COMPUTER-AIDED RECORDING OF CONTROL WIRING*

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Summary

Most particle accelerators have extensive networks of control wiring. The usual stream of minor modifications requires hundreds of control wires to be added, deleted, or changed in function every few months. Conventional terminal and cable record books and wiring diagrams are difficult to keep up to date and often are cumbersome to use. We have devised improved computer-aided techniques for organizing information about a control wiring network into compact forms convenient both for trouble-shooting and for new design work. Additions and deletions require only a single data card per wire. The computer prints out a pattern of interconnections for each circuit, adds information on circuit functions, and finds and marks such probable errors as dead-end wires and redundant circuit paths. The computer-aided system has been in use for nearly two years at the University of Minnesota proton linear accelerator, which has a control wiring network containing about 10,000 wires. A complete set of record books can be worked out in about 18 minutes on a Control Data 1604 computer. Trouble-shooting, identification of wiring errors, and design of system additions all have benefited from the speed, convenience, and accuracy of the computer-aided system.

Introduction

The control wiring network of a particle accelerator must be on record in a form that is convenient for use both in trouble-shooting and in new design work, and that record must be continuously kept up to date as changes are made.

Conventional terminal and cable record books and wiring diagrams are difficult to keep up to date, and often are cumbersome to use. There is a tendency to make the drawings of control systems quite large, in order to get as many as possible of the interrelated circuits on a single sheet and reduce the number of interconnections between drawings; but in a large drawing even simple wire-tracing may be difficult, and the logic of circuit relationships is easily lost. The steady influx of unpredictable additions and modifications requires frequent correction of the drawings; before long the constant squeezing-in of a relay here and a group of interlocks there results in intolerable crowding of parts of the system schematic diagram, and a man-month must be invested in making a new drawing.

We have devised a computer-aided system of recording control wiring which, at least for the conditions at our laboratory, seems to be quite advantageous.

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One of our major objectives in developing this system was to reduce the amount of effort required of technicians and draftsmen in keeping records up to date. We expect in this way to gain accuracy as well as to save money.

No large drawings are needed; in most cases the only drawings necessary are the schematic diagrams from which individual control panels and chasses were constructed. If several identical ionization gauge controls, for example, are used in different parts of the system, a single drawing is sufficient for them all. Changes in wiring within a control chassis require correction of the drawing in the usual way, but changes in external wiring do not; the external wiring is not shown on a drawing, but appears on a computer printout.

The interconnecting wiring is specified on business-machine cards. A single wire is described on each card by specifying the location of its ends. If one end of a wire goes to a terminal which is part of a circuit diagram, the drawing number and a function note are included on the wire card. Space is provided for wire color and gauge information.

One such card must be added to or removed from the file for each wire added or deleted.

Data Presentation

With information on all control wires available in machine-readable form, one may choose many different ways to organize that information and print it out for use.

We use two distinct formats, which we call (1) the cabling book, and (2) the rack book. The cabling book is intended to enable one to trace a function from one control chassis to every other piece of equipment connected to it. The rack book is a more-or-less conventional tabulation of terminal strips in control racks and junction boxes, listing all wires attached to each terminal.

Figure 1 shows a small portion of a diffusion pump control circuit in block diagram form. The task of the cabling book, Figure 2, is to trace the control wiring between blocks. The rack book, a portion of which appears in Figure 3, tabulates the wires connected to each terminal. The figures will be discussed in more detail below.

It is desirable, for speed and convenience in trouble-shooting, that full information on the connections to any individual chassis or panel in the system should be listed at the part of the cabling book assigned to that chassis. This means that a group of interconnected wires that join, say, six different chasses will be printed out at

