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THE PEP INSTRUMENTATION AND CONTROL SYSTEM*)

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ABSTRACT

This paper describes the operating characteristics of the primary components that form the PEP Instrumentation and Control System. Descriptions are provided for the computer control system, beam monitors, and other support systems.

1. INTRODUCTION

This paper will describe the operation and performance of the main components of the PEP Instrumentation and Control (I&C) System. The PEP ring has been operational since April, 1980, so all of the systems described here are operational except where explicitly stated.

Most of the I&C system equipment for PEP is distributed in six support areas (See Fig. 1), equally spaced around the 2200 meter circumference ring, and a seventh area near the entry point of the injection lines. The placement of electronic equipment in the ring tunnel was minimized so all beamline sensors and control elements are hardwired to the nearest support area. All relevent control and monitoring signals associated with the system are either sent through computer links or through a relatively small hardwired cable plant to the PEP Control Room (PCR) which is located in the same building as the Region 8 support area. All of the normal ring control and monitoring operations are conducted from the PCR main console area shown in Fig. 2.

Section 2 of this paper describes the system architecture, interface hardware design and applications support software associated with the computer control system. Section 3 describes the computer control and monitoring of the power supply, RF and vacuum systems. Section 4 describes the operation of the beam monitors, and Section 5 provides a brief description of the timing, communications, and personnel protection systems.

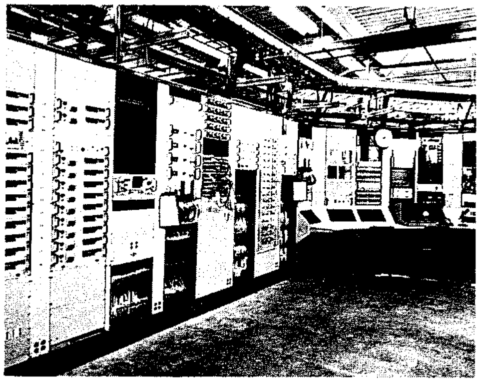

Fig. 1. A photograph of a typical PEP Instrumentation and Control equipment area.

Fig. 2. The PEP main console area located in the PEP Control Room (PCR).

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2. THE COMPUTER CONTROL SYSTEM

2.1. System Architecture

A block diagram of the computer control system is shown in Fig. 3. It contains a network of 10 ModComp computers and one Digital Equipment Corp. (DEC) PDP 11/780 (VAX) computer. The MCIV central computer is attached to a single operator control console, and is connected via high speed (500 kilo-baud) serial links to 9 MCII remote computers as well as the MCIV central secondary computer. The MCII remote computers are interfaced to a total of 50 CAMAC crates via high speed (1 mega-baud) serial links based on Synchro-

