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USE OF INTERACTING COMPUTING AT LAWRENCE BERKELEY LABORATORY

John S. Colonias

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August 1971

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USE OF INTERACTING COMPUTING AT LAWRENCE BERKELEY LABORATORY

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Berkeley, California

August 1971

ABSTRACT

During the past few years there has been a considerable amount of hardware and software development in the area of graphic display interaction. This relatively new mode of operation has received considerable attention as evidenced by the fact that most major computing installations are either seriously investigating this area or presently have access to such devices for scientific computation.

Graphic display interaction radically departs from the conventional mode of batch processing and it offers very attractive features particularly suited to research type calculations. In this mode, the user is no longer a passive observer tacitly accepting the idiosyncrasies of his computational device, but rather a dynamic member of the computational loop directing the progress of his problem solution at his descretion.

This paper describes the Laboratory's contributions in this area and the progress made in applying graphic and interacting techniques to the solution of problems in nuclear physics.

At first, we describe the existing computer environment, followed by the software developed to implement the graphic display and interacting mode of operation, and finally some of the prominent inter-

acting programs are described.

The first program, TRANSPORT, allows the experimenter to design beam transport systems; that is, the transformation that a beam of charged particles undergoes as it passes a series of magnets and lenses. The desirability and importance of graphic displays is demonstrated and the interacting process, as applied to the solution of this type of problem is shown to be an indispensable tool in the better understanding of the behavior of beam transport systems.

The second program, TRIM, is used to design magnets for particle accelerators. Here, also, the graphic displays play a very important role in understanding the behavior of magnetic fields and allows the experimenter to investigate various magnet models, analyze the resulting magnetic fields, alter their geometries, and, in general, investigate alternative designs to arrive at the desired magnetic field.

INTRODUCTION

The introduction of graphic display terminals to the solution of problems relating to physics, has added one more degree of freedom in the contemporary nuclear physics laboratory. The importance of this device as well as the resulting interacting mode of operation, has not been emphasized well, probably, because its wide spread use has been restricted, due to the large capital investment involved and the prerequisite of a large computer environment.

In this paper, we describe our experiences with interacting computing, its applications to problems in physics, and we describe some experimental set-ups which provided invaluable information with a minimum capital cost.

The examples described in this paper do not exhaust by all means the applications of interactive or graphic devices, however, they indicate the capabilities that the computer graphics offer.

Computer Environment

Presently, there are two CDC 6600 and one CDC 7600 computer systems at the Lawrence Berkeley Laboratory in Berkeley running under the BKY and SCOPE operating systems. The graphic display environment consists of five model 250 display consoles attached to the CDC 6600 computers via a controller and a microfilm recorder for on-line or off-line use.

For interacting and remote processing purposes, the Laboratory has implemented a system which allows a large number of user to utilize the computer facilities from remote locations. Approximately 130 teletype terminals have been implemented thus far in this manner. Also a Remote

Batch Job entry system is provided allowing one to submit from a remote terminal, a punched card deck as a batch job on the central computer. Upon completion of the batch job on the central computer the printed output may be directed to a remote terminal for printing. Some terminals may also have the ability to send and receive queued files for use or other peripherals such as plotters, card punches, and magnetic tapes.

The Remote Batch Job Entry System consists of a control computer which performs the tasks of connecting remote lines to the central computing facility. This remote batch control computer determines the type of connection and the type of terminal. The following terminals may be connected on a dial-up facility

CDC	200 UT	
UNIVAC	1004	
GE	415	Via evulation of UNIVAC 1004 type terminal
HP	2116	
IBM	1130	
IBM	360/20/28/30	
UNIVAC	9200/9300	
XDS	940	

It is planned that by July 1972 dial up support will be given for IBM Multi-Leaving type terminals as well as IBM 2780.

For semi-permanent data storage, there is an IBM data cell and an IBM 1360 photodigital storage system (the chipstore). Both systems are attached to the CDC 6600's through the appropriate hardware. The IBM 1360 is capable of storing about a third of a trillion bits of data which is equivalent to almost 3000 full mangetic tapes. Fig. 1 shows a generalized block diagram of the system, showing only the remote access and graphic hardware.

Software

To perform interacting and remote functions the following software packages have been developed:

a. Berkeley Remote Facility (BRF)

b. Peoples Time Sharing System (PTSS)

c. Graphic Display Routines

A brief synopsis of these systems follows:

1. Berkeley Remote Facility (BRF)[1]

This software package allows the remote user to perform the following functions:

a. Test editing (EDIT). This facility provides for entering text on line into a buffer, and to subsequently examine and modify part or all of that text. An example is shown in Fig. 2.

b. Calculator (COMUT). This subsystem evaluates a one line arithmetic replacement statement. The ability to use standard FORTRAN arithmetic functions coupled with an interactive capability allows this subsystem to be used as a sophisticated desk calculator. An example is shown in Fig. 3.

c. ↑XEQ. The ↑XEQ subsystem consists of a compiler for a subset of FORTRAN IV and an interpretive evaluation program. Its function is to compile and execute programs entered via the test editing (↑EDIT) subsystem. The maximum number of statements is 70. (See Fig. 1).

d. Miscellaneous. There are various file manipulation subsystems allowing the storing, loading, retrieving of files from

the Data Cell or the Photodigital storage device, or to perform remote batch or interactive job processing. (Some of these features are shown in Fig. 2).

2. Peoples Time Sharing System (PTSS)[2]

PTSS is a general purpose system for entering, running and debugging CDC 6600 program from a remote console. It consists of two principal parts - a text editor, which allows the user to create, delete or modify programs, and an interactive debugger, which helps the user to debug his program by allowing him to examine core, examine the compilation listing examine the central registers etc. When an error occurs while the user is interacting (either editing or debugging) PTSS occupies less than 6K of central memory. The source and binary programs are kept on the disk and do not require any core. The difference between BRF and PTSS is that the latter speeds up the debugging of small or medium size programs by providing turn around time on the order of a few minutes.

3. Graphic Display Package

The CDC 252 graphic display consoles provide instantaneous visual readout of selected portions of the computer memory in the form of alphanumeric symbols (characters, symbols, numbers, etc.), vectors (lines), or points (dots).

Incoming data are displayed directly on the display console 19 inch CRT within a 1024 by 1024 horizontal and vertical position raster. The use of a light pen allows the identification of any part of the displayed data as well as editing the memory contents. The addition of a function keyboard simplifies programming and enables the operator to

interrupt and sort information to the computer. A teletype is also attached, to provide for entering of data or external program interrupts.

The software package prepared provides for the utilization of the light pen, for programmable interrupts, use of teletype to enter of extract data, and for performing various plotting functions.

The BRF and the PTTS systems may also utilize the graphic displays to output files of jobs which have been run in the ordinary batch mode, or to interact with the user in cases where such interaction deems desirable.

The microfilm recorder is also accessible at any time to record displayed information. This device has the capability of on-line and off-line performance.

Fig. 4 shows a view of the display console and teletype.

Applications

Having established some qualitative and quantitative characteristics of our graphic and interactive computer environment we proceed to describe some of the prominent applications.

No doubt an inexhaustible number of programs may be described to demonstrate the importance of interacting systems and their immediate adaptability to research type calculations. In this paper, we will describe a few applications which we hope will demonstrate the wide range of problems that may be solved in this fashion, and the variety of equipment that may be used.

1. Electron Ring Accelerator Experiment

Since 1968, this laboratory has embarked into a program to investigate the possibility of designing an accelerator, based on the

concept of acceleration of ions by collective effects[3].

To accomplish this and to study means of extracting an electron ring from a compression chamber into an accelerating column, several computational programs were developed, tested and placed in production.

Further computational work lead to a design of a program that permitted tracing particle motion through both the compression and rollout stages, and finally, giving an indication of the ring motion after spill-out, when acceleration in the B field can act to give the ring substantial speed in the axial direction.

Since the experimental work was performed at the Astron injector facility in Livermore, California (some 50 miles away), it was necessary to develop the appropriate mechanisms to operate these programs at the Berkeley computing center and transmit the information to the experimental site at Livermore.

A telephone link was designed, (see Fig. 5) which in its simplest form consisted of two commercially available accoustic couplers, a PDP-8L computer and a Tektronix 611 storage scope.

This link operated successfully, and it allowed the experimenters at Livermore to connect the teletype attached to the PDP-8 directly to the CDC 6600 computer residing in Berkeley. Use of the BRF system allowed uninterrupted communication between experimentalists and computer, transmitting back and forth information through telephone lines. Results were displayed on the Tektronix 611 oscilloscope, while the interaction was performed through the teletype keyboard.

The success of this device lead to a permanent remote facility at Berkeley serving experimenters residing elsewhere. For example, the

Los Alamos Scientific Laboratory operates such a link, allowing them to utilize all the computing power resident at Berkeley.

2. Beam Transport Design

One of the major activities of nuclear research centers is to carry out experiments in low-and high-energy physics. Such experiments necessitate the design of beam transport systems to carry the beam from the device to the experimental area. Although there are many computer programs available to aid the experimenter in his design, they all suffer from generality and lack of convenience. TRACE[4,5] provides a vehicle on which man and machine can cooperatively make up for each other's deficiencies in problem-solving capacity, maximizing at the same time the advantages peculiar to each.

Basically, program TRACE is the outgrowth of program TRANSPORT, originally written in Balgol by Butler et al.), and implemented for various machines by many people in the field. Briefly, program TRACE provides means for describing an injected beam and a magnetic system.

The beam is specified by a six-dimensional ellipsoid. The magnet system includes the following types of beam elements:

1. Drift spaces
2. Bending magnets: with arbitary angles of entry and exit
3. Quadrupole magnets
4. Sextupoles
5. Solenoids
6. Slits, etc.

The manner by which TRACE produces a solution for a beam transport design is not described here. It is sufficient to say that the program is versatile, to allow for a variety of constraints to be applied to the system. Parameter fitting is also possible with TRACE. This allows the experimenter to specify the parameters he wants to adjust, such as lengths, gradients, or apertures, and the program computes the first-order correction by a least-squares method.

