COMPUTER CONTROL OF THE INDIANA UNIVERSITY CYCLOTRON FACILITY *

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ABSTRACT

The control system for the Indiana University cyclotron facility is designed to provide monitoring and display of accelerator status, logging and display of operational history, automated beam diagnostics, and presetting of operational parameters, in addition to manual operator control.

The operator interacts with a control console which incorporates alphanumeric display terminals, a graphic display, a digital plotter, and various analog input devices. The console is connected to the computer, rather than directly to the accelerator, and the computer acquires data from and sends control information to the accelerator by means of multiplexed ADC's, DAC's, stepping motors, etc. The console and control devices are linked to the computer via a network of modular digital multiplexers which are attached to a common bidirectional data bus. This approach provides decentralization of the interface and allows orderly growth of the system.

The computer runs under control of a multiprogramming monitor which executes data acquisition, logging, display, and control programs concurrently, on a priority basis, in response to external signals, operator requests, or on independent schedules. Program development proceeds without interruption of accelerator control.

INTRODUCTION

The control system of the Indiana University cyclotron facility must coordinate the simultaneous operation of the three interdependent stages of the accelerator. In addition to direct operator control, it is designed to provide monitoring and display of accelerator status, logging and display of operational history, automated beam diagnostics and presetting of operational parameters. Figure 1 is a diagram of the computer-based system which has been implemented to carry out these objectives. It should be noted that communication between the control console and the accelerator is not direct, but passes through the computer.

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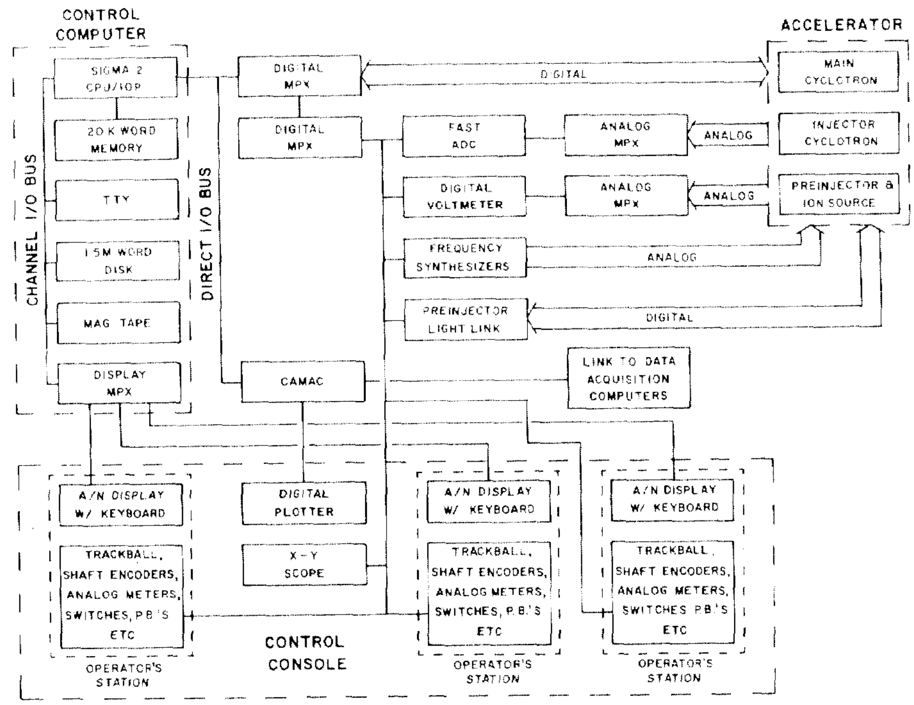

Figure 1. Control system.

COMPUTER

The control computer is an XDS Sigma 2 with 20K (K = 1024) 16-bit words of 1 microsecond core memory, a teletypewriter, a 1.5 million word fixed head disk unit, and a 7-track magnetic tape unit. The computer communicates with the control console and the accelerator through a direct to/from accumulator input/output (DIO) bus and through the block-transfer channel I/O bus.

