OPERATIONAL ASPECTS OF THE SLAC MAIN CONTROL CENTER*

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Summary

The SLAC Main Control Center (MCC) incorporates functions that were previously handled in two separate control rooms; i.e., (1) the setup and maintenance of interlaced beams in the accelerator and (2) the delivery of the beams to separate experimental areas. The complexity of beam operation has increased with the activation of the new SPEAR facility. This experimental area uses low energy electrons and positrons which run simultaneously with a full complement of six other beams. Considering all the operational requirements, the MCC instrumentation plays a major role in determining the operation efficiency.

Introduction

A number of control rooms were established at SLAC according to the original plan shown in Fig. 1. These included the rooms at the injector, the positron source area, Central Control Room (CCR), and Main Control Center (MCC). Mini-control rooms were also provided at each of the 30 sectors along the machine in the I&C alcoves. In early stages of operation, the rooms were all manned by operating crews. However, as experience was gained and equipment installations were completed, it became evident that operators were not required in those rooms located in the klystron gallery, at least after the initial startup for each machine cycle. Maintenance personnel, stationed in Sector 10, could be dispatched to activate those devices not coupled by control channels to CCR. For some time then, operators in CCR established and controlled beams in the accelerator and a second set of operators in MCC received the beams, guided them through the switchyard, and delivered them to the experimenters.

Steps were taken in 1970 to consolidate the accelerator and switchyard operations using linked computers.[1] In this plan, operation (at least after initial setup) was to be achieved with one crew using two operating positions located in MCC. As the number and complexity of beams increased at SLAC, including the new SPEAR operation, a third operating position in MCC was found to be necessary. In the fully consolidated arrangement, various beams will be run from each position and the operators will be able to control their beams all the way from the injector to the experimenter's target. When several experimenters make simultaneous requests for minor changes in their beams, the operators should be able to accommodate them without the numerous intercom exchanges that have been required in the past.

We are in a transition phase toward this goal. Developments in the computer system are sufficiently advanced so that operators in MCC now control many of the parameters necessary to maintain beam from injector to experimenter. The third position is not fully operational at present, and it is still necessary to man CCR.

MCC Equipment Layout

The layout of the MCC console and electronic equipment racks is shown in Figs. 2 and 3. The main console consists of three similar operating positions for the purpose of maintaining multiple beams and conducting other activities in a concurrent fashion. The personnel protection system console contains the equipment necessary for controlling access to the research area end stations and to the beam switchyard (BSY). Racks behind the operators contain the various magnet ON/OFF controls, vacuum displays, beam containment electronics, interlock displays, etc. Equipment racks at the rear of the main console contain additional electronics and secondary displays. An SDS 925 computer and its peripherals are also located in this area.

Typical Operating Position

The controls and displays needed to perform the beam setup and operation are illustrated for a typical operating position in Fig. 4. At present the operators must contend with two types of control systems. (1) Conventional hardware panels are provided to control switchyard functions. (2) Computer-generated displays with "touch panels" are used to control and monitor the accelerator.[2] The touch panel consists of a TV monitor with a nearly invisible crossed-wire matrix overlay. The operator touches a computer-generated "button" on the monitor face causing an X and a Y wire in the matrix to make contact. The computer decodes the X and Y input and generates the appropriate control signal. This hybrid arrangement is a direct result of the method that was adopted for the consolidation of the control room.

It is expected that there will be a gradual unification of these control systems as more of the switchyard functions are connected to the computer system. This transistion is already under way. For example, interlock status is now displayed both on TV monitors as well as on the usual status lamps. Also, the new SPEAR beam line is monitored using either computer displays or conventional hardware panels.

Operator Functions

The following operator activities demonstrate the utilization of the preceding equipment:

Machine preparation. The accelerator housing, beam switchyard, and research area end stations must be searched and secured prior to bringing a beam into an experimental area. Personnel protection systems,[3] independently controlled and monitored in MCC, establish that each area is safe. Access to an experimental area is the direct responsibility of the operators who must follow the requirements and procedures set forth in the Radiation Rule Book. A beam containment system[4] prevents hazardous radiation from reaching any areas occupied by personnel. Those electronic and mechanical devices needed for beam containment functions are prescribed by health physics procedures.

Once the accelerator housing has been secured, the variable-voltage-substations (VVSs) can be brought on to power the modulators and the klystrons are brought up to full output. The BSY and research area magnet power supplies are checked for proper operation; new equipment installations are checked out and all systems are brought to stable operation. This machine preparation usually requires seven shifts to complete.

