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SLAC CONTROL ROOM CONSOLIDATION USING LINKED COMPUTERS*

K. Breymayer, T. Constant, K. Crook, J. Hall, T. Huang,
D. Reagan, P. Sandland and W. Struven

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Summary

Consolidation of two large accelerator control rooms using digital computers connected by a data link is described. Several consolidation plans are discussed and the adopted solution is described. The key elements are touch panels operating with a TV display system.

Introduction

At SLAC, the Central Control Room (CCR) is located beside the klystron gallery and now controls the linear part of the machine. The Main Control Center (MCC) is in the Data Assembly Building (DAB), much nearer to the experiments, and presently controls the Beam Switchyard (BSY). From the beginning it was recognized that eventually a single control room would be more efficient. Important initial advantages were gained, however, by starting with two control centers. Certain problems were avoided with building site availability and schedules for excavation and land fill nearby. Separate crews were able to build and to begin running the two parts of the machine without mutual interference. Furthermore, it was expected that the design of a combined control center would benefit from operating experience. Since the accelerator began running, the DAB has been enlarged and a new console has been built to prepare for consolidation. It has been decided that, from an operating standpoint, changeover to the single control room must be done in a short period rather than gradually. The adopted plan depends very heavily upon the two computers, an SDS-925 in DAB and a PDP-9 in CCR.

Comparison of Consolidation Methods

Beam operation started at SLAC in late 1966. Soon thereafter, experimenters began to complain that there were delays and misunderstandings caused by not being able to communicate directly with the operator controlling the appropriate switch. For example, when an experimenter called the DAB to report an unwanted energy shift, the DAB operator called the CCR operator who made the necessary adjustment. The CCR operator then informed the DAB operator who, in turn, called the experimenter. This situation was alleviated by installing an improved intercom system. In addition, studies were started in 1968 to plan and estimate the cost of combining the two control rooms. Various alternatives were considered: moving the CCR equipment to an expanded DAB, moving DAB to CCR, and numerous variations of these two extreme solutions, such as moving some panels and chassis from one control room to the other. The main disadvantages of the extreme solutions were the cost and downtime involved: approximately \$500,000 and 3 to 4 months respectively. The approach of moving selected panels was finally rejected because there was no confidence that any small set of panels would be sufficient for beam operation. An operator would still be needed in the secondary control room to perform a reduced set of tasks.

It was finally decided that consolidation using the two control room computers as I/O multiplexers offered the lowest cost solution and one that could be carried out without any downtime beyond that normally scheduled. The main control center would be in the DAB. CCR would remain as a fully operational control room available as a backup in the event of computer equipment failure. There were two important reasons for selecting the DAB as the Main Control Center. First, it was closer to the experimental areas than is CCR. Experimenters felt that there were advantages in being able to walk to the DAB control room which is some 200-300 yards from most experimental trailers, whereas CCR is 700-800 yards away. Second, the CCR control and monitoring systems could be interfaced to the CCR computer at a much lower cost than the DAB systems could be interfaced to the DAB computer. Cost savings result because many of the accelerator signals are already coded for transmission to and from CCR. Some 3000 status signals are time division multiplexed and transmitted in serial binary form, and the remote control system uses parallel binary transmission. On the other hand, signals to and from the DAB use individual wirepairs or coaxial cables. Thus, the I/O multiplexers can be smaller and the wiring interconnection costs lower in the CCR case.

Having decided that the main control center would be in DAB, the problem of locating duplicate CCR control panels in DAB remained. It was soon realized that the DAB console would have to grow to an unacceptably large size and that the cost would be prohibitive if "hardware" panels alone were considered. It was therefore decided to make use of computer generated TV displays for status and analog readout, and to provide for control by mounting an overlay or "touch panel"[1] on the display screen. By pressing on the CRT screen at a point over a software generated "control button" display,[2] the appropriate remote control device can be actuated.

Eight such touch panel TV displays will be mounted in the DAB console. These together with a small number of oscilloscopes for accelerator video displays will provide control and monitoring for nearly all accelerator functions.

Present Accelerator Control and Monitoring

The Central Control Building is located near the klystron gallery at Sector 27. It has three floors; the lower floor houses the battery system and air compressor equipment. The middle floor contains an extensive cable tray system and shops, and the upper floor is the control room proper. The control area comprises some 4000 square feet and contains wiring frames, the PDP-9 computer, 112 equipment racks and 16 low racks which form the console.