CONTROL CONSOLE

Figure 2 shows the prototype operator's station currently used to control the dc preinjector and injector cyclotron. An operator's station consists of an alphanumeric display with a keyboard, display selection pushbuttons, a trackball which is used primarily to move the display cursor and, with its associated "enter" button, to signal the computer, and a second display without a keyboard. Shaft encoders, digit switches, and momentary contact switches also serve as control inputs. In the near future, computer driven analog meters will be installed to aid in tuning.

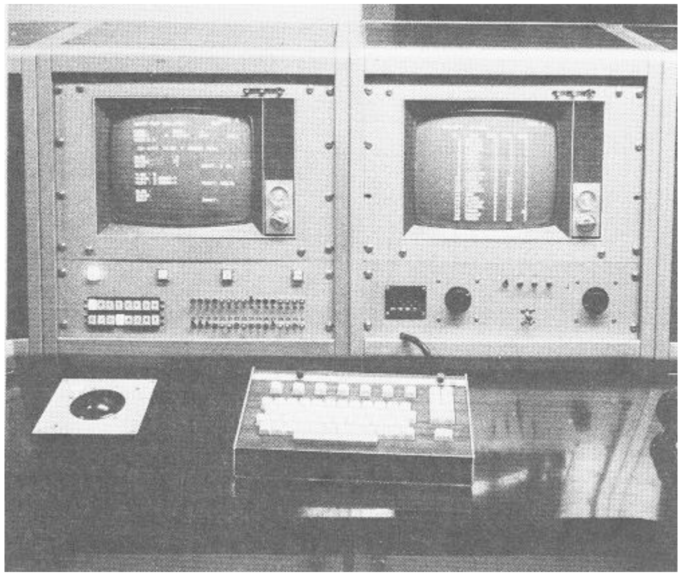

Figure 2. Prototype operator's station.

An x-y scope and digital plotter provide graphic capabilities.

It is planned to eventually implement a total of three operator's stations: two in order to be able to control two separate subsystems of the accelerator simultaneously and a third for maintenance and checkout of control hardware or program development and debugging.

ACCELERATOR INTERFACE

The linkage from the computer to the accelerator and control console is through a digital multiplexer network which is connected to the Sigma 2 DIO bus. A block diagram of the multiplexer is shown in Figure 3.

The multiplexer network is built from three basic modules: control units, write units, and read units. Each control unit can handle a maximum of sixteen write units and eight read units. Each write unit contains up to eight 16-bit storage registers to hold output data and each read unit contains up to sixteen 16-bit input gates for inputting data to the computer. Thus, a total of 128 16-bit bidirectional data words can be handled by each control unit. Although only two control units are currently in use, up to eight may be implemented, each, if desired, at a different location, so that the system can be expanded to randomly address up to 1024 digital input words and 1024 digital output words.

In addition, each control unit contains two 16-bit status registers. The outputs of all status registers are "or"ed together to an interrupt line. Thus when an external device requires service, it simply raises its status line, which causes a computer interrupt. The computer then interrogates the status registers to determine which external device requested service and takes appropriate action. Physically, each status register is attached to the computer through a read unit.

