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PEP COMPUTER CONTROL SYSTEM*

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Introduction

This paper describes the design and performance of the computer system that will be used to control and monitor the PEP storage ring. Since the design is essentially complete and much of the system is operational, we will describe the system as we expect it to exist by the scheduled completion date of October 1, 1979. Section 1 of the paper describes the system hardware which includes the computer network, the CAMAC data I/O system, and the operator control consoles. Section 2 describes a collection of routines that provide general services to applications programs. These services include a graphics package, data base and data I/O programs, and a "director" program for use in operator communication. Section 3 describes a collection of automatic and semi-automatic control programs, known as SCORE, that contain mathematical models of the ring lattice and are used to determine in real-time stable paths for changing beam configuration and energy and for orbit correction. Section 4 will describe a collection of programs, known as CALI, that are used for calibration of ring elements. A class of programs that provide the usual manual "look and adjust" type monitoring and control functions will exist at PEP but will not be described since their operation is similar to programs providing such functions in most large accelerators.

1. The Computer Equipment

The PEP computer system (see Fig. 1) will contain a network of 10 ModComp computers. The ring will be controlled from four operator control stations interfaced to the MCIV central control computer which is connected via high speed (500 kilo-baud) serial links to 8 MCII remote computers as well as a second MCIV that serves as the central secondary computer. The MCII remote computers are interfaced to a total of 45 CAMAC crates via high speed (1 mega-baud) Synchronous Data Link Control (SDLC) serial links.

The two central computers are essentially identical— they contain the same amount of memory and their primary peripherals are the same. By using 3 manual bus switches, the two CPU's or the two sets of peripherals may be interchanged to provide backup in the event of hardware failure.

The central control computer will provide the following functions: communication with the operator consoles; data I/O capability through the remote computers; "downloading" programs for the remote computers; mass storage for all computers in the system; collection and logging of all system error messages; execution of "look and adjust" control and monitor programs. The central secondary computer will execute the SCORE programs when required by ring operation and will be used for program development at other times.

The remote computers will primarily serve as data I/O concentrators. Six of the computers will be located in the six equipment support buildings distributed around the ring, one computer is located in the injection equipment support area, and one will be used as a spare and for program development. Initially, these computers will not have any significant local control algorithms. However, as the total system grows, the unused capability of these computers may be used to reduce the computational load of the central control computer.

The remote computers are interfaced to the ring devices through a high speed CAMAC system which provices a serial communication link that uses the Direct Memory Access (DMA) capability of the MCII's. The

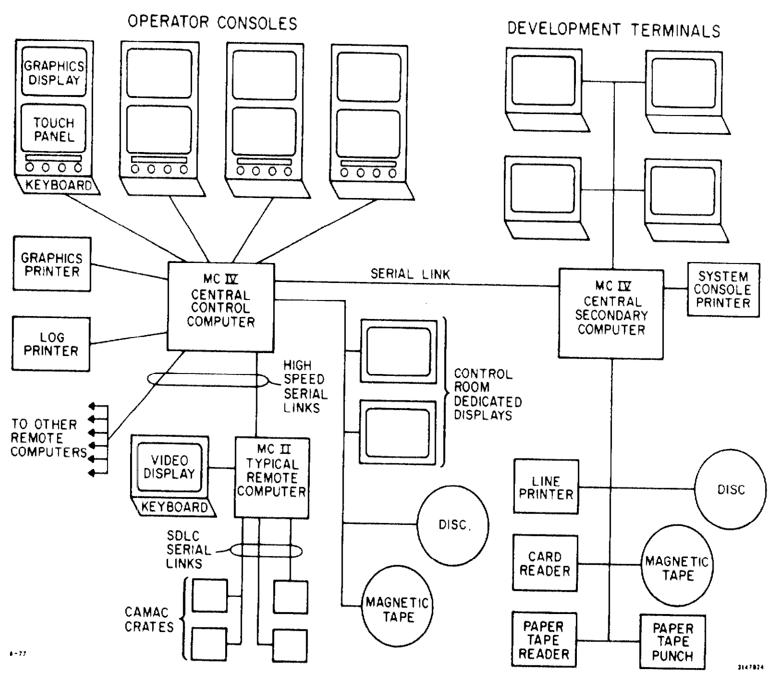

Fig. 1. PEP computer control system.

