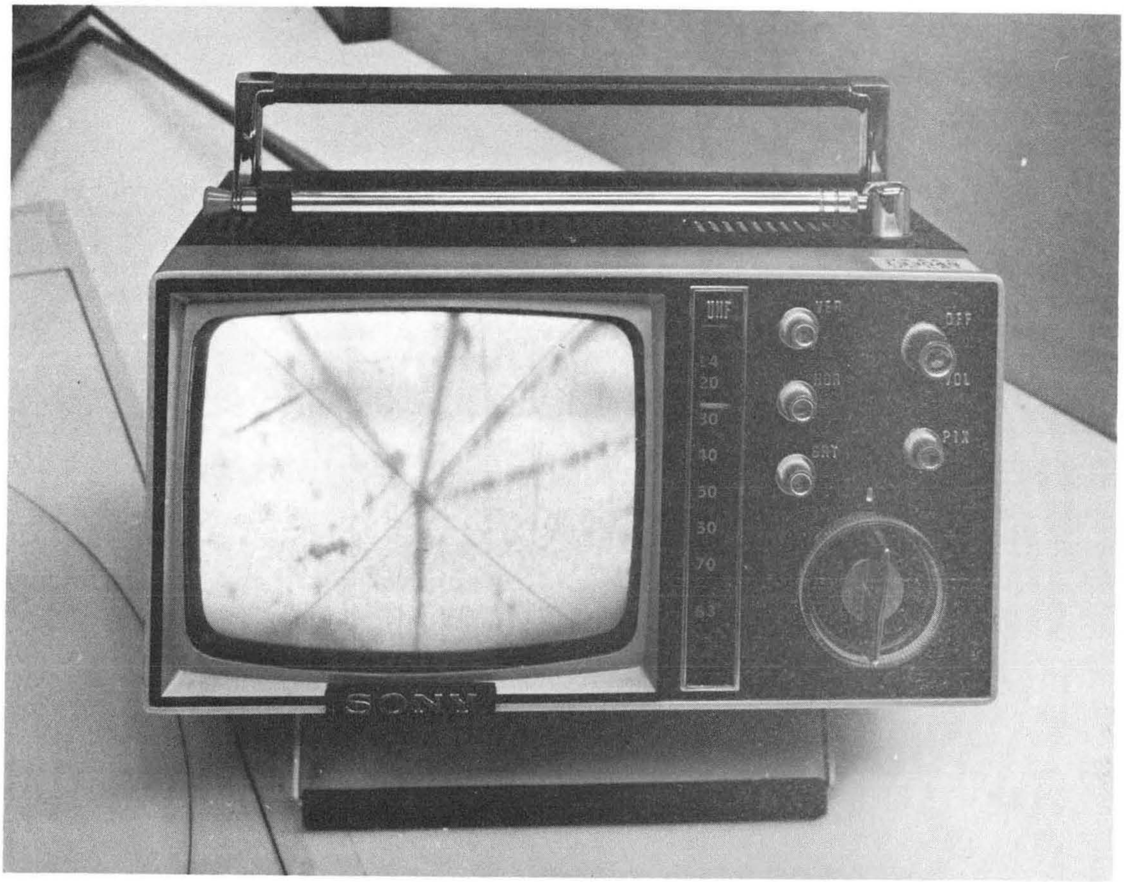
Fig. 2



BBH 674-117

Fig. 3



BBH 674-119