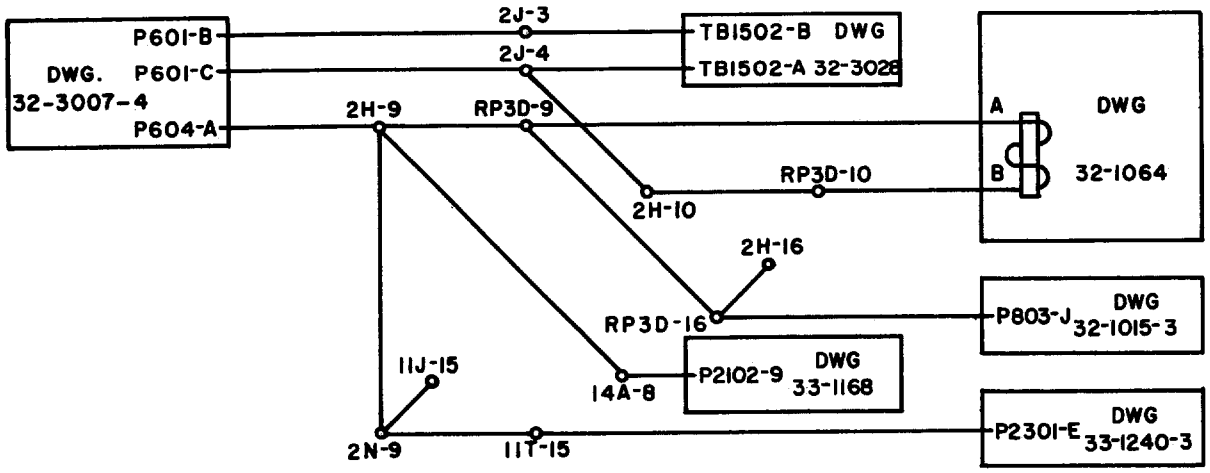

FIGURE 1 BLOCK DIAGRAM SHOWING TYPICAL CONTROL WIRING

FEBRUARY 24, 1965 PAGE 114 DRAWING 32 3007-4

RESNATRON 3 D-P CONTROL LOCATION- RACK 2, PANEL 5 DRAWING 32 3007-4
SERIES NUMBER 600

A-C POWER SUPPLY HOT							
P601-B	2J-3	TB1502-B	-	-	-	-	DWG NO. 32 3028
A-C POWER SUPPLY NEUTRAL							
P601-C	2J-4	TB1502-A	-	-	-	-	DWG NO. 32 3028
		2H-10	RP3D-10	K3101-B			DWG NO. 32 1064
PUMP ON OUTPUT POWER							
P604-A	2H-9	2N-9	11T-15	P2301-E	-	-	DWG NO. 33 1240-3
			11J-15				DEAD END••••••••
		RP3D-9	K3101-A	-	-	-	DWG NO. 32 1064
			RP3D-16	P803-J			DWG NO. 32 1015-3
				2H-16	-	-	DEAD END••••••••
		14A-8	P2102-9				DWG NO. 33 1168

FIGURE 2 PORTION OF CABLING BOOK CORRESPONDING TO FIGURE 1

FEBRUARY 24, 1965 PAGE 45 TERMINAL 2H-7

2H-6					OPEN
2H-7					OPEN
2H-8					OPEN
2H-9	P604-A	ENDWIRE	32-3007-4	BR	RESNATRON 3 DIFFUSION PUMP CONTROL
	RP3D-9	CABLE			
	2N-8	JUMPER		WH/RD	
	14A-6	JUMPER		BK	
2H-10	2J-4	JUMPER		YE	
	RP3D-10	CABLE			

FIGURE 3 PORTION OF RACK BOOK

six different locations in the book. Manual entry of wiring changes in such a book would be intolerably difficult, since some wire changes may require scores of entries; but with computer techniques this poses no particular difficulty.

The Cabling Book

The cabling book is primarily a trouble-shooting tool, laying out complete wiring networks in compact form. When trouble appears in an established control wiring system, it usually means that an open-circuit, short-circuit, or ground fault must be found. In the cabling book each conductor path is traced with all its branches, and every intermediate terminal is identified, so that one can perform rapid tests to isolate the region in trouble.

The computer program is given the wire card information (and a limited amount of related data, such as functional titles and locations of the various panels and chasses in the system) and organizes it into circuits which can be printed out in the forms shown in Figure 2. It does this by starting at one assigned point after another, identifying the terminal to which it is connected, and searching its memory to find other wires which are connected to that terminal. Those wires are in turn checked for further connections. Every conductor path is followed until each is traced to a terminal on a piece of equipment, or to a dead end, which the computer marks as such on the print-out. (Two dead ends appear in Figure 2).

It is helpful to compare a conventional circuit diagram, Figure 1, with its cabling book equivalent, Figure 2. Figure 1 represents a small part of a diffusion-pump control system. The pump control panel is the block on the left, drawing 32-3007-4. It receives power from a circuit-breaker panel, drawing 32-3028, and controls the diffusion-pump power contactor, K3101 in drawing 32-1064. Three other chasses receive information that the diffusion pump is turned on.

