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COMPUTER CONTROL OF THE INDIANA CYCLOTRON *

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Summary

The Indiana Cyclotron control system consists of several hundred cyclotron devices and two operator stations linked to a small digital computer via a bi-directional, multiplexed digital bus. All communication between operators and the cyclotron is by means of 64 displays. Provision is made for readout, control, data logging and retrieval, alarm warning, and initiation and termination of automatic control programs.

Special features of the system are the modular and dynamic master table which uniformly describes the cyclotron devices to all the programs which drive them, and the dynamically reconfigurable cyclotron control displays.

Hardware

The basic computer configuration and digital bus system have been described elsewhere[1] in detail. The computer is a Sigma 2 with 20K of memory, a fast disc, magnetic tape and teletype. The digital bus will accomodate up to 1024 16-bit input gates, 1024 16-bit output latches, and 16 16-bit interrupt registers; the bus and associated multiplexing and logic is expanded as needed. It is divided into 8 basic decentralized modules. Most analog hardware is located in close proximity to one of the 8 digital stations.

Console Stations

Each console station includes a 960-character CRT display with refresh and local memory; a two axis trackball used for cursor control on the CRT; a 2 x 8 push-button matrix for display selection; dual knob/lever/meter combinations for attaching to devices of interest; and several interrupt buttons. A full keyboard is present, but is not used in normal cyclotron operations; rather it is used only when reconfiguring the displays themselves or the master tables.

Fig. 1: Main control console. Point-plotting scope is at left, operator stations #1 and #2 in center, closed -circuit TV at right. Auxiliary equipment and multiplexer sub-unit #1 in background.

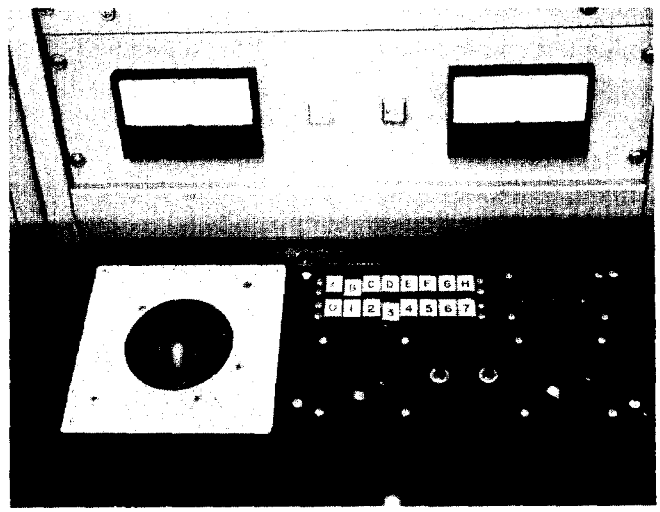

Fig 2: Close-up of operator station input hardware. Meters and two interrupts are above; trackball/GO button at lower left; push-button matrix, digi-switches, two shaft encoders and two levers at lower right.

Interface

A major concept, which has allowed the significant software generalization described below, is the standardization of interfacing hardware to include families of integrating A/D converters; families of latching D/A converters; two-speed, bidirectional, preset-count stepping motor controllers; and a versatile on/off control circuit with status readback.

Software

Operating System

Also described in a previous paper[1], the operating system is a disc-based, priority multi-programming, interrupt-driven system residing in about 6K of memory. It provides basic computer peripheral handlers, intercepts all interrupts, and dynamically loads up to 16 programs into the remaining 14K of memory from a pool of 255 disc-resident programs. The major emphasis in its design is on efficiency of memory usage, disc accessing and CPU time, in that order.

Display Programs

Up to 64 programs are designated "push-button selectable" by virtue of being keyed to the push-button matrix on the console station. This allows the operator a very simple direct means of sharing a single station among many different tasks. These tasks fall into families which are described below.

All push-button programs are interlocked against interference on any single station; display switching time varies from 0.1 sec to 3 secs, depending on how long the individual display programs require to save and restore themselves.

Cyclotron Control Programs. Forty specialized programs are structurally identical and re-entrantly coded. All open-loop cyclotron control is performed using one of these displays at any operator station. The displays must be originally configured with the desired mix of devices up to a maximum of 18 and occassionally re-configured as needed, by the operators themselves.

The knobs, levers, and meters are used only by these displays. In conjunction with the numeric and alphabetic capability of the CRT, they provide, on a responsive basis (0.1 sec), readout of device setpoint, control of device status; adjustment of knob "speed" and meter scaling; setting and removal of warning limits; and the addition and removal of the basic device reference by which the foregoing takes place.

