A prototype automatic control system using crossbar relays for switching was built for experimental study. Eleven sets of these highly reliable and inexpensive relays can provide computer or manual access to the control of 1000 magnets or other regulated systems. The system consists of a computer, several manual-control panels, a set of crossbar relays, digital regulator references and actuating devices, and a corresponding readback system. The manual-control panels contain an address keyboard, which controls the crossbars, and a data-entry keyboard. The data are routed to the desired regulator reference or actuator. Since any number of manual-control panels may be used, each maintenance specialty can have its own control of the accelerator on "down" days. For automatic operation the computer simply replaces one of the manual-control panels. The coil-to-contact isolation in the primary crossbar relay connects the control chassis and digital read-out systems provide essentially infinite noise isolation between the accelerator and the control system. Without the computer, the cost is comparable to a conventional manual-control system. Design considerations of the special devices which are unique to this type of control are included.

Introduction

Control of a particle accelerator is essentially a problem in communication between the operator and the accelerator at minimum cost. A few of the vast number of communications channels require very high information capacity, but most do not. For these latter channels, which account for most of the cost of a control system, crossbar relays appear to be well suited. Small computers have become widely used in the experimental programs of many accelerators. In this application, they have become almost essential. Most accelerator designers feel that an electronic computer is very useful in an accelerator control system.

At this stage in the development of computer-control systems one is impressed by the diversity of design philosophies of the different design groups. Lewis, at Argonne, started his design from the point of view of chemical-plant technology; Littauer, at Cornell, from communications technology; Butler and Machen, at Los Alamos, from scientific computer technology; Struthers, at Berkeley, from regulator technology; and Lancaster, at Berkeley, from servo system technology. Most groups have had as an ultimate objective on-line beam optimization. So far this has not occurred. Progress has been limited by difficulties in making good nondestructive beam measurements.

However, it may be that on-line beam optimization is not worthwhile. Accelerators are really very stable. Most will maintain an optimized beam without attention for many hours, and even when the beam does drift from optimum, re-setting the offending electrical parameter restores it. A small computer with a large memory may be the most economical solution to the computer control question, and all that is required "on-line". If rarely required, beam optimization may be more economically achieved by a larger "off-line" computer from data taken by the small computer. Presumably the large computer would be a general-purpose computation facility for all scientists associated with the accelerator and its experimental program.

We have developed an automatic control system for the Electrion. It includes a set of primary crossbar relays and as many sets as necessary of secondary crossbar relays. The primary crossbar relay connects the control panels to any secondary crossbar relay. Each secondary crossbar relay is located at an information gathering station of the accelerator and provides access to 100 channels, each consisting of

Design simplicity became important when preliminary specifications called for any of 30 manual data-entry stations to be able to address any of 10,000 remote actuating devices, and to be able to transmit 16 bits (four decades of binary coded decimal (BCD) while maintaining extremely good electrical isolation between such sensitive devices as precision bending-magnet regulators and the noise sources of a vast control system. The isolation specifications (1200μ) coupled with the necessarily low on-resistance of the switch closure in the precision regulator references, effectively eliminated everything but relays as the coupling medium at these interfaces. The relay decision having been made, parallel transmission became necessary in order to be able to set all the references in a reasonable time, given the relatively slow switching-time characteristics of relays.

Figure 1 is an overall block diagram of the system showing the four information-transfer stages: manual data-entry panel, primary crossbar, secondary crossbar, and remote data acceptor.

Manual Data-Entry Panel

To properly consider the data-entry section of the manual panel system we must digress for a moment and discuss the sequence of operation of the system as a whole, or in other words, defining what is desired of it. The operator first brings his manual panel into service by punching the "Lock" button, providing, of course, that no other manual panel is already locked on the line. This enables his data-entry panel and disables all other panels. He may have previously selected the address of a remote terminal, or he may at this point punch in the address; the sequence is immaterial. The receiving device is not disturbed, even though selected, until the "Enter-Data" button is punched, in order that the read-back system (which is activated as soon as the address is selected), may observe the present set point of the reference, giving the operator an opportunity to reset that value into his data-entry push buttons before punching the Enter-Data button. In any case, as soon as the Enter-Data button is pushed the relay memory in the selected receiver is unlatched, i.e., the latching contacts that lock each relay on or off are opened. During the Enter-Data time of the manual panel operation, the relay memory in the receiver follows exactly the data entered in the data-entry decades section of the manual panel. If that information is changed, the relays in the receiver change. This mode of operation is useful so that the operator can, with a minimum of difficulty, use the decade switches to tune the system controlled by the receiving device. When the set point has been selected and set into the receiver, the Enter-Data button is pushed "off" and power is immediately removed, allowing the latch relay in the receiver memory to drop out and provide latching voltage to the latching circuit contacts of all the 16 memory relays.