Ray trace ability has been provided, and up to 50 vectors may be displayed at the same time. Phase-space ellipses are calculated at any point in the trajectory and the projections on the coordinate axes are displayed.

COMPUTER ENVIRONMENT

Program TRACE is operational under the BKY and SCOPE systems for the CDC 6600 Computer System using a 252 Model Display Console with an 8K buffer, character and vector generator, light pen, and teletype.

The program is written in Fortran IV. A typical session using TRACE on the CDC 6600 requires approximately 60 K_8 words of main storage, and it lasts for about an-half hour. Since the CDC 6600 is a multiprocessing computer system, the program occupies a control point for the duration of the session; however, the CPU (Central Processor Unit) is released to other programs when not in use. Thus, the total CPU time is, at most, 5% of the total session time. Figure 6 shows a flow chart of program TRACE.

PROGRAM OPERATION

The session begins with the user viewing part of the input data as shown in Fig. 7. The data correspond to a Bevatron secondary beam No. 5D, the characteristics of which appear in Table 1 and the beam layout in Fig. 8.

The source of this beam is in front of the first magnet (30-deg bending magnet) followed by a quadrupole double, the first element of which is vertically focusing. We request a parallel beam in the long straight section. The next quadrupole section has its first element horizontally focusing, followed by a 47.7-deg bending magnet. We request a waist after the first-gradient quadrupole. The beam then passes through a quadrupole, to a 55-deg bending magnet, through a doublet, and to the target, where we expect a horizontal and vertical focus.

The data displayed on the screen correspond to the input needed to calculate the first-order optical properties of the Bevatron 5D secondary beam used in this example, and consist of the appropriate parameters for each constituent element. The formatting of this input is almost identical to that of program TRANSPORT[1].

At this point, the user may exercise any of the options listed in the bottom of the screen. The functions of these options are listed in Table 2.

This list by no means exhausts the multitude of other options that the user might want to incorporate. The modularity of program TRACE allows such expansions, as is mentioned later.

Now--returning to our example: upon initiation of the option "ITER", the executive program of TRACE decodes the action, and signals the beginning of execution, resulting in Fig. 9 which displays the beam envelope. Program TRACE again waits (releases CPU) for the user to resume an interaction cycle based on the information displayed.

The user may decide to observe the phase-space ellipse at some location along the beam line; to do so, he points the light pen at the function MATRX. Next, the light pen is pointed at the location on the beam line where the phase-space ellipse is desired, and also specifies the planes on which the phase-space ellipse is to be projected. Upon initiation of the interrupt, Fig. 10 results. Here, the user has a wealth of information at his disposal. At first the beam envelope is shown, which is defined as the plot of beam size versus position along the system. Interpretation of the trace is fairly obvious.

A rectangle is drawn to represent a magnet; the size of the rectangle reflects the magnet length and aperture. The beam size is interpolated linearly in drift spaces.

Both the horizontal and vertical planes are displayed, as shown, along with the cumulative beam length.

Below the beam envelope, the RC matrix (cumulative transfer matrix) is displayed along with the SI matrix (beam matrix).

The RC matrix represents the transfer matrix of the beam transport system up to the point at which it was requested.

The beam transfer matrix (SI) includes the projections of the ellipse upon the coordinate axes. The SI matrix shown in arranged so that the diagonal elements occupy the first column as shown below:

$$\sqrt{\sigma_{11}}\ \mathrm{CM}$$

$$\sqrt{\sigma_{22}}\ \mathrm{MR}\ r_{21}$$

$$\sqrt{\sigma_{33}}\ \mathrm{CM}\ r_{31}r_{32}$$

$$\sqrt{\sigma_{44}}\ \mathrm{MR}\ r_{41}r_{42}r_{43}$$

$$\sqrt{\sigma_{55}}\ \mathrm{CM}\ r_{51}r_{52}r_{53}r_{54}$$

$$\sqrt{\sigma_{66}}\ \mathrm{PC}\ r_{61}r_{62}r_{63}r_{64}r_{65}.$$

Since $\sigma_{ij} = \sigma_{ji}$, we have $r_{ij} = r_{ji}$. The off-diagonal elements of this matrix represents various quantities such as dispersion, tilt, etc.

At this point, the user has the option of returning to the display of input data, ALTER, some parameter, and execute (ITER) again, or he may request to view the phase space at a different location on the beam line.

Figures 11, 12 show the phase-space ellipses at various points along the trajectory; Fig. 13 shows a ray trace of six particles while Fig. 14 shows an enlarged section of the first quadrupole doublet.

Once the computational loop has been completed, the user may repeat the same loop again, or new problems may be brought to the screen by exercising the option NCASE.

At all times, the experimenter may use the options SNAPD or SNAPB to take microfilms of whatever is displayed on the screen. This microfilm is later developed to a hard copy for permanent record.

Thus, by showing the results in an interacting way, the operator can quickly examine the overall characteristics of the system and take immediate action. Errors are detected easily, and time loss because of erroneous data is effectively minimized. During the course of the session, warning messages are available to guide the operator to avoid invalid conditions. In general, a program like the one described could be used effectively both as a design tool and as a teaching tool.

CALCULATION OF MAGNETIC FIELDS

The mathematical model involved in the application under consideration has been set forth in previous paper; (7, 8) however, for the sake of continuity a brief description follows:

A wide and significant class of phenomena in many areas of science and engineering may be described by Poisson's equation,

$$\vec{\nabla}\cdot(\lambda\vec{\nabla}\cdot\vec{\phi}) \tag{1}$$

where λ is a function of ϕ or its derivatives, S is a function of position, and ϕ is specified on the boundary. Poisson's equation describes magnetostatic problems by making use of the magnetic vector potential $\vec{A}$. The magnetic field, $\vec{B}$, may be determined from the magnetic vector potential $\vec{A}$, by

$$\vec{B} = \mu\vec{H} = \vec{X}\vec{A}, \tag{2}$$

and the curl of the magnetizing force $\vec{H}$ is equal to

$$\vec{\nabla} \times \vec{H} = 4\pi\vec{J}, \tag{3}$$

where $\vec{J}$ is the current density.

Substituting $\vec{H}$ from Eq. 2 into Eq. 3 gives

$$\vec{\nabla} \times \left(\frac{1}{\mu} \vec{\nabla} \times \vec{A}\right) = 4\pi\vec{J}. \tag{4}$$

Now, since $\vec{A}$ and $\vec{J}$ each have only one component (for two-dimensional problems) Eq. 4 reduces to

$$\nabla \cdot (\gamma \vec{\nabla} \cdot \vec{A}) = 4\pi\vec{J},$$

where $\gamma = \frac{1}{\mu}$

Equation 5 is of the form of Eq. 1, and it is approximated by finite-difference equations, which are solved by a relaxation process.

Recent additions to the existing programs include the calculation of cylindrically symmetric magnetic fields and the calculation of magnetostatic energy in both air and iron regions.

The computation model of this program is described (in the references) as consisting of an irregular triangular mesh of about 4000 points, on which the magnet geometry is outlined. No geometrical restrictions are imposed on the magnet; symmetrical planes may or may not be included, depending upon the requirements of the problem; any current distribution may be considered; also several different kinds of iron may be used in the same magnet.

The calculation of magnetic fields involves basically five distinct stages: preparation of input data; generation of the resulting triangular mesh; examination of CRT plots to insure proper triangle distribution (repeated attempts may be necessary before good "zoning"

is produced); calculation of the resulting field distribution; generation of field distribution plots.

Under the present graphic display method these five stages have been combined in the manner described below.

GRAPHIC DISPLAY METHOD

a. Preparation of Input Data

Under the graphic display method, the geometry of the magnet is drawn on CRT screen with a light pen, while the coordinates of the specified boundary points may be entered by a teletype attached to the CRT console. Let us consider an example.

Fig. 15 shows the completed geometry of the magnet as it appears on the isometric grid. The next phase consists of the transformation of the isometric triangular grid into the grid shown in the sequence of Figs. 16, 17, 18, and 19. This transformation is obtained by methods described in Ref. 7. In cases of input error (as shown in Fig. 18) or if the user wants to change any portion of the displayed geometry he proceeds as follows:

1. He points the light pen at the point where the error appears or at the point he wants to change.
2. He presses the "interrupt" button
3. Next, he moves the light pen to the new location desired.
4. He presses the "interrupt" button.

Immediately, the screen is refreshed with the corresponding change displayed or the error corrected. This process may continue until the

experimenter is satisfied that both the geometry and the distribution of triangles are correct.

b. Execution of Main Program

The main program is initiated by the experimenter from the console, once he is satisfied that the generated mesh properly represents the magnet geometry under consideration. He may view the progress of the solution to check convergence, or wait for the final solution. The final flux distribution in both air and iron is displayed, as well as pertinent curves relating to the character of the solution on the median plane and elsewhere in the magnet.

The experimenter either accepts this solution as satisfactory and records the results on microfilm for permanent record, or takes action to change some input parameters, according to the needs of the experimenter. Thus the calculation loop is closed with the experimenter dictating the action to be taken.

The adaption of this program for graphic display purposes is outlined in Fig. 20, which shows the overall flow chart of the program FIELD. The time response is almost instantaneous except in blocks 11 and 12. Here the response is perceptibly slow, depending on the number of points used to simulate a magnet. That is an 800-point problem requires about a minute; a 2500-point problem, about 5 minutes; and a 4000-point problem, 15 minutes.

Since the accuracy of the solution is a function of the number of mesh points used, the maximum number of points should be utilized to obtain the maximum attainable precision. This, however, drastically reduces not only the time response of the system, but also the

feasibility of the program, since it requires about 150000_8 memory locations for a 4000-point problem, and such a large amount of memory cannot be easily allocated to an experimenter even with a multiprocessing computer system such as the CDC 6600. For this reason, a "strategy" was devised which would reduce the time to about 1/6 and the storage required to about 1/5. This strategy consists of the following scheme: (a) simulate a magnet by a coarse mesh, say 30 X 30, (b) obtain a solution, (c) determine the region at which the highest accuracy is required, (d) enlarge this region, (e) insert the vector potentials obtained from the coarse solution in the enlarged region, (f) interpolate for the in between vector potentials, (g) freeze the boundary, and finally solve this enlarged or "zoomed" region.