Fig. 4

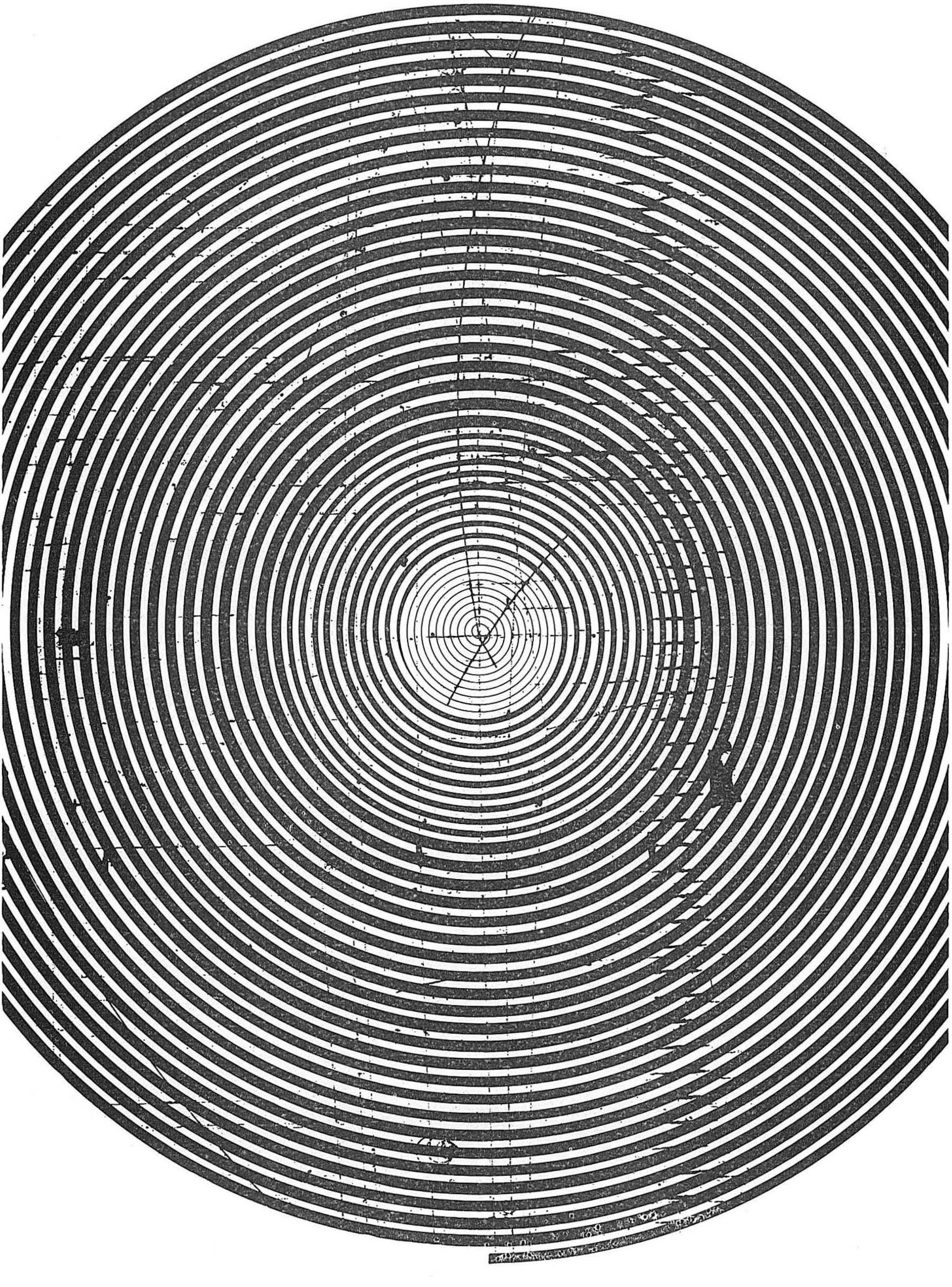
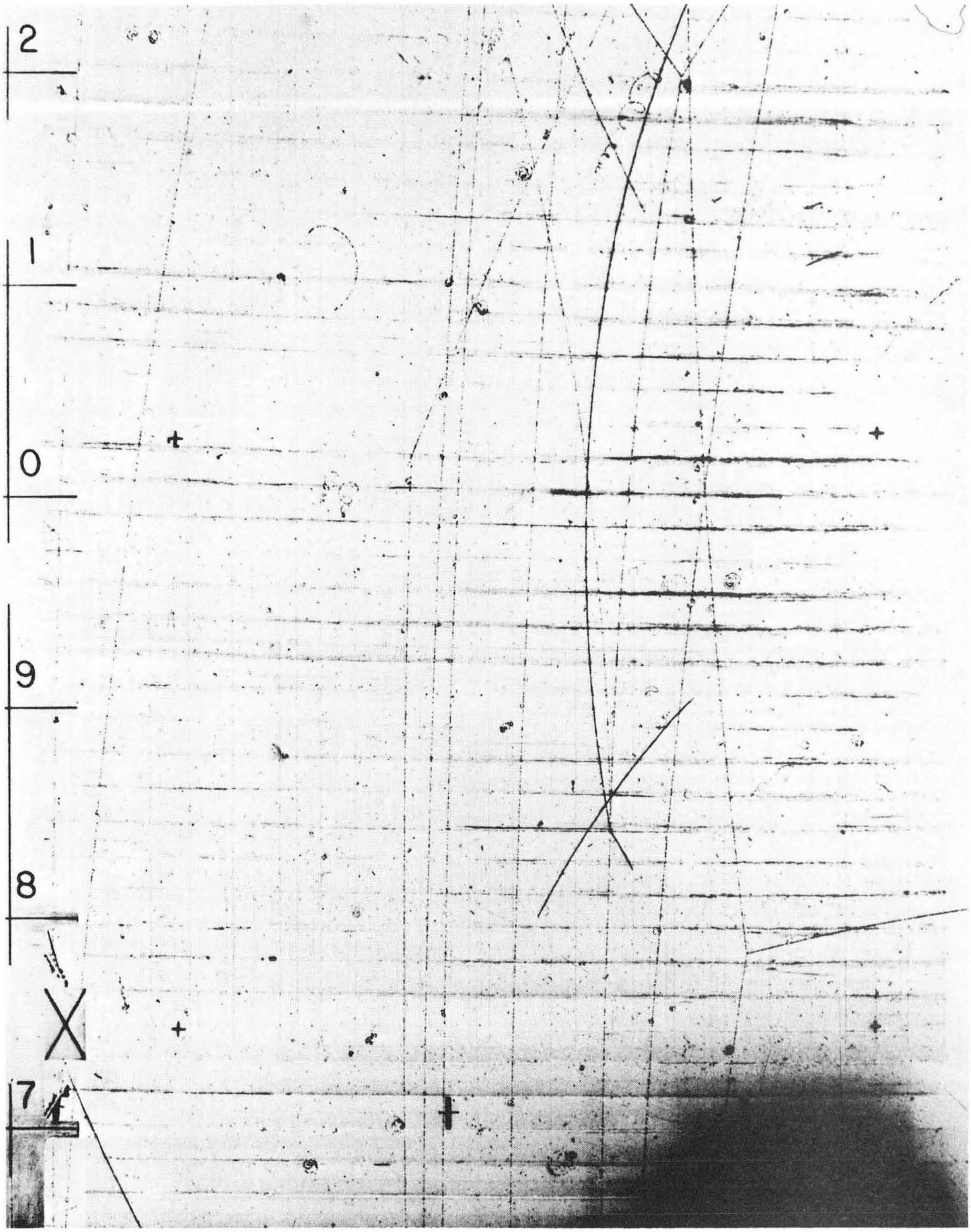