Beam setup. Once all accelerator systems are operating normally, the magnets required for each experiment can be set. Triggers are then assigned for: (1) the desired gun pulse level, (2) the number of klystrons needed for the desired beam energy, (3) the repetition rate, (4) the pulsed magnets and other special devices needed to function at beam time. When all equipment interlocks in the machine

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protection system are cleared, a "beam permissive" can be generated and an electron beam turned on. At this point adjustments must be made to: (1) capture and optimize the electron bunches out of the injector, (2) match the phase of the klystron outputs to the beam, (3) steer the beam through the accelerator or to a positron target located at the one-third point, (4) set energy, and (5) optimize the energy spectrum and the beam spot size. Once the beam is properly transmitted through the accelerator and its energy is correct, the beam can be steered to an appropriate target and dump for experimental or checkout use. This setup may take up to three or four shifts if eight beams are to run.

Beam operation. When all beams are established, the principal work of the operators is the control and maintenance of the beams to satisfy the experimenters' requirements. In the following paragraphs examples of tasks frequently performed by the operators are discussed by analyzing certain parameters of a beam.

The contribution of a klystron will be approximately 94 MeV when its output is properly phased with the electron beam. The total beam energy is the sum of the contributions of all klystrons pulsed at beam time and is monitored by bending the beam through a known angle in the beam switchyard. The energy and the spectrum width of the beam are monitored by a display consisting of a series of secondary emission (SEM) foils mounted transverse to the beam after the horizontal bend. The amount of beam transmitted along a beam line can be monitored by toroid sensors located at the beginning of the switchyard and at points downstream of the slit. Energy defining slits can be adjusted to allow only the desired momentum spread to pass. Abnormal readings on ion chambers and temperature detectors indicate the location along the transport system where beam is being lost.

Beam energy will change with time due to RF phase shifts and to klystrons cycling off. When a klystron cycles off, the computer which is interfaced to the accelerator will add a spare klystron to the appropriate beams to restore the energy. Incremental energy changes (less than one klystron's worth), are made with a "pulsed energy vernier" consisting of a klystron whose output phase is adjusted to provide the exact energy increment needed.

Achievement of a desired small spread in energy begins with proper beam setup at the injector. The limiting value of spectrum width of the beam is determined by the phase length of the electron bunches and is controlled by adjustment of the input power and relative phase angle of the prebuncher and buncher cavities. A special bunch monitor is used in this optimization procedure.

A sequence is followed to correct spectrum deterioration. The operators first adjust "phase closure." Phase closure controls the phase of the bunched beam to align it properly with the resultant sum of all of the klystrons accelerating the beam. As a result, a spectrum which has broadened due to off-crest debunching can be narrowed with phase closure adjustment. A change in phase closure will be accompanied with a change in energy so the operator must make small adjustments in both parameters in the optimization procedure, keeping the energy of the beam on the center foils of the spectrum monitor. Beam loading delay is the next major control available to correct a deteriorated spectrum. This is a timing adjustment that compensates for the energy changes within a beam pulse due to high current loading effects. A zinc sulfide screen or Cerenkov cell inserted into the beam after it has been bent by the magnets will show a high or low energy "tail" that accompanies the deteriorated beam. The current toroid monitors, furthermore, will show a pulse shape with a ragged, structured peak value instead of the desired rectangular shape. The operators check the beam loading delay for each sector against the required values. If the delay times for a particular set of sectors are not optimum, they are corrected.

The average energy gain per klystron can next be checked. If the value drops lower than about 90 MeV (because of phase drifts), it will be difficult to achieve a narrow spectrum and the operator must re-phase the accelerator, a process that usually takes about an hour. If the energy gain per station is not at fault or has been corrected, and other adjustments described fail to produce a proper spectrum, the injector bunch monitor must be checked for abnormality and the bunch length reoptimized. Final tuning involves iteration of small changes in phase closure, beam loading and energy vernier until optimum results are achieved. During these adjustments the operator attempts to narrow the spectrum, to increase the beam transmission through the switchyard, to decrease the ion chamber and temperature detector readings, to make the pulse shape nearly rectangular, and to make the beam profile nearly circular. With typical high current beams and powers on the order of hundreds of kilowatts, tens of kilowatts of beam can be lost in the switchyard causing radiation and heating problems. A narrow energy spectrum will minimize this power loss.

Beam steering is performed to position properly the electron beam on the experimenter's target to maintain the desired secondary particle yield. Secondary emission monitors and/or profile monitor screens at the location of the target are monitored by the operators and by the experimenters to aid in this task. A reading of the experimenter's particle detection device is transmitted to the MCC and is displayed on a television monitor. The operator can then adjust the beam while observing the same reading seen by the experimenter. This monitor then becomes a primary indicator of beam performance.

Multiple Beam Operation

The operational work load at the Main Control Center is greatly influenced by the number and complexity of experiments that are run at the same time. Recently as many as eight simultaneous beams have been scheduled. Multiple beams can be run because a beam can be transported to experimenters in one end station while setup is under way in the others, or alternatively, several end stations may be in operation at the same time.