This scheme was used in the magnet shown in Fig. 15 with excellent results. We first ran this magnet with a 50 X 50 mesh and saved the results for comparison; (see Fig. 21) then we ran the same magnet with 25 X 25 mesh. We zoomed the region within the poles shown in Fig. 15 to a 17 X 17 mesh, and solved the 17 X 17 mesh with fixed boundary obtained by interpolating from the fector potentials of the 25 X 25 solution. The results were almost (Fig. 22) identical to the 50 X 50 solution, indicating that a coarse mesh may be used as an initial solution and the region where high accuracy is desired may be "zoomed"; significantly less time and core memory are used without sacrificing accuracy.

CONCLUSIONS

The experiences derived from the applications mentioned, and from many others already in use, indicate that graphic interactions are extremely attractive in research type calculations. Perhaps, the outstanding feature, is the ability of the experimenter to communicate with the device, and guided by the displays to arrive at a solution for his contemplated design. This man-machine interchange of information does not by necessity imply that graphic displays are indispensable in this mode of operation. Our experience has shown that even in the absense of graphic displays the information obtained was invaluable in simulating various physical processes. The ability of the device, guided by the experimenter to search for a better solution and to type the results (in some abbreviated mode) has produced equally good results in cases where graphic displays were not available.

One constant criticism is that this on-line process, requires a portion of the computer memory to be dedicated to this process, which is a waste, since only 5% of the real time is consumed by the resident program. This argument is not valid because any computer system having online interaction as an integral part of the computer environment necessitates the appropriate mechanisms of rolling-in and rolling-out of such types of jobs.

In our system, we have 64-control points, and a priority system, which allows the roll-out of an on-line job once an I/O request is made. At the completion of the I/O request and the subsequent initiation of the interrupt the job is rolled-in for the extremely small fraction of

time required to execute the detected interrupt. The 64 control points are sufficient to handle a large number of jobs simultaneously so that very little is lost if two or three on-line jobs are occupying control points.

Finally, our experience with the installation of remote terminals to serve experimenters residing in states other than California, has shown conclusively that their interacting dialogue with the resident at Berkeley computer, is not hampered by the absence of graphic displays, and it is not very far into the future that remote terminals possessing all the interactive qualities needed, will become a permanent member of all nuclear physics installations.

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Table 1. Beam No. 5B.

General description	500-MeV/c K^+ or K^-, separated
Physicists responsible	T. Elioff (LBL)
Installation date	June 1967
Target location	External beam-Channel 1 - 2nd focus
Target material	Uranium
Target size	1/8 in. vertically, 3/8 in. horizontally, 1.5 in. in length
Momentum range	$\approx$0.2 to 0.60 BeV/c (positive or negative)
Momentum width	4%
Solid angle	$\approx$6 millisteradians
Production angle	24 deg
Type of separator	Electrostatic Mark V (10 ft long) 4-in. Gap
Separation factor	Pion rejection $\gtrsim$50 at 550 kV (capable of 600 kV)
Emittance	0.02 radian in. (horizontal); 0.017 radian in. (vertical)
Flux transmitted	$\approx$4000 K^+(500 MeV/c) per 5 X 10^{11} EPB protons; K^+/all positives $\cong$ 1/20
Other information	1. Mass split is at first focus with submomentum recombination 2. At first focus, vertical magnification = 1.5; horizontal magnification = 0.95; K - π vertical separation = 0.5 in. 3. At final focus, vertical magnification $\approx$4.5; horizontal magnification = 0.5. For stopping K^+ in 5 grams of CH, the rate is $\approx$1200 K^+/5 X 10^{11} p^+ (EPB). Approximately 60% of K^+ pass through a 3/8X3/8-in. cross section at the final focus. 4. Target is not mounted in either EPB or secondary-beam vacuum, and is easily accessible.

TABLE 2

OPTION	FUNCTION
ALTER	Alter data. The alteration is performed by entering the appripriate address in the DATA array. This number is shown on the left column of Fig. 7; for example, to change the first drift length to 15 inches, we type 22, 15.$^{C}_{R}$ (carriage return).
DLINE	Delete one line of input. In other words, delete one element of the beam system.
ALINE	Add one line of input. This option allows the user to enter all his input via teletype, or to add a new element in the beam system.
SNAPB	Record this display on microfilm. (This option is used to record the beam envelope.)
SNAPD	Record this display on microfilm. (This option is used to record the data displayed.)
MDATA	This option (presenting an addition frame) allows the user to view more data; in many instances, one frame is not enough to display all data.
GO	Execute the data (without application of constraints).
INTER	Execute data, applying constraints.
FIN	End of session.
VECT	Perform changes on the vectors displayed. This option allows the user to alter vector parameters to enter new vectors or to remove those already specified.
RAYS	This option provides for the display of all rays specified, or individual rays may be displayed at will.
BEAM	This option allows the user to review a beam already calculated.
SCALE	Scaling of both horizontal and vertical beams. The user enters via teletype the region he wants to scale and the scaling factor.
MATRIX	This option allows the user to specify the location where he wants to observe the phase-space ellipse and the RC and SI matrices.

<u>MA</u>TRX (Later paragraphs describe these matrices in more detail). The user initiates this option by teletype, enters the location where the ellipse is desired, and specifies the planes of the projections of ellipse (x, Ø, y, o, etc.)

NOTE: If a teletype is used to initiate any of these options, only the letters underlined need be specified. If a light pen is used, it is pointed at the option desired and, by depressing the microswitch on the light pen, the interrupt is initiated.

