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THE CONTROL COMPUTER FOR THE CHALK RIVER ELECTRON TEST ACCELERATOR

by

G.E. McMICHAEL, J.S. FRASER and J. McKEOWN

Chalk River Nuclear Laboratories

Chalk River, Ontario

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L'ordinateur de contrôle pour l'accélérateur d'essai de Chalk River

par

G.E. McMichael, J.S. Fraser et J. McKeown

Résumé

Un système polyvalent de contrôle et d'acquisition de données a été développé pour un accélérateur linéaire de dimensions modestes employant principalement un hardware et un software de procédés I/O. Ce rapport décrit l'évolution du système depuis 1972, les modifications nécessaires pour répondre aux diverses exigences des expériences physiques effectuées dans l'accélérateur et les limitations d'un tel système dans le contrôle des procédés.

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ABSTRACT

A versatile control and data acquisition system has been developed for a modest-sized linear accelerator using mainly process I/O hardware and software. This report describes the evolution of the present system since 1972, the modifications needed to satisfy the changing requirements of the various accelerator physics experiments and the limitations of such a system in process control.

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THE CONTROL COMPUTER FOR THE CHALK RIVER ELECTRON TEST ACCELERATOR

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1. Introduction

The development of effective control techniques for and operating experience with high-power linear accelerators are major objectives of the Chalk River Electron Test Accelerator (ETA) project(1). A multi-channel data acquisition system, which provides rapid storage and retrieval of the many machine parameters together with analytical power and convenient display, is essential to this development.

The accelerator has two accelerating structures whose electrical properties are studied with a bunched electron beam. A proposed proton accelerator for electronuclear breeding(2) would include a few hundred structures of the type used in ETA. The ETA project is being pursued in part to study the behaviour of the control systems in the breeding accelerator which is expected to be similar to that in the electron model.

By 1970, digital computers were firmly established at many accelerator laboratories as the best means for data acquisition and on-line data analysis. Experiments on direct digital control had also begun, but the role of the computer in a diverse system requiring limit checking, data logging and automatic control had not been clearly defined.

To assist in defining this role, specifications were drawn up for a digital computer system which could handle the data acquisition and many of the control requirements then envisaged for ETA.

Because of the experimental nature of the ETA project, these requirements, and as a consequence the computer system, could not be rigidly specified. Minicomputer-based real-time process control and data acquisition systems released since 1970 provide the required flexibility. The role that special application software, computer response and custom hardware play in accelerator control is better understood now than in 1970. This role has significant economic implications in a large accelerator.

The ETA computer now performs many functions including data logging and display, limit setting and checking, fault annuciation, set point modification and system start up. These functions, or variants of them, are common to many other accelerator control computers. In addition, active control loop functions, such things as temperature control of the accelerator structures and electron source control, are included. Such functions are not normally feasible for time-sharing systems but are possible with the ETA computer system because the time scales of the processes are long enough that the computer need not be dedicated to them alone.

This report describes the evolution of the ETA computer system since its delivery in 1972, the modifications needed to fulfill the requirements of the various accelerator physics experiments, and the limitations of such a system in process control. Details of the computer's role in controlling the beam transport system are discussed in a companion report(3).

2. ETACON Computer System

The Electron Test Accelerator Control Computer (Fig. 1) is referred to by the acronym "ETACON". A block schematic of the system is given in Fig. 2. The processor is an Interdata M70 minicomputer with 64 kilobytes of 1 μs core memory. This computer, which is similar in architecture to the IBM 360 series, includes such features as floating point hardware (75 μs multiply time), 16 general purpose registers, memory protect, and 255 separately vectored input-output (I/O) interrupts. Two 2.5 megabyte moving head disks and a 9-track magnetic tape unit are available for bulk storage through separate direct memory access ports to the main memory. Additional data or program storage is provided by a dual "Philips" cassette tape transport unit. One time-of-day and two millisecond clocks permit real-time scheduling and interval timing. A card reader with modest capacity (125 cards/minute) is provided to facilitate program development. An ASR 35 teletype functions as the main operator control console for communication with the Executive program. A KSR33 teletype is available as an interactive accelerator control console. A 1200 lines/minute printer is used for program listing and bulk data printing. A storage oscilloscope with a keyboard serves as a teletype substitute or for presentation of graphical data, lists and messages.