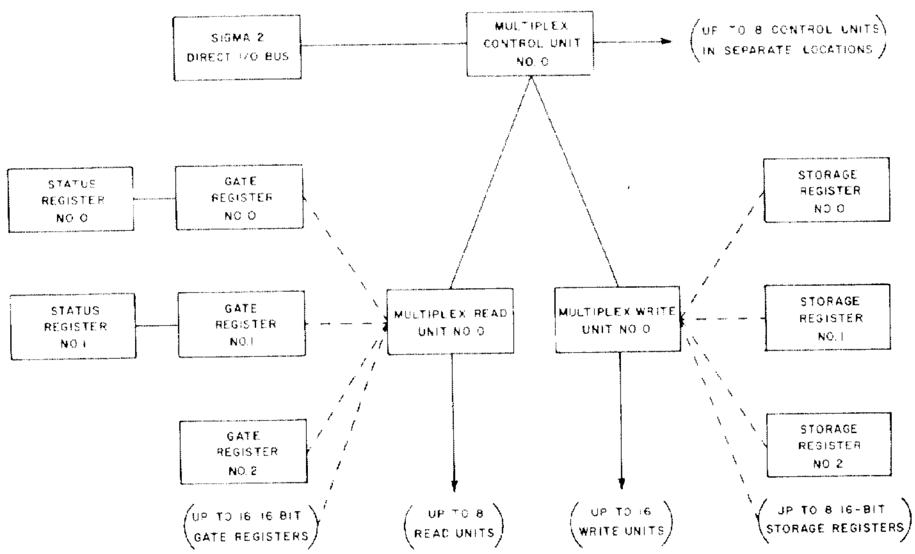

Figure 3. Digital multiplexer.

OPERATING SYSTEM

A real-time monitor (RTM) has been developed to facilitate control of the cyclotron. It is designed to optimize the utilization of available core, computational speed, and disk transfers. RTM is a disk-oriented, priority multiprogramming, time-sharing operating system which allows up to sixteen programs to be resident in core simultaneously. Each program has a software priority number associated with it and those programs currently in core with the same priority number are time-shared.

RTM supervises the loading, execution, and unloading of programs and their segments, on a priority basis, in response to external signals, operator requests, or on independent schedules. Programs load in a single disk access which has an average latency of 17 milliseconds. Since almost all programs are written in self-relocating form, core allocation for separate "floating" program segments ordinarily need not be contiguous and core is allocated for each segment only while it is resident. A total of 13K of core is available for allocation in blocks of 256 words. The monitor provides a protection service which prevents the currently executing program from destroying either RTM or other resident programs.

RTM provides many services for the executing program. All I/O for the standard peripherals and a number of the devices attached to the digital multiplexer is performed on an interrupt basis, using handlers which exit the calling program until the operation is complete. A program may also "attach" itself to a status bit and wait until that bit is triggered to resume execution or it may unload, to be reloaded from the disk if and when a trigger occurs. Output to the teletype is spooled to a disk file so that the calling program may proceed or unload without excessive delay. Disk transfers are not initiated until the last moment so that higher priority requests are not locked out; lower priority requests will be satisfied first if this will not delay service at higher priority. Encoding of formatted output and decoding of free field formatted input are provided. A program may halt, restart, activate (i.e., cause to load and execute), request the status of, or change the priority of another program.

The operator communications package is a non-resident program which is loaded when the operator keys in a command. It enables a program to be added to or deleted from the system, to be scheduled to run at a time in the future and, optionally, thereafter at a set frequency. Programs also may be activated, aborted, halted, restarted, attached to or detached from a status bit, or have their priorities changed. Diagnostic commands, which use the alphanumeric display, interactively generate a snapshot of all programs currently in core, read specified areas of memory or the disk, and allow modification of selected locations. A map of the current use of the digital multiplexer status bits and software triggering of any status bit are also available.

PROGRAM DEVELOPMENT

Program development goes on concurrently with cyclotron operations from one or more alphanumeric display terminals which usually operate in the time-shared mode at the same (relatively low) priority so that each terminal gets similar service. Unlike most multiprogramming systems, no fixed partition is required for this activity. Core residency is minimized by utilizing floating segments and re-entrant code. Code is written, edited, assembled, and link-loaded using the terminals for display and disk files for on-line storage. Both binary and source code are compressed and stored on magnetic tape for off-line bulk storage.

A versatile debug segment allows a new program to be executed in step mode without stopping the computer. All registers and selected core locations are displayed after each step. Monitor service calls are recognized and executed without pause.

The almost exclusive use of alphanumeric display terminals in all phases of program development is a novel aspect of the system. It is believed that this approach has resulted in a substantial increase in the rate of production of well-debugged code as compared to more conventional methods.

OPERATOR/DISPLAY INTERACTION

The operator interacts with the display terminal using a number of different techniques. Any one of 64 displays may be selected using an 8 by 2 pushbutton matrix. The display thus activated normally performs certain periodic functions automatically: readouts of accelerator parameters are updated (usually at about a 3 Hz rate) and the information necessary to restore the status of the display program is stored on the disk. Thus the operator may deactivate and reactivate displays with impunity since they always "remember" what he was doing previously.