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CAMAC crates are physically located near the equipment to which they are connected. Most interface requirements for the ~10,000 signals in the system are satisfied by five basic modules: a 16 channel 12-bit analog monitoring module; a 8 channel 12-bit analog control module; a 16-channel latched relay module; a 16-channel pulsed relay module; and a 16-channel opto-isolated digital monitoring module.

Microprocessor based controllers for the CAMAC crates and SDLC serial links have been developed for PEP. Tasks in the remote computers communicate with the crate controllers by means of messages describing CAMAC actions to be performed. The crate controllers are designed to quickly execute lists of random CAMAC commands. By using these features, it is possible to collect input data or to provide output data at the rate of 3 ms of overhead for the message transaction plus 40 μs per CAMAC command. Since the crates may be located as far as 1000 feet from the remote computers, a local RS-232 terminal port is provided at the crate controller to allow maintenance personnel to communicate with the controller and the I/O modules in the crate.

The four operator consoles each contain the following equipment: a 512 element by 256 line eight-color full-graphics raster-scan CRT display; a 512×512 monochrome full-graphics raster-scan CRT display with an integral tough panel having the capability of providing an 8 by 8 matrix of touch buttons; an alphanumeric keyboard; and 4 incrementally encoded general purpose slew knobs, each with its own 15 character plasma display. The operator will be able to perform the following functions through the use of the touch panels: the selection of displays to be presented on the CRT's; the assignment of slew knobs to the set point control of specific signals; the binary control (on/off, in/out, etc.) of specific signals; the initiation of control algorithms; and the selection of other touch panels.

2. Applications Support Routines

The routines described in this section provide a systematic and convenient method for FORTRAN application programs to communicate with the ring operators, to perform data I/O functions, and to communicate with other applications programs.

The PEP data base routines provide a means for application programs to be written without detailed knowledge about the memory or CAMAC location of the signals of interest, the units associated with the signals, or their conversion factors. Instead this information is maintained on a common disk oriented data base which provides one disk sector for each signal in the PEP system. The creation of this data base begins with a tree-structured description of the approximately 10,000 PEP data signals. The following excerpt from that description defines 1080 signals associated with vacuum ion-pump power supply chassis:

V = vacuum signals in regions = 2,4,6,8,10,12

Each V has 15 supply chassis (VS)
Each VS has: class DM on/off monitor

Each VS has 3 channels representing ion pumps (VSP)
Each VSP has: class DM on/off status
class DC pulsed on-control
class DC pulsed off-control
class DV pump current I

A computer program expands the tree description and assigns a unique signal name and disk sector to each signal. The name is formed by a combination of letters and indices. For instance, "V6S2P3/DC1" refers to the first digital control (DC) signal for the third pump supply chassis in the region 6 equipment support building. A group of signals may be named by omitting indices. For example, V6SP/DC1 refers to the first dc signal for all pumps in region 6 and VSP/DC1 refers to the first dc signal for all pumps in the ring. The structured signal names provide an efficient way for programs to access data, but because they are not sufficiently mnemonic for operator use, a "display name" is provided as a data base attribute for each signal.

The data base structure has been extended to include calculated quantities. Applications programs may read/write information to/from the disk by using structured names similar to the structured signal names described above. In this case the indices can be used to denote physical region, e^+/e^-, or horizontal/vertical. This concept is very useful since programs that operate on this data need not be concerned with its origin. For example, real or simulated data may be stored on the disk by other programs.

An important criterion for any large signal data base is that the data for signal names can be quickly located. This is accomplished by preprocessing the tree-structured signal list to form tables and lists which can be used to quickly compute signal locations.

