MULTIPLEX CONTROL AND MONITORING OF A LARGE ACCELERATOR

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Summary

A time-sharing pulse multiplex system is described which will perform most of the control and monitoring functions for the Cornell 10-GeV electron synchrotron. Beyond the reduction in the number of cable runs and the more compact presentation of data at the control desk made possible by this system, the control language is also suited for communication with a computer. Operation of the accelerator under computer control is envisaged.

Introduction

As accelerators are built on an ever larger scale, some of the control and monitoring functions increase in complexity: those which are concerned with individual elements rather than with the system as a whole. For example, monitoring the pressure in an extended vacuum chamber with small pumping speed, pumped from many points, requires more gauges in proportion to the circumference of the machine. Again, measuring the excitation current in a magnet power circuit consisting of many series-connected resonant elements, each driven and tuned individually, is a problem of this type; controlling the main power for the circuit, by contrast, is likely to be a single function independent of the number of elements involved.

Standard control and monitoring techniques become less attractive as the accelerator grows; not only does the number of wires involved rise prohibitively, but also the command and display transducers become clustered at the control console, hindering effective supervision. For these reasons a multiplex system appears attractive.

This paper presents the basic features of the system designed for the Cornell 10-GeV electron synchrotron. This accelerator has 192 guide magnets extending over a circumference of about one half-mile; there are four straight sections 20' long and two 40' long. The magnets are excited at 60 cps (with a superimposed dc bias) in the well-known manner. Each magnet is individually resonated with a capacitor bank and choke. The chokes carry excitation windings which are driven, in parallel, from one ignitron inverter.

There are 96 vacuum pumps and associated gauges. Beam steering and "bumping" controls are somewhat fewer, but still numerous enough to make multiplex control and automated setting-up procedures desirable.

The pulse techniques used for multiplexing are, in themselves, entirely standard and will therefore not be presented in detail. The aim is to illustrate the simplifications which can be achieved through multiplexing, and to draw attention to the fact that such a technique makes the control system ideally compatible with computers. Use of a computer for operating the machine is envisaged here, as in several other laboratories.

Outline

Presentation of groups of correlated variables is conveniently done in histogram form on an oscilloscope. A time-sharing multiplex system leads to this naturally if the oscilloscope time base is synchronized with the multiplexing cycle. Such a system is used on the Cornell 10-GeV synchrotron.

The cycle is established by a central clock which delivers bursts of 240 pulses, 60 bursts per second synchronized with the line frequency. The repetition rate within the burst is 20 kc/sec. A 240-element shift register is distributed around the accelerator ring, each of its individual binaries constituting the nucleus of a "station". (240 stations leave a margin for accessory functions beyond the 192 required for individual magnets.) At a zero time a pulse is injected into the shift register; this pulse travels around the ring in steps dictated by the clock. Each binary is thus energized only at a specific time correlated with its position in the ring. The binary's pulse is the basic control signal which renders the various functions at the station sensitive at the appropriate time. In the central station, meanwhile, clock pulses are counted to provide a digital address code for any desired station.

The 20 kc/sec clock rate leads to a dwell time of 50 μsec at each station, long enough in principle to permit further time sharing between the various functions to be performed there. We have decided against this alternative, however, in order to keep the system simple and maximize its chances of reliability. The circuits may then be slow in response: this avoids risetime and synchronization problems associated with the long cable runs, and permits us to make the circuits insensitive to the fast pickup pulses which are to be feared in most accelerator environments.

Each type of function is controlled or monitored by a single, separate cable. Command pulses are gated by the binary pulse at every station and activate only the particular station addressed, where a time coincidence occurs. Every monitor signal is gated by the binary pulse before being impressed on the common monitor line for that particular variable. The total number of cables required by this system is not negligible, but it is of course very small compared to the number of separate lines which would be needed without the multiplexing.

Some Examples

Magnet Positioning System

The magnets are mounted, in pairs, on I-beams which are supported on precision jacks to permit vertical and radial alignment of the accelerator. (The small aperture and large size of the machine make this desirable; ultimate alignment will be carried out by reference to beam-position measurements.) By dialing the address code of a particular station, the operator can make manual adjustments of the motors controlling the jacks at that station. A relay connecting the motors to the common control lines is held energized while the address code remains set.