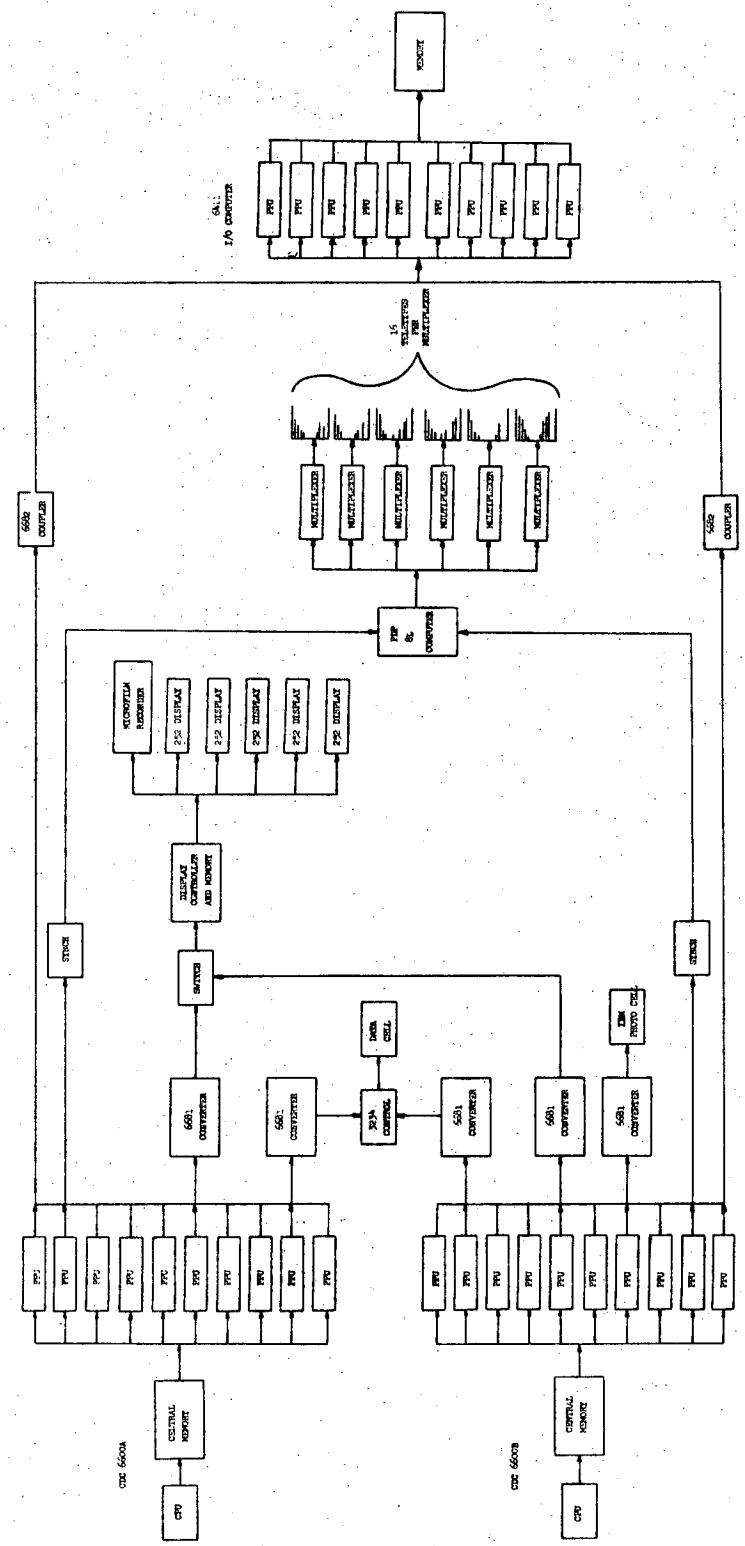


Fig. 1 ORGANIZATION OF L.R.L. COMPUTING FACILITY SHOWING INTERACTING & GRAPHIC DISPLAY HARDWARE

```
>BRF!
CONNECTED
 BRF 2.9  *10/29/70. 15.21.32. *B. ENTER NAME,ACCOUNT
COLONIAS,424201!
OK
!EDIT!
OK

   1.        *CALCULATE FLUX DENSITY ON THE AXIS OF
   2.        *A NONFERROUS SOLENOID OF SMALL CONDUCTOR
   3.        *SIZE(CROSS SECTION)
   4.        *
   5.        *INPUT DATA NEEDED
   6.        *
   7.        * TN = NUMBER OF TURNS
   8.        * C  = CURRENT IN AMPERES
   9.        * S  = LENGTH OF SOLENOID(INCHES)
  10.       * R  RADIUS (INCHES)
  11.       * Z  = AXIS OF SOLENOID
  12.       * DZ = INCREMENT ON Z AXIS WHERE B IS CALCULATED
  13.       *
  14.      1 CONTINUE
  15.       READ,TN,C,S,R,Z,DZ
  16.      IF(TN.LT. 0. ) GO TO 20
  17.      COEFF=4.0*PI*TN*C*1.E-7/(2*S*0.0254)
  18.       ICOUNT=(Z/DZ)+0.0001
  19.      ICOUNT=ICOUNT+1
  20.       DO 10 I=1,ICOUNT
  21.      UP=S/2 - Z
  22.      UP2=S/2+Z
  23.       DOWN = SQRT(UP**2 + R**2)
  24.       DOWN2= SQRT(UP2**2+ R**2)
  25.       PAREN = (UP/DOWN + UP2/DOWN2)
  26.       B = COEFF*PAREN
  27.      PRINT,Z,B
  28.      Z=Z-DZ
  29.      10 CONTINUE
  30.      GO TO 1
  31.      20 CONTINUE
  32.      END
OK

!XEQ!
 BEGIN XEQ
 ENTER... TN, C, S, R, Z, DZ,
5.0,0.5,5.0,0.5,7.0,0.5!
  Z= 7.0  B= 5.8554E-08
  Z= 6.5  B= 7.6468E-08
  Z= 6.0  B= 1.0297E-07
  Z= 5.5  B= 1.442E-07
  Z= 5.0  B= 2.1279E-07
  Z= 4.5  B= 3.3786E-07
  Z= 4.0  B= 5.9828E-07
  Z= 3.5  B= 1.2631E-06
  Z= 3.0  B= 3.5718E-06
  Z= 2.5  B= 1.2307E-05
  Z= 2.0  B= 2.1039E-05
  Z= 1.5  B= 2.3336E-05
  Z= 1.0  B= 2.3978E-05
  Z= 0.5  B= 2.4199E-05
  Z= 0.0E+00  B= 2.4257E-05
 ENTER... TN, C, S, R, Z, DZ,
-2!
 END XEQ. ENTERING !EDIT
OK
!STORE,SOLEN1!
STORE IN PROCESS
STORE SUCCESSFUL
ENTER SUBSYSTEM NAME
!CLEAR!

>DC.!
OK
```

LINES 1 thru 32 ARE TYPED IN FROM THE CONSOLE

BEGIN EXECUTION

ENTER PROBLEM CONSTANTS

RESULTS

ENTER PROBLEM CONSTANTS

SENTINEL TO END

STORE THIS PROGRAM IN FILE CALLED SOLEN1

EMPTY BUFFER

DISCONNECT EQUIPMENT

Fig. 2 INTERACTING USAGE OF BRF, SHOWING USAGE REMOTE STORING AND LOADING OPTIONS

XBL 7011-6884

```
>BRF
CONNECTED
 BRF 2.9  *11/02/70. 10.07.17. *A. ENTER NAME,ACCOUNT
COLONIAS,424201
OK
↑COMUT
 OK
FOX=X**3+X*Y**2+ALOG(SIN(Y)+10)
 ENTER... X, Y,                          ....Request Parameter Values
1,2                                       ....Set  X=1, Y=2
  FOX= 7.3896154                          ....Value of Fox= 1³+1*2²+ln(sin(2)+10)
2,2                                       ....Set  X=2, Y=2
  FOX= 13.3896154                         ....Value of Fox
,1                                        ....Null field for X, previous value is used
  FOX= 12.3933787


>DC.                                      ....Disconnect Equipment
 OK.
 EC 41 READY
```