Data monitoring functions for the ring are performed by a program with an initialization phase that searches through the disk data to form lists of CAMAC commands associated with all of the monitored signals for each CAMAC crate in the system. These named lists are transferred to their respective CAMAC crate controllers. In normal operation, the remote computers continuously collect data from their respective CAMAC crates and forward the refreshed data to the central control computer. The central control computer maintains a copy of the lastest data for each signal in its core memory. Applications tasks can access data by providing signal identifiers (SID's) which are offset pointers into the data arrays in the Central Control Computers. A subroutine is provided that quickly converts signal names to SID's using tables created by the tree-structured signal list pre-processor.

Applications programs can output data to digital CAMAC modules by supplying SID's and data to the data I/O routines. That information is then transmitted to the remote computers which use the SID's to find the appropriate CAMAC commands from previously initialized tables. The remote computers then send messages to the appropriate crate controllers which execute the CAMAC commands.

There are two forms of analog control available to applications programs, direct and ramped. For direct analog control (AC), the applications programs supply the SID's and data values. This information is transmitted to the remote computer which updates the data values in a table contained in its memory and then sends the table of values to the AC CAMAC modules.

Ramped analog control is used to change a group of setpoints simultaneously. The user supplies the end point value of each signal to be changed and a maximum step size. The system computes an increment value for each signal which will cause all signals to reach their end-point values after the same number of steps. A common interrupt pulser is used to synchronize ramping activity in all remote computers.

The Director program provides application program communications with the PEP operators through the touch panels and slew knobs and provides communication with other programs. The structure and operation of the touch panels is defined by an object code created by a touch panel compiler that executes on SLAC's Triplex central computing facility. This compiler allows the specifications of the location of a button, its title, and the actions to be taken when it is touched by an operator. The following actions may be defined: a specified program may be initiated or or terminated; specified data may be sent to a specified signal; a slew knob may be attached to a signal; an "event" may be declared which can be used to notify programs that the button has been activated; another touch panel may be activated. The compiler also makes it possible to display specified data signals. The Director allows any program to simulate operator actions and it also provides a flexible method for program to program communications by allowing several methods for enqueing/dequeing arbitrarily named messages to/from a common message pool.

Primary graphics support for the full graphics CRT's has been provided by modifying the Unified Graphics[1] and Handypak[2] packages, originally written for the SLAC "Triplex" central computing facility, for use on the MCIV in conjunction with the PEP graphics hardware. Having graphics "calls" compatible with the Triplex system has proven useful because most applications programs have been developed more conveniently using WYLBUR and then moved to the MCIV's by use of a RS-232 serial link.

3. Score

The Score programs are a collection of mathematical models representing the ring lattice. These models are used to compute the strengths of the ring elements which can be divided into two groups depending on the strength of the element is adjusted (A) automatically or (B) semi-automatically. For the elements in group (A) the computed strength is the only solution possible so that the power supply can be set to the computed setpoint value immediately and automatically. For the elements in group (B) there is more than one possible solution so that the operator must make a decision on the accepted solution before the power supply setpoint values can be changed. The elements in group (A) are the bending magnets, quadrupole magnets and sextupole magnets; those in group (B) are the orbit correctors, skew quadrupole magnets, wiggler magnets and rf cavities.

In the operation of PEP, it is often necessary to change the lattice configuration as defined by the value of the betatron numbers ν_x, ν_y, the betatron functions β_x, β_y, the dispersion function η at the interaction points, and the beam energy E. In order to change from one operating point to another without beam loss, the changes must be made in sufficiently small increments. Each incremental configuration change and energy change is called a ministep. The allowable ministep size and the strength of the bending magnets and the quadrupole magnets are determined by the program QUADS[3] as follows. The incremental change in the quadrupole magnet strengths for a given ministep change in the values of ν_x, ν_y, β_x, β_y, and η is found using Newton's method by solving a set of linear equations. The ministep size is adjusted until a linear solution is found that satisfies a set of specified tolerances. This method has been found to work exceedingly well while keeping online computation to a minimum. The sextupole magnet strengths are computed as follows. Sextupole solutions which compensated both linear and nonlinear effects for some typical lattice configurations were obtained offline using the program HARMON.[4] These solutions and their corresponding lattice solutions are stored as standard solutions. For small changes in the values of ν_x, ν_y, β_x, β_y and η from the standard values, it is very simple to find the changes in the sextupole magnet strengths which will compensate only the linear chromaticities by grouping the sextupole magnets into two sets and assuming that all of the magnets in each set are scaled by the same factor. The values of the two scaling factors can be obtained by solving two linear equations. It has been found by the offline particle tracking program PATRICIA[5] that these approximate solutions are adequate over the typical range of lattice changes to be expected. The typical time required to compute a ministep is 1 s.