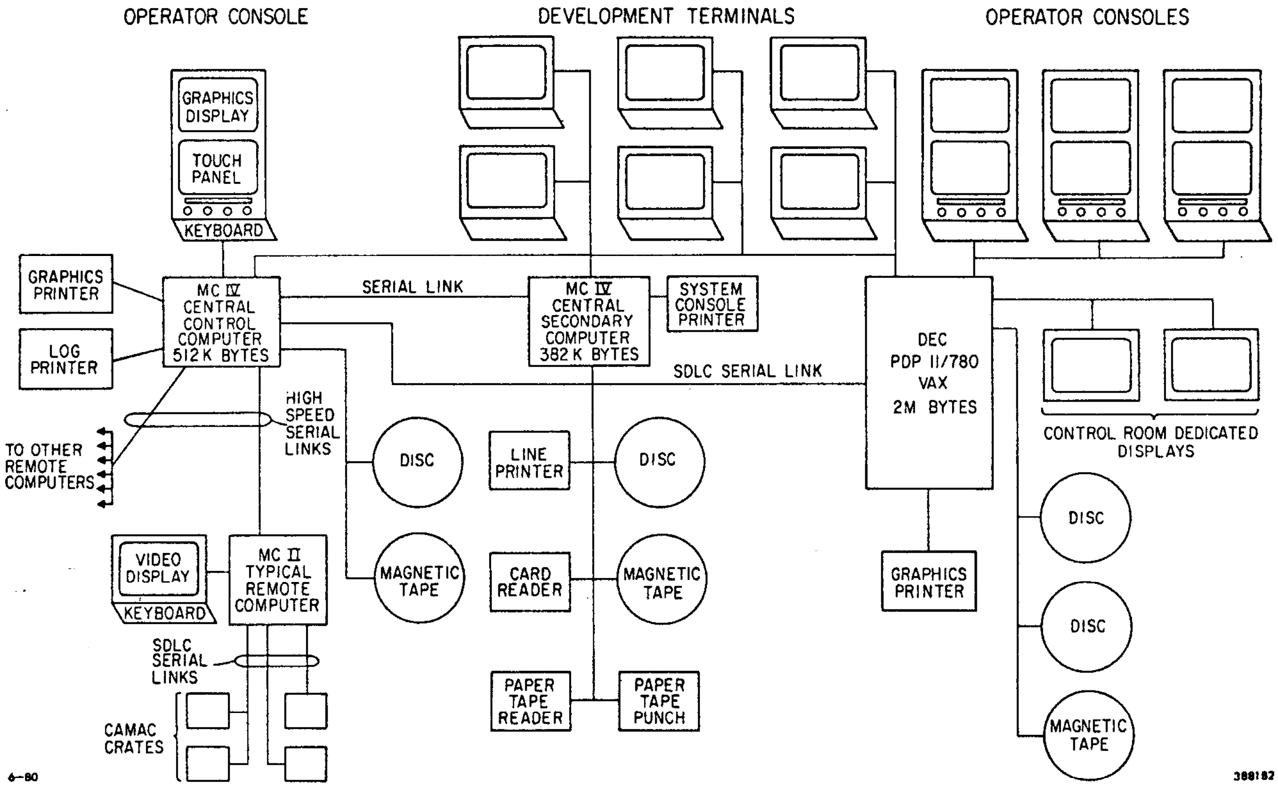

Fig. 3. PEP Computer Control System.

nous Data Link Control (SDLC)[1] technology. A similar link is used to connect the MCIV central control computer to the VAX.

The addition of the VAX computer to the system is a departure from earlier planned implementations[2]. For this reason, the system is presently in a state of flux with respect to the functions provided by the VAX and the two central MCIV computers. The system is evolving towards a configuration that will optimize the use of the strongest features of both the ModComp and VAX software operating systems: the MCIV provides a fast and flexible I/O structure and fast task switching; the VAX provides an operating system that can simultaneously support many physically large operating programs and online users, and provides an environment for fast, efficient program development and maintenance.

Within the next year, the system will evolve to the state where the MCIV central control computer will serve to "download" the remote processors and support the fundamental I/O data acquisition and control tasks. It will also be used to communicate with the operators through a single console to provide minimal control and monitoring functions in the event of a VAX hardware failure. The VAX computer will provide operator communication through three consoles and will perform essentially all of the higher level monitoring and control functions required for flexible and efficient operation of the ring. The VAX will communicate with the CAMAC crates through the MCIV central control computer. The central secondary MCIV will serve as a hardware backup to the central control MCIV.

A remote MCII computer is located in each of the seven I&C support areas. The eighth MCII is used as a spare and for program development. Presently, these computers are primarily used as data concentrators for the central computers. As the operational requirements of the ring become more and more demanding, it is expected that more local control and monitoring tasks will be implemented with the remote computers.

2.2. Interface and Operator Console Hardware

The remote computers are interfaced to the ring devices through a high speed CAMAC system which provides a serial communication link that uses the Direct Memory Access (DMA) capability of the MCII's. The CAMAC crates are physically located near the equipment to which they are connected, and are located as far as 500 m from the nearest MCII. Most interface requirements for the ~10,000 signals in the system are satisfied by five basic CAMAC 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. Figure 4 shows a profile view of a typical CAMAC crate in the system.

