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tables in turn, round robin fashion, to see whether the program, if any, occupying that slot can make any further progress. When a program signals that it is finished, its core reservation is cancelled and its space in the tables may be freed. The program is not written back onto disk by exec; however a very few programs perform this function for themselves.

The shared segment of core is partitioned into eight blocks; it is therefore possible to have as many as eight independent strings in simultaneous execution in core at any given time. There is no priority of execution of these programs.

I/O Drivers

Five programs in the core-resident system are devoted to the operation of the disk, CRT display, teletype units, and the computer interface unit. These programs, at the request of other programs, schedule, perform and check transmissions to and from the peripheral units. They contain interrupt servicers for error or end-of-transmission conditions, and they have the duty of informing the requesting program when the transmission is complete.

Interrupt Servicers

Priority interrupts cause an interruption of the normal sequence of instructions and start a program in a new location. Many of these interrupts are associated with input/output units, and the associated I/O drivers contain subprograms to handle them. A few are not connected to peripheral units, and therefore their servicing programs exist independently. A priority interrupt is simply a method of rapidly informing the computer that something has happened. The events are varied, ranging from a teletype key having been pressed to a power failure. Consequently the computer responses are also varied. Their common characteristic is that they must restart the interrupted program so that it will perform as if there had been no interruption; consequently they are denied the use of many useful system functions which it is possible for them to interrupt.

Message Handler

The message handler is a nonresident system program which prints or displays messages at the request of other programs on either of the teletypes, the line printer, or the CRT. Messages are stored in core and on the disk in a standard format which includes a destination code. If the destination unit is not available, the message handler automatically chooses an alternative unit for output. In order to lessen the probability for programs having to wait for slow devices like teletypes, a ten-position queue is maintained, and a program is given a finished signal when its message has been entered in the queue rather than when the transmission actually occurs.

Interpreter

In order to facilitate the writing and testing of accelerator sequencing and control programs a special language has been devised. Programs written in this accelerator language are assembled by the accelerator language assembler and the resulting object code is executed interpretively under the system by the accelerator language interpreter. The interpreter is brought into core whenever an accelerator language program is in operation and remains until there are no more interpretive codes running. The interpreter and the codes which are being interpreted occupy together about 1500 words of core storage during this time. Its functions are to manage storage for the codes it processes (it uses a demand paging scheme to allocate about 500 words of the 1500), to maintain displays, to deal with light pen hits on the display, and to interpret and execute the instructions of the interpretive language.

Application Programs

Programs which can be commanded to run at the discretion of the accelerator operator and whose principal function is to provide services for him will be called application programs. A functional description of the more important ones should provide a picture of the kind of operation toward which we are working.

Data Scan

A fundamental task of the computer is the gathering and recording of data on accelerator operation. The data must also be checked to be sure that various devices are in the correct state. The data scan program provides a comprehensive service of this type. It reads all data channels and stores the data both on the disk and in special core locations reserved for this purpose, where it is easily available to other programs. On request data scan checks to see that on/off data is in the correct state and that analog data falls within prescribed limits. Not all data are necessarily checked. A channel may be added to or removed from the set that is checked either by the operator or by another program. When a channel is found to be wrong, the standard procedure is simply to log the fact and inform the operator, who can then take appropriate action. While this is adequate for current EPA operations, more elaborate analyses of problems will probably be developed for LAMPF so that troubles can be more accurately pinpointed and corrective measures taken either by operating personnel or by the computer.

Data scan is capable of performing its routine task within one second, and the usual mode of operation is for it to run every second. However, the console buttons provide controls by which it can be started, stopped or run one time only at the operator's discretion.

Line-by-Line Display

The second basic task of the computer is to present information about the accelerator to the operator in a convenient form. The primary display device is the CRT, and the most general and most commonly used display is known as line-by-line. By setting dials to channel numbers and pressing function buttons the operator can display up to fifteen different data channels on the face of the CRT. Each channel is identified by number and by an eighteen character label. The on/off status or scaled analog value is displayed next to the label and updated either once per second or four times per second, depending on what else is taking place. A channel which is no longer of interest can be erased with a light pen and a new channel requested to take its place. Since it is rather tedious to dial up a long list of channels, a facility is provided for saving a list on the disk and then calling it back with a minimum of dialing and button-pushing.

