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SLAC ACCELERATOR CONTROL COMPUTER*

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Summary. A digital computer system is being installed in the SLAC accelerator control building. Initially, the computer will recognize losses of klystrons due to malfunction, and will switch on suitable replacements. Later, it will prepare and analyze records, assist in setting up new experiments, and perform certain other control operations where rapid response is desirable.

Introduction

The SLAC central control room (CCR)[1] contains monitoring and remote control facilities to cope with normal behavior of the systems that produce, accelerate, and guide electron and positron beams as far as the entrance to the Beam Switchyard. In addition, there are facilities in CCR for finding and correcting faults, and for tending pertinent protection systems and utilities. When the control systems were planned, it was recognized that it would be very difficult to subject the major beam parameters directly to automatic control. Certain operations were recognized that could be done well automatically, notably the phase adjustment of individual klystrons. Most CCR controls were, however, made manual. Furthermore, except for information recorded by a few event counters, elapsed time clocks, and strip chart recorders, CCR data logging was to be done manually.

After an operating period during which many small improvements have been made on the manual systems, we have come to a stage at which it appears that some increases in operating efficiency can most economically be made by installing a digital computer system in CCR. We have accordingly installed the first increment of such a system, which now consists of a PDP9 with high speed paper tape and teletypewriter, a fixed head 10^6 word disc file, and the equipment required to connect the computer to our remote control, status monitoring,[2] and trigger systems. Since we are seeking to improve a system that already works well, we intend that the computer will, at least at first, be limited to doing chores in such a way as to interfere as little as possible with established operating procedures. For those activities that do affect the operation, we plan to provide pushbuttons with which the operators can initiate computer actions of limited duration, and handy toggle switches which can enable or disable computer functions which are continuous or which are intermittent over some indefinite period.

Klystron Replacement

Whenever an active klystron suffers a fault, the electron beam energy drops suddenly, usually by about 90 MeV. The status monitoring system reports each such event to the computer, including data with which the duration of the fault can be roughly predicted. Unfortunately, the data can arrive with up to ~ 0.7 sec delay. For faults which are likely to last longer than a few seconds, it is planned to use the computer to select properly programmed standby klystrons and to switch them to the "accelerate" state. The hardware to do this is already working; it remains to settle the program details. These are complicated by such problems as multiple beams, what to do about repeatedly misbehaving klystrons, and coupler asymetry, which causes certain klystrons to deflect the beam.

In the future, we plan to speed response to klystron loss by developing a pulse-to-pulse beam energy monitor system for the computer. In this system, the computer will evaluate two numbers, representing upper and lower parts of the beam spectrum, after each beam pulse. When the two numbers suddenly shift in accord with certain criteria, the computer will respond by quickly switching a klystron to "accelerate" or to "standby," as required. Some klystrons have already been provided with special trigger circuits, and can be switched on or off in a time sufficiently short that beam energy can be restored in one interpulse interval, or 2.78 msec.

The two klystron replacement schemes will complement each other. The fast system will keep the beam energy nearly steady by switching a klystron on quickly when a fault occurs, and switching it off quickly when the slow system brings an ordinary klystron on line. The slow system will supply replacements so that special klystrons can be restored to the ready state.

Data Logging

The computer is already connected to the accelerator status monitoring system. This system reports the states of some 3000 remote binary sources at 0.7 sec intervals. It is the main source of information in CCR on modulators, power supplies, valves, interlocks, etc. The computer now watches all these signals, and can type out messages, reporting unit, location, new state, and time for each change. The typing routine is for demonstration purposes. For a useful log, we plan to store the messages on the disc, and, at intervals, to cause the computer to edit and type out selected information. The status system at present generates such data at a rate which fluctuates widely, but which probably averages several words per minute. The disc can thus store a complete record for at most a few weeks. For some purposes it would be useful to store data on a semi-permanent basis. We are thinking of using a magnetic tape recorder for this purpose. With tape recorded data, the analysis could be done off line by the 360-91 at SLAC. When additional data sources are connected to the computer, we plan to include information from them in the recorded data.

Quadrupole Adjustment

There are about 45 quadrupole current supplies[3] along the klystron gallery that occasionally need gross readjustment when experimental beam requirements change. This is a tedious job for the operators, and

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often causes delay. We are now installing an analog-to-digital converter and switch gear so that the computer can read the currents in these circuits. Since the computer is already connected to the remote control channels, it will soon be possible to do automatic current adjustment.