Microprocessor based controllers for the CAMAC crates and MCII SDLC serial link controllers have been developed for PEP[3,4]. Tasks in remote computers communicate with the crate controllers by means of messages

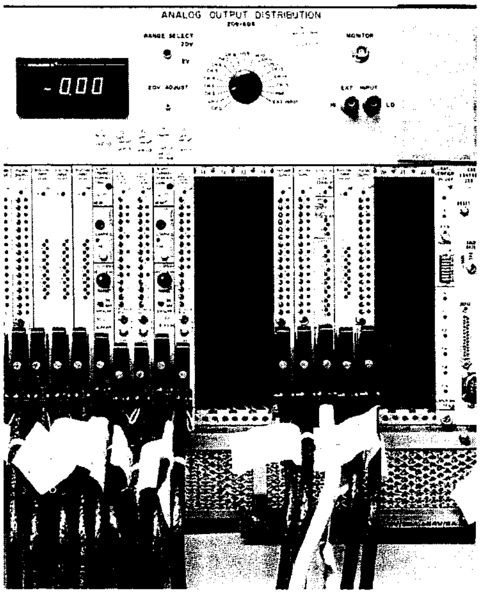

Fig. 4. Typical CAMAC crate containing an assortment of digital and analog I/O modules. The rightmost two slots contain a PEP SDLC crate controller.

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.

Each of the operator consoles in the system contains 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 touch panel having the capability of providing an 8 by 8 matrix of touch buttons; an alpha-numeric keyboard; and 4 incrementally encoded general purpose slew knobs, each with its own 15 character plasma display. The operator can 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. Figure 5 shows two adjacent MCIV and VAX operator consoles.

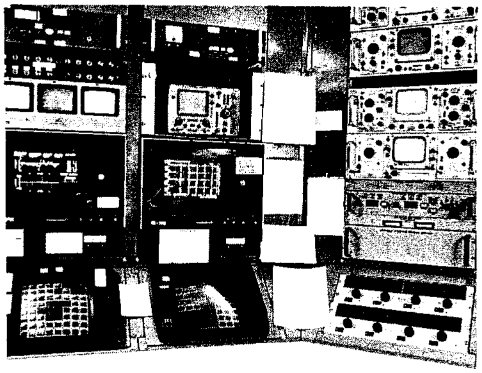

Fig. 5. Two operator consoles. The leftmost touch panel and display, and the topmost knob panel are connected to the MCIV central control computer. The remaining elements are connected to the DEC VAX.

2.3. Applications Support Software

The routines described here 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.

2.1.1. Data base routines

The PEP data base routines provide a means for application programs to be written without detailed knowledge about the memory or CAMAC location of 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 record for each signal in the PEP system. The creation of this data base begins with a tree-structured description of the approximately 13,000 hardware and software 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 record 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 channel in the second chassis connected to the region 6 remote computer.

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 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.

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 at run time to quickly compute the locations of signal data.

2.2.2. Data acquisition and control routines

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 rate 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 latest data for each signal in its core memory. Applications tasks can access data by providing signals identifiers (SID's) which are offset pointers into the data arrays in the central control computers. A subroutine is provided that quickly converts user oriented signal names to SID's using tables created by the tree-structured signal list preprocessor.

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.

2.2.3. Touchpanel routines

The director program provides application program communications with the PEP operators through the touch panels and slew knobs, and provides communication between programs. The structure and operation of the touch panels is defined by an object code created by a touch panel compiler. 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 terminated; specified data may be sent to a specified signal; a slew knob may be attached to a signal; an "event" may be decleared which can be used to notify programs that the button has been activated. The Director allows any program to simulate operator actions and it also provides a flexible method for program to program communications by allowing several options for enqueing/dequeing arbitrarily named messages to/from a common message pool.

2.2.4. Graphics routines

Primary graphics support for the full graphics CRT's has been provided by modifying the Unified Graphics5) and Handypak6) packages, originally written for the SLAC "Triplex" central computing facility, for use on the MCIV and VAX in conjection with the PEP graphics hardware. Having graphics "calls" compatible with the Triplex system has proven useful because many applications programs have been developed on the Triplex and then moved to the PEP system by use of a RS-232 serial link.

3. CONTROL AND MONITORING OF THE MAGNET POWER SUPPLY, RF, AND VACUUM SYSTEMS

3.1. Power Supply Control and Monitoring

There are approximately 25 main chopper power supplies and 150 trim and steering supplies in PEP. The chopper supplies require high-precision control and monitoring, so their analog set-point is determined by 16-bit DAC's located within the power supply controllers and their supply current is monitored with high precision transductors attached to a relay-multiplexed integrating digital voltmeter (DVM) system. The trim and steering supplies are interfaced to the computer through standard 12-bit resolution analog output and analog input CAMAC modules.