The same facilities available through the console are available to other programs and this capability is useful in providing for easy human monitoring of automatic accelerator control sequences. The control program requests the line-by-line display which will permit following its progress.

Console Command Programs

Four programs service the control buttons and switches on the operator's console:

Binary Command. The binary command program reads the module and channel numbers from the console dials, checks them for legality, converts them to the correct form for transmission to the interface hardware, and transmits the requested on or off command.

Analog Command. The analog command program adjusts setpoints and potentiometers to desired settings. It reads the channel identification and desired setpoint from console dials and the current position from a data channel associated with the setting. It then calculates from calibration curves the correct number of pulses to be issued to a pulse motor to make the change. The reading of the data channel is checked after the motion has stopped, and the process is repeated until the target value has been achieved. These repetitions tend to correct for mechanical lash, hysteresis, and coarseness or inaccuracies in the calibration curves.

Slew. The operator's console contains three sets of switches and dials referred to as slew controls. The switches may be raised or lowered and they return automatically to center when released. When a switch is deflected, the console generates interrupts to the computer at a rate of ten per second. The program which services these interrupts then sends pulses to the command channel specified by the dials associated with the switch. The number of pulses sent is

such that the channel will move .1% of full scale for each interrupt. While one of the slew switches is deflected the line-by-line display update rate is increased to four times per second rather than the customary once per second, and data is read more frequently on the channel which is being slewed. In this way the operator can follow progress on the CRT with good response.

Video Commands. Another set of console buttons and dials enable the operator to switch signals to the two-trace scope in the control area. The computer plays a minor role in this process, serving only to transmit the commands to the remote switching equipment.

Special Purpose Displays

The programs discussed up to this point serve only to make manual control of the accelerator possible through the computer. They provide functions which might be expected to exist in one form or another at any control panel. The application programs which are described next generally will provide a degree of automation in the operation or else provide some feature which would be expensive or difficult without a computer. The first set of these programs to be described, the special displays, present data in more easily comprehended form than is possible with the line-by-line display.

Vary. This program provides a facility for stepping any command channel through some range and plotting some data channel as a function of that command channel setting. Once given the range and increment, the program issues the commands automatically. There are possibilities for both linear and logarithmic scales, different plotting characters and multiple plots on the same graph. There is no easy way of obtaining good permanent copies of the graphs; however, a rough sketch can be produced on the line printer. Fig. 3 shows a picture of a graph produced by Vary.

Timeplot. Program Timeplot plots the value of any data channel as a function of time. The plotting takes place in real time at intervals specified by the operator. The program is similar to Vary in its plotting capabilities, but no commands are issued, and the abscissa is always time. Figure 4 shows a picture of a graph produced by Timeplot.

Beamplot. The Beamplot program is used to facilitate manual beam steering by the operator. It plots the beam current and the x and y coordinates of the beam position at seven stations along the length of the accelerator. The channels are read and the plot updated four times per second. An associated program provides the operator with the ability to assign the slew switches to different focusing and steering magnets with the light pen. A pointer below the graph indicates which station is being manipulated. The slew switches are connected through the program to the magnet controls for the indicated station. Since the pointer can be moved from one station to

another with the light pen, the operator can switch quickly and easily from station to station without the relatively slow and awkward dialing of channel numbers on the slew dials. A picture of the plot is shown in Figure 5.

Automatic Accelerator Procedures

A number of programs have been written to run EPA and its associated power supplies through various standard sequences. To date these have fallen into four categories: turn-on, turn-off, hardware diagnostic, and beam search. The earlier programs of this kind were written in SEL assembly language. Since the beginning of this year, however, they have been written primarily in the new accelerator language, which was invented for this purpose. Although the language is a so-called "low-level" language, being an assembly language for an imaginary computer, it offers a great deal of simplification and economy in the coding of these procedures, and the associated interpreter provides many useful features for program debugging, simultaneous execution of sequences, communication between programs, and operator communication. A detailed description of two programs should illustrate the kind of things that these programs are doing.