Fig. 3 EXAMPLE OF COMUT SUBSYSTEM.
UNDERLINED STATEMENTS CORRESPOND TO USER RESPONSE

XBL 7011-6886

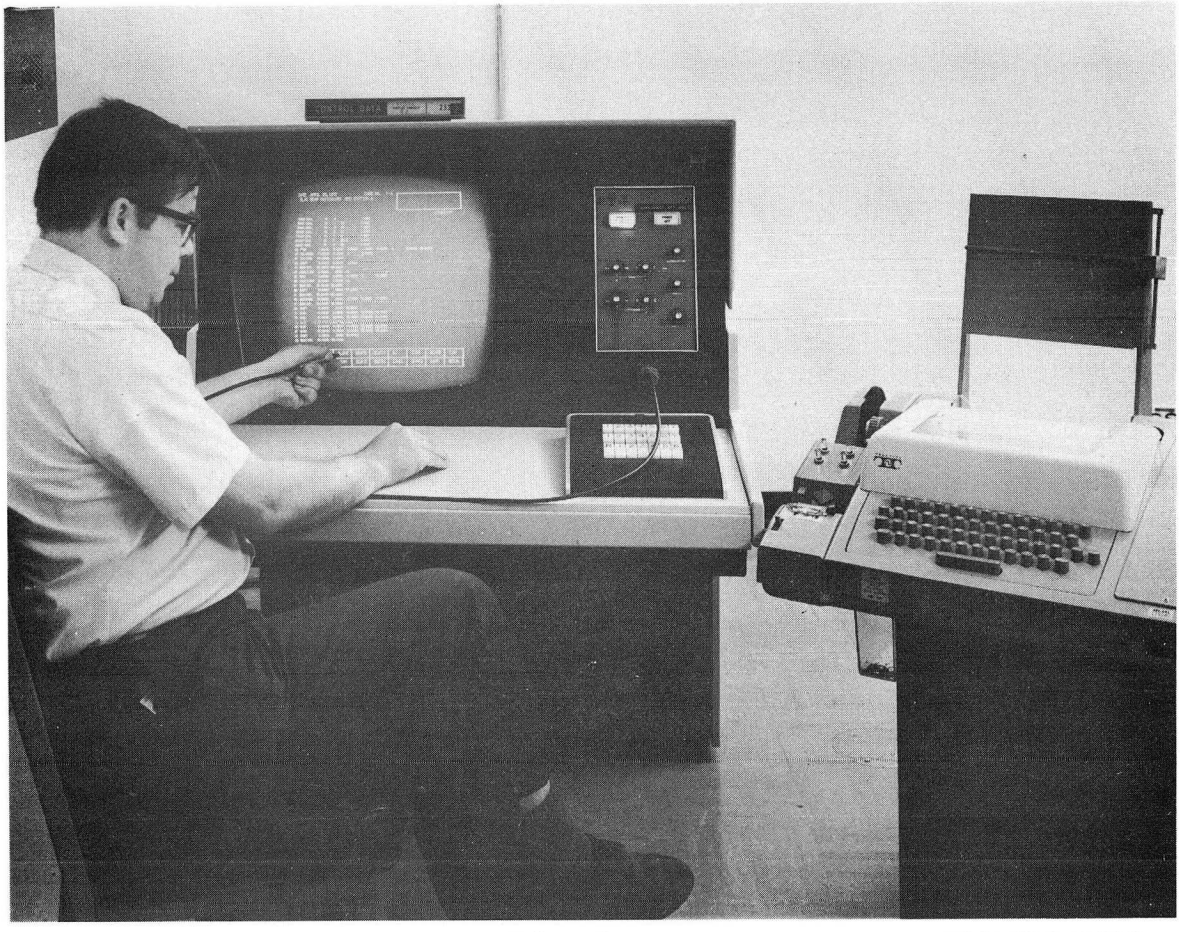


Fig. 4 XBB 704-1883

Graphics station showing display console and teletype

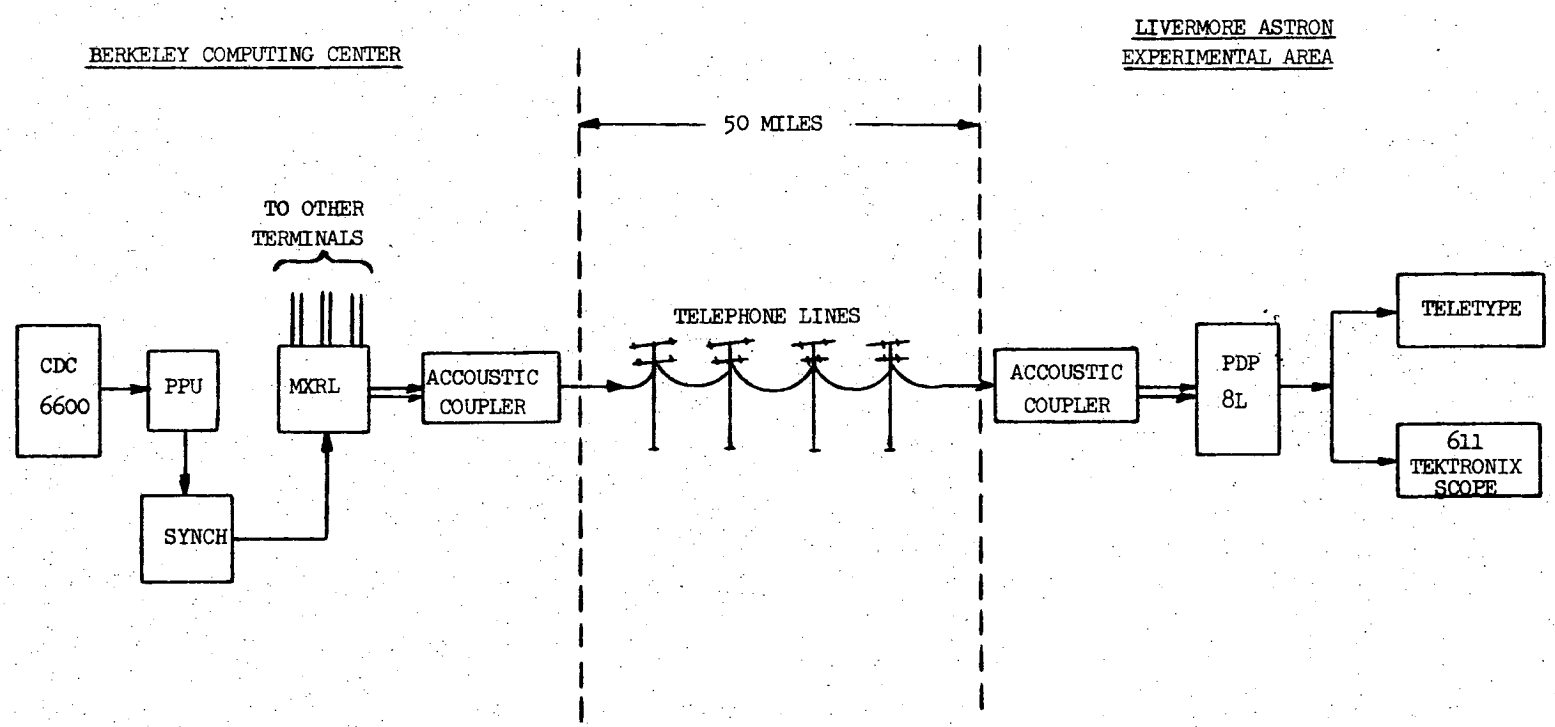


Fig. 5 **COMPUTING SET UP FOR E.R.A. EXPERIMENT**

XBL 7011-6887

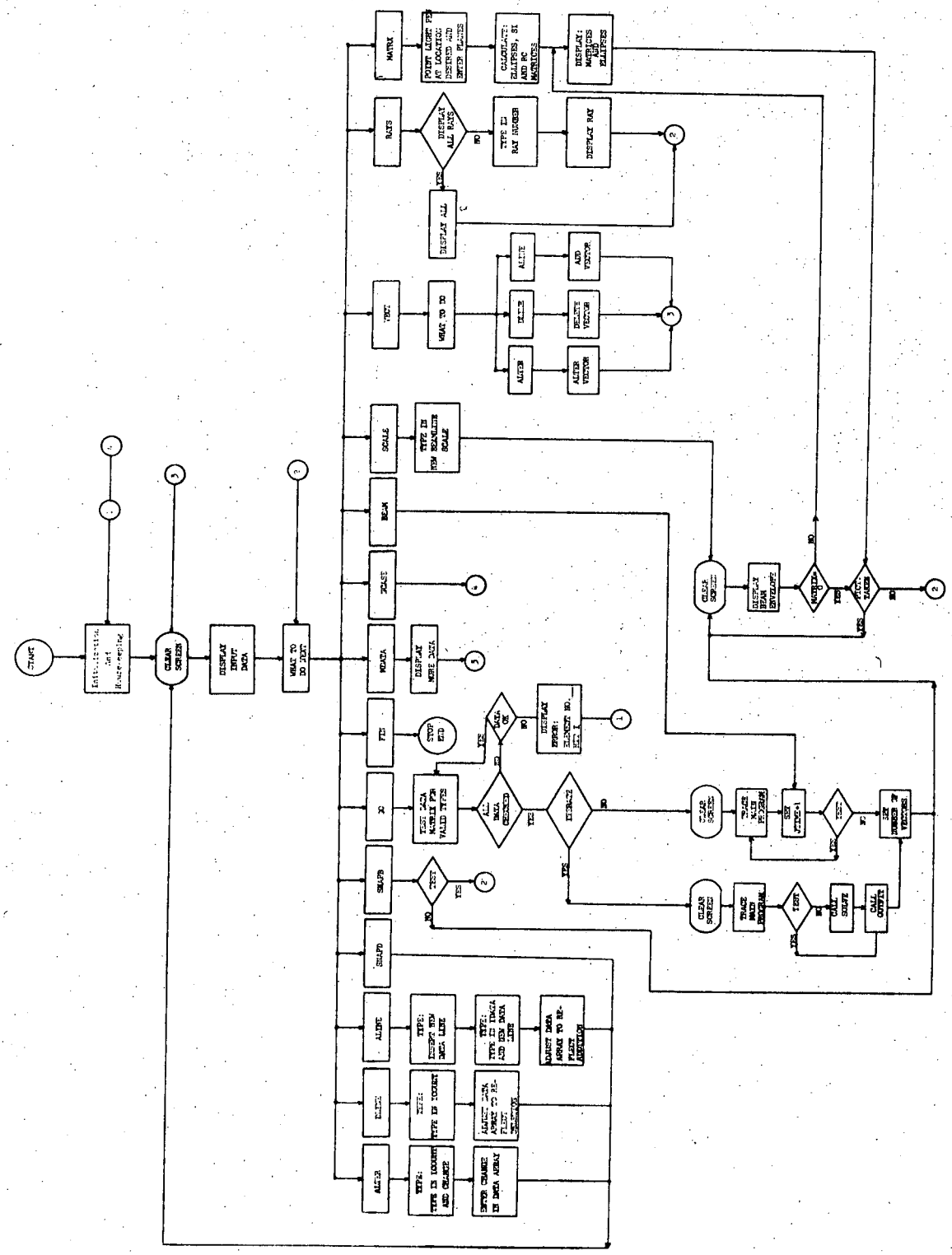
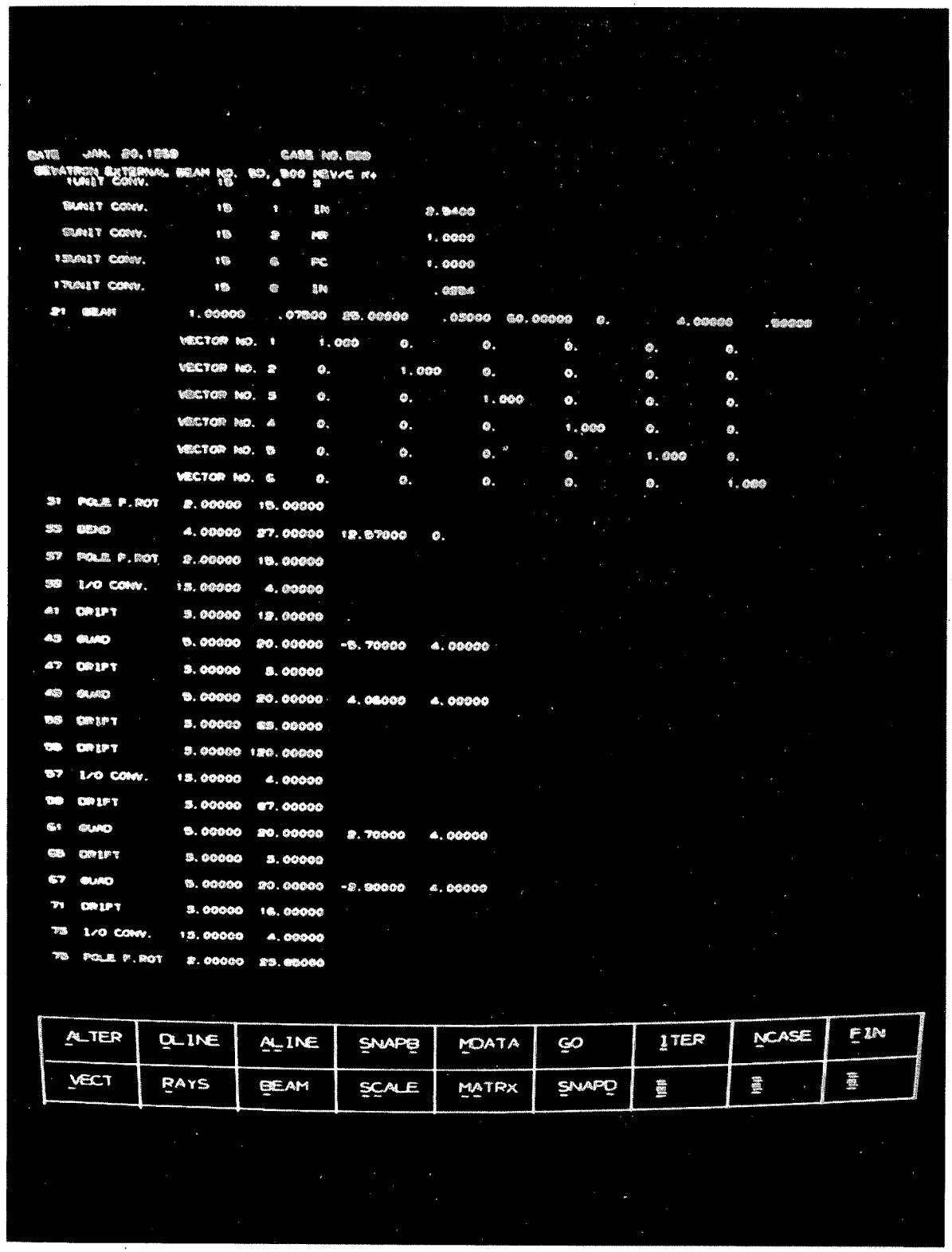