Control and monitoring software has been written to allow operators to perform the following functions:

- Display the setpoint and monitored current for each supply in amps and display the operational state of the supplies.
- Attach any supply to a manually controlled knob or ramp any supply to a desired setpoint entered through a terminal.
- Save a set of monitored currents for future use.
- Restore magnet currents to a previously determined set of currents.
- Perform a calibration procedure to determine correction constants to the nominal output current vs DAC setting transfer function.
- Perform a test procedure to test the linearity of the DAC-power supply system.
- "Standardize" the magnet system.

In addition to the relatively straightforward control and monitoring functions described above, an extensive set of on-line lattice modeling and control programs[2,7-8]) are provided that allow the ramping of power supplies without loss of beam to a new lattice described only in terms of the following beam parameters: the betatron tune ν_x, ν_y; the betatron functions β_x, β_y; the interaction dispersion function η; the chromaticities; and the beam energy E. Magnet strengths are derived from the on-line theoretical mathematical models of the ring and are then passed through polynomial transfer functions for magnetic measurement and transductor calibrations in order to obtain the required magnet currents.

3.2. RF System Control and Monitoring

Typically, RF systems for storage rings are very large and complex, and PEP is no exception. Approximately 3000 computer signals are related to the control and monitoring of power supplies, phase controls, thermocouples, tuner positions, etc., that are associated with the 12 PEP RF stations. Up to the present time, most of the RF programs have been of the "look and adjust" type. Further software efforts will center on providing extensive surveillance programs. Also, fully automated routines will be provided that set up a group of stations for a specified operating configuration and will automatically adjust RF controls to maintain a constant synchrotron tune ν_s while the magnetic lattice is ramped between configurations.

3.3. Vacuum System Control and Monitoring

Approximately 250 channels of vacuum ion-pump power supplies are used for the ring. Each channel provides 5 kV to an open circuit and 50 mA of current to a short circuit. The current provided by each channel is monitored by the computer system over its range of interest -- 1 μA to 10 mA -- by the relay-multiplexed DVM system. Individual ion-pump current readouts are used to provide coarse information concerning the ring vacuum. Approximately 100 ion-gauges are interfaced to the computer to provide more accurate information for specific geographic regions.

A system to help pinpoint the location of a catastrophic vacuum failure has been provided, but is not yet operational. This system utilizes a CAMAC module to continually scan "overcurrent" outputs from all ion-pump channels in a given region. The time of the last transition to the "overcurrent" state is logged into the module. Then after the failure, the computer system produces a record of the sequence of pump overcurrent readings. This sequence can be used in determining the location of the vacuum fault.

4. BEAM MONITORS

4.1. Beam Position Monitoring System

Figure 6 shows a block diagram of the beam position monitoring equipment. Bi-polar pulses from 4 buttons associated with 18 monitors in each region are multiplexed with coaxial relays to provide signals to a single detector system[10]. This detector system linearly stretches and integrates the pulses to provide a broad 20 ns pulse. A computer controlled CAMAC timing module provides a reference to a high speed synchronous sampling circuit that creates a dc voltage directly related to the peak of the input pulse.

Upon a command from the operator, 72 dc voltages (18 monitors × 4 buttons) are read by the local remote computer and passed to the central computer. Horizontal and vertical beam positions are then calculated by using the button values. After the scan has been completed, a display showing the orbit is

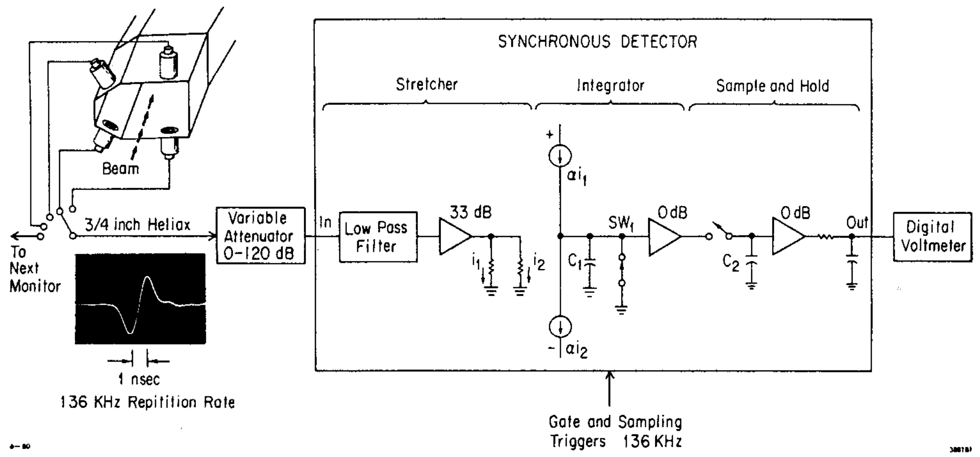

Fig. 6. Beam position monitoring system block diagram.