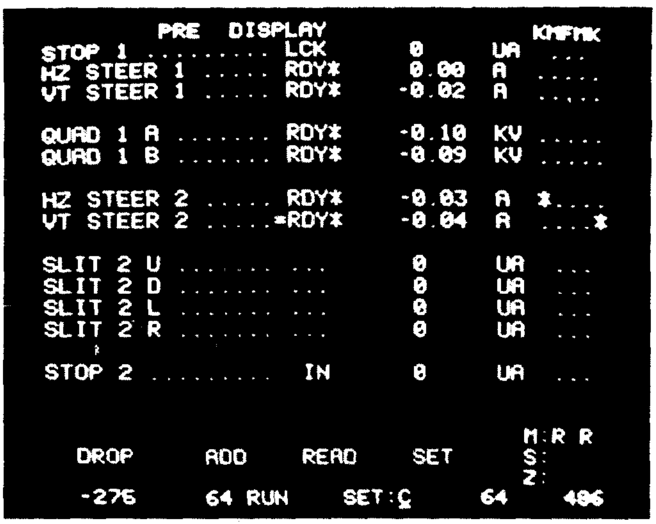

Fig. 3:Close-up of Alphanumeric CRT. Shown is typical cyclotron control display configured for part of interstage beam line.

Logging Programs. Six programs serve to define logging formats, schedule logging, read back, graph and save on tape previously logged data, and perform manipulations of logged data to generate new data.

Table Definition Programs. Five programs read back, define, and alter the master table by which readout, control, logging, and alarm is accomplished by all other programs. Within broad constraints, new devices may be added at will; their external (symbolic) names, units, and display format are defined; the conversion constants and details of readout type, address, resolution, etc., are set; then control type, address, limits, etc., and on/off details are added if applicable. Devices may be temporarily or permanently disabled.

A useful feature is the provision for non-hardware devices, i.e., pure internal entities whose value may be set by the operator or a program and queried by the operator or a program. These entities typically serve as variable parameters to automatic (non-display) programs which are themselves controlled by the operator (using the cyclotron displays) as internal "on/off" entities. The entire substructure of automatic control is thus presented to the operator through the familiar open-loop displays, making the transition between the two very natural.

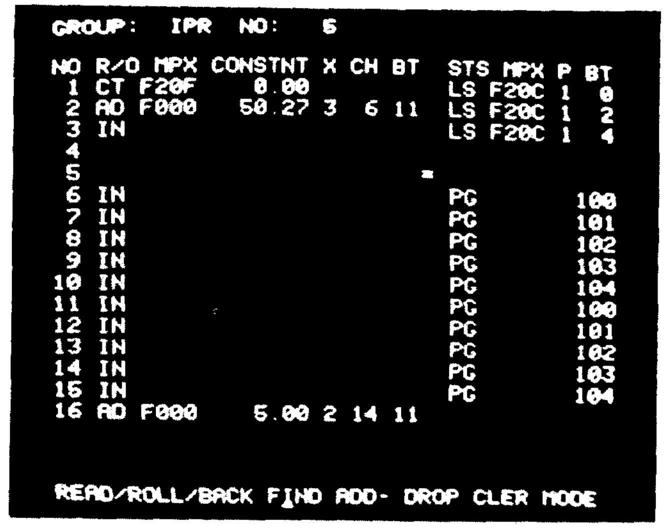

Fig. 4: Close-up of Alphanumeric CRT. Shown is device table display for injector probe block, including A/D, Counter and INternal types.

Certain modifications of the device tables are allowed while the devices are being used. It is possible, for example, to adjust the scaling constants on an analog readout and view their effect simultaneously on another display.

Mathematical Model and Preset. A series of displays is devoted to a mathematical model of the cyclotron. For a given charge, mass and energy, all other operating parameters are calculated and displayed. Alternatively, a particular cyclotron parameter, such as magnetic field, may be specified, in which case the algorithm is reversed to find the energy, whence the normal algorithms are carried forward. A feature that is planned for early implementation is the ability to actually allow the computer to set the physical devices to the desired values, i.e., true cyclotron preset.

