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CONTROL AND MONITORING OF THE SLAC ACCELERATOR UTILIZING A PDP9 SYSTEM*

Warren C. Struven
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

A PDP9 system is being installed to supplement the manual controls and visual readout of the SLAC accelerator and to provide data logging from some 3000 points. Initially, malfunctioning klystrons will be sensed and suitable spares will be switched to multiple beams. Switching will be slow at first (up to 0.7 seconds) but a future parallel system will switch klystrons within one interpulse period (2.7 ms). Summarized data will be readout weekly or bi-weekly from the disk. Later, magnetic tape will be used to transfer data from the disk to an IBM 360-91 for extensive off-line data reduction. Beam steering, focusing and spectrum control will be implemented.

INTRODUCTION

The accelerator Central Control Room (CCR) contains all of the equipment to control and monitor the operation of the 10,000-foot SLAC accelerator. The accelerator proper is divided into an injector area and 30 nearly identical sectors. The control and monitoring systems are repeated for each of these 30 sectors and the injector area.

The accelerator control and monitoring concept is based primarily on manual controls, that is, the operations console contains clusters of control knobs, buttons, meter and status lights. Two operators can tune and operate up to 6 sequential electron beams using these instrument clusters. A limited number of accelerator systems are automatic in nature with manual initiation and override. Klystron phasing, modulator-klystron station operation, changeover to auxiliary units in the rf drive and trigger systems are examples. It is our intention not to replace manual controls with the computer system, rather we intend to supplement this mode of operation with specific computer performed chores.

PRESENT CONTROL AND MONITORING SYSTEM

Several types of control and monitoring systems are presently utilized by CCR. A relay switching remote control system (RCS)[1] permits CCR to access and operate up to 64 sector equipments. The system response time is approximately 1/2 s. A status monitoring system (MUX)[2] provides two-state monitoring of up to 156 signals in each sector. This system continuously scans and updates the information from each sector once every 850 ms. A dc meter system (Analog)[3] presents up to 20 signals from each sector. Each sector has beam focusing and steering equipment.[4] Steering controls are not multiplexed with other controls, however, steering currents are transmitted to CCR via the analog system. Steering currents are changed by applying pulses to sector stepping motors. Quadrupole magnet currents are controlled using the RCS and monitored by the analog system. A transmitted beam current signal (LIN Q)[5] is sent to CCR from each sector and displayed as a series of horizontal dots on CCR oscilloscopes. The signals are updated 360 times per second. The x and y position of the electron beam is determined at each sector and sent to CCR on a baseband transmission system. This information is also updated at a 360 cycle rate. One of the many jobs of the trigger system[6] is to provide a flexible means of determining which klystrons will contribute energy to one or more of the six beams. The allocation of klystrons to these beams is determined by the assignment of sector patterns in CCR. In addition, synchronizing pulses are supplied to the injector, rf drive system, and the data transmission system along the accelerator by the trigger system. A long ion chamber (PLIC)[7] consisting of a coaxial transmission line operated as an ion chamber extends the full length of the accelerator. This device provides a signal which indicates beam loss along the machine.

PDP9 SYSTEM

The accelerator PDP9 computer has an 8K core with the following options: Memory Parity, EAE, API, Memory Protection, Direct Memory Access Multiplexer (DMA), Input Multiplexer (DS01), Pulse Input Detector (DS04), 18-bit Output Relay Buffer (DR09), and a 10^6 word disk (RB09).

The input multiplexer is a direct interface between the accelerator status monitoring equipment, the analog system, and the computer, the 18-bit output relay buffer is the interface between the computer and the accelerator remote control system. The pulse input detector reads signals from pushbuttons located on the accelerator control console which are used by the operators to call specific programs.

COMPUTER ASSISTED OPERATION

The primary purposes of the computer will be to store and record the state of the accelerator, turn equipment on or off and to adjust analog levels to previously determined values. The system is arranged so that lists of values cannot be conveniently typed or read into the computer by paper tape. The operators will instruct the computer to use previously recorded data to setup a required operation, i.e., the operator-computer will be a learning system. The initial effort does not emphasize operational programs, rather we are providing a computer that is connected to most of the existing control and monitoring equipment. Programming to date has been confined to producing a main driver with "hooks" where specific subroutine may be attached. Operational programming will be specified by the needs of the machine operators. As the operators find the system useful, more operational subroutines will be written. Klystron replacement and quadrupole presetting, to be discussed later, are exercises to prove the interface. They have not been planned to be operationally useful. The computer will make new control methods possible, i.e., a button to initiate multiple functions throughout the machine, however, if the computer fails, the initiation of these

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functions will still be possible using the existing manual system. Remote control of the accelerator from a location other than CCR will be possible but only through a computer-computer link. At that time manual control of the accelerator will still be possible from CCR. The connection of a computer was made feasible because early designs of control and monitoring equipment anticipated this eventual use.