In the SLAC remote control system, the quadrupoles share a very few control channels with each other and with other systems. We are studying methods for modifying the control system to make it possible for the computer to adjust many controls simultaneously. If the modifications work well, the time saved in quadrupole readjustments may average an hour or more a week.

Beam Steering and Focusing

The accelerator is equipped with about 40 sets each of vertical and horizontal steering dipoles,[3] which must be adjusted for good beam transmission at the beginning of each run, and sometimes touched up at intervals during runs. The current in each dipole may be read and adjusted from CCR. For certain beam conditions, proper values or current have been recorded. When this is so, it is customary for the operators to preset the currents before attempting to run the beam. It usually happens, however, that further adjustment is necessary, partly by trial and error to produce good beam transmission, partly by using RF beam position monitor signals, and partly by observing ion chamber signals which show the location and magnitude of beam loss along the accelerator. During this initial steering operation, it is often necessary to readjust quadrupole current settings, as well.

It does not appear practical to make the computer do the initial tuneup. It may prove helpful for the computer to preset all the dipole and quadrupole currents. The computer will no doubt set the currents to closer tolerances, and read the "good" values for later use more accurately than the operators do. This in itself may reduce the tuneup time. Once the beam has been established, it may be practical for the computer to optimize the steering, and possibly also the quadrupole focusing. Since the beam orbit drifts very slowly, it is likely that a simple trial and error routine would be satisfactory. In one proposed program, at each step, the computer would record the maximum value of the PLIC pulse,[4] which is a measure of the maximum local beam power loss anywhere along the accelerator tunnel. Beginning with a vertical steering dipole near the injector, the computer would increase the steering current by a small amount, δI, measure the PLIC pulse, decrease the current by $2\delta I$, measure the pulse, and restore the current to its original value, but it would terminate the operation and step to the next downstream vertical dipole whenever the PLIC pulse became smaller. Having made at most one small net adjustment to each of the vertical steering dipoles, it would start again, this time adjusting, one by one, the horizontal steering dipoles. In the next sequence it would tweak the quadrupoles, at each step observing the effect on maximum beam loss all along the accelerator. The process would be repeated until the PLIC pulse became smaller than some predetermined value. This is clearly a wasteful procedure, and could be improved by giving the computer a signal representing the arrival time of the largest PLIC signal. The computer could then skip the adjustments of dipoles and quadrupoles known to be too far downstream to affect the pulse. Using the simple routine, the computer would normally be able to complete a set of trial adjustments in a few seconds.

Multiple beams introduce complicating features into schemes for steering and focusing the beam. If it were necessary to record the PLIC pulse height belonging to a very low rate beam before proceeding with each step, the routine would be much slower. A 1 pps beam would stretch out the time for a set of trial adjustments to several minutes. This procedure would probably be quick enough; the operators can usually neglect the steering for many hours. Another set of signals is available from the RF beam position monitors.[5] One proposal suggests the use of the vertical and horizontal position signal trains, in a procedure similar to that outlined above, to adjust the vertical and horizontal dipoles respectively.

Spectrum Control

To adjust the beam energy, the CCR operator must watch an oscilloscope which shows a spectrum bar graph. He begins with all klystron phases properly adjusted. He switches klystron triggers between the "accelerate" and "standby" modes until the beam energy is a bit high. He then precisely adjusts the beam energy by misphasing one or two of a set of klystrons which are specially equipped for this purpose.[6] To be sure that the total accelerating vector is centered on the 2856 MHz bunches, he adjusts an injector phase shifter, verifying that spectrum width is minimum. After an operator does the initial setup, the computer could maintain proper beam energy by making small adjustments to the special klystron phase shifters and possibly to the injector phase shifters. To maintain the energy is straightforward, since the computer can decide which way to crank the klystron phase shifters by analyzing the spectrum bar graph signals. To adjust for minimum spectrum width will require a trial and error adjustment procedure. In evaluating the spectrum signal train it will be important for the computer to inhibit fine adjustments when a gross adjustment is called for, e.g. when a klystron fault occurs.

References

1. R. B. Neal, Editor, The Stanford Two-Mile Accelerator, (W. A. Benjamin, Inc., New York, 1968).
2. Ibid, p. 529-532.
3. Ibid, p. 517-520.
4. Ibid, p. 814-817.
5. Ibid, p. 500-516.
6. Ibid, p. 541, 542.