Each 10-bit data-entry push-button decade is converted into four bits of BCD by the four encoding matrices. These are simply diode matrices converting 10-line input into four-line output.

Primary Crossbar

Addressing of one of the hundred possible crosspoints in the crossbars is effected by selecting one of ten possible "Select" magnets (vertical magnets) and one of ten possible "Hold" (horizontal magnets). The construction of the crossbar dictates that the Select magnets must be energized and must settle to their steady-state position before the Hold magnets may be energized. Each Select magnet has associated with it a set of contacts called the "off-normal pileups", which may be used to prevent excitation of the Hold magnets until the Select bars have completed their travel.

Data-entry section considerations in the primary crossbar are rather straightforward since each individual crossbar simply acts as a hundred position, ten-pole switch.

Secondary Crossbar

Address selection in the secondary crossbar varies only slightly in execution from the primary crossbar. There is, as before, a 10-pair address bus connecting all of the secondary crossbars to the units and tens positions of the address keyboard. Only one secondary crossbar should be operated by the voltage impressed on the address bus. A voltage brought through one channel of the primary crossbar crosspoint references the particular secondary crossbar of interest. Thus voltage from the 10 pair of the secondary crossbar address bus is impressed on to the top of all the Select and Hold magnets of all the secondary crossbars, but only one secondary crossbar will have its return circuit closed.

The data transmitted through the secondary crossbar, out to one of the hundred possible receivers connected to the particular selected secondary crossbar, consists of 17 lines: 16 bits worth of four decades of BCD information, and one bit used to Latch/Unlatch the relay memory in the receiver.

Reference Power Supply

For regulated systems such as magnet power supplies and servo systems, the receiver consists of a digitally operated reference power supply (see Fig. 2). The range 0 to 10 V is desired at the power-supply output, consequently the control resistor string is a four-decade, 1-2-4-8 ratio string, with a range from 0 to 10,000 Ω in 1-Ω increments. If a relay is selected and energized, its resistor-shorting contact will open, allowing an incremental voltage drop across the string due to the constant 1 mA current through it.
Numerically Operated Contactor

This device is intended to permit control of remote on-off equipment such as power supplies, filament transformers, blowers, and pumps. The basic circuit is shown in Fig. 3. Four such circuits can be built on a common panel; each panel is addressed by the address keyboard of the control panel. The data relays are connected to the data keyboard in a manner similar to the digital reference. Relays 10 through 19 are control relays. The hundreds and thousands columns can be used for turn-on of equipment, while the units and tens columns can be used for turn-off.

Computer Integration

The computer is easily integrated into the system to simulate another manual panel. Since the system is entirely digital, the computer integration demands only simple input-level changes, output-level amplifiers, and either external hardware or internally generated time delays to allow for relay settling.

One automatic operation mode is Record and Reproduce. In this mode, after the accelerator has been tuned, the computer sequentially cycles, and, using the read-back system and a digital voltmeter, records all manually set reference set points, storing them in memory and on magnetic tape. Later, if it is desired to reset the accelerator to the previous configuration, the applicable magnetic tape can be pulled and read, and the computer used to automatically set (and check) each receiver.

Fig. 1. Block diagram of control system. An electronic computer may be substituted for one of the manual data-entry panels for automatic operation. In addition to being installed in the main control room, manual panels may be located at any of the information-gathering centers of the accelerator, e.g., at an RF station, switchgear room, or experimental area.
Fig. 2. Precision regulated programmable-reference power supply. The output voltage is adjustable from 0 to 10V in 1-mV steps.

Fig. 3. Basic circuit of numerically operated contactor. Four such circuits are included on each panel. Control relays RE10 through RE19 actuate any on-off-type equipment.