COMPUTER CONTROL

The computer will be programmed and hardware has been or will be interfaced to perform the following specific chores.

Status Logging

The computer is presented with status from 3000 two-state sources along the accelerator. A piece of the system program now reads in status information and compares it with previously stored information. If a change is detected, the teletype prints out the change (+ = increase, on or up; - = decrease, off or down), the sector number and the status monitoring channel number. This program has been used as part of the system checkout and is operationally useful only in a limited sense. An auxiliary program, however, has been written which types out columns and rows of "1" and "0" to represent the condition of the trigger pattern switches. In addition, the program also prints out a list of standby klystrons, and a list of klystrons which are not on. This program initiates a printout about every 8 hours which becomes part of the operations log.

Consideration is being given to preparing a more complete computer prepared log. Two possibilities exists: Store all status changes for an operating period and produce an edited copy upon demand, or select status changes of interest prior to storage. In either case, data would be stored on the 10^6 word disk and only edited material would be typed out.

We are considering the addition of an IBM compatible tape unit to our machine as a transfer medium to the SLAC 360-91 computer for extensive data reduction and printout. An edited log for an operating shift (8 hours) would be produced by the disk and teletype while accelerator operation statistics and analysis would be presented by the 360 system for a period of about a week.

Slow Klystron Replacement

The accelerator contains 245 modulator-klystron stations which can contribute energy to the beam. The assignment of these stations to one or more electron beams is determined by the required beam energies and maintenance status of klystron stations. Each klystron station has a local automatic control system[8] which suppresses the station in event of station faults. Some faults last less than 2 seconds after which the station automatically returns to usable or "accelerate" status. Other faults, which last longer than 2 seconds, require a "standby" station to be switched to "accelerate" status. The first chore of the computer is to replace faulted stations. The computer must sense the trigger patterns to find sectors which contain available spares. The computer also requires klystron station information from the status monitoring system and then must switch a station to "accelerate" or "standby" using the remote control system. Synchronizing of status monitoring "words" and program initiation is provided by a 360 pps trigger which is interfaced to the P.I. bus. This chore has been successfully demonstrated recently with replacement occurring in less than 2 seconds.

Quadrupole and Steering Setup

Beam focusing is accomplished by about 50 quadrupole doublets spaced along the accelerator. These focusing magnets are set to initial values as determined by the beam energy. The computer will sense quadrupole current via the analog system. These analog signals will be converted to digital format by a 8-or 12-bit A/D converter in CCR. When the remote control system selects a sector and channel, i.e., quadrupole control, a control bit will be set in the 18-bit output relay buffer which will connect the digitized quadrupole current to the input multiplexer. The computer then will automatically set each current to a prescribed value. A sector memory for the remote control system is now being designed which will store the quadrupole command and allow the computer, remote control and analog systems to quickly access all sectors. The response time of the remote control system is about 1/2 second, but it is estimated that a quadrupole command could be set into the sector memory and acknowledged in about 50μs thus allowing nearly simultaneous adjustment of all quadrupole doublets with a considerable saving in time.

Beam steering is performed by two sets of dipoles in each sector. Initial beam setup occurs with all steering currents set to zero. The final adjustment depends upon beam energies, accelerator alignment and klystron steering effects (which are variable) and is usually different than zero. The computer will set each steering dipole to zero prior to beam setup.

Millisecond Klystron Replacement Hardware

The accelerator contains two sectors of klystrons (sectors 27 and 28) where each klystron has individual trigger patterns and phasing controls. These sectors are presently used as fine energy verniers and occasionally to provide "accelerate" klystrons on various beams. If a pulse-to-pulse beam energy signal were available to the computer for each beam, klystrons in these sectors could be switched to "accelerate" or "standby" in one interpulse period (2.78 ms). The control signals for these klystrons are transmitted by direct wire pair thus not restricted by the slower remote control system. The computer would sense an energy change and switch a "fast" klystron to compensate for the change. This action would initiate a similar change in the "slow" klystron replacement system. When the "slow" system has responded, the "fast" system would revert to its previous condition thus assuring a nearly constant beam energy.

