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COMPUTER CONTROL SYSTEM FOR ORIC*

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ABSTRACT

A computer control system is being implemented for the Oak Ridge Isochronous Cyclotron (ORIC). At the start of a run, operating parameters are set automatically using data stored in a disc library. Adjustments of these parameters are made through an operator-computer interface consisting of a CRT unit with a keyboard. An array of assignable push-button switches is available for fine tuning various machine parameters. ORIC has 43 ungrounded power supplies requiring adjustment resolution to within 1 part in 10^3 to 1 part in 10^5 depending upon their function. These supplies are controlled by reference voltages derived from 12- to 16-bit digital-to-analog converters (DAC's). A programmable comparator associated with each power supply relays information on power supply performance to the computer. The power supplies, DAC's, and comparators are isolated from the computer by optical couplings and blocking capacitors. The control system sets and fine tunes the rf system, monitors and controls binary functions, switches power supplies to required circuits, alerts the operator if any cyclotron parameter exceeds the specified limits, and processes and stores new run parameters.

INTRODUCTION

Computerized control systems are considered as standard equipment for many new accelerators. For existing facilities, the expense of converting to computerized controls is justified only if it will result in improved machine utilization and performance. ORIC has always been a rather complex facility and it is becoming more complex with the addition of new external and internal ion sources,[1,2] new experimental areas, and an isotope separator (UNISOR). Also in the National Heavy-Ion Laboratory (NHL)[3] Proposal ORIC is included as

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an injector. Computer control will be essential for such an operation. Converting ORIC to computerized controls will save hundreds of hours in set-up and maintenance time. This time will be used in productive research activity. In addition, experiments requiring frequent energy changes will become practical, and the operating staff will be able to provide more assistance to users.

The set-up routine at ORIC typically involves setting a large number of parameters at values logged on previous runs. As a run gets underway, an assortment of component malfunctions are often discovered through their preventing normal beam extraction and transmission. Data interpretation errors often result in prolonged set-up time.

The computerized control system planned for ORIC automatically selects power supply polarities and output settings. It pretunes the rf system and performs a multitude of "switching on" operations. Parameters for a given ion beam are read from the computer's disc library and the computer interpolates between sets of data where necessary. Automatic diagnostic routines locate and evaluate faulty components. Convenient, reliable bookkeeping is provided for recording useful operating parameter data and upgrading the disc library as required.

An instant changeover to computerized controls would be convenient, not withstanding operator consternation; however, computerization will be a gradual process. Interfacing the computer to the cyclotron is fairly simple for most analog instrumentation and controls, but implementing contact closure functions will require rewiring portions of the present control system. Long range plans include automatic compensating adjustments on several parameters as one or more other parameters are being optimized. Automatic beam optimization will also be considered.

AN INVENTORY OF ORIC CONTROLS

An approximate inventory of existing instrumentation and controls is given in Table I. High resolution implies nominally 1 pp 10^5, medium resolution - 1 pp 10^4, and low resolution - 1 pp 10^3 or less. Analog references are required for setting power supply output levels and pre-setting tuners in the rf system. Many of the devices considered here are already "remotely programmed" via potentiometer controlled reference voltages. "Contact closures" include many functions from push button and toggle switches on the control console to trim coil polarity reversing switches and quadrupole selection switches.

High resolution analog data are digital voltmeter readings representing currents in each of the magnet windings. The main field, trim coils, valley coils, harmonic coils, and beam optics are included. Low resolution analog data is presently acquired from a multitude of panel meters in assorted sizes, shapes, and calibrations. Contact sensing is presently accomplished through appropriate sensing switches with readout via pilot lights, flashing lights, bells, and buzzers in the control room.

Table I ORIC Instrumentation and Controls Inventory

High resolution analog reference	3
Medium resolution analog references	80
Contact closures	240
High resolution analog data	46
Low resolution analog data	110
Contact sensors	425

THE CONTROL COMPUTER AND PERIPHERALS

Table II lists the components of the computer system which have been ordered for ORIC. Delivery of the equipment is expected during the fall of 1972.

Table II Control Computer and Peripherals

A general purpose computer, 16 bits/word, 24K memory.
An operator keyboard/printer.
A high speed paper tape reader.
A high speed paper tape punch.
A magnetic tape drive.
A disc storage device.
A card reader.
A high speed serial printer.
A CRT graphic and alphanumeric display with semi-conductor memory and keyboard.
A digital input/output subsystem.
An 80-channel, multiplexed input, analog-to-digital converter/system.

A library of operating parameters for various ions and energies will be kept on the storage disc. The main operator-computer interface will be through the CRT graphic terminal and keyboard. Future plans include a touch actuated system for the CRT display, but for the present time, direct interaction with the display will be via a cursor and the keyboard. A set of assignable push-button controls will permit simultaneous fine tuning of several selected parameters.