Miscellaneous. Several other useful displays fill out the reportoire:

--list of all 64 displays
--system message log
--basic digital bus and device tester
--alarm warning and summary

Modularity

In order to maintain a working system at all times, and yet react quickly to the highly varying demands of a multi-stage facility where one stage may be operational and another not yet planned down to the interface or even device level, and also to accomodate a variety of possible operators, both trained and untrained, certain features of the system are implemented in a highly modular fashion. Three basic approaches are used here. First, certain families of programs use re-entrant coding and/or copies of public segments; second, data and coding may be separately coded and accessed; and thirdly, special non-resident services are provided in which an active control program contains within it the access subroutines to the tables it shares with the user programs. It can watch over the users and clean up in case of software or hardware mishap. Thus the service and its tables are not resident in memory if no one is using them, nor does the system become burdened with details particular to the uses to which it is put; since the access subroutines come along with the tables, the entire scheme can be revised without reloading all the using programs. The service can be either active or passive, i.e., be loaded upon first user request, or load a user after responding to an external interrupt, or both.

At present there are five such non-resident services:

--point-plotting scope buffer display
--calcomp plotter spooler
--external computer link handler
--display sequencer
--master device table loader

Display Sequencer. This program responds to an interrupt from the pushbutton matrix on any station. It ensures that only one display is actively using the station hardware at a time, and that an orderly transition takes place when the push-button settings are changed. It notifies the operator if a duplicate selection has been made, or if a display program is disabled. It will automatically fill a deferred request when the original one of a duplicate request has been cancelled. It makes immediately available a station which has been unintentionally vacated by a program abort. If the number of operator stations should be increased, all programming changes would take place in the sequencer itself; none of the 64 display programs would change.

Device Table Loader. The device tables are divided into 31 blocks, each capable of handling 32 devices. Each block contains the coding necessary for any special interpretation of the tables so that almost any concept of "device" can be accommodated. However, the loader program already contains reentrant coding for standard interpretation, so that no additional programming is required if only standard hardware (see "Hardware", above) is implemented. Only blocks needed by active programs are resident. It is the function of the block loader to field load, unload, and entry requests from those programs. Full interlock is maintained on conflicting requests for setpoint control of a device. Altered blocks are written back to disc periodically (this allows smooth recovery from any system crash) and when unloaded.

The sequencer also detects loss abort of a user program and is able to free up memory that might otherwise accumulate.

Robustness

This term is used to describe the ability of the overall system to recover from occasional software and hardware problems. It is a function of the active controllers which detect abnormal situations and clean up and return resources to the system. It is also due to the general simplicity of the system and to the close coordination of the software/hardware interface. It is partly attributable to the interrupt-driven concept which allows the basic system to be almost totally unaware of the overall timing scheme; it can respond to a few interrupts very quickly, whereas it could not possibly consider all the status changes that might occur in any reasonable amount of time. (There will be more than 300 cyclotron devices, and 10 devices per operator station.)

Man-Machine Interaction

One of the important contributions to overall satisfaction with the IUCF control system is the general robustness of the system. Another is the short response time to needed changes that the general modular technique allows (in spite of the fact that all actual coding is done with a simple, non-macro assembler). But most important feature is the overall consistency and straightforward design of the display programs themselves.

Display Features

Action Labels. Each display generally has a single line devoted to one or more "verbs". An action by the program is initiated by slewing the cursor underneath the desired label (using the trackball) and pushing the GO button. The trackball and GO button are used exclusively and identically in all displays. Typical verbs might be "ADD", "DROP", "PLOT", "READ", etc.

Options. Certain optional characteristics may apply to an action label. The options may be previewed prior to initiating the action by using the trackball GO sequence to rotate all possibilities into view. A typical series might be "LOG,LINEAR". In other cases the original action request is deferred and a second line of sub-actions is printed. When one of these is now selected the action proceeds to completion. A typical sequence following "DROP" might be "DEVICE, WARNING, HI-LIM, LO-LIM".

Input. Certain displays are so versatile that only full keyboard input is flexible enough to serve. In such a case a standard prompt character and "input space" is provided. Defaults are automatically filled in if the space is left intentionally blank, but perhaps more significantly, the last supplied input is always returned in the input space whenever the display is brought up. This serves as a time saver for experienced operators and as a training aid for inexperienced ones. Even the cursor is reset to its last known position for each particular display. When combined with the rapid ability to switch between displays, the effective display space is expanded enormously.

Operator training is reasonably simple. A simulator is set up on a few displays by defining some internal "devices". The trainee may then display, control, log, graph, plot,and exercise the alarm system at will. Reference documentation is also available.

Conclusions

A flexible, modular control system has been implemented on a modest hardware base. Although the original concept was partly a response to a lack of detailed foreknowledge, it has proved advantageous even as the cyclotron matures and the control system with it.

References

1. B.M. Bardin, S.A. Lewis, D.J. Plummers, T.E. Zinneman, "Computer Control of the Indiana University Cyclotron Facility", AIP Conference Proceedings No. 9, 1972, p. 490-497.

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