Steering and Focusing Optimization

After initial setup of the steering and focusing as described above, the electron beam is threaded from the injector through each sector toward the experimental area. Steering is done manually using x and y position indicators and ion chamber readings as monitors. Each operator has a favorite scheme to accomplish this task in the least possible time. In two years of operation a "best" method has never been agreed upon so it is unlikely that this operation will be computer optimized initially. Many variables in the first six sectors make this procedure nearly impossible to predict. Any focusing malfunction or modulator-klystron station outage changes the "recipe" radically. Furthermore, a quadrupole magnet will deflect the beam if the beam goes through the magnet off axis. The amount of steering is proportional to the magnet current, the amount the beam is off axis and to the beam energy. However, when a low loss beam is achieved or when the steering is compromised to transmit beams of widely different energies, the signal from the Long Ion Chamber could be used to pinpoint the beam loss and reduce this loss by a combination of resteering and refocusing in the area. This is a difficult correction to make because of the periodic nature of the accelerator beam transport system. Intuitive procedures have worked reasonably well using manual controls. This experience will allow us to modify a proposed theoretical approach to make it usable. Klystron stations are known to have steering effect which seem to be related to asymmetry in the microwave accelerating components. Several schemes have been proposed to correct this effect, none of which is thoroughly practical. Investigation of the cause is of primary importance and must be solved to make a klystron replacement system thoroughly operational. Resteering and refocusing can only be a partial correction at best.

Spectrum Control

Beam energy is now changed by making fine energy adjustments utilizing klystrons in sectors 27 and 28. One pair of klystrons is assigned to each beam and with the klystron complement adjusted about 1 klystron too high, the pair is dephased. The spectrum is displayed in CCR on an oscilloscope. The presentation is in bar graph format. Spectrum width can also be read on this bar graph and is adjusted by varying the rf phase of the injector for that beam. For computer control, this bar graph must be digitized and values derived which indicate that the beam is centered in the energy defining slit and that the amplitude of the signals from the side foils are minimized or are less than predetermined values. Suitable computer signals do not exist in CCR at this time either from the spectrum system or from the slits. In addition, steering changes at the entrance to the beam switchyard can cause the spectrum display to change and produce a false spectrum indication.

Klystron Phase Checking

The automatic klystron phasing system[9] has within its circuitry, provisions to inspect the phase of each klystron as well as to initiate phasing of selected klystrons in a sector. Video signals from this system are now transmitted to CCR via a video cable transmission system.[10] In the inspection mode, computer interpretation of these video signals would initiate rephasing of a klystron providing it is determined that the klystron station is in the "rf OK-standby" mode or that a substitution could be made. Alternately, the computer could be programmed to search through the machine and phase all newly available klystrons (those recently returned to operational status). A later version of this program might make periodic replacements and rephase portions of the accelerator upon demand. An interface device to digitize these video signals is the only hardware required. Control of the video cable switching is accomplished by using the present remote control system.

SOFTWARE SYSTEM

We wish to extend the computer tasks to an ever-increasing set of accelerator parameters. The design of the system monitor reflects this "open ended" requirement. By interpreting the available inputs and other data, the system monitor creates or detects certain status or circumstances. When one occurs, it executes subroutines (using XCT) stored in a predetermined set of slots located in a fixed area of memory. The user connects his special program by putting a JMS (USER program) into the appropriate slot. Empty slots are filled with NOPS. Examples of circumstances for which there are slots at present are:

- a change of accelerator status has occurred (change in Ac.)
- end of accelerator status signal scan has been reached
- a change in accelerator pattern switches has occurred (change in Ac.)
- ready to process a subprogram from the background queue
- a 2.8 ms clock interrupt has occurred

Because our monitor has many accelerator-oriented features built into it (e.g., we use the SLAC 360 cycle timing pulse rather than the PDP9 real time clock), we have decided not to embed our operational system in the framework of DEC's disk monitor. We are rewriting necessary subprograms required to drive the I/0 etc., tailored to our applications. The DEC disk monitor will be used solely for program development.