presented to the operator. The operator can then initiate a program to calculate magnet steering currents for global or regional orbit corrections[11]. The predicted "corrected" orbit is calculated and is then superimposed on the orbit scan display for the operator's approval. The operator can then reject the correction or initiate the correction process to ramp the steering supplies to their new values. The whole process of making the position measurement and performing the orbit correction requires 5-10 minutes.

Because of their extreme importance to the successful operation of the ring, a special effort has been taken to insure that the orbit measurements are as accurate as possible. The electrical response of each monitor in the system was measured before its chamber was installed. A precision jig developed for this purpose inserted a 30 cm transmitting antenna into the end of the chamber. The response of the buttons was measured for several transverse antenna positions. This information was then used to derive monitor-specific constants for the on-line position calculations polynomials. Alignment data is also factored into the calculations to correct for small positional installation errors.

4.2. Synchrotron Light System

The synchrotron light emitted from the bending electron and positron beams at PEP are used to determine many important beam parameters related to beam shape and intensity.

Two thin beryllium mirrors, one for e^+ and one for e^- beams, are located within the beam chamber. They reflect visible light through a 17 m path, consisting of a quartz window and a series of mirrors, to a small surface building. The surface building houses a light table that supports a system of light splitters and sensors used to perform the following measurements.

- A portion of the light is focussed directly on TV cameras for direct viewing by operators.
- A portion of the light is focussed on photodiodes to provide a measurement of the total current for each beam, and to provide individual bunch current measurements.
- The horizontal and vertical profile of each beam is displayed on CRT's whose input is derived by photomultipliers sensing a portion of light reflected by oscillating mirror scanners.
- A high speed (100 ps) photodiode and sampling oscilloscope are used to examine the length of a single bunch. The light for this measurement is delayed with a 50 m optical delay path to accommodate the use of a beam derived trigger for the sampling scope.

4.3. Tune Measurement

The betatron tune of the beam is measured by transversely exciting the beam with excitation amplifiers. Fast pulses received from striplines are demodulated and analyzed with a low-frequency wave analyzer. The synchrotron tune is obtained by phase-modulating an RF klystron and measuring the frequency of resultant transverse motion with the wave analyzer.

4.4. Transverse Beam Feedback System

Figure 7 shows the block diagram of a closed-loop feedback system[12] that has been developed for PEP to damp transverse oscillations of the beam. Twelve wide-band detectors[13] are used to sample-and-hold vertical and horizontal "error" signals for the 3 bunches in each beam. A modulated suppressed-carrier 9.8 MHz excitation amplifier is used to drive the beam and close the loop. The excitation amplifier is modulated by a complex timing and multiplexing system that selects the appropriate horizontal and vertical detected "error" signals to apply to a bunch as it passes by the excitation electrodes.