Fig. 6 TRACE FLOW CHART

XBL 694-369



XBB 694-2243

Fig. 7 CRT screen displaying input to program TRACE

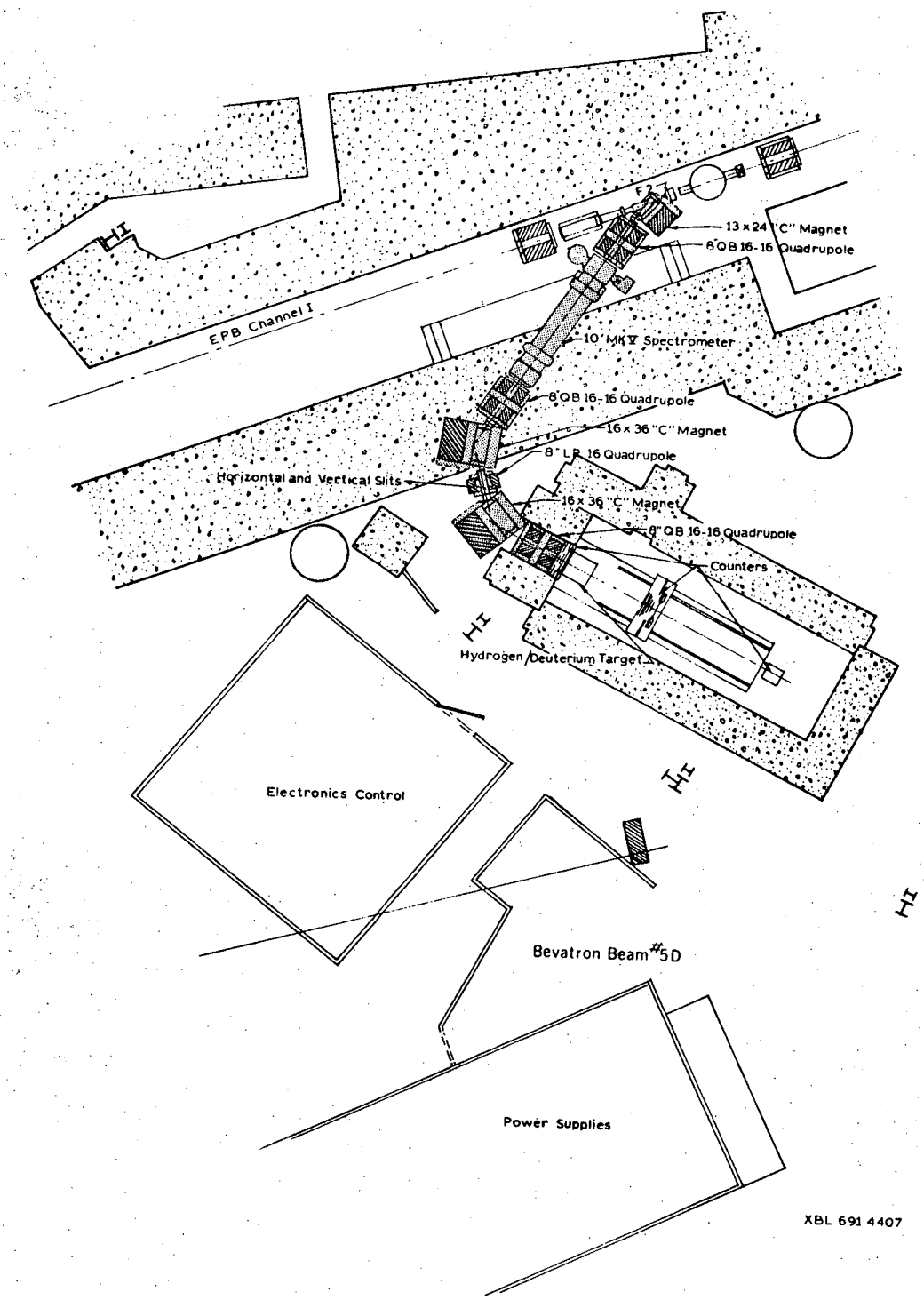


Fig. 8 Bevatron Beam #5D

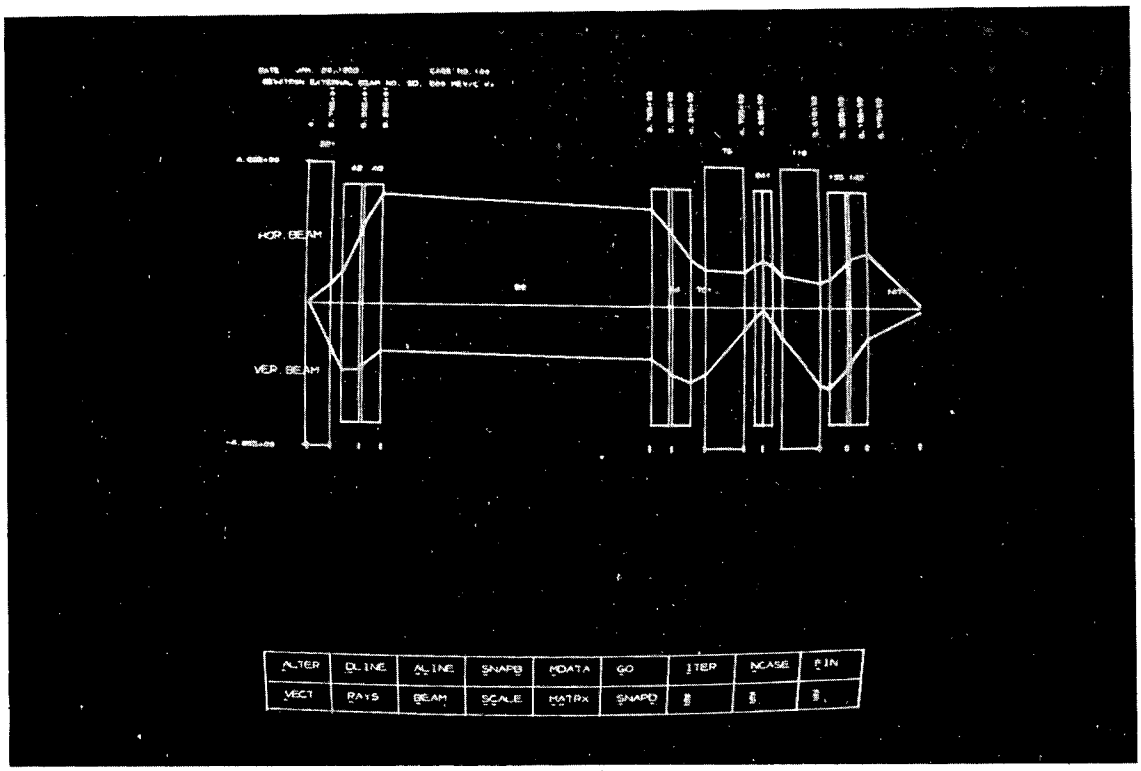
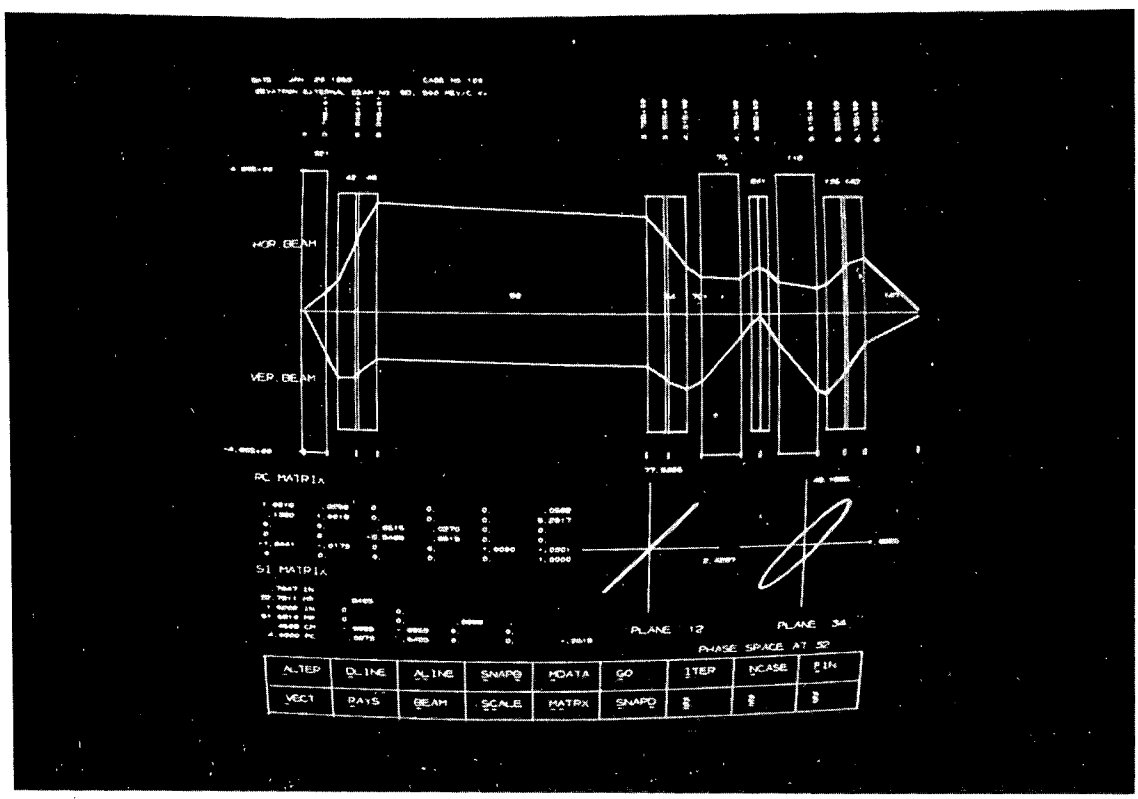