DISK

The disk in our system serves 3 main functions.

1. DEC disk monitor storage.
2. Storage area for run-time logging of data. The data will be processed by either the PDP9 or, by the SLAC central computer, an IBM 360-91.
3. Storage for overlay segments of the run-time system. At present all of the programs fit in our 8K memory. However, a simple overlay scheme will be necessary in the future. We plan to have a 4K resident portion and many 1K segments on the disk competing for the remaining four 1K blocks of memory. The operator will, in essence, control which segments are in core by specifying which jobs are to be done. For example, if he wants to "steer" the electron beam through the narrow aperture of the accelerator, he selects "steer" which will cause that segment to be loaded into core.

DIAGNOSTIC PROGRAMS

As interface hardware is developed, an attempt has been made to write diagnostic programs to facilitate initial checkout and to troubleshoot later failures. The program format is similar to that developed by DEC so that a faulty operation which causes a program halt can be looked up in an annotated listing. In general, each program loops back to the beginning and runs until halted by the operator. These programs fall into two categories: One, to check a complete command — monitoring loop and two, to check selected pieces of interface equipment. In future programming, these two categories may be combined so that accumulator switches can select part or all of each program. The programs are on paper tape at present and will probably continue to be punched on tape until faster access is required. At that time we will decide whether to put them on the disk or to allocate one magnetic tape reel to diagnostic routines. A list of programs at this time follows.

1. Trigger (pattern) switch — input multiplexer test. A program which tests for shorts or opens in the pattern switch — diode selection matrix. The output is printed by the teletype in a column/row configuration which physically follows the panel switch layout. The program takes two passes, one with all switches closed and a second with all switches open. The printout allows immediate determination of open or short conditions.
2. Status printout. This program is part of the main system program to read the changes of status from

the accelerator. Several options are available:

a) Filter out a status channel from all 30 sectors.

b) Filter out all status channels from a selected sector.

c) Filter out all status channels from a group of sectors.

3. 360 pps synch test. This program checks all of the logic functions in the circuit which converts the local 360 pps trigger to a program interrupt bus signal.

4. Remote control — status monitoring loop test. A non-interfering test which commands a control change in each sector and checks to see that the computer received that status change. This test can loop continually through sectors 1-30. Commands are issued about every three seconds to facilitate visual observation of status or scope indications within the loop.

5. Pushbutton input test. A test program which reads the program initiation command buttons signals to the computer via the pulse input detector (DS04 option). This test checks the diode matrix, buttons and DS04. Results are printed out on the teletype.

6. Remote control — analog loop test. This program will issue a command to equipment in each sector which will respond with a change in analog value. The change will be recognized by the computer and the program will repeat in each adjacent sector. This test will be non-interfering with respect to accelerator operation and therefore may be run during operational period if required.

FUTURE PLANS

All of the chores discussed so far are or will probably be in operation within the next year. The chores have been listed in an approximate priority. Probable expansion of the system beyond that capability may include the following:

1. Additional 8K core to facilitate automatic steering, spectrum control, beam setup and on-line programming. More core will reduce the access time to programs stored on the disk.
2. Addition of a line printer to produce annotated listings and more rapid printout.
3. Development of a 360-91: PDP9 assembler program to facilitate offline assembly.
4. Fast multiplexing of sector analog data from pulsed steering magnets, pulsed quadrupoles, pulsed beam loading and perhaps a sector oriented pattern system to replace the present CCR system.[11] "Pulsed" here implies that these beam guidance systems will respond to each sequential electron beam with unique preset values thus greatly reducing the beam interaction now present in the dc system.

ACKNOWLEDGEMENTS

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REFERENCES

1. R. B. Neal, Editor, The Stanford Two-Mile Accelerator, (W. A. Benjamin, New York, 1968); pp. 533-534, and Fig. 1.
2. Ibid., pp. 529-532, and Fig. 2.
3. Ibid., pp. 534-536.
4. Ibid., pp. 517-520, and Fig. 3.
5. Ibid., p. 513.
6. Ibid., p. 463.
7. Ibid., pp. 814-817.
8. Ibid., pp. 496-500.
9. Ibid., pp. 383-408.
10. Ibid., pp. 536-538.
11. See Fig. 4.