Many display functions are selected from a list by placing the cursor under a particular word or line of the display and pushing the "enter" button. The option picked may cause immediate action or may simply be remembered for later reference. Small sets of logically related options may be conveniently selected on a cyclic basis; as the "enter" button is pushed, the next option "rotates" into view. The operator may also enter parameters through the keyboard and in some cases default parameters are supplied automatically. Certain functions (e.g., radial probe scans) require the display to be active for initiation only; once started they run to completion independently. In general, a particular variable is chosen for operator control by placing the cursor on the same line as the readout of that variable. The angular position of the control knob may then be used to drive a DAC, for instance, or to set the rate at which a stepping motor is driven by a momentary-contact bidirectional switch. Control knob settings are displayed and "remembered"; an interlock is provided to prevent accidental control when changing display programs.

LOGGING

The logging of related groups of variables is performed on independent schedules by separate logging programs. Each logging program activates an associated acquisition program which acquires the data and converts it to engineering units. The logging program then writes the formatted data on a disk file in chronological order. Before file space is exhausted, files are transferred to permanent storage on magnetic tape from which they may be read back into the system if desired.

An interactive service is provided to select and display the contents of logging files, including the names of the variables and their units. All numeric data on the logging files can be displayed in graphical form on the x-y plotting scope with great flexibility in formatting. Automatic features with manual overrides make graphing extremely easy. A hard copy service which automatically supplies appropriate headings, axes, and units, is provided using the digital plotter.

CONTROL

The first section of accelerator hardware to come under computer control was the preinjector. It consists of a duoplasmatron ion source mounted in an air-insulated 500 kV dc terminal. Information is transmitted to and from the terminal via a light link. A block diagram of the system used is shown in Figure 4. Data from the computer is transmitted serially to the high voltage terminal through fiber optical light pipes, where it is converted back to parallel format and used to control one of sixteen stepping motors or to program a thirty-two channel analog multiplexer and 12-bit ADC. Simultaneously, data digitized during the previous programming cycle is transmitted back to the ground station.

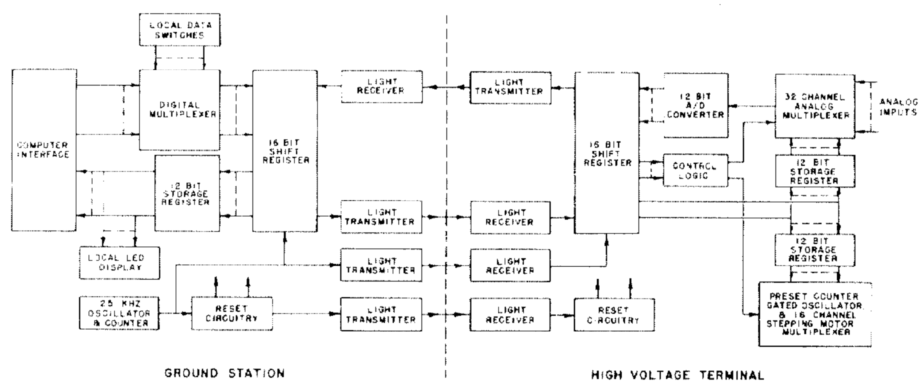

Figure 4. Preinjector light link.

Computer control of the beam line from the preinjector to the injector is essentially complete. The power supply currents of the various steering and focusing elements can be read and controlled through the computer. Beam stop currents, as well as slit currents, are monitored and displayed.

A number of readouts for the injector cyclotron have already been interfaced, including magnet and trim coil current shunts, beam probes, and several system pressure gauges. Some trim coil supplies and the frequency synthesizer which drives the rf system are controllable. Automated radial probe scans with both scope displays and hard copies became available during the later stages of initial operation of the injector cyclotron. As rapidly as readouts and controls are connected to the interface, they are incorporated into appropriate logging, display, and control programs.