Position transducers (linear differential transformers energized by short pulses) transmit information back to the control console, where a gated amplitude analyzer displays the jack positions in digital form. The control loop can be closed via a computer, if so desired, to feed back beam-position data and make adjustments in desired patterns automatically. Also, jack-position data may be punched out in digital form on cards to preserve a record for future reference. If necessary, information from the cards may be read back into the system to obtain a desired set of jack positions.

Correction and Bumping Magnets

These are wound with multiple coils, with field impulse values in a binary system, so as to permit digital control of the amplitude with the help of relays. Each magnet is assigned to a nearby multiplex station; here a set of binary memory elements (tunnel diodes) retains information about the desired amplitude. Information may be read into and out of these memory elements via the usual multiplex gates.

In setting up beam conditions for a particular excitation energy, intensity, radio frequency, and beam spill pattern, the operator may program the correction and bumping magnets from a punched card previously prepared. He may then wish to tune conditions manually, with incremental binary commands (programmed out of normal increase/decrease rotary controls) which may be addressed as required. When satisfactory operation is obtained, the new conditions may be punched out on a card.

Extension to computer control is again natural. A procedure which might prove fruitful would be to explore the available beam aperture at various azimuthal positions in the machine by introducing controlled bumps in the orbit, and then to set in computer-calculated correction conditions which would tend to maximize the aperture at all points.

Vacuum Monitoring and Control

The pressure at each pump is measured with a cold-cathode discharge gage whose current is admitted to a common monitor line through a diode gate energized by the binary pulse at that station. At the control desk, an oscilloscope displays the pressure as a function of position in the ring. Interlocks to isolate faulty ring sections may be controlled from the same signal. The required gate valves are operated by relays whose control is again relegated to the multiplex system. Manual control, both locally and from the control desk, is easily added.

Practical Considerations

Reliability

The system so far outlined constitutes what may best be termed the central nervous system of the accelerator, malfunction of which would lead to neurotic symptoms of a paralyzing and possibly paranoid nature. The danger aspect of such a malfunction is avoided by providing overall interlocks on each system (not element-by-element) in conventional circuitry, assuring personnel and equipment survival even in the face of a nervous breakdown. However, it is clear that we are still putting a lot of eggs in one electronic basket: high reliability and complete self-checking facilities are essential in such a system.

We believe that intrinsic reliability can be obtained by standard computer techniques, helped in this case by the long pulse durations involved. The system is mounted in a self-contained conduit and box system; residual pickup problems are likely to center chiefly on short pulses and may thus be eliminated by giving the circuits sufficiently slow response times.

Self-checking is built into the system at every stage. A trouble signal is delivered when any fault is detected, and critical control functions are immediately brought to a safe condition. Standardization of circuits, and availability of plug-in spares from an operative duplicate system (without the half-mile spatial extension, however), should reduce maintenance time to a minimum. Monitor signals to indicate the location of most faults are made available.

Cable Runs

Time delays due to long cable runs are insignificant in a system as slow as the one here considered. However, cable attenuation is a more serious problem. We have found a method of driving cables which possesses several advantages. Using subminiature cable, such as RG-174/U, one obtains a high attenuation on any signal which has to drive the cable impedance (50Ω) through a long cable. As a result, reflections from the end of a long cable are so seriously attenuated as to become negligible. It is not necessary to worry about proper termination of such cables, provided no reflections are generated at each of the tapping points which are served by it (station after station).

The cable attenuation disappears, however, when the cable is fed from a voltage source and drives only high-impedance loads. Alternatively, the cable may be fed from a current source and drive a short circuit. In either case, beyond the worsening of the signal risetime which is here of no consequence, the amplitude of the delivered signal is independent of the length of the cable. In our system, most monitor cables are driven by current sources at the various stations, and are terminated in a virtual short-circuit at the central console. Most command cables carry voltage signals, care being taken that all non-energized gates present a very high impedance to the cable.

Power Supplies

In the face of possible power-line interruptions, information stored in tunnel-diode circuits is preserved by providing a maintained-power line (backed by a battery).

To protect the system against failures or accidents at particular stations, the power supplied to each station is passed through current-limiting transistors which isolate the stage in case of overload. The remainder of the system may continue to function normally, with the exception of sequential signals ruined by the faulty station. No resetting of circuit breakers is required after the fault is cleared. Such individual current limitation is better than overall power-supply protection: in case of trouble, shutting down the entire system would seriously delay tracing of the fault.