FIGURE CAPTIONS

1. Remote control system block diagram.
2. Status monitoring system block diagram.
3. Block diagram of beam monitor system.
4. Beam monitoring block diagram.

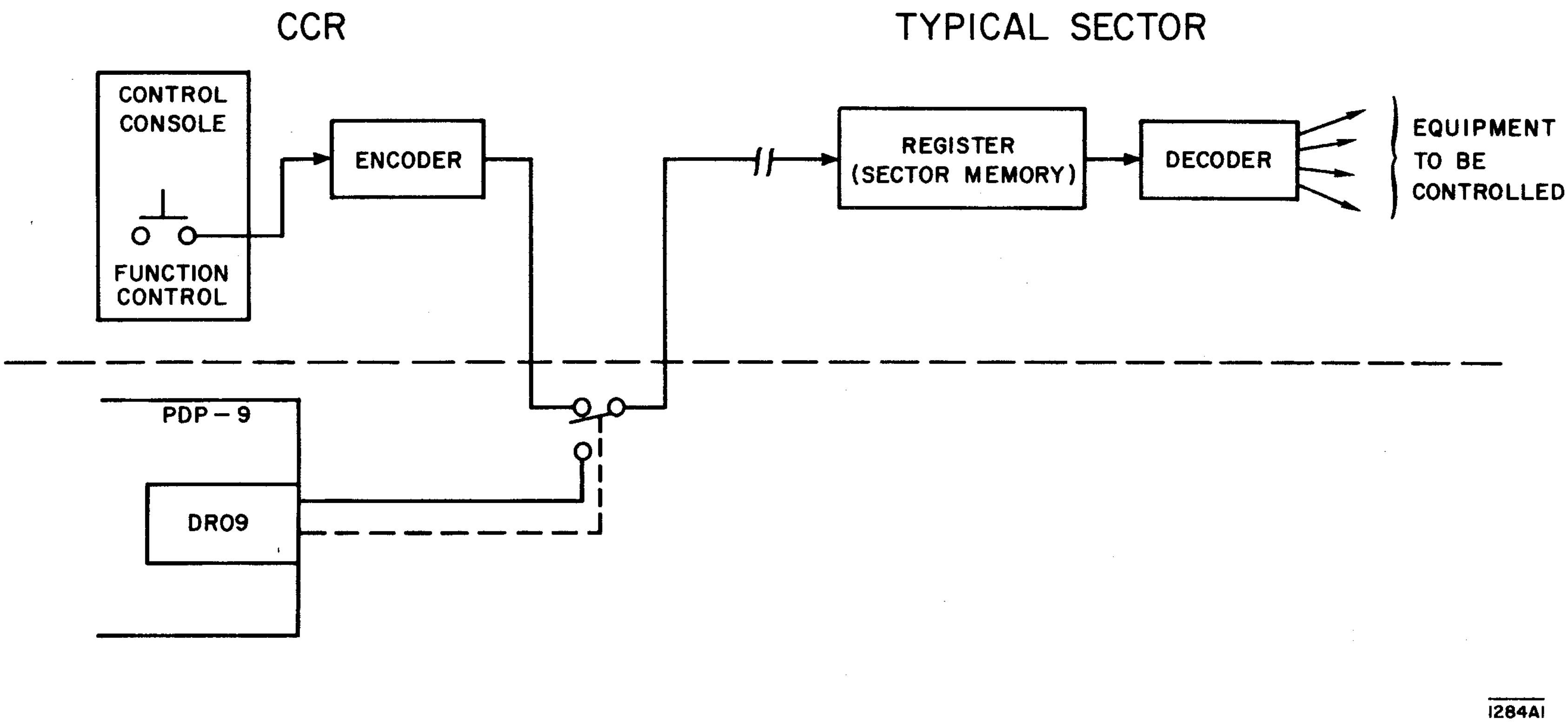
CCR
TYPICAL SECTOR
CONTROL CONSOLE
FUNCTION CONTROL
ENCODER
REGISTER (SECTOR MEMORY)
DECODER
EQUIPMENT TO BE CONTROLLED
PDP-9
DR09
1284A1