Typically, 15 signals are monitored by an operator for each of the beams he controls. The operators are limited in the number of different signals and controls that they can handle at the same time, and therefore, an experimenter may have to wait for work on his beam if the operator is busy with another experimenter. For this reason, beam tuning and recovery from equipment failures has become an increasingly larger fraction of the total beam downtime as the number of simultaneous experiments has increased. (See Fig. 5.) With several hundred equipment interlocks for machine protection and beam containment, beam trip-offs are common, adding to the complexity of operation. These trip-offs may affect either a single beam or all beams. If all beams trip-off, the operator must first determine which one caused the interlock to trip and then cure the problem. An example of this situation occurs when a beam misses its appropriate dump as a result of steering changes or energy shifts. In this instance the beam containment system causes all of the beams to trip.

Beams with substantially different energies require different focusing and steering conditions, and compromises must be made to transport these beams through the accelerator. A particular example of this complexity is the beam requirement for the SPEAR facility.[5] SPEAR requires 1.5 GeV positrons and 1.5 GeV electrons that are produced at a target at the one-third point in the accelerator. Concurrently, high energy electron beams for other experimenters are accelerated from the injector and must be steered around the positron target.

Operating Efficiency

The operational efficiency is defined as the ratio of the number of hours satisfactory beam is delivered to an experimenter's target, to the number of hours scheduled. The accelerator provides satisfactory beam to at least one experimenter 85% of the time. However, the average of the operational efficiencies for all experimenters over the fiscal years beginning with 1968 to the present time is only about 70% (see Fig. 6). The 30% unscheduled downtime is about equally divided between accelerator failures and research area failures. Even with such relatively low efficiency, multiple beam operation has permitted more physics to be done in the later years as compared to 1968. For example, the accelerator operated 57% of the year in 1968 and achieved nearly 6600 hours of satisfactory beam time. In 1972, on the other hand, the accelerator ran only 45% of the year, but achieved 14,500 satisfactory hours of physics time. This represents an increase by a factor of 2.2 while the length of time the accelerator was running decreased by 20 per cent.

The number (averaged over each fiscal year) of simultaneous experimenters that were scheduled to run is shown in Fig. 7. In 1968, an average of 2.2 experimenters worked at the same time and in 1973, 5.8 experimenters ran at the same time. The SPEAR experimenters in 1972 and 1973 required two beams to be set up in the machine even though only one is used at a time. Therefore, from the operators' standpoint, the equivalent of 6.8 beams were in simultaneous operation during the present year.

Conclusions

While machine utilization in terms of satisfactory hours of physics has increased over the years, it would be even higher if the overall efficiency could be increased. Improved instrumentation and the distribution of the work load to three operator positions should raise efficiency. With so many signals to monitor and controls to adjust, careful consideration must be given to the location and arrangement of the equipment at the console. Close coordination has been established between the operators and the Instrument and Control Engineers to review the human factors involved in the design of equipment used by the operators. In addition, improvements to the computer system should result in a reduction of time spent on manually performed functions.

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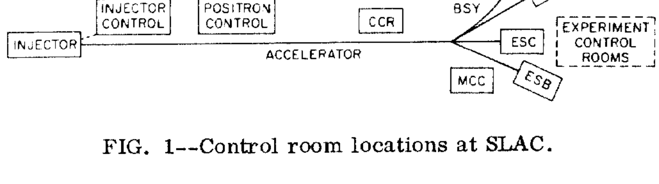

FIG. 1--Control room locations at SLAC.

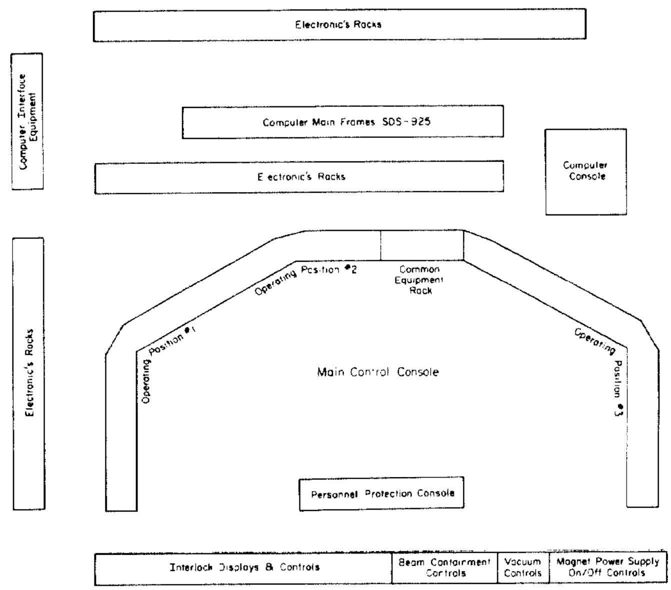

FIG. 2--Main Control Center layout.