The circles along the lines with names such as 2J-3, RP3D-9, and 14A-6, identify terminals on barrier terminal strips located in various control racks and junction boxes.

The computer printout in Figure 2 represents the same group of inter-connecting wires that is shown in Figure 1. We are working out from the diffusion-pump control, so the terminals (in this case, connector pins) on which we leave that drawing are tabulated at the left, together with appropriate function notes.

An easy way to trace the wire runs from the cabling-book printout is to look first left and then up from any terminal. Start at a terminal, such as 2J-4. There is another terminal name in the next column to the left of it on the same horizontal line, P601-C; therefore there is a wire joining those two points. In the same group, start with 2H-10; there is no terminal name in the next column to the left on the same horizontal line, so look up that column until a terminal name is found. There is a wire between 2J-4 and 2H-10.

The same principles can deal with more complex networks. Thus, in the "Pump On Output Power" group at the bottom of the figure, there are wires from 2H9 to 2N-9, to RP3D-9, and to 14A8. Terminals 11T-15 and 11J-15 both connect to 2N-9, but K3101-A, below them, has another terminal to its left on the same horizontal level; therefore K3101-A connects to RP3D-9.

Display of Large Circuits

The printout of Figure 2 is somewhat condensed to meet the limitations of space available in this paper. In our actual cabling book format, there is room for eight columns of terminals before the drawing number notations are reached. Occasional circuits will go on from terminal to terminal far enough to exceed that limit. When this occurs, or when a circuit must be continued past the bottom of a page, the computer assigns letters to columns and numbers to rows, and prints out the entire circuit in sections; it also enters "CONTINUE" notations in the drawing number column of lines to be continued. The right-hand column of the original section overlaps the left-hand column of the following section (that is, they carry the same letter and have the same terminals printed in them) to make coordination across the boundaries easier. The second group of columns is printed offset a few spaces from the first group to make it less likely that an unwary user would overlook the break between circuit sections. A few circuits are so large that they would take up excessive space in the cabling book if no special arrangement is made, since they will be printed out in full in as many places in the book as there are chasses connected to the circuit. In these cases markers on the wire cards have been used to identify the circuit as one selected for special treatment, and the circuit network is printed out in full only at the first place it occurs in the cabling book; at other locations where it would normally appear a page reference is made to that printout.

The Rack Book

The rack book is a tabulation of terminal strips in control racks and junction boxes, with a listing of the wires attached to each terminal. Figure 3 is part of a typical rack book page. The terminal block being considered here is designated 2H, which means the strip lettered H in control rack 2. Its terminals are listed in the left-hand column. There is a wire from a given terminal to each of the points listed with it in the second column; sometimes the wire goes directly to a piece of equipment found on a drawing, in which case it is called an endwire (note in column three) and the drawing number appears in column four. Other times the wire is part of a standard 16-conductor control cable, or is a jumper wire; in either case the terminal to which

it goes is listed in column two. No attempt is made to trace the circuit further.

The color of the wire, when known, is listed in column 5, together with its gauge if it differs from our usual standard (18 gauge in 16-conductor control cables, 20 gauge elsewhere). The last column contains the title of the drawing if one is listed in column 4.

For example, terminal 2H-9 in Figure 3 has four wires connected to it. One goes to pin A of connector P604 of drawing 32-3007-4 (the resnatron 3 diffusion pump control) and is known to be brown. Another is part of a 16-conductor cable, and connects to RP3D-9, which is terminal 9 of terminal strip D in the RP3 junction box. RP3 is used for Resnatron 3 (vacuum) Pump functions.

The other two wires are jumpers to other terminal strips in the control room; one goes to 2N-8, another to 14A-6.

The first three terminals of Figure 3, 2H-6, 2H-7, and 2H-8, have at present no wires connected to them. In these cases the computer inserts the notation "OPEN" in the last column.

The rack book is particularly useful for design work, where open terminals and unused cable conductors must be found, and is also used in identifying those wiring errors that result in terminals having incorrect numbers of wires attached. A common error in installing new wires is to attach a wire to a terminal one above or one below that which was intended. A wire count often can reveal such a mistake quickly.