Several types of beam control and monitoring systems are presently used in CCR. A relay switching remote control system (RCS) permits a CCR operator to control up to 64 channels in each of the 30 sectors of the accelerator. The system response time is approximately 1/2 second. A status monitoring system (MUX) provides two-state monitoring in CCR of up to 128 signals in each sector. This system continuously scans and updates the information from each area once every 720 ms. A dc analog meter system presents up to 15 slow signals from each sector. Steering controls are connected to the RCS. Steering currents are transmitted to CCR via the fast analog system. Quadrupole magnet currents are controlled using the RCS and monitored by the slow analog system. A signal proportional to beam charge (linear Q) is sent to CCR from each sector and displayed as a series of horizontal dots on CCR oscilloscopes. The X and Y positions of the electron beam are determined at each sector and sent to CCR together with a signal proportional to the logarithm of beam charge as a three pulse serial waveform (log Q,X,Y). Beam position and charge signals are updated at a 360 cycle rate. The trigger system provides a flexible means of determining which klystrons will contribute energy to one or more

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of the six beams. The allocation of klystrons 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. A personnel protection system extends along the total length of the machine. Except for certain high-security circuits, control and monitoring functions for this system operate largely through the RCS and MUX systems. A machine protection system causes the electron gun to be turned off if any system along the accelerator or in the beam switchyard indicates a possibility of equipment damage. Status signals from this system also appear in CCR.

Present Status of the CCR Computer

The CCR computer, a PDP-9, contains 8K of 18 bit words in core and has a 1 μs cycle time and a 10^6 word disk file. All MUX and control channels from the injector and 30 sectors along the machine have been connected to the computer. (See Fig. 1.) Most of the slow sector analog signals have been interfaced. The analogs from the injector, special signals from some sectors, and certain CCR analogs will be connected in the near future.

Pulsed steering dipole and quadrupole current analogs are transmitted to CCR via the log Q system. The log Q and X, Y position signals are interfaced through the direct memory access channel of the PDP-9. Hardware is being built so that the PDP-9 can control the trigger patterns.

The PDP-9 input multiplexer is capable of reading seven 18-bit words. Five words are now active. Word one is reserved for signals which must be read just after each beam pulse, such as beam identifiers. Words 2 and 3 are assigned to the sector MUX information. Words 4 and 5 are used to connect digitized slow analog signals and trigger pattern status signals.

An intercomputer link now connects the PDP-9 to the SDS-925. Coaxial cables are used for high speed data and wire pairs are used for the low speed commands. Both data interface units are capable of handling a 50K baud duplex data rate. The data clock is now set at 3 kHz. Standard EIA RS232C data formats are being used.

Programming to date has provided the accelerator operators with a number of useful functions, that is, slow klystron replacement, data logging, quadrupole setting, modulator reference voltage monitoring, and hardware checkout programs. Future programming will involve some closed loop control of the accelerator system including beam steering and spectrum control.

Present BSY Control and Monitoring

The DAB is located adjacent to the Beam Switchyard (BSY) at a point some 300 feet downstream from Sector 30. It consists of a single story building, housing 43 large magnet power supplies, 90 equipment racks, the SDS-925 computer, wiring frames and 24 console racks. It originally had 5000 square feet, but has been expanded to 9000 square feet to accommodate the consolidated control room which includes duplicate (East and West) console positions for improved BSY control. The DAB control and monitoring systems enable the machine operator to route high energy beams through the Beam Switchyard to various target areas and their respective secondary beam transport systems. The control systems can be divided into three major categories as follows: interactive controls, monitoring systems, and "support" systems. These are hard-wire systems and in certain instances are interfaced to the SDS-925 computer.

The interactive controls are those which affect the on/off status of various beam paths and parameters such as beam size, shape, location, energy spread, and repetition rate. Systems included in this category are the machine protection system, personnel protection, magnet control, triggers and collimator control. The machine protection system incorporates controls for beam on/off, interlock reset, repetition rate limit and mode selection. Protective interlocks include ion chamber detectors, high temperature detectors, cooling system flow switches, and beam current limits on an average as well as a pulse-to-pulse basis. The personnel protection system comprises keybank control, intercoms, closed circuit TV monitoring, and radiation level indicators. The magnet system provides for bending, steering and focusing, as well as controls for turning power supplies on and off, setting polarity, degaussing magnets and adjusting magnet currents. The trigger system routes various accelerated beams to their respective targets and secondary beam lines by pulse-to-pulse control of beam switching and steering magnets as well as providing protective interlock gating and instrument synchronization. Controls are also provided for high-power slits and collimators, beam stoppers, dumps and targets.