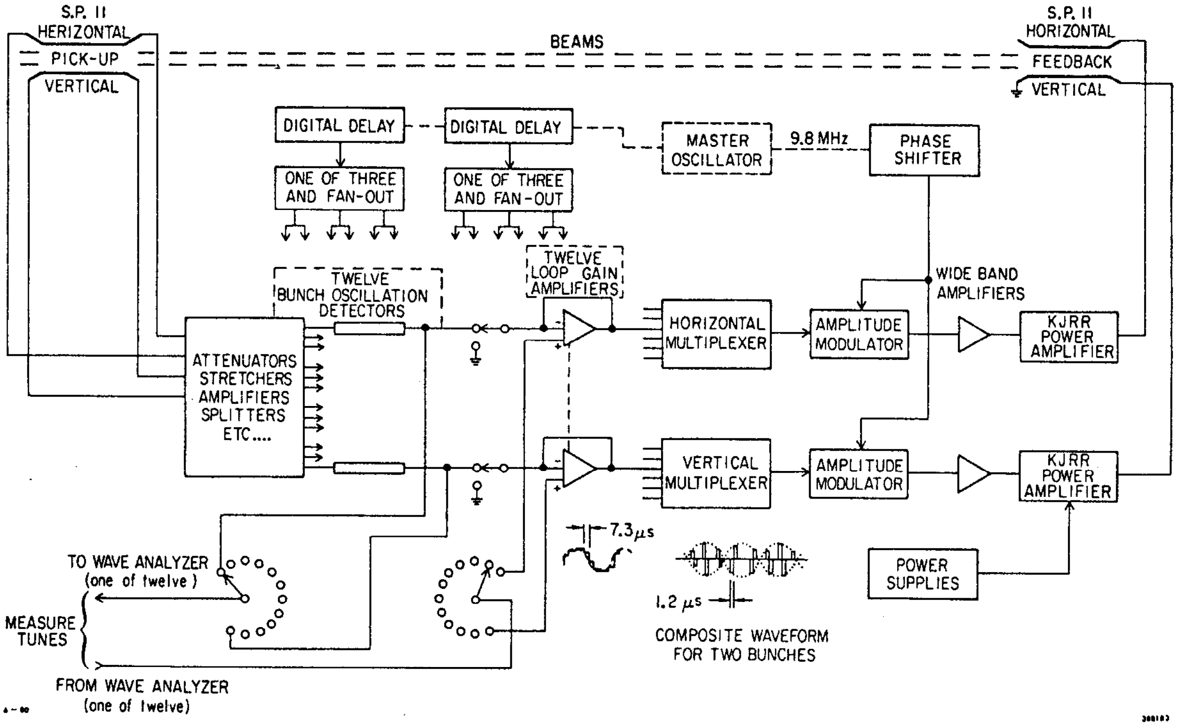

Fig. 7. Transverse beam feedback system block diagram.

4.5. Direct Current Current Transformer (DCCT)

A DCCT is provided to obtain the total current in the ring. The DCCT is primarily used as a calibration device for other beam intensity measurement devices which have no means of absolute calibration. A non-conducting ceramic gap is placed in the beamline to prevent the measurement of low frequency leakage currents and current induced into the beamline as a result of magnet ramping.

5. TIMING, COMMUNICATIONS, AND PERSONNEL PROTECTION SYSTEMS

5.1. Timing System

The PEP timing system generates gates and timing pulses for use by all beam sensors and exciters. The system supports modules that produce timing signals synchrotnous to the beam and allow for manual or computerized phase adjustment in 2.7 ns (1 RF bucket) steps. The system also provides complex timing patterns used by the SLAC LINAC during the injection process.

5.2. Communication

Quality voice communication has proven to be one of the most vital components in the checkout and maintenance of PEP equipment. All main equipment and control areas at PEP have been connected by a system of high-fidelity intercoms. Additionally, ~200 12-channel headset intercom stations have been located in the beam tunnel and near all equipment racks. This system allows convenient communication between any two pieces of equipment on the PEP site.

5.3. Personnel Protection System

The physical layout of the ring requires that six experimental areas be shut down if access into any experimental area is desired. Because of this fact and the fact that emergency repair entries into the tunnel provide major disruptions in a physics program, extensive efforts have been made to provide a Personnel Protection System (PPS) that minimizes the downtime created by entries into protected areas without sacrificing the overall safety aspects of the ring. The ring and its injection lines have been divided into 14 individually monitored and controlled zones. By carefully monitoring and controlling personnel accesses to specific zones, an operator can switftly and safely resecure the ring after the entry by securring only those specific zones that were compromised.

A prototype automated entry system is presently undergoing tests. This system maintains records of entries and exits to/from an area that is in "controlled" access. A "bar-code" strip, similar to those used in retail stores, has been attached to the dosimeters of all SLAC personnel. An inexpensive reader is used at the entry gate to transmit the coded data via a RS-232 message to a micro-processor system in PCR.

ACKNOWLEDGEMENTS

We wish to acknowledge the efforts of all the people associated with the specification, development, construction, installation and checkout of the PEP Instrumentation and Control System. The success of the system is a function of the hard work and dedicated performance of literally hundreds of people associated with all aspects of the project.

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