Fig. 1

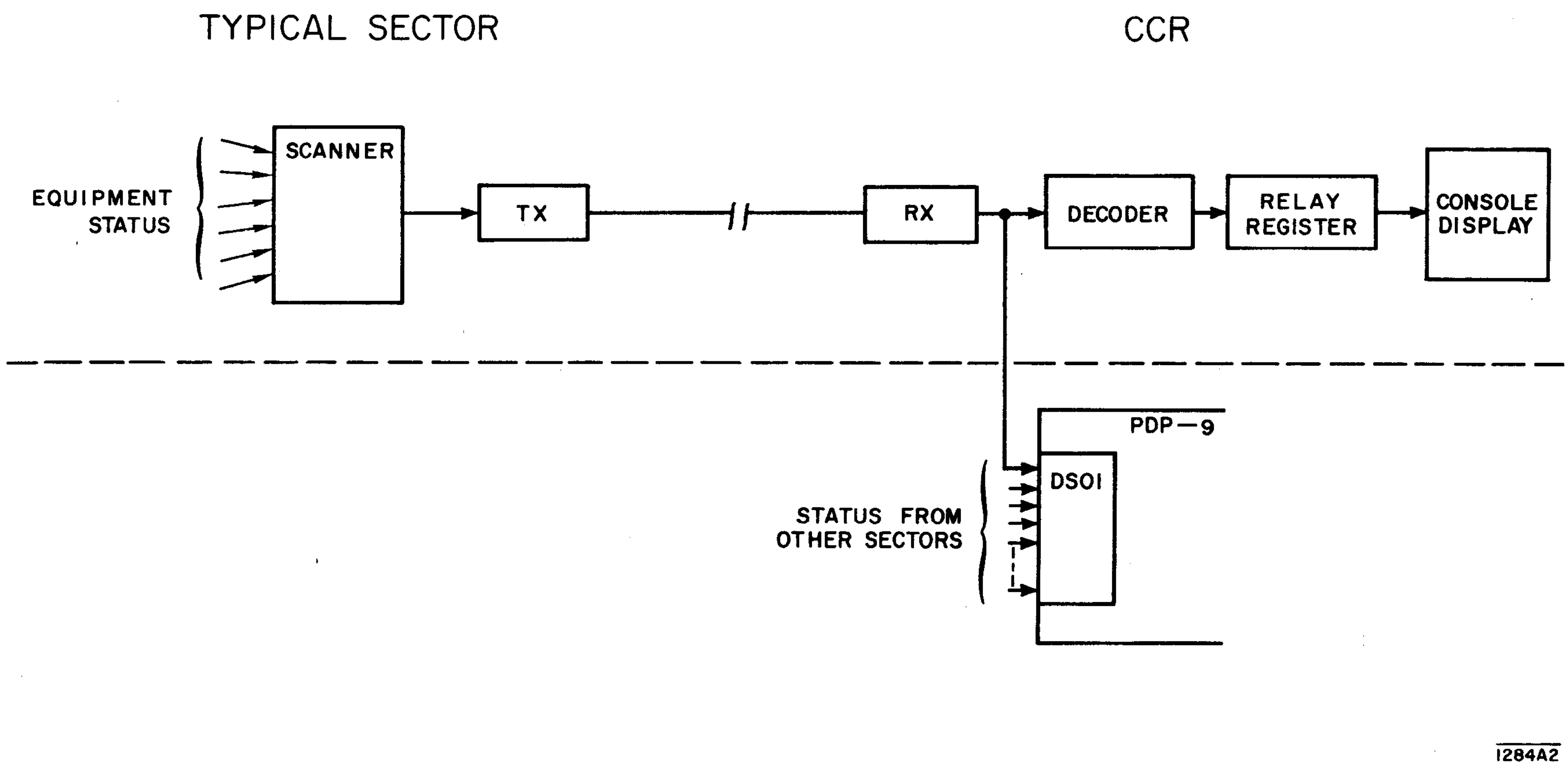
TYPICAL SECTOR
CCR
EQUIPMENT STATUS
SCANNER
TX
RX
DECODER
RELAY REGISTER
CONSOLE DISPLAY
PDP—9
DSOI
STATUS FROM OTHER SECTORS
1284A2