The process I/O system includes both an analog and a digital multiplexor. The 512 line analog multiplexor (256 currently installed) is a 200 readings/s guarded reed-relay sytem with a single programmable gain (10.24 volt to 2.5 millivolt input for full scale) amplifier and 12 bits + sign analog-to-digital converter. All inputs are true differential, with the guard also being switched, thus providing a system with good noise immunity (100 dB common mode rejection, crosstalk 120 dB down) and a high common-mode voltage limit (200 volt dc)*. The digital multiplexor permits the installation of a wide variety of digital I/O. The present installation comprises:

- 96 digital interrupt lines with interrupt queuing and automatic line identification
- 368 polled input lines
- 416 electronic switch or logic level output lines
- 48 relay outputs.

In addition, there are 16 vectored-interrupt input lines, each of which can command the Executive to load and execute a named task (see Appendix A). These are connected

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* The equipment must work reliably in a very hostile environment. High-voltage equipment in this and adjacent experiments occasionally generates 50 to 100 volt spikes on power and ground lines.

to two 8-channel task request modules, permitting the accelerator operator to execute tasks by actuating toggle switches on the control panel.

A time-sharing Real Time Operating System (RTOS)(4) was provided by the computer manufacturer. This supervises and controls all I/O, job scheduling, system security and task-to-task communication in response to operator or task requests. Multiple applications tasks can be operated concurrently with interleaving, with their execution sequence determined by priority level and with time sharing between those of equal priority. As tasks can be resident on a mass storage device, the number of tasks is, for practical purposes, eliminated. Some of the other features important for real-time applications are summarized in Appendix A.

Programming may be in assembly language or FORTRAN. In the ETACON system FORTRAN is used for data logging, plotting, most interactive programs and programs which involve appreciable algebraic operations. Test versions of real-time control programsare often coded in FORTRAN to check the control algorithms. However, a single central processor limits the control bandwidth, i.e. the number of real-time control and data acquisition functions that can be performed in a given interval. Consequently,most real-time programs are eventually recoded in the more efficient assembly language. For large accelerators, as discussed in Reference 5, network systems with many processors can be justified and sufficient control bandwidth can be made available such that almost all programming can be in a high-level language. However, for small accelerators similar in complexity to ETA, reversion to assembly language for frequently called programs still appears necessary.

3. Analog Data Logging and Display

(a) Requirements

The analog data acquisition and display requirements for ETA are as follows:

- For full accelerator operation, approximately 200 parameters (voltage signals) must be recorded at rates varying from several times per minute to once per hour.
- Simultaneous experiments involving accelerator subsystems must be accommodated. This may require frequent recording of a few parameters for a short experiment at the same time as hourly recording of many parameters for an experiment requiring days to complete.
- The data must be available for on- or off-line analysis and graphical display.
- The data must be retained indefinitely for further analysis.
- To provide sufficient control bandwidth, tasks must be core-resident only when executing, and if frequently called, must be as small as possible. Large tasks must be capable of being suspended by high priority control and data acquisition tasks.

- Optional hard-copy output of the data is required.
- The data must be transferred to magnetic tape for archiving or further analysis on the main computing centre's CDC 170/6600 computer, or both.
- Immediate hard-copy tabular output of accelerator operating parameters is required.

These requirements have all been met by a set of programs which now have been in use for several years.