Prepare Tanks for R.F. The object of this program is to check the temperature and vacuum in the main accelerator tanks, to bring the temperature to the correct value, and inform the operator if the vacuum is not satisfactory. There is a local temperature controller which will maintain the temperature at a setpoint during operation. There is also a water heater connected to the apparatus which provides a source of hot water to speed the warm-up.

The program first checks the position of two local/remote switches which must be set to remote in order for it to have control. Two water pumps are then turned on, if they are not already on, and the water flow is checked. The mixing tank heaters are checked and turned on if they were off. If the tank copper temperature is more than half a degree below the required value, the hot water valve is opened and left open until the water temperature either comes within half a degree of the setpoint or else begins to drop, indicating that the water heater has been emptied. The program then loops, watching the copper temperature. An hour later if the temperature is still not within half a degree, another slug of hot water is dumped into the system, the water heater having recovered by this time. This process will be repeated indefinitely. In practice two hot water dumps are usually necessary, starting with the tanks cold. At the beginning of the warm-up the vacuum is checked and the operator is notified of the result so that he can take advantage of the long warm-up time to make any necessary repairs or adjustments. At the end of the warm-up the vacuum is checked again, and if it is all right, the program terminates.

Beam Search. At the time of writing, the beam position monitors on EPA are not yet functioning. Consequently the task of this program is to locate the beam and center it as well as it can, using only beam current information. The program assumes that a previous program has turned on all the necessary power supplies and checked the local/remote switches. It is also assumed that there exists a low-intensity beam. Beam Search executes a search pattern, changing the currents in the horizontal and vertical steering magnets in a systematic way in steps sufficiently small so that it will not be in danger of stepping across the beam without seeing it. After each change in the steering magnets the beam current is read. When a current above some threshold is measured, the program attempts to center the beam by finding the cutoff settings on each steering magnet and then setting the currents to the means of the cutoffs. A final procedure checks this setting by attempting to maximize the current reading at the station. Small steps are taken in all directions away from the assumed center position, and if any of these results in an increase in the current, it is taken as the new center position. If no improvement is found, the program is finished with the station.

These two programs are representative of about twenty which have been written to implement turning on and off and equipment testing. Essentially all the parts of EPA which are controllable by the computer now have such programs to service them. Since EPA is an experimental prototype, its parts are run separately on a piecemeal basis as often as it is run as a whole. Consequently there is not yet a program which will bring up the whole facility from a cold start, run it, and then shut it off. Since a program can start up another program, however, it would be an easy matter at this stage to write a master control program which would, by calling the various component sequences, do such a thing.

Experience

During the past four months the basic programming system has undergone only minor modifications while being used extensively for manual operation and for developing automatic sequencing programs. Observation of the performance of the system during this time has indicated no major flaws in the general design, success in performing several tasks in parallel, and some problems in speed of response and system reliability. The problems which have turned up thus far appear to be soluble in straightforward ways.

As was mentioned earlier, half of the core storage of the computer is devoted to system programs and tables which are always in core. The other half is again halved and the resulting blocks assigned to two categories of programs which are not always in core. About 2000 words are assigned to programs which occupy core for long periods of time such as the interpreter,
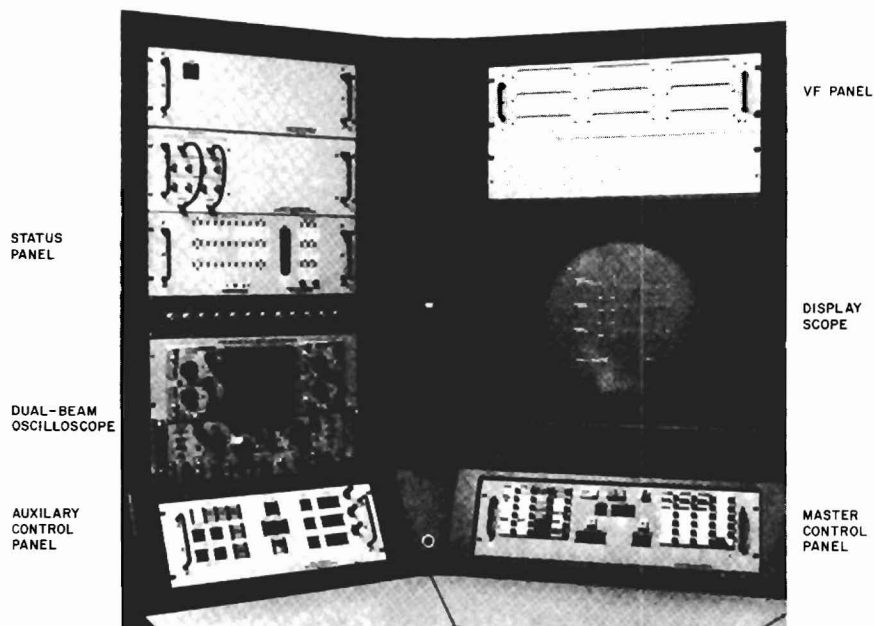
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STATUS
PANEL