Fig. 5



BBH 674-114

Fig. 6

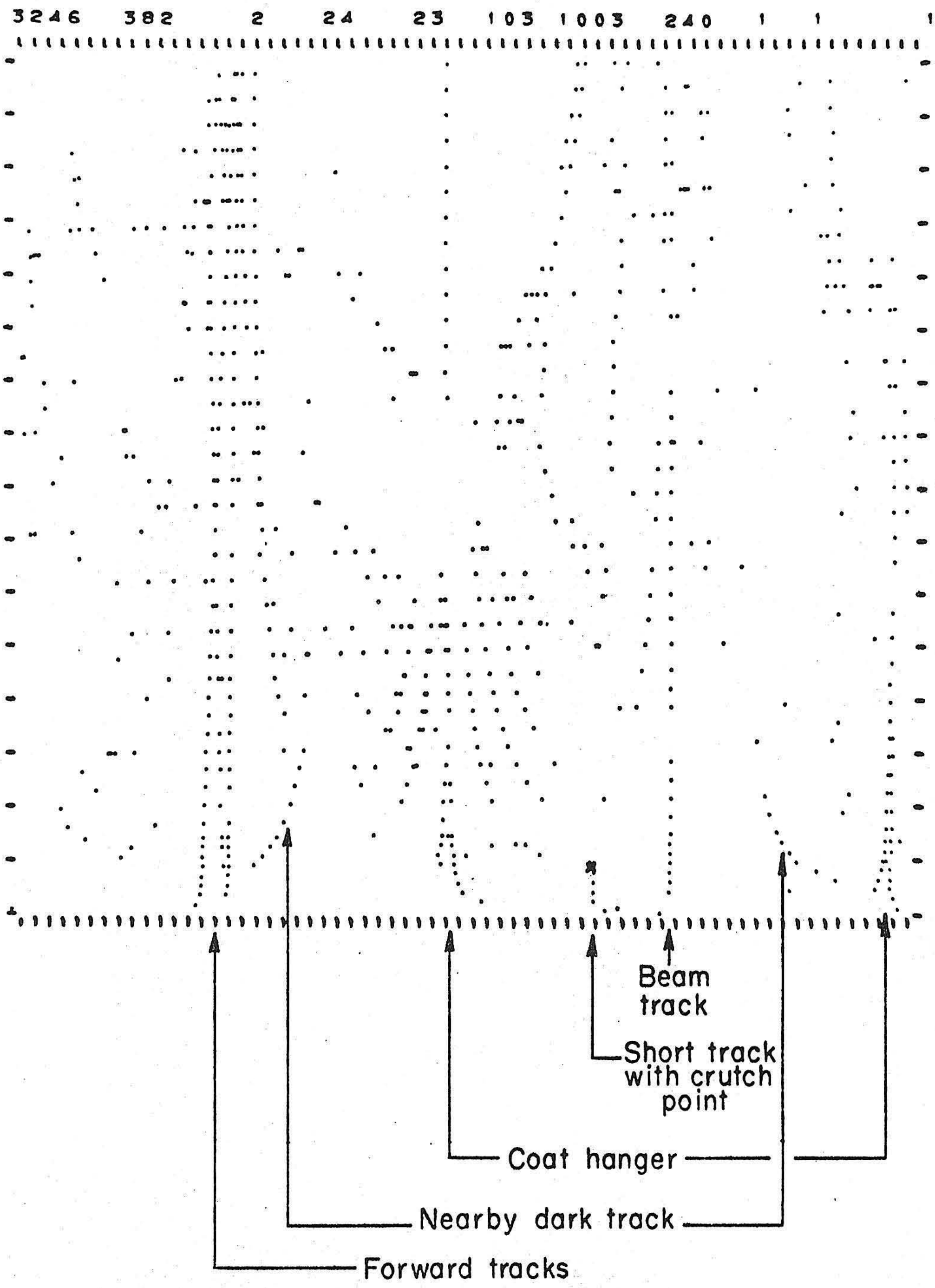


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