(b) Data Acquisition

During an experiment, data are accumulated on one or more disk files* so that access to the data may be time-shared by the analysis and display tasks. Disk capacity is insufficient to permit the requirements to be met by the simple procedure of recording 200 parameters every 5 seconds. Instead, it is necessary to record only those parameters relevant to a particular experiment and at a rate appropriate to its needs. Five disk files are provided, each of which may store readings of up to 240 parameters which are assigned by the operator using a special task for setting up files. Thus five

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* RTOS provides for up to 32 files per disk. In ETACON, the file lengths are fixed at system generation time and the data logging files are 250 to 800 sectors long. Each sector holds 256 bytes of data and may be randomly addressed.

simultaneous experiments may be accommodated, or several files with different parameters and recording rates may be used for a single experiment.

The data acquisition process involves several independent functions: assigning parameters to a file, scheduling the recording for each file, accumulating the data on each file, and archiving the data once the experiment is finished or the file is filled. This independence is maintained by using the first 5 sectors on each file for general information and pointers (identifiers, parameter identification numbers, dates, times, and index information as outlined in Appendix D), which gives unambiguous identification of the data on that file and provides for time-shared access to it. This procedure, along with having separate tasks for each of the independent functions, takes maximum advantage of the powerful features of the multi-task operating system and maintains the required system control bandwidth. A description of these tasks will indicate how this is achieved.

Task INITSC

This background task accepts card or console input of the information required to set up the first five sectors of the data files.

Tasks SCAN1, SCAN2, ... SCAN5

These tasks, one for each of the five data files, are identical in all respects except for the file accessed. Each time one of them executes, it adds one more set of parameter readings as well as the time and date to the appropriate file. Between scans they are disk resident. All five may be simultaneously accumulating data in a time-shared mode. Allowing for disk access time and software overhead, the effective rate for normal parameters is about 100 readings per second. Rf fields in the accelerating structures are a special case. To economize on rf cabling and detectors, the 36 field probes are submultiplexed, by computer-controlled coaxial switches, onto 6 crystal detectors. A reading rate of about 5 per second is the best that can be achieved for these parameters.

Task SCHED

For most experiments, periodic readings are required. RTOS accepts requests from tasks to suspend their operation for a time interval or until a particular time-of-day. While suspended, however, the task must remain core resident, a condition which is not acceptable for the SCAN tasks. Instead, such scheduling is controlled by the task SCHED which maintains a queue of up to 10 named tasks and their execution rates (seconds between successive executions) and can bring the scheduled tasks into core for execution at the appropriate time. Information in this queue is easily changed by console commands (Appendix E).

Task SCNDMP

This interactive task will copy a SCAN file to magnetic tape or retrieve archived data from magnetic tape so that it may be accessed by the analysis tasks.

Summary

The data logging tasks (SCAN1 - SCAN5) are controlled by one or more of the following:

- directly by SCHED at operator specified intervals.
- by LIMCHK (Section 4) in combination with SCHED.
- directly by operator requests from the control console or the control desk Task Request Module.
- by requests from accelerator control tasks.

The anticipated advantages from having separate tasks for each function have been achieved with the result that:

- only SCHED need be core resident and it requires only 1 core block of 1024 bytes (the minimum size for an RTOS task).
- SCAN tasks do not require coding for limit checking or scheduling.
- SCAN tasks do not require interactive coding because file setup and archiving are handled by INITSC and SCNDMP respectively.

(c) Graphical Display

Data recorded by any one of the SCAN tasks can be retrieved for graphical display on a storage oscilloscope using the task PLOTS. Two types of graphs are available. Time histories of one or two variables may be plotted between specified dates and times of day or these variables may be plotted as a function of another variable. Any plotted variable can be a specified function of two parameters; eleven functional forms are available. Any variable can be "gated" by one or two specified variables, that is to say the points plotted are only those where the constraining variables lie within particular limits.

Features of task PLOTS are best shown by some example outputs. The upper left graph in Fig. 3 shows how rf power and beam current varied over a 20 minute period. There is a correlation between the two variables, i.e. as the beam current (upper curve) increased from 0 to -15 milliamps, the rf power went from about 30 to 50 kilowatts. On the upper right is a graph of the same data with the scale adjusted, and the sign changed for the beam current so that the upwards direction is now increasing negative current. The correlation is more evident. Although operator input or limits from the disk may be used to scale the axis, we generally start, as in these cases by letting the computer determine the scale so that two thirds of the plotting area is filled. The time axis limits,however, are always specified by the operator.