Fig. 2

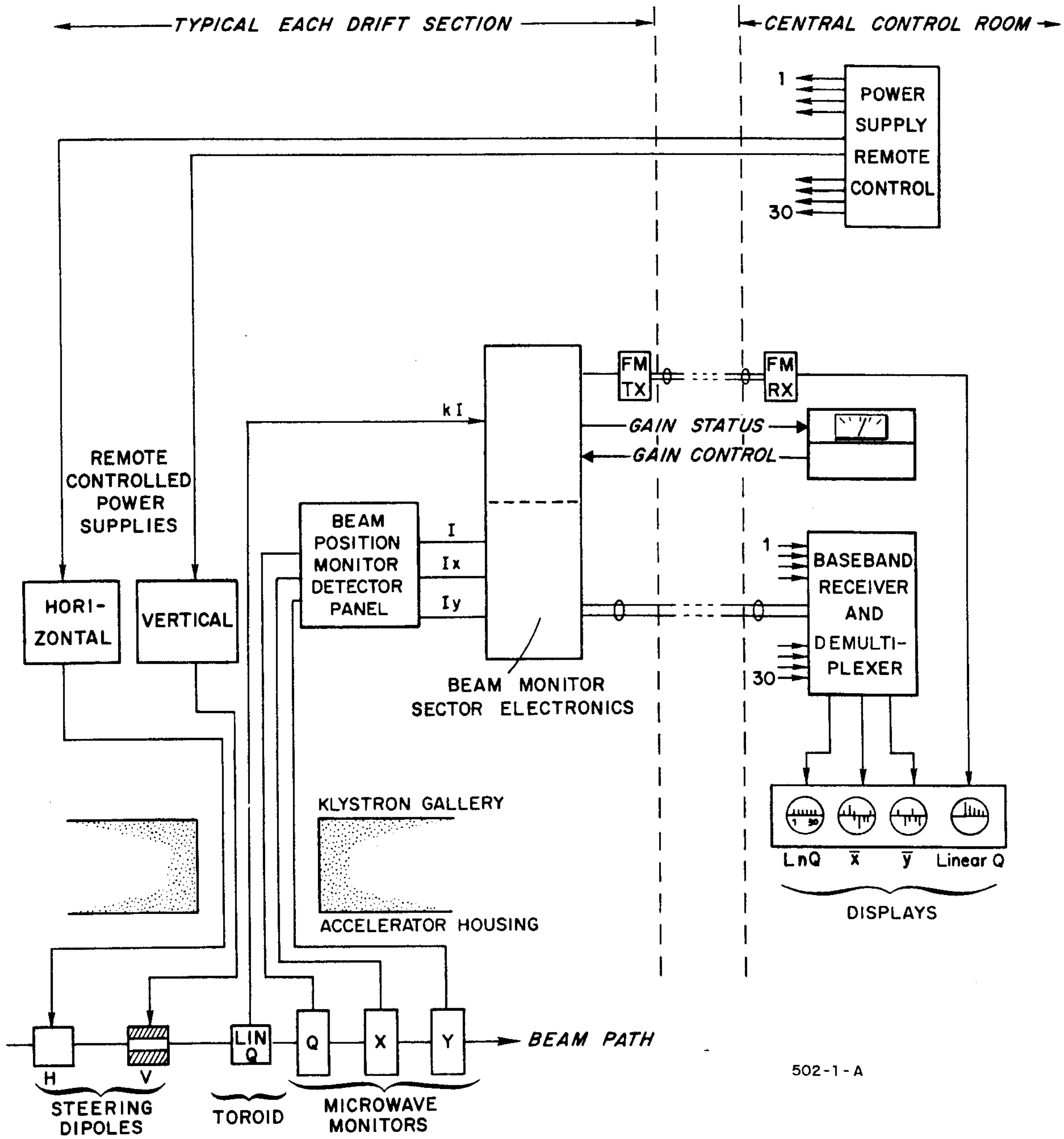
TYPICAL EACH DRIFT SECTION
CENTRAL CONTROL ROOM
1
POWER SUPPLY REMOTE CONTROL
30
FM TX
FM RX
kI
GAIN STATUS
GAIN CONTROL
REMOTE CONTROLLED POWER SUPPLIES
BEAM POSITION MONITOR DETECTOR PANEL
I
Ix
Iy
1
BASEBAND RECEIVER AND DEMULTI-PLEXER
30
HORI-ZONTAL
VERTICAL
BEAM MONITOR SECTOR ELECTRONICS
KLYSTRON GALLERY
ACCELERATOR HOUSING
LnQ
x̄
ȳ
Linear Q
DISPLAYS
H
V
LIN Q
Q
X
Y
BEAM PATH
STEERING DIPOLES
TOROID
MICROWAVE MONITORS
502-1-A