The beam monitoring systems display digital, analog, video or dc data describing beam parameters such as intensity, energy spectrum, repetition rate and position. These systems include displays for beam toroid and position monitor pulse outputs, average current and power indicators and energy spectrum monitor histograms for tuneup and beam maintenance. Closed circuit TV is used for profile monitor displays of beam spot size and shape from ZnS screens and Čerenkov cells.

"Support" systems encompass a variety of facilities such as vacuum, water cooling, alignment, gas and fire detection, ventilation, communications and power distribution.

Controls and displays essential for beam guidance and monitoring are located on the main consoles. Video displays at operator eye level are segregated on a primary beam basis with BSY beam steering and focusing controls close at hand. To facilitate multiple beam operation, MCC has been divided into two identical operating positions, one each in the East and West consoles, with facilities for operating all beams at each position. Control functions which are essential but can be preset and need not be close at hand are located in a common area between the two operating positions.

The personnel protection system access controls are located on a low-profile island console behind the two operating positions in the main control area. All other functions such as power supply on/off controls and machine protection systems are located in rows of racks away from the main console.

Present Status of the MCC Computer

The SDS-925 computer in the DAB has 16K of core with a cycle time of 1.7 μs and a mass storage capacity of 500K 24 bit words. The present computer connections are shown in Fig. 1. The computer is used primarily to set magnet power supplies in the BSY. As part of the closed loop adjustments, the computer uses 20 ladder-type DAC's and reads shunt signals through the DVM to set quadrupoles. The dc for bending magnet currents in the A and B beams is adjusted by slo-syn stepping-motor driven potentiometers. The energy of the A and B bend magnet systems may be set either by teletype input or by two "tune" boxes mounted on the console. The A and B magnetic fields are measured using two separate flip coil systems. In addition, about 300 status bits from BSY equipment are continuously monitored by the computer and changes are displayed on the console display scope. An alarm is sounded when there is a status change. Two prototype touch panels are connected for hardware shakedown and software development.

There has been a continuing hardware improvement program for the SDS-925 computer during the last 3 years. Most of the new increase in capability needed for consolidation will be accomplished by expanding the present systems. One planned change is a new 5 digit DVM including a low level reed relay input multiplexer ($1\mu V$ resolution). The DVM will be fully software controlled (range, mode, etc.) and the multiplexer will be channel addressable. The DAC and slo-syn interfaces will be combined in a new general purpose Serial Data Device (SDD) interface. The input multiplexer capacity will be increased to handle about 800 status bits as well as the eight touch panel inputs. All magnet power supplies in DAB will be controlled through the output multiplexer.

Programs are being written to assemble the desired display formats in the SDS-925, and to send these displays to the console monitor. More programming is required to accept command inputs and for the computer to communicate over the link with the PDP-9.

Display and Control for Consolidation

The concept of computer driven displays followed naturally from the decision to use linked computers as I/O multiplexers. However, the high cost of standard CRT terminals was a major obstacle. Fortunately, the availability of commercial equipment using disk storage techniques and standard TV displays made the concept economically feasible.

The program of control remained. Light pens are inconvenient and difficult to interface to the low cost TV system and the use of panels of control buttons adjacent to the display seemed unattractive. The adopted solution was a touch panel over a TV screen. By displaying buttons on the screen, console space would be saved and most important, an operator would use the display in much the same way as hardware panels are presently used. The TV display panels would be programmed to display the buttons together with status and analog information as needed.

TV Display System

The TV display equipment employs a DATA DISC Inc. 16 channel time shared system comprising a disk memory with 32 tracks (170K bits per track) and an I/O hardware controller to convert parallel 9-bit data and 10-bit function codes to disk data and TV raster scan displays. Only eight channels have been procured initially. The TV display is a 512×512 dot matrix allowing 5×7 dot minimum size characters. The character size can be expanded by a factor of two in both directions.

Input of new data to the system takes about 15 μs of CPU time per character, exclusive of software character setup. Because of the disk transfer time, the asynchronous data rate will be about 60 characters per second. Synchronous block transfer can approach 5000 characters per second. The controller is interfaced to the SDS-925 through the digital output multiplexer.

