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THE MULTIPLEX CONTROL SYSTEM FOR THE CORNELL 10-GeV SYNCHROTRON*

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Summary

The outlines of a time-sharing multiplex control system for the Cornell 10-GeV electron synchrotron were presented at the First National Particle Accelerator Conference, March 1965[1]. The synchrotron is now nearing completion; injection studies involving more than half the guide-field ring were carried out in 1966. At that time, the multiplex control system was working for most of the needed parameters: we report below on the results of this operating experience. We also present an outline of the steps which are being taken to use a computer for supervision and control of many of the accelerator components.

The Basic System

The synchrotron consists of 192 guide-field magnets forming a ring of about a half-mile circumference. It differs from most other accelerators of this size in its pronounced modular nature. Almost all components and functions are distributed around the ring with the 96 unitized modules (each holding a pair of magnets). The control system follows the same layout: there are 96 pairs of stations around the ring, forming a long shift register. A single pulse can be stepped around this register under central clock control. This establishes the time-sharing cycle and makes available at each station the basic gating signal which identifies the command or return signal pulses addressed to (or emanating from) that station. Figure 1 illustrates this system in block diagram form.

The salient advantages of a time-sharing system are these: compactness and ordering of command signals; compactness and accessibility of monitoring signals; avoidance of central switching equipment to achieve the multiplexing; easy compatibility with computer interfaces; and economy in terms of wire runs and terminal equipment.

Operating Experience

Although the complete system has not yet been used, sufficiently large sections were operated during the injection studies that some definite conclusions can be drawn.

Signal Transmission

Two 3/4-inch cables, each of 28 individually shielded 50-ohm conductors, carry signals around the ring. These cables have somewhat lower attenuation than the RG174/U conductors used in the first trials[1]; hence reflections become more important and the cables are terminated. Due to careless design, some small common-impedance coupling between conductors exists in the ground connections at the cable ends at each of the 96 ring stations. This results in cross-talk and has caused some difficulty. Separation of high-level command and low-level monitor signals into the two cables overcomes this trouble to a large extent; it was also found helpful to terminate all unused wires within each cable.

Command pulses are transmitted each way around the ring up to a point diametrically opposite the feed station. Attenuation under terminated conditions is then by about a factor of 0.65, which has no effect on the operation of the circuits. The return monitor signals, which originate as currents at each station, are terminated at the receiving end only; reflection by the open end of the line is not significant. Apart from slight distortion at the leading edges, the monitor signals are then not subject to attenuation.

Interference from nearby high-level sources (e.g., linac klystron modulators) has not so far been troublesome. In this respect, the fact that the basic clock interval of the system is as long as 60 μs is a major advantage.

Operating Convenience

Although final control panels have not been installed, the benefits of multiplex control for an accelerator of this size have been dramatically obvious. Using thumbwheel switches--or, later and more conveniently, pushbuttons--the operator can communicate with the whole machine from a small panel and an oscilloscope. The compactness of the installation is particularly valuable when initial operation must be attempted from a temporary control location, as is being done at Cornell to avoid being tied to the building schedule. The control console can be installed and moved with relative ease.

Wide-Band Signals

As an adjunct to the multiplex system, a method for carrying wide-band signals from any point around the ring to the control center has been installed. There are a few (in our case, three) wide-band cables carried all the way around the ring. At each station, relays permit injection of signals onto these cables (Fig. 2). Careful layout avoids mismatch at the relays not in use and minimizes injection of unwanted signals. The cables are triaxial, with the inner ground system completely floating except for the point at which the signal is injected. Hence the system is exceptionally quiet and permits effective monitoring of relatively low-level (tens of mV) wide-band signals. Switching of the desired signal source is done via the multiplex system, which energizes the appropriate relay.

The system has so far been used only for beam monitoring, both for intensity and position. Very simple terminating amplifiers and drivers are used for each detector (a ferrite-core device). The relay which connects to the triaxial cable also closes the circuit for the quiescent current of the driver stage, so that unused stations do not draw power needlessly. At the control console, the wide-band signals may be observed directly; this can yield important information which might be lost if the signals were processed to lower bandwidth at each station before transmission. The signals may also be handled automatically to make appropriate plots of beam position versus machine location. In this case, the relays are stepped automatically from station to station to assemble the data; a complete plot can be obtained in a few seconds. We plan to link such a system to the control computer.

Magnetic Corrections

There are about 50 sets of "kicker" coils around the guide-field ring which introduce vertical and horizontal low-field corrections. Contrary to original planning, these coils now carry only a single winding[2] which is driven by a switching-mode amplifier illustrated in Fig. 3.

Information about the desired correction comes from control via the multiplex system in the form of a 6-bit command; this is stored locally in tunnel-diode memories and a 6-bit confirming monitor signal is returned to control. The memory drives a digital-to-analog converter whose output controls the switching driver. If the coil current, as monitored in R, has decayed below the desired value, the switch S is closed and current is permitted to build up at the natural L/R time constant (about 100 ms) of the coil. The coil voltage is thus a duty-cycle modulated rectangular pulse train; the current, however, does not fluctuate by more than a fraction of a percent because of the long inductive time constant. Switching techniques were used to minimize the power loss; the coils require somewhat more than 100 W each at maximum excitation.

Arc suppression in the reversing relay proved to be an obstinate problem. A special quenching circuit for the switching drive, together with appropriate diodes, had to be provided.

An analog monitor signal from the current shunt R is returned to control, where it may be compared with an analog signal manufactured from the digital monitor pulses. All coil driver systems can therefore be monitored continuously during the multiplex cycle and failures reported at once. This is of great practical importance in a large accelerator whose correction system contains much redundancy. If the beam is reduced due to a coil failure, the operator can generally retrieve it with other coils. However, after some accumulated failures have become built into the operating conditions, servicing of the equipment is likely to produce a major upset.