Fig. 7

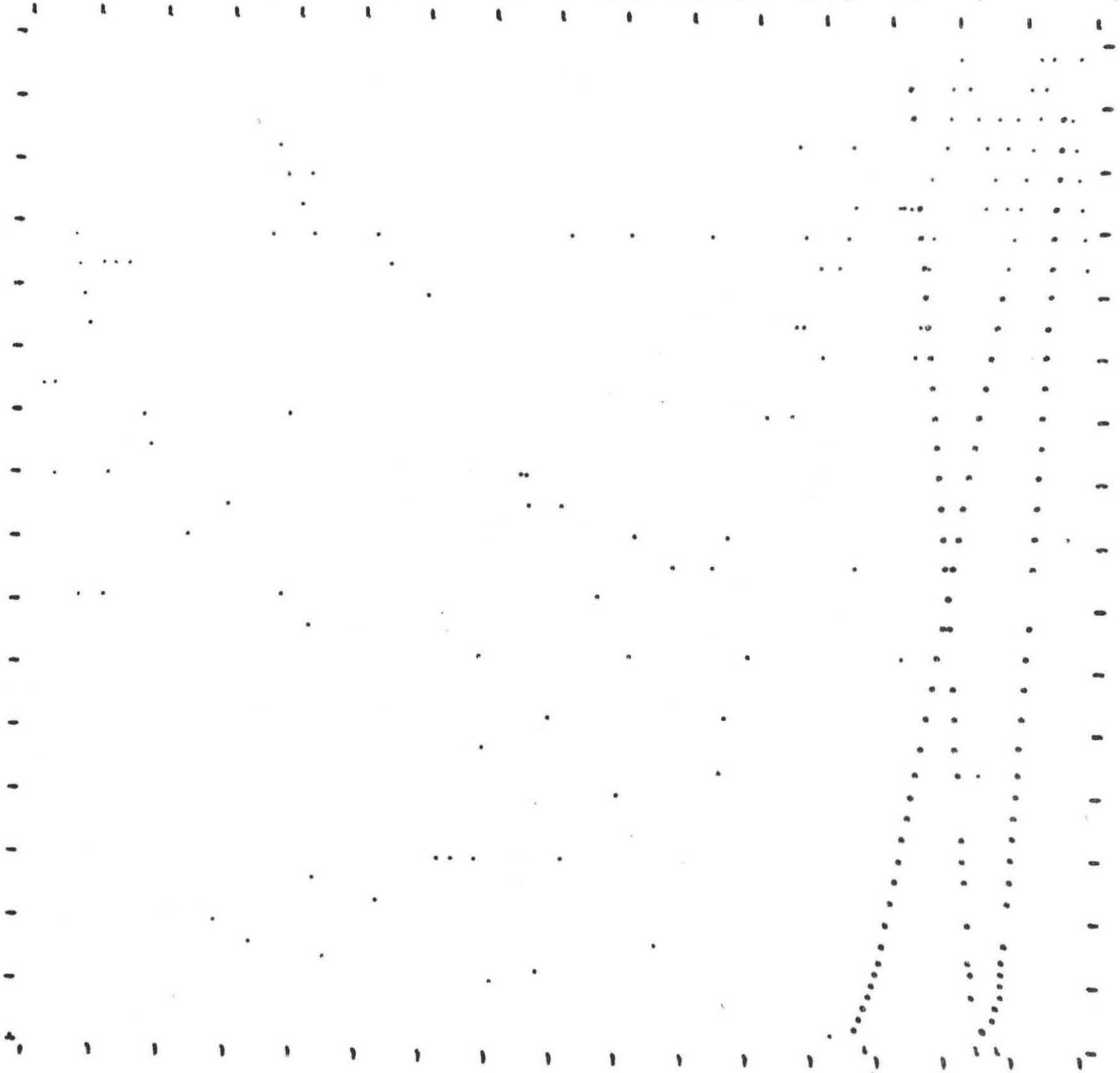

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Fig. 8