Touch Panel

The touch panel is intended to accommodate a 10×13 matrix of "buttons" on each 14-inch monitor. The TV unit will show appropriate legends for each button and pertinent status and analog information. Several approaches are being investigated. A flat glass panel using Rayleigh waves was developed and operated successfully over a year ago. Because parallax error near the corners was thought to be excessive, development of a curved-screen version to fit the contour of the CRT face was started. Some interference between adjacent channels has been observed on this model. Flat screen TV monitors are available but they are considerably more expensive than those using a curved tube. A crossed wire panel has been built using fine gold plated stainless steel wires with a y-grid separated from the x-grid by a few thousandths of an inch. A thin flexible overlay covers both grids. Pressure at the intersection makes contact between one x and one y wire. This is an extremely simple and inexpensive device and tests so far indicate it will operate satisfactorily. A generalized digital input multiplexer to interface these panels has been built and tested. This device scans 256 words of 24-bit data separately (one word for each panel) and gives an interrupt to the 925 only when a data change is detected. The "buttons" are essentially dc devices and can remain active for as long as they are depressed thus performing continuous functions.

Consolidation Schedule

The present schedule calls for the necessary CCR signals to be completely interfaced to the PDP-9 by late this summer. By that time, the eight touch panel-TV monitor assemblies will be installed in the DAB console.

Certain other signals which are not suitable for transmission by computer link will be handled in other ways, for example, position and intensity signals will be transmitted from CCR over existing coaxial cables and will be displayed on oscilloscopes in the MCC.

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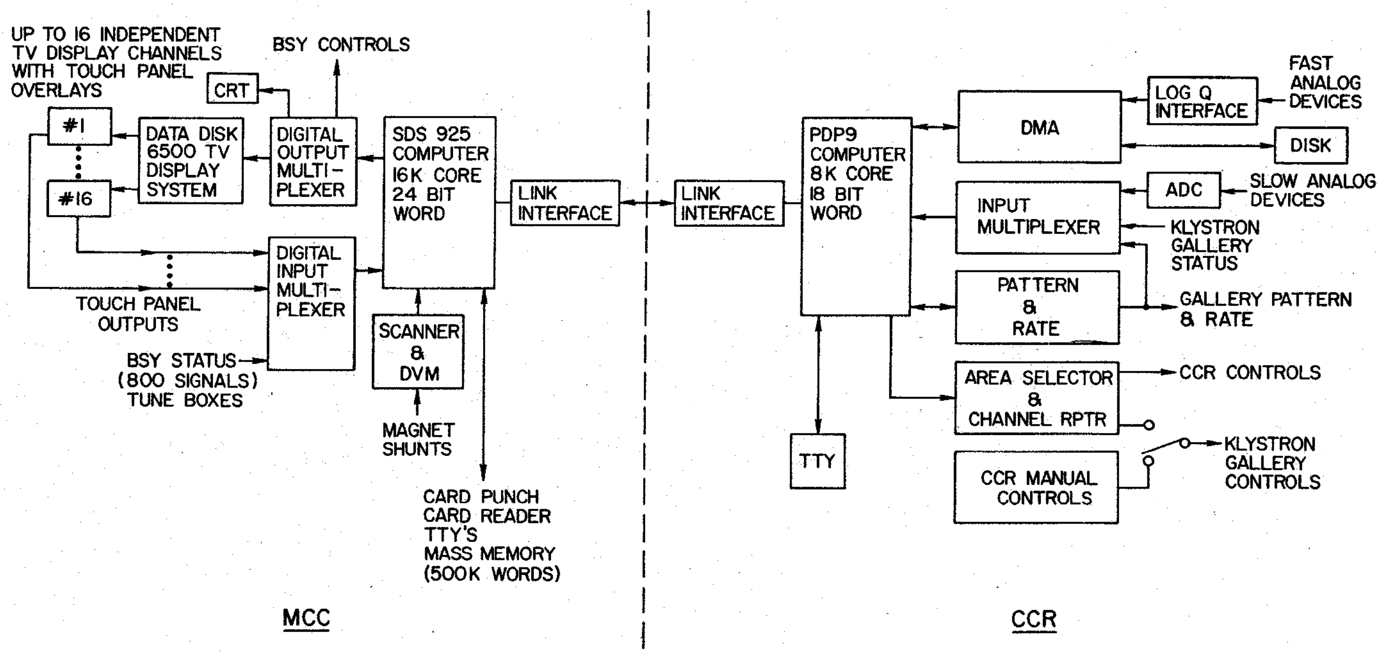

SIMPLIFIED BLOCK DIAGRAM OF CONTROL ROOM
CONSOLIDATION USING TWO COMPUTERS

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