DUAL-BEAM
OSCILLOSCOPE

AUXILARY
CONTROL
PANEL

VF PANEL

DISPLAY
SCOPE

MASTER
CONTROL
PANEL

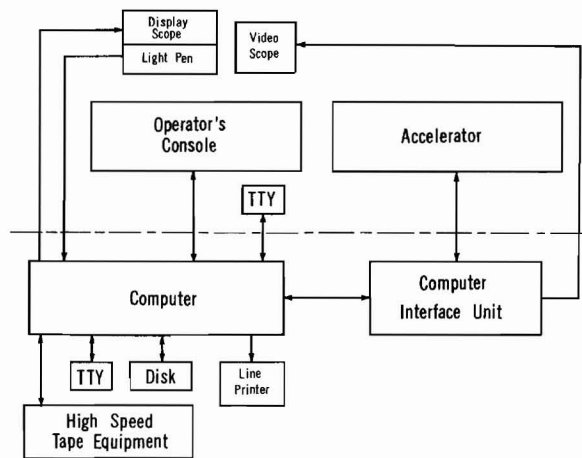Figure 1.   EPA Control Console

Figure 2.   EPA and Computer System. The accelerator operator is con-
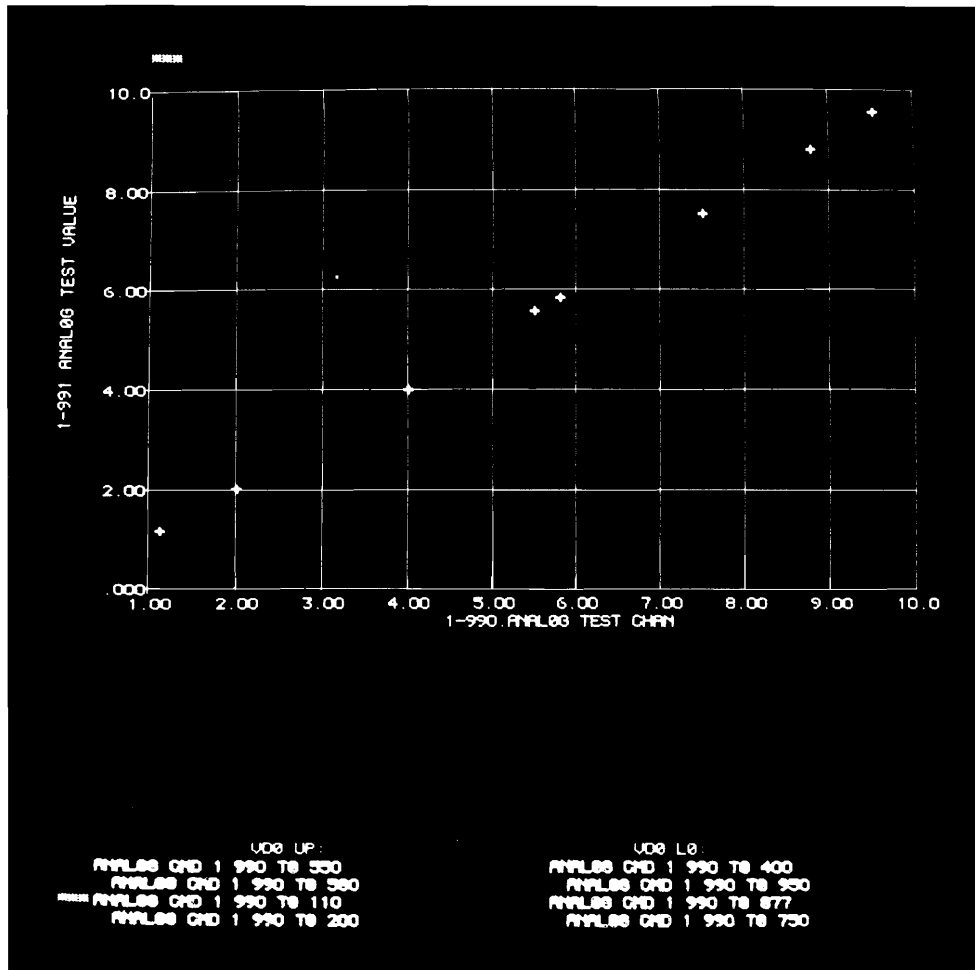cerned primarily with the units in the upper half of the
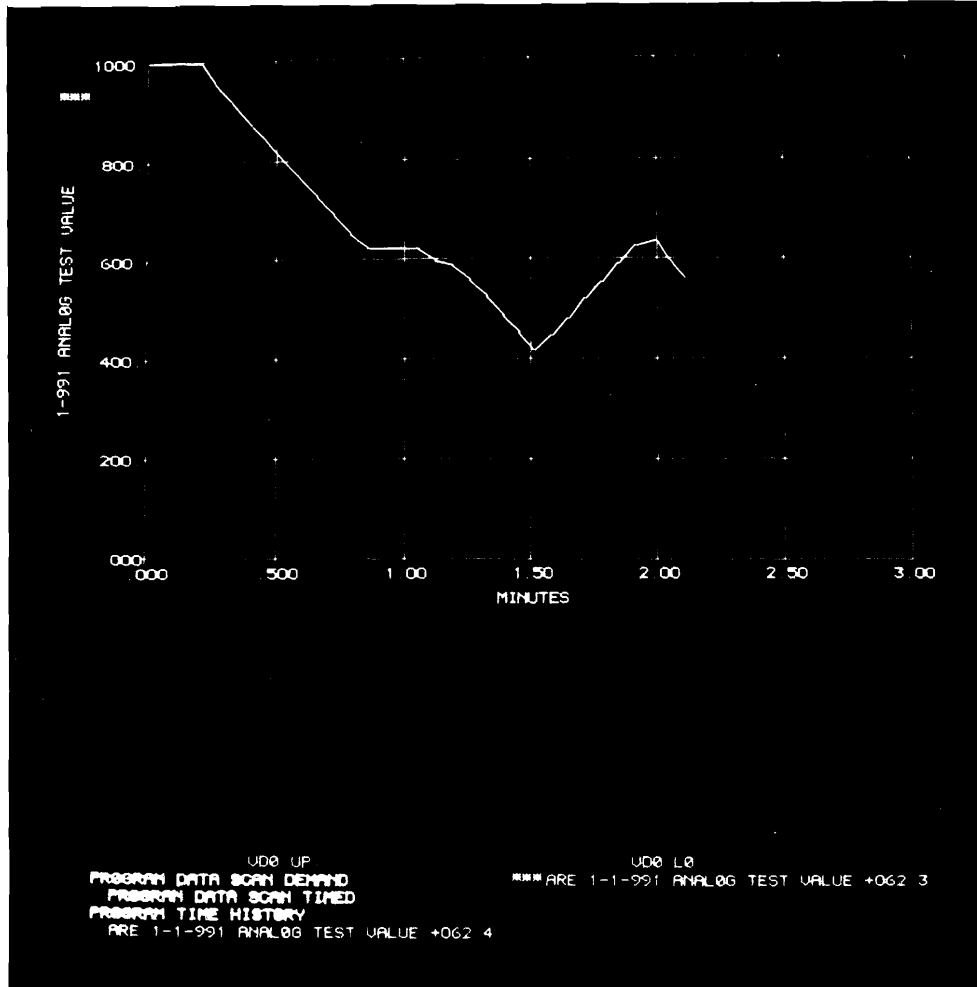drawing.