Fig. 9 Beam Envelope of Beam #5D



XBB 7011-5124

Fig. 10 Particle phase space projection at various locations along the beam line

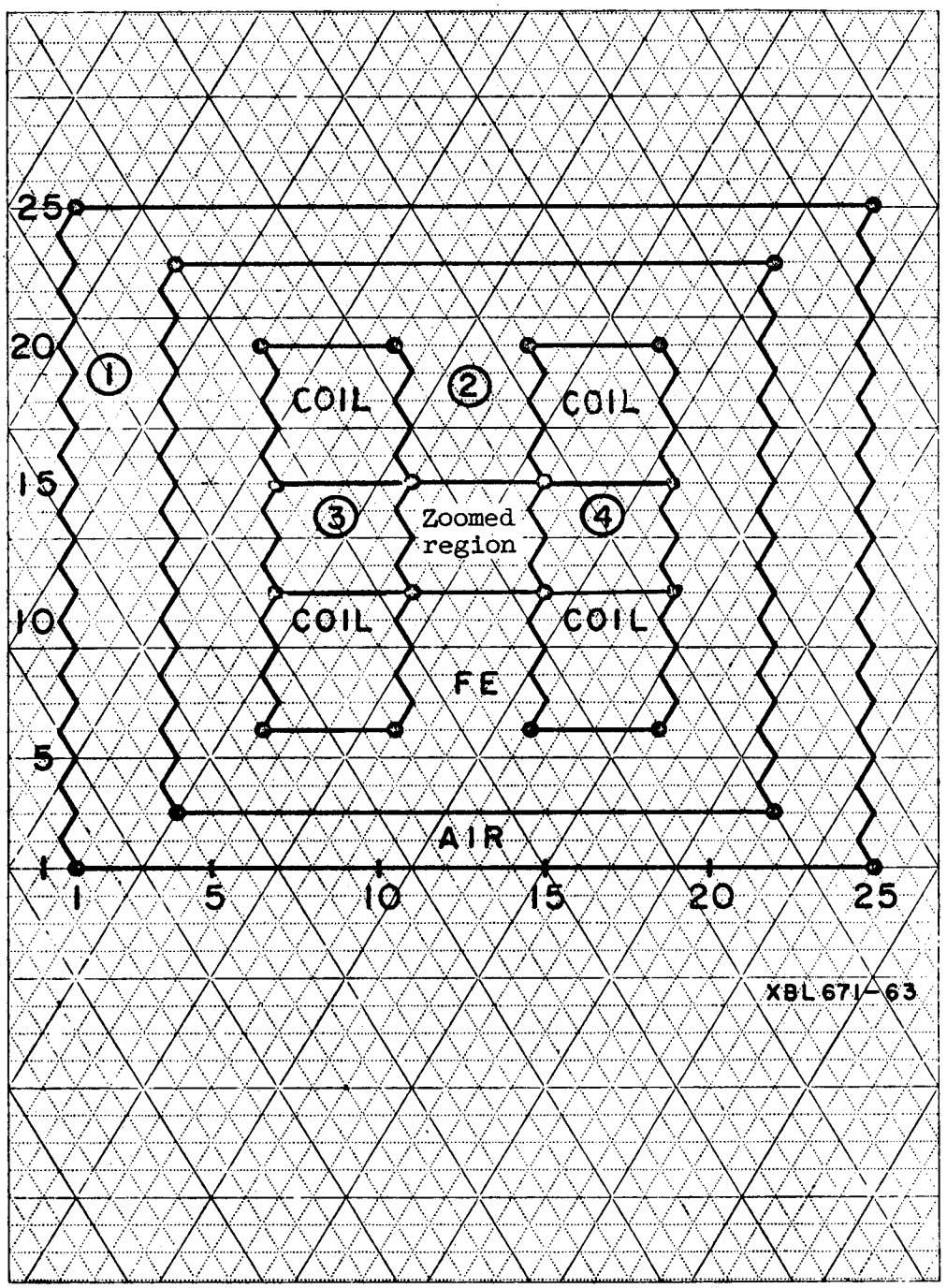


Fig. 15 Window frame magnet geometry outlined on isometric paper. Dots signify input points.

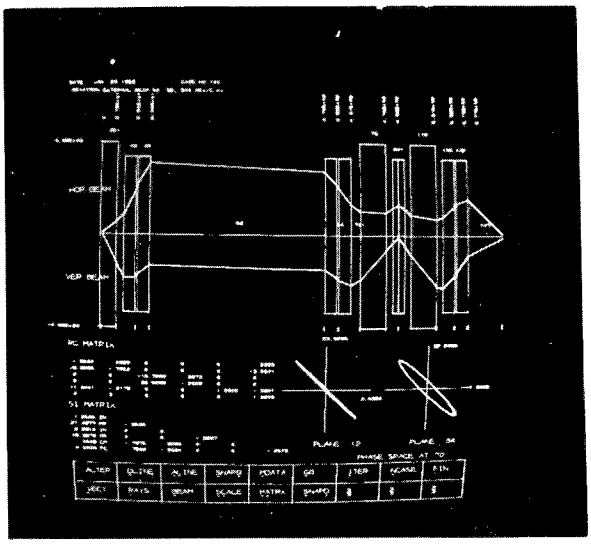


Fig. 11 Particle phase space projection at various locations along the beam line

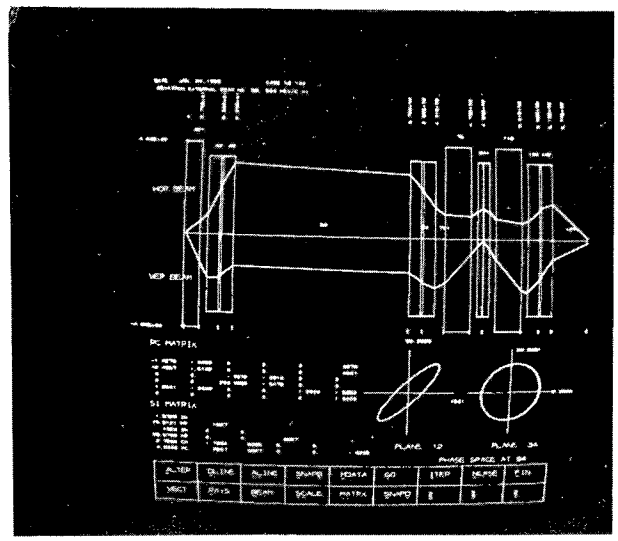


Fig. 12 Particle phase space projection at various locations along the beam line

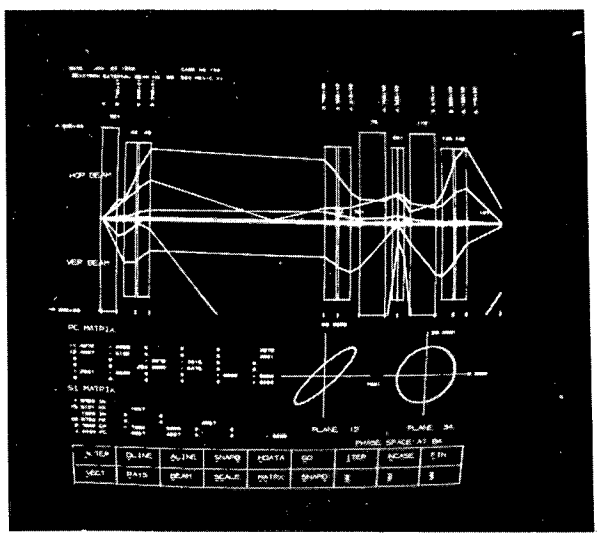
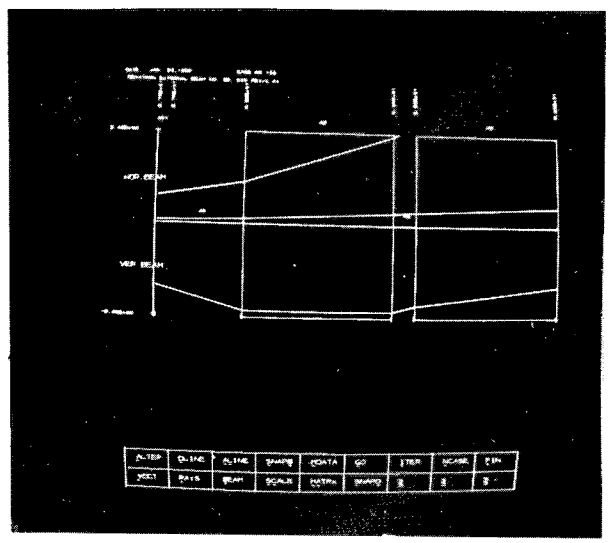


Fig. 13 Ray trace of six particles



XBB 7011-5125

Fig. 14 Enlarged section of beam line

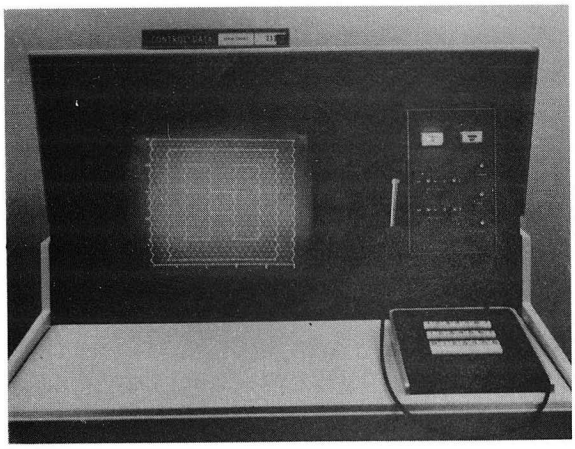


Fig. 16 Simulated window frame magnet on cathode ray tube

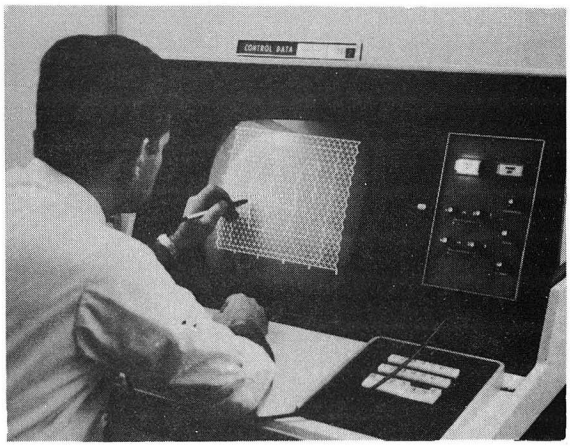


Fig. 17 Simulated window frame magnet on cathode ray tube

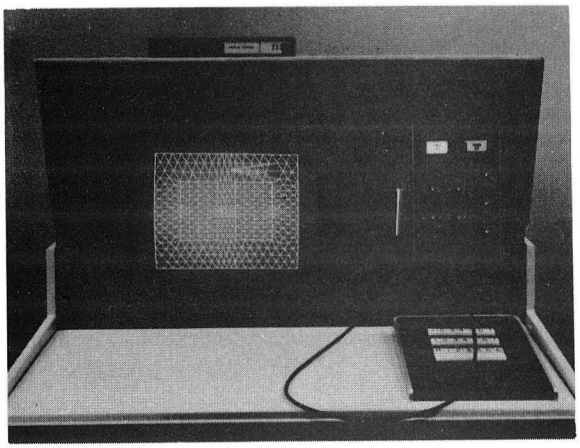
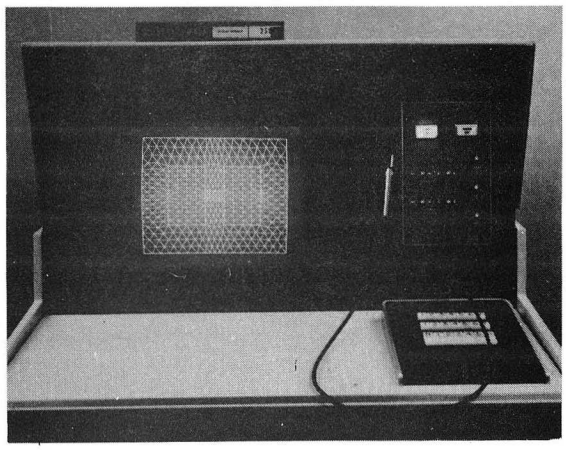