An example of semi-automatic control is orbit correction. Closed orbit deviations will be measured at the beam position monitors around the ring. Both rms and local orbit corrections will be calculated by the program PEPORB.[6] The rms scheme calculates the strength of a set of n correctors up to a maximum of 48 which minimizes the rms value of the residual orbit. The residual orbit is equal to the sum of the measured orbit and the orbit change due to the corrections. Since the solution depends upon n, the number of correctors, the operator must decide which of the 48 possible solutions is the best before the setpoint values of the correctors can be changed. The offset and slope of the beam closed orbit at any interaction point can be estimated from the measured orbit at the interaction region. The local correction scheme can be used to change the values of the offset and slope by using the 4 correctors nearest the interaction point. Only the orbit within the 4 correctors is affected by the scheme. It is also possible to take into account the RF distribution effect upon the observed horizontal orbit in both correction schemes. The computation time required varies with the number of correctors n and for 48 correctors is approximately 1 minute.

4. CALI

CALI is a collection of programs which contain the calibration models for all of the ring elements. All input and output data for CALI resides in the calculational data base described in Section 2. It converts the strength values of the bending magnet, quadrupole magnets, ... given in units of kg, kg/m, ... respectively, to the setpoint values of the control devices in unit of volts. In addition, magnet standardization is done by CALI. Since the calibration of magnets is affected by hysteresis, the same method of standardization used in the magnetic measurement and calibration is used in CALI.

The output from the monitoring devices such as transductors for the magnet current and position monitors are interpreted in CALI.

The same mathematical formulation is used for all of the position monitors. A constant correction is assigned to each position monitor to take care of the difference from the measured calibration.

Summary

Experience has shown that it is very useful to provide a comprehensive set of utility routines that can be shared among application programs. A great deal of effort has been devoted to designing and implementing these routines such that they are easy to use and efficient in terms of both memory and time utilization. Further, these routines assist in creating a modular and uniform system which aids in the checkout and maintenance and provides a pattern for orderly growth.

Acknowledgments

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REFERENCES

1. R. C. Beach, "The SLAC Unified Graphics System Programming Manual," Stanford Linear Accelerator Center report CGTM #170 (1976).

2. C. A. Logg, A. M. Boyarski, A. J. Cook, and R.L.A. Cottrell, "DPAK and HPAK— A Versatile Display and Histogramming Package," Stanford Linear Accelerator Center report SLAC-196 (1976).

3. A. S. King and M. J. Lee, Stanford Linear Accelerator Center internal note PEP-262.

4. M.H.R. Donald, P. L. Morton, and H. Weidemann, "Chromaticity Correction in Large Storage Rings," IEEE Trans. Nucl. Sci. NS-24, 1200-1202 (1977).

5. H. Weidemann, Stanford Linear Accelerator Center internal note PEP-220.

6. E. Close, M. Cornacchia, A. S. King, and M. J. Lee, "A Proposed Orbit and Vertical Correction System for PEP," these proceedings.

7. P. A. Belshe, V. P. Elisher, and V. Jacobson, "The Feasibility and Advantages of Commerical Process I/O Systems for Accelerator Control," IEEE Trans. Nucl. Sci. NS-22, 1036-1041 (1975).

8. A. M. Boyarski, A. S. King, M. J. Lee, J. R. Rees, and N. Spencer, "Automatic Control Program for SPEAR," IEEE Trans. Nucl. Sci. NS-20, 580-583 (1973).

9. S. Howry, R. Johnson, J. Piccioni, and V. Waithman, "SLAC Control Room Consolidation— Software Aspects," IEEE Trans. Nucl. Sci. NS-18, 403-303 (1971).