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Figure 3.   Vary Plot.

Figure 4.   Timeplot.

INTENSITY
FULL SCALE:
A   1   3   10   30 MA

30

*18.0
*10.8 *10.1 *09.0 *07.5   *06.7 *06.0
                                        ERR
1   3   5   7   9

EAST   1 CM

HORIZONTAL
POSITION   1   3   5   7   9

WEST   1 CM

UP   1 CM

VERTICAL
POSITION   1   3   5   7   9

DOWN   1 CM

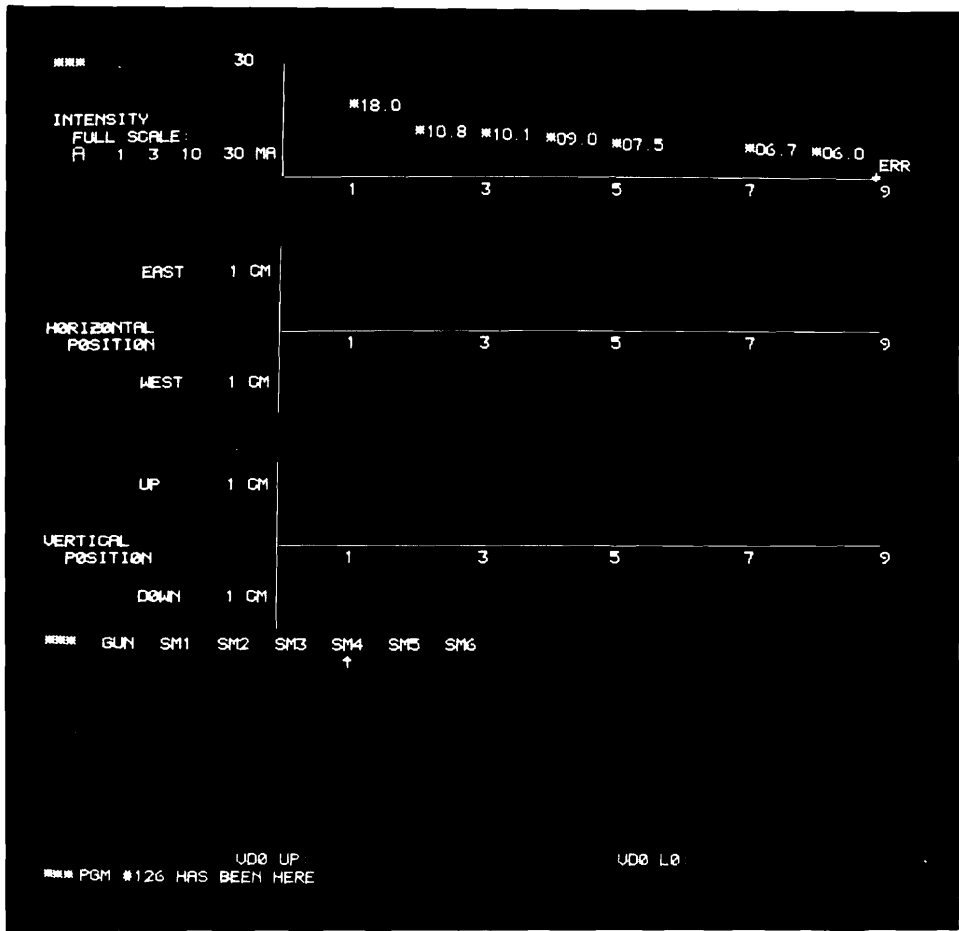GUN   SM1   SM2   SM3   SM4   SM5   SM6

VD0 UP   VD0 L0
PGM #126 HAS BEEN HERE

Figure 5.   Beamplot display.