Fig. 18 Generated mesh for window frame magnet displaying error in upper right part of magnet



XBB 7011-5126

Fig. 19 Final geometry

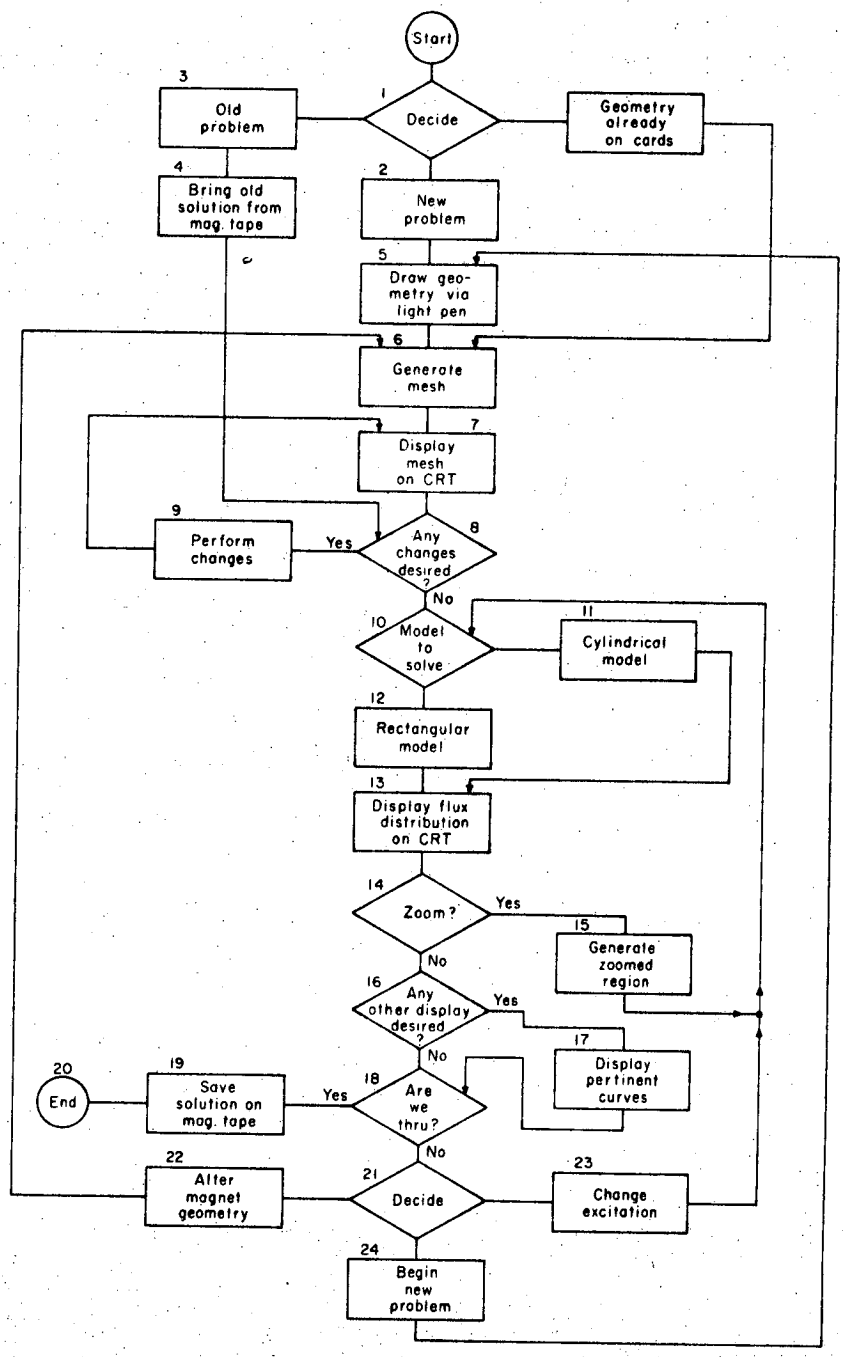


Fig. 20 Flow chart of interacting magnet design program

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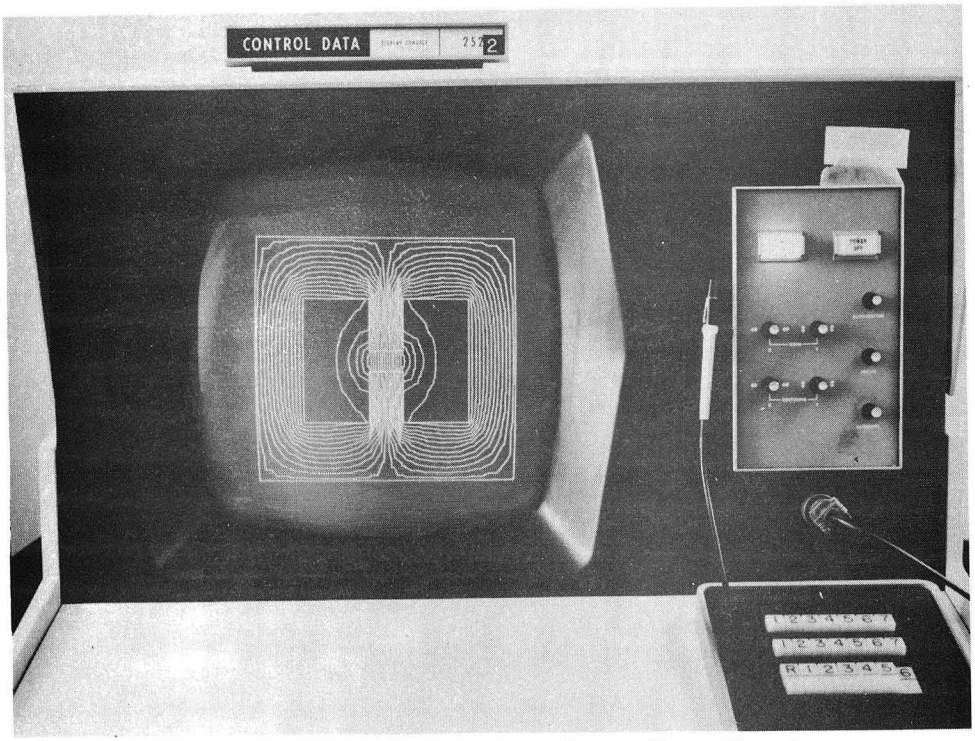
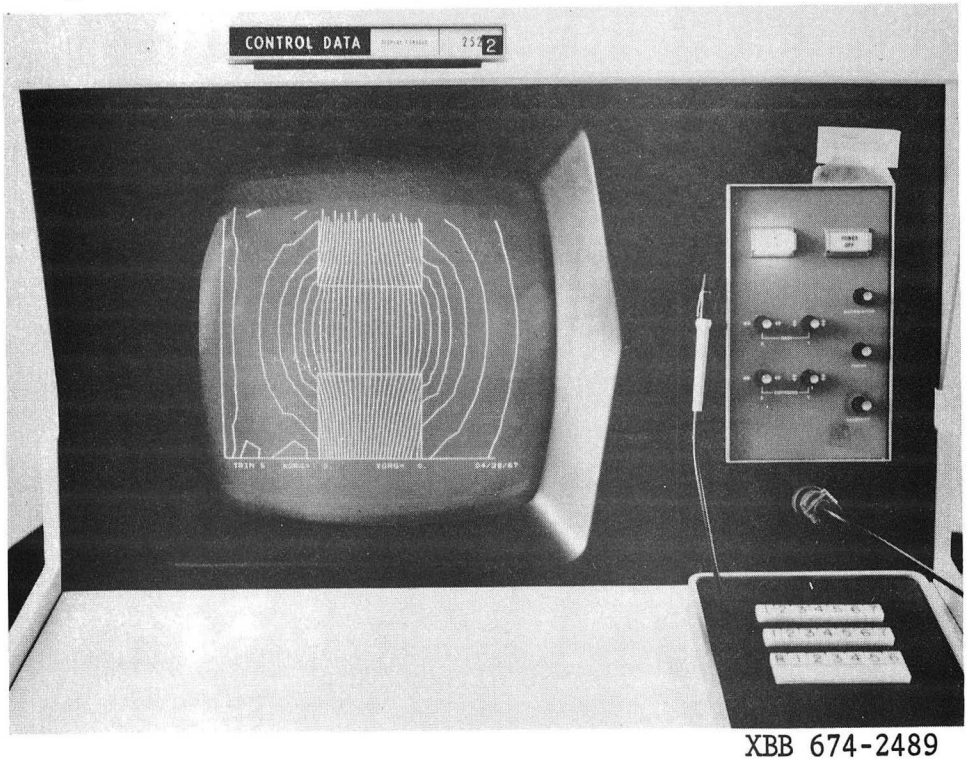


Fig. 21 CRT console displaying flux distribution



XBB 674-2489

Fig. 22 CRT console displaying flux distribution for "Zoomed" region

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