CONCLUSION

The major hardware components of the system have been in continuous operation in substantially their current form for at least two years. The reliability of the computer, its peripherals, and the alphanumeric displays has been generally good and only one minor failure has occurred in the multiplexer. During the last nine months, logging, control, and program development have been executing concurrently under the supervision of the real-time monitor and the system has been remarkably stable: it has been in continuous multiprogramming operation for up to seven days (between scheduled maintenance periods) without a failure. The experience to date indicates that the system will handle the tasks outlined above without saturation of the CPU. Most planned features of the control system have now been implemented, at least in prototype, and performance has been satisfactory during the initial period of accelerator operation.

DISCUSSION

SCHUTTE: You made me very curious with the picture you showed with all those dots. Is this some sort of emittance measurement or phase space or something like that, or was it something else?

BARDIN: I think it was a vacuum pumpdown of some kind. It just happened to be what I had a picture of.

SCHUTTE: Because I am really curious about the beam diagnostics work you can perform with this type of automatic control.

BARDIN: Up to now the only beam diagnostics we have done is associated with automated scans of the injector cyclotron--automated radial probe scans.

SCHUTTE: But that is destructive.

BARDIN: Yes, that is destructive. We have under development a non-intercepting phase probe system which will allow us to determine the phase of the particles relative to the radio-frequency voltage.

JOHNSON: Could you describe for me the operation necessary by an individual to set a quadrupole on a beam line using your console?

BARDIN: He simply would press the combination of buttons associated with the display which had those particular parameters available on it for control. He would then use the cursor to select the line associated with the particular currents he wished to change, and then he would use the shaft angle encoders, the knobs if you will, to run the power supply, and he would watch the current change on the display. He could either watch that current or the beam current or whatever else he wished to monitor simultaneously. I haven't gone into great detail; there are certainly more steps in that process but that is basically how it is done. I should mention that any time you switch displays, the system automatically remembers exactly what the status of that display was previously. There is an interlock to prevent you from accidentally controlling something. So you do have to do something; at the moment it is lift a switch to restore control to the knobs that have been used for control previously. But the operator can change displays with impunity and come back to where he was when he left the display.

JOHO: I just wonder, out of curiosity, how much it would cost to modify my TV set into an alphanumeric display?

BARDIN: The control units that we are using are about $7,000 apiece but there is a channel interface--they do run on a block transfer channel--so they are not terribly inexpensive. The TV displays themselves are just standard TVs which are modified very slightly, so we can have as many repeaters as we like. The primary cost is for the display controller.

BURGERJON: Could you tell me what the cost is for this system, including the equipment for the whole facility?

BARDIN: At this point in time we have about $335,000 expended, with the anticipation of up to about $100,000 more.

FLOOD: How many functions do you think you will need to display in parallel simultaneously?

BARDIN: Each display has up to 20 or 21 variables on it. There are two displays which can be simultaneously selected, and you can control variables then on either of those displays, and so you have about 40 variables at your fingertips at any instant in time. And, of course, by simply pushing the buttons you can bring up any other display you wish, essentially instantaneously.

FLOOD: What is the lag between the display and the function you are measuring?

BARDIN: That depends, of course, on the type of control. We update the variables which are not being controlled at about a 3 Hz rate. We plan to update variables which are being controlled at about a 10 Hz rate. We also have plans to drive analogue meters with the computer. This sounds perhaps a little strange--to go back to analogue--but for tuning purposes we feel the operator will have a better feel for what he is doing if he has an analogue meter to look at rather than watching a digital display.

HEYWOOD: How big physically is your machine, how many parameters do you have to control, and how many analogue signals do you have to monitor?

BARDIN: It is certainly smaller than TRIUMF. We do have three accelerators; the total number of analogue signals has not been well determined at this point, but it is certainly going to be smaller than what you are attempting to use. At the moment we have 64. Now we are only partially interfaced to the injector cyclotron, and there is the final stage cyclotron to go plus any beam line control. So it is nowhere near your 1300 figure.

HEYWOOD: When you say 64 analogue channels, is that outgoing or incoming?

BARDIN: Incoming. The outgoing channels are considerably fewer. I guess I didn't fully answer that question about response because some devices have stepping motor controls, and there the rate is limited by the rate at which the stepping motor can run. The display is updated all right, but the stepping motor provides a considerable lag, for instance with regard to many of the parameters in the pre-injector.