Fig. 3

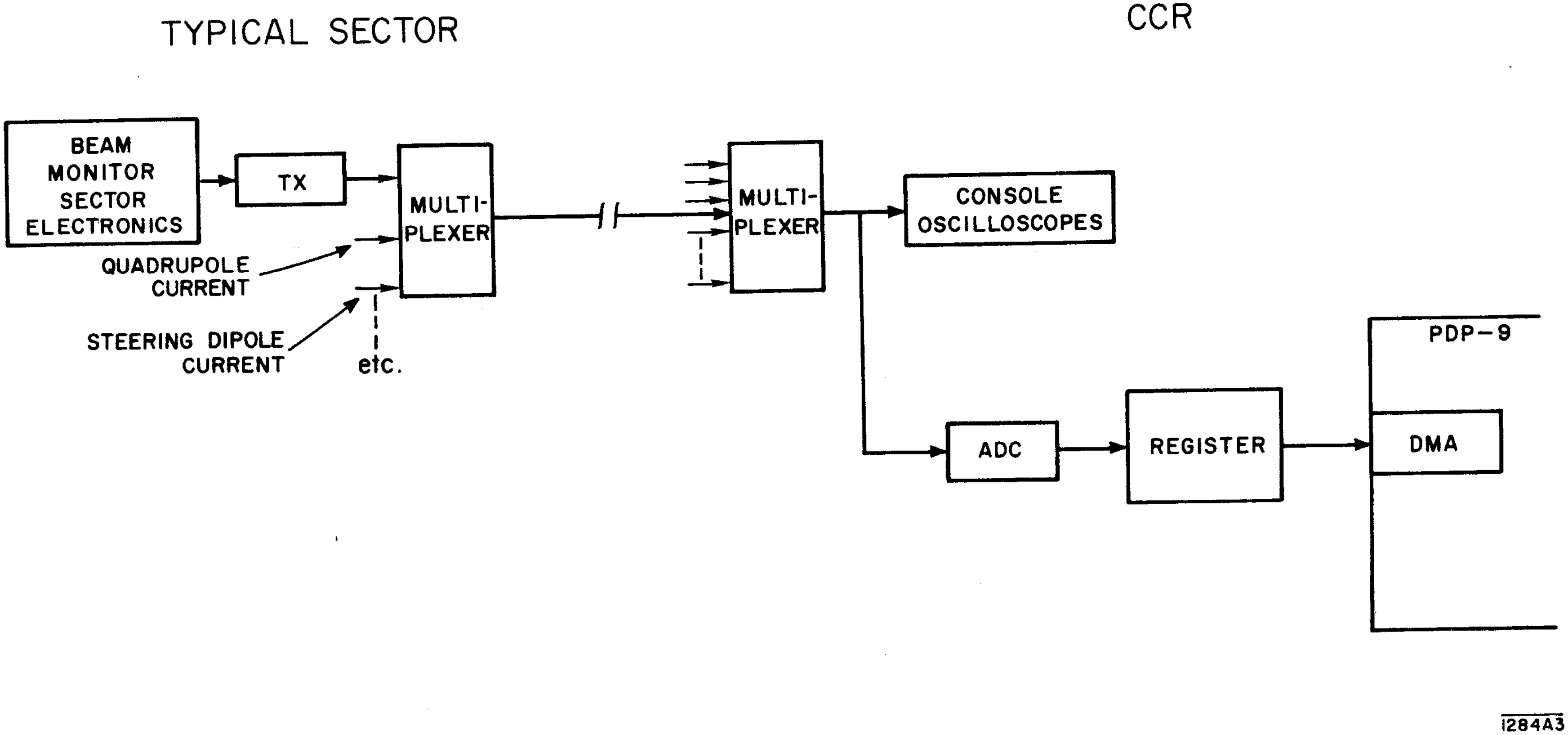
TYPICAL SECTOR
CCR
BEAM MONITOR SECTOR ELECTRONICS
TX
MULTI-PLEXER
QUADRUPOLE CURRENT
STEERING DIPOLE CURRENT
etc.
MULTI-PLEXER
CONSOLE OSCILLOSCOPES
PDP-9
ADC
REGISTER
DMA
1284A3

Fig. 4