Before start-up, the operator will call for a index of run parameters in the library, and select an appropriate reference run. When commanded, the computer will begin its set-up program. The computer will continually monitor the many surveillance channels and alert the operator if any component requires special attention.

Interfacing between the computer and the cyclotron will be through 23 digital input-output channels (16 bits each) in the I/O subsystem. The 80 channel ADC unit will scan and read all parameters which are presently on panel meters. An existing 6 digit DVM and crossbar scanner which scans all power supplies and several position indicator devices will be interfaced to the computer to provide high resolution input data. Interfacing for the analog output channels and binary I/O channels will be via dataways as in the CAMAC system.

POWER SUPPLY CONTROL AND SURVEILLANCE

The first stage in implementing the computerized control system is automatic set-up and surveillance of the 43 magnet power supplies. The central processing unit, CPU, transmits digital data to a digital-to-analog converter, DAC, associated with each power supply. The DAC generates an analog reference signal suitable for controlling its respective power supply. A surveillance device informs the computer whether or not the power supply is responding correctly to its instructions.

Numerous DAC schemes are available including stepping motor actuated potentiometers and relay switched ladder networks. At ORIC we are using microcircuit DAC's which offer excellent performance and are available at very low cost. Twelve bit DAC's are used for most power supplies and 16-bit DAC's for those requiring especially high resolution as on the main field and the 153° beam analyzing magnet.

The use of surveillance devices and microcircuit DAC's is complicated by the electrical isolation requirements for each power supply. At ORIC, all magnet windings and power supplies are insulated from ground and from each other. Consequently, all associated circuitry requires common mode insulation ratings up to 400 V. Optical coupling is suitable for transmitting logic levels, and capacitor or transformer coupling may be used for transmitting pulses between the CPU and the power supplies. Analog input information is best handled by analog-to-digital conversion prior to transmission.

A computerized control system is especially useful if it provides continuous surveillance of all power supplies. It should be able to resolve errors in power supply regulation of a few tenths of one percent and to detect excessive ripple at frequencies up to 360 Hz or oscillation at frequencies up to a few kHz. A digital voltmeter with multiplexer can provide sufficient information if it has a sampling rate of at least 10,000 samples/sec and at least

12 bit resolution. Such devices are available; however, they are typically single -ended or otherwise unable to withstand common mode potential greater than a few volts.

The possibility of providing a microcircuit analog-digital-converter, ADC, for each power supply was considered, but an examination of how an ADC works led to a less complicated and more economical device. Since an ADC typically consists of a DAC and a voltage comparator and a DAC is already being provided for each power supply, the addition of a comparator results in a system which generates all the required performance information.

A power supply control loop incorporating DAC's and comparators is shown in Fig. 1. When a change in magnet current is required, the CPU generates a "data word" representing the magnitude of the change and an "address word" representing which power supply is to be changed and related instructions. The data word is converted to a series of pulses and routed to the power supply controller by a decoder which is controlled by the address word register. Conversion is accomplished by loading the data word into an intermediate UP/DOWN counter. A NOR gate, "clear indicator," senses the non-zero state of the counter, informs the CPU that the loop is "busy," and opens the "pulse gate." As pulses are transmitted to the decoder, the intermediate counter counts down. When the counter reaches zero, the clear indicator closes the pulse gate and informs the CPU that the loop is ready for more data.

There are three DAC's associated with each power supply. Each DAC is controlled by an UP/DOWN counter. Each UP/DOWN counter has inputs for count up, count down, and reset. The power supply DAC provides a reference signal for the power supply regulator. An analog signal from the power supply shunt is inverted and compared to the DAC voltage at the summing point on the input of the two differential comparators. For normal conditions both comparators, monitored by the CPU, have low logic levels. If the power supply current is too high, the upper limit comparator switches to a high logic level where it remains as long as this condition persists. Likewise, the lower limit comparator switches to a high logic level if the power supply current is too low. The trigger points for the comparators are programmable through offset signals derived from the upper limit and lower limit DAC's, respectively.

Normally, the comparators are set for some predetermined tolerance. If the tolerance is exceeded, the CPU, alerted through an interrupt, locates the faulty unit by scanning its input channels, and transmits a warning to the operator. If desired, the operator initiates a diagnostic routine where by the CPU scans the comparators as a function of time to evaluate ripple and noise structure if any. Then the CPU raises the comparator thresholds sufficiently to keep them at low logic levels so that the limit DAC's settings represent either peak to peak ripple and noise level or a power supply tracking error. An actual display of data taken for a power supply with excessive ripple is shown in Fig. 2. The display is composed of three sets of comparator scans with the comparators checked at 1 millisecond intervals. The DAC settings are shown at the beginning of each set. The symbol "I" indicates power supply within tolerance. The symbol "*" indicates power supply high or low depending upon whether it is left or right of center. The time scale for each set of scans is printed for scans which indicate a change in logic levels since the preceeding scan. The scan rate is variable as needed for resolving noise structure. Frequencies of several kHz can be resolved.