Error Detection

Errors can occur at many stages in the recording of a wiring system; to help detect them, a number of self-checking features have been included in our programs.

When data cards are being entered, a number of tests are made for correctness of data on each card. Error messages are printed out on the list of changes, to help the operator to find the cards in question, identify the problem, and take corrective action. For example, cards filed out of order are noted (manual reference is often made to the file of wire cards; cards out of order are difficult to find). Many errors made in punching the cards can be detected because the notation used to indicate terminals and wire endpoints is redundant in its natural form. For example, four alphanumeric characters are reserved for each junction box name, which means that a possible total of 36^4 or more than 1.6 million names could be distinguished. In practice, however, only about 100 are used. A typing (punching) error is likely to produce a name that does not correspond to an actual junction box, an error the program can recognize automatically. Other parts of the wiring data are checked similarly during the input phase of a cabling book run, before they are reduced to a nonredundant binary form.

Errors are also detected by the computer during the generation of the cabling book. These situations cause diagnostic messages to be printed in the cabling book.

For example, a CIRCUIT LOOP message is printed whenever a circuit is found to have redundant wiring. This is not necessarily an error, since cable conductors are sometimes paralleled for high-current applications. Besides the message, the computer also generates a list of the wires in the circuit and prints it after the circuit in the cabling book. This is done because the cabling book format does not provide an obvious means of representing parallel wires.

Another diagnostic aid is the DEAD END message that was described in the section on the cabling book.

At the end of the cabling book the computer compiles a list of jumper wires that are open at both ends. Usually these are wires which should be removed.

Finally, of course, errors are detected by the design engineer who compares the circuit as it appears in the cabling book with his original schematic diagram. We find that the computer-compiled cabling book is more likely than a comparable manual compilation to reveal incorrect connections of new circuits with existing but unrelated functions. This is because the computer finds every connection, while a man doing the same job tends to be blind to unexpected or unreasonable interconnections.

Recording Changes

Whenever a new set of books is run off, we make duplicate sets; one to be kept in the engineering offices for design work and the other to be kept in the accelerator control room for use in maintenance and trouble-shooting. Because of this duplication, and because each change requires a minimum of three (up to dozens) of entries in the books, we make no attempt to correct the books manually. As changes occur, they are accumulated in a loose-leaf notebook. The only information given is that a particular wire was added or removed; the person using the books must look through the whole change list to find any wires connected to terminals of interest to him. At some point this procedure becomes too difficult, and a new set of books is prepared on the computer. In our case, we have averaged about four new printouts per year since mid-1965.

To compute the cabling book and rack book for a system containing about 11,000 wires takes about 18 minutes on a Control Data 1604 computer. This is actual computation time, with the output going on to magnetic tape. Print-out, with a 1000 line/minute printer, takes about three hours for two full sets of books. About 15,000 wires can be handled within the memory capacity of the 1604 computer (32,768 48 bit words).

Possible Improvements

There is a small number of circuits which are inconvenient to trace with this system. A typical case is that of a metering circuit which originates in a VTVM chassis but passes through three or four remote meters in series. In the present cabling book system, such a circuit does not appear completely in any one place; one must turn to other parts of the book associated with one or more of the intermediate panels in order to fill in the gaps.

It seems likely that a modification could be devised which, in the case of selected special circuits, would trace a function from an originating chassis on through a number of intermediate panels and back to the originating chassis. We have not yet settled on a way of displaying such a circuit in the printout, but once this is agreed upon there should be no special difficulty in modifying the computer program to include this feature.

Each "end wire" - one connected to a terminal on a piece of equipment with a drawing number - has a function note associated with it. These notes appear in the cabling book at the origination of each circuit traced (see Figure 2). There has been some interest in printing out the function notes associated with the terminals at the right-hand side of the cabling book circuits, and also at appropriate places in the rack book. This would probably be a worth-while improvement in the system, but would require going to a multi-pass procedure because of the limitations of our present computer's memory.

In a few instances we have been able to help the designer of a new system to check his work, catching a number of errors and omissions, by punching wire cards for the new system while it was still in the design stage and using them to prepare a set of cabling sheets. At the moment we cannot conveniently put in information on all of the existing wiring while printing out only the new system; such a change in the program should be feasible, and might lead to more frequent use of this technique for checking new designs.