During injection studies, only a few kicker-coil drivers were available. These were controlled by a rudimentary system of binary switches to send out the desired instructions. The system being developed for permanent use has several levels of control:

1. For manual adjustment of individual coils, the station is addressed and its present setting is stored. This serves as a point of departure for operator tuning. Using a rotary knob, the operator may increase or decrease the coil current from this point, the system following in digital steps of course. He may return to the original setting or freeze-in his new condition, as desired.

2. For computer adjustment of individual coils (e.g., to center the injected beam on its first turn), similar control is yielded to the computer, which uses beam-position data from appropriate stations as its input.

3. For computer adjustment of closed orbits, beam-position data are taken. Processed with stored programs of known beam orbit dynamics, they yield changes of coil currents which are then implemented.

4. For manual adjustment of closed orbits, beam-"bumping" techniques are used. Each bump consists of three adjacent coils so tracking each other as to deflect the orbit locally without significant perturbation elsewhere. The operator selects the desired bump location and then obtains suitably ganged control of three coils in that vicinity. This control is incremental with respect to the original currents in the coils, as before.

Computer Plans

Our program calls for an IBM 1800 computer to be used mainly for experimental on-line or off-line purposes; this will be available on time-sharing for machine control also. Delivery of the computer is expected toward the end of this year; meanwhile, some urgent functions are being implemented with a CDC 160A computer in a temporary installation.

Our approach to computer use is somewhat tentative; we envisage several stages of involvement which might be brought about in steps, and do not wish to commit ourselves to the final degree at this time.

Stage 1 is concerned with the recording of machine conditions. The mere task of writing 100 6-bit binary numbers (or their equivalents) for the kicker coils, and of checking them, is quite prohibitive. Computer printout of such numbers, obtained in a trivial manner from the multiplex data pulses, is desirable. The computer needs no command functions at this stage: to reset conditions, one reads the present status and asks the computer to call out only those functions which deviate from the desired reference set. With luck, the number of required adjustments will not be large.

At stage 2 we intend to extent this simple readout function to all significant variables in the machine, including many which are not normally subject to adjustment. In this way, the computer can be asked to check all variables at regular intervals, and to signal any detected changes (beyond specified limits) which did not come about as a result of operator tuning. Thus, working from a reference set which is continually updated as the operator tunes, the computer can sound an alarm whenever a failure occurs and identify its source.

Stage 3 arms the computer with command functions. It can now be asked to reset specified conditions into the machine; more importantly, the door is open to automatic beam tuning, a process which can be implemented to various levels of sophistication without at any time giving up the operator's overruling autonomy. This development is clearly a challenging and thrilling one--it represents the prize plum. The obstacle, of course, lies in the difficulty of implementing the computer control functions.

Insofar as the functions come under the sway of the multiplex system, the computer link is relatively straightforward. Problems arise mainly in the host of functions which traditionally come with a bewildering variety of control techniques, mostly starting with knobs and switches. We have our share of such problem children, inherited mostly from commercial sources--but partly also from local tradition. Here is an area where psychology enters strongly: can the operator be persuaded to give up his favorite knob and use momentary-contact (raise/lower) switches instead? It seems clear that for some time to come we shall be operating a hybrid system, but we feel confident that the advantages of computer supervision, not to mention those of computer control, will be such as to force a rapid standardization.

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[1] Multiplex Control of a Large Accelerator, R. Littauer, IEEE Trans. Nucl. Sci., Vol. NS-12, p.36 (1965).

[2] The multiple-winding design was abandoned because of probable production difficulties, and because the self-heating caused resistance changes which upset the binary current relationships.

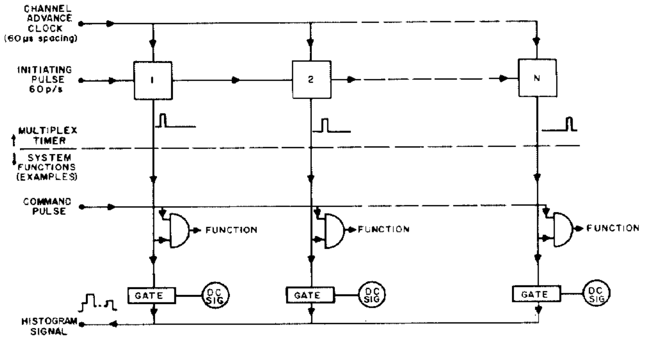

Fig. 1. Block Diagram of Time-Division Multiplex System.

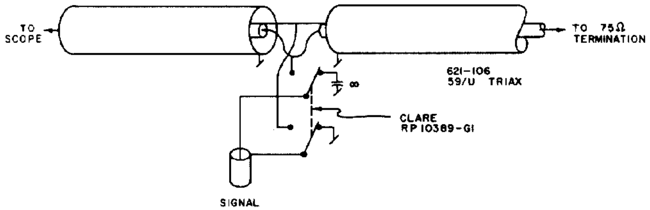

Fig. 2. Feed Relay for Wide-Band Triaxial Cable.

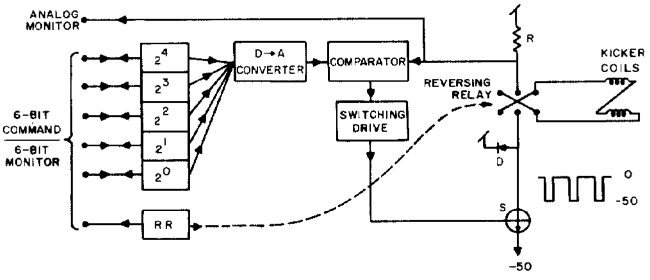

Fig. 3. Control Station for Kicker Coil.