One data-to-pulse conversion unit may be used for controlling several power supplies through appropriate decoder addressing. The repetition rate of the pulse generator is fixed at some value compatable with the slewing rate of the power supplies. While the conversion unit is busy, the CPU is available for other tasks.

The CPU will periodically check the existing DVM and crossbar scanner for calibration purposes.

STATUS OF THE CONTROL SYSTEM

The computer and its peripherals have been ordered. Delivery is expected during the fall of 1972. A single power supply control channel has been assembled and tested using the on-line data processing system, an SEL 840A, as a CPU. One of the trim coils was operated for two days using computer control.

Low resolution analog signals which are presently displayed by panel meters are immediately available for the computer's ADC system. Control units will be fabricated for 43 magnet power supplies and installed early in 1973. The next stage of the program includes interfacing the computer with the power supply polarity and quadrupole selection switch gear. Later stages will include hardware for pretuning the rf system and operating the ion sources.

Initial control software will be developed with sufficient flexability for incorporating software additions and changes required with later stages of hardware development. Adapting computer control to more difficult problems such as beam optimization and diagnostic routines will offer a continuing software challenge.

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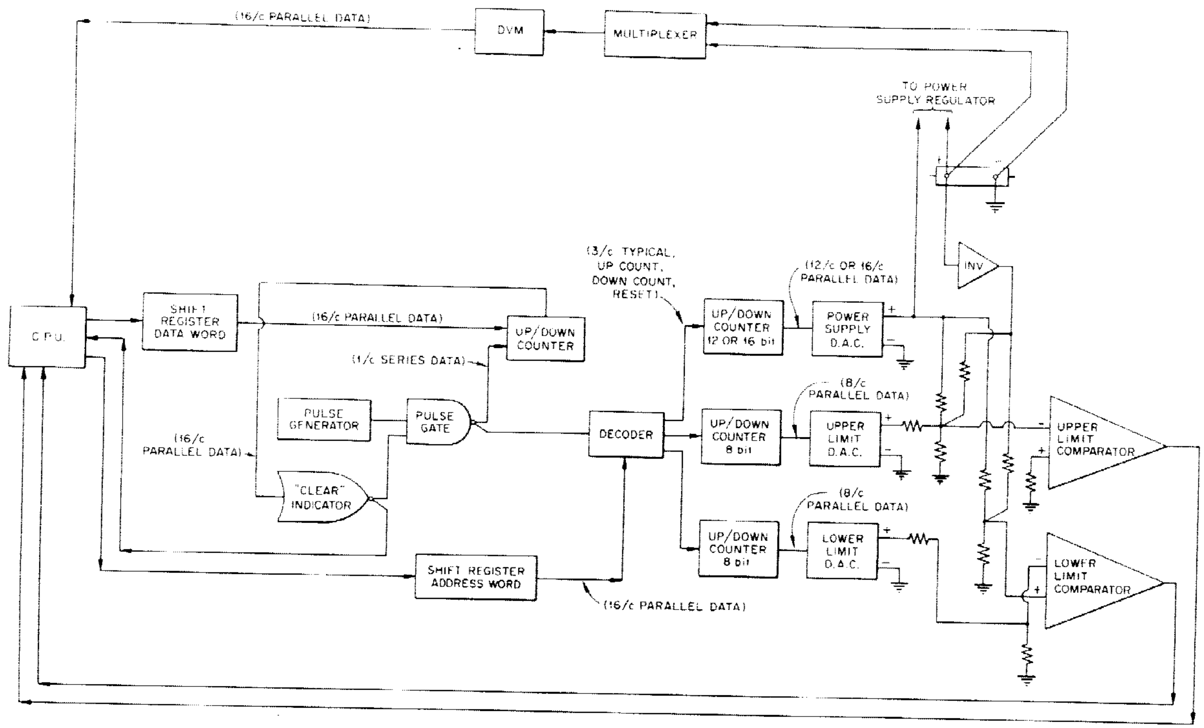