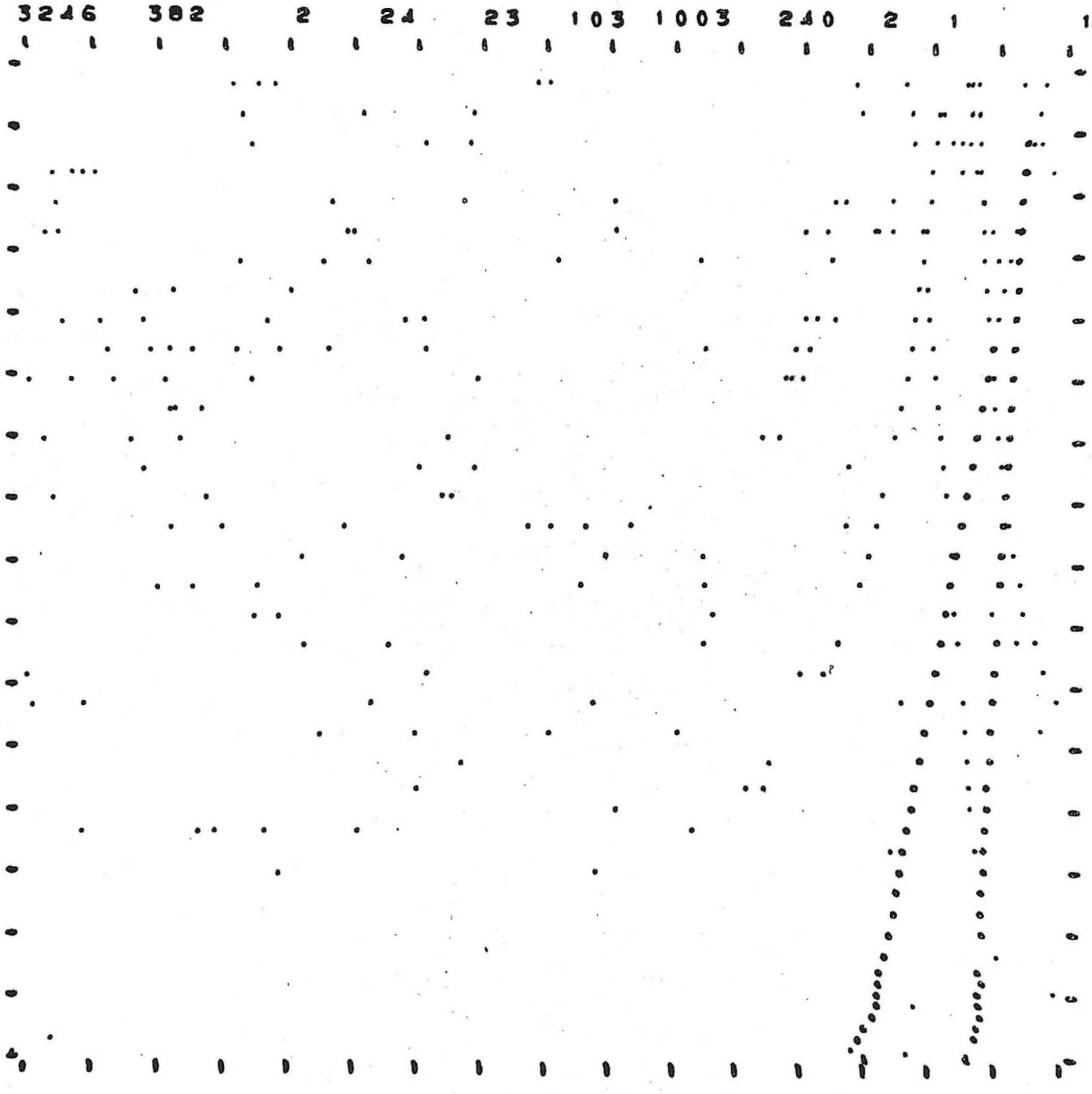

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Fig. 9