FIG. 3--Main console in MCC.

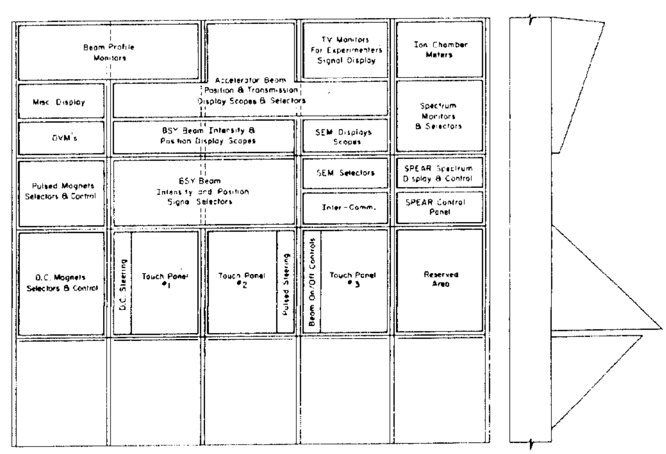

FIG. 4--Typical operating position.

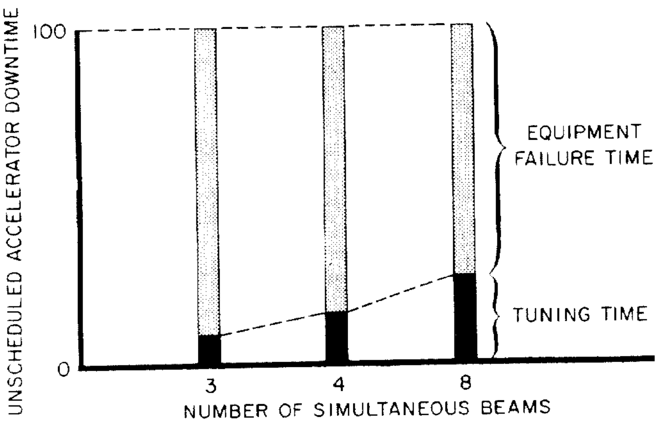

FIG. 5--Effect of multiple beams on unscheduled downtime.

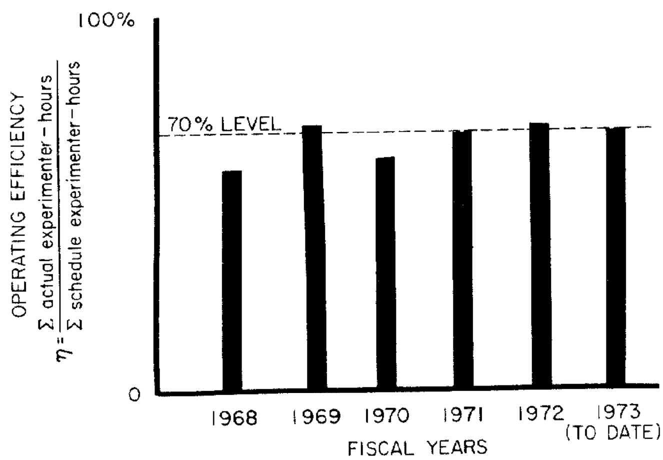

FIG. 6--Average operating efficiency for all experiments since 1968.

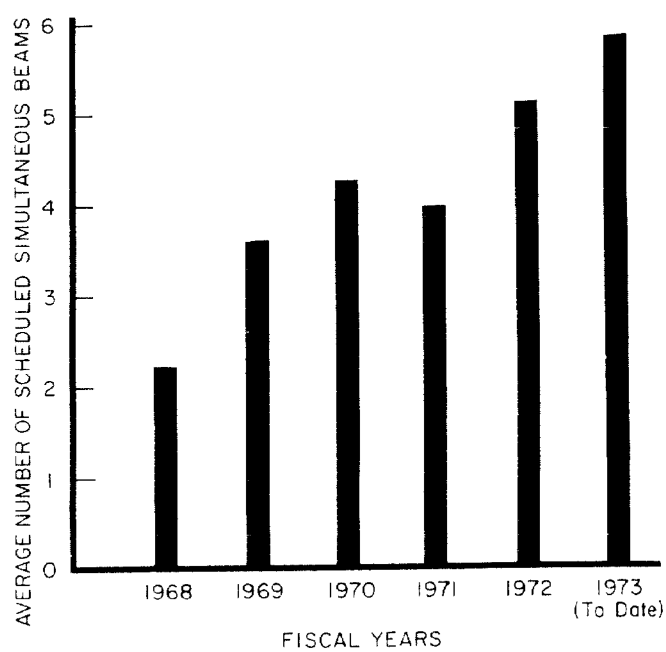

FIG. 7--Increase in average number of simultaneous beams since 1968.