Fig. 1 A typical power supply control loop incorporating DAC's and comparators. Additional power supplies are controlled by appropriate data branching from the decoder.

```
SAMPLE RATE IS 1000/SEC
12-BIT DAC 3372
UPPER LIMIT DAC 50
LOWER LIMIT DAC 50

 1              *
 2         I
           I
 4              *
                *
 6         I
 7              *
                *
 9    *
      *
11         I
           I
13    *
      *
15         I
           I
17    *
18         I
19              *
20         I
           I
22              *
                *
24         I
           I
26              *
27         I
28    *
29         I
           I
31    *
      *
33         I
34              *
35         I
36    *
37              *
38         I
           I
40              *
                *
42         I
43    *
44              *
45         I
46    *
47         I
           I
49    *
      *
      *
52              *
53    *
      *
55              *
                *
57         I
           I
```

```
SAMPLE RATE IS 1000/SEC
12-BIT DAC 3372
UPPER LIMIT DAC 100
LOWER LIMIT DAC 100

 1         I
 2              *
 3         I
 4    *
 5         I
           I
           I
 8    *
      *
10         I
           I
12    *
13         I
14              *
15         I
           I
17              *
                *
19         I
20              *
                *
22         I
23    *
24         I
           I
26    *
      *
28         I
           I
           I
           I
32              *
33    *
34         I
35              *
                *
37         I
38    *
39              *
40         I
41    *
42         I
           I
44    *
      *
46         I
47              *
48         I
           I
50              *
51         I
           I
           I
54              *
55         I
           I
57              *
58         I
```

```
SAMPLE RATE IS 1000/SEC
12-BIT DAC 3372
UPPER LIMIT DAC 225
LOWER LIMIT DAC 225

 1         I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
24              *
25         I
           I
27              *
28         I
           I
           I
           I
           I
33    *
34         I
           I
           I
           I
           I
           I
           I
           I
42              *
43         I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
           I
```

Fig. 2 Print-outs for three sets of computer scans of the limit DAC's for various tolerance settings. Elasped time in milliseconds from the first scan in each set is shown on the left of the comparator state.

DISCUSSION

SCHUTTE: Could you mention which part of the inputs will be devoted to beam diagnostics and which part is just for setting and monitoring?

MOSKO: Practically none of this is for the kind of diagnostics that I mentioned where we want to see what the power supplies are actually doing. This is, in fact, a diagnostic capability that we do not have at all at the present time. In a sense it is going to make the computer act as an oscilloscope and voltmeter.

SCHUTTE: Are you planning to have such a diagnostics device in future?

MOSKO: You mean as I have shown on the power supplies?

SCHUTTE: No, real beam diagnostics.

MOSKO: Of course, we hope to do this later on as we get the entire cyclotron on the computer, which may be several years along. We will add to it as we go along and find time for working on it. We don't think the computer can go all the way to bringing a beam out, but once it is out perhaps the computer could look at keeping it on target. This should be a relatively simple routine.

NEED: I will ask the cost question which seems to have been asked of everybody.

MOSKO: Well, the cost of the computer peripherals will be somewhere around $100,000. We will have a little bit of money left over for building interface hardware.

JENKINS: Everyone keeps asking how much it costs to put in a computer system, but no-one has asked about the difference between that and the alternative hard-wired system. I should like some information from TRIUMF and from Indiana as to what this difference is.

MOSKO: Does someone want to answer that from TRIUMF or Indiana? I would personally throw in the comment that if you are building a new machine it probably doesn't cost any more to use computer controls. It might even cost less than hard-wiring for some functions. Really it is just the new style for doing things. Lots of this equipment is becoming quite inexpensive. In the case of what we are doing at ORIC, it is a lot of extra expense. It is not something that you can immediately subtract from something else and say that we saved that.

JOHNSON: As the host institution, we would invite Bryce Bardin to give the first answer.

BARDIN: I would say simply the following: When we purchased the Sigma 2 in our system it had a hardware cost of $145,000, which represents about 40% of the cost of the system. We could easily reproduce that system now for somewhere on the order of a third to a half less. So the computer portion of the control system, in terms of overall cost, is actually going down fairly dramatically. The additional flexibilities which a computer system provides for beam diagnostics and ease of operation of the system, because it can preset parameters and provide an operational history, more than repay you for any additional expense that you might have in implementing a computer control system.

JOHNSON: Counting development, they come out even. There is a break point for a hard-wired system. I am not very popular at TRIUMF; I was not in favour of computer control for the CRM. That currently has 60-70 reference voltages, is monitoring 256 readings, and has no serious digital inputs at the present time. The break point is around there.

WEGNER: I was curious about your introductory statement when you said the machine had been running well for many years. It seems to me it is very hard to run an accelerator on a research program. It is one of the most demanding requirements, but you indicate the necessity of the computer control for use on an injector. I should think that would be easier than a research program, and I am just wondering about the reason. It might be a perfectly valid reason--to get the hang of it so you can build the next machine, or something.

MOSKO: It is a matter of simplifying what is becoming a complicated control system. The more controls you put in, the more you have to look after. You need a bookkeeper to tell you what you have been doing. But when ORIC is used as an injector for something else, we probably won't be able to give it quite as much direct attention as we do now. Further, it would be a more expensive facility that we are talking about. If it is down because we are taking too long to get ORIC set up, that's not good. So a computer will certainly speed that up and be very useful in that sense.