Examples of correlations between variables are shown in the lower two graphs. On the left is rf forward and reflected power, for the same time period as in the two upper graphs, plotted against beam current. The linear correlation between rf power and beam current is now obvious. On the right are the same data but with the axes limits specified by the operator to give a more suitable graph for reports.

Other useful features are shown in Fig. 4. On the left are graphs of three variables as a function of beam current. Noise from some unknown source degraded the quality of the data. "Gating" on a variable sensitive only to the noise allows the good data to be extracted as shown on the right.

(d) Hard Copy

The recorded data can also be output in engineering notation in lists on any one of several devices. The line printer and two teletypes produce hard copy directly. Lists may also be recorded on 9-track magnetic tape for printing or further processing at the CRNL Computing Centre.

Tasks LOG and RFLOG produce printed lists of selected accelerator parameters for immediate inspection during accelerator operation. For all parameters including such non-linear ones as thermistor temperature or vacuum readings, the data are converted to engineering notation.

4. Limit Checking

Comprehensive limit setting and checking facilities are provided by ETACON. As with the data acquisition tasks, separate tasks are provided for setup (LIMSET, LIMLIS), scheduling (the task SCHED previously discussed) and limit checking (LIMCHK).

Limit checking may be performed on up to 75 parameters. For each, the operator may specify that action be taken for any of the following reasons:

- parameter value greater than an upper limit
- value less than a lower limit
- value between upper and lower limits
- value of parameter has changed by more than x percent (resolution 0.1%) since action last taken.

If action is to be taken, LIMCHK will execute any one or two of up to 16 named tasks. Using these facilities, the operators may easily arrange for frequent data logs during times when, for instance, the beam current is rapidly changing, or for infrequent logs when conditions are steady. Alternatively, corrective programs may be executed if such things as temperatures or radiation levels are excessive.

5. Digital Interrupt System

ETACON supports two types of single-line digital interrupts - the 16 line Interdata digital-interrupt system and the Computer Products multiline interrupt expander system. Under RTOS, each of the 16 separately vectored lines is 'connected" to a task. RTOS starts the "connected" task in response to an interrupt. Two 8-line Task Request Modules (Fig. 5) at the control desk permit the operator to execute named tasks by closing a toggle switch. These modules are equipped with light-emitting diodes controlled by the tasks to inform the operator when they are executing.

The Computer Products interrupt system is used for fault detection and to initiate corrective action. Each of the 96 lines may be separately enabled (to generate an interrupt in response to a level change) or disabled. Interrupts on one or more lines cause INTSER to be started and the numbers of all interrupting lines to be passed to this task. INTSER then refers to a table on the disk, logs mnemonic identifiers for all interrupts and executes service tasks to either correct the faults causing the interrupts or shut down the accelerator. In this respect INTSER's function is very similar to that of LIMCHK described in Section 4.

6. Control Functions

The control functions of ETACON fall roughly into two categories. The first of these is where the computer takes action in direct response to an instruction from the operator. The second includes all those cases where computer action is determined, at least in part, by information received directly from the accelerator. Automated start-ups and closed loop control functions fall in this category.

(a) Set Point Modification

(i) Beam Transport Control System

The beam transport system for ETA comprises steering coils and solenoidal focusing magnets driven by voltage-controlled current-regulated power supplies. The computer's function in this system is to adjust the control voltage to these supplies in response to the operator's demands via two assignable control knobs. In addition, it controls two meters with associated numeric displays which may be "connected" to any two of the 256 analog parameters. Details of this system are given in Ref. 3. In brief, the computer acts as a control multiplexor, providing a simple operator control station with all necessary controls and displays conveniently grouped for ease of operation.

(ii) Other Control Set Points

In addition to the 40 set points for beam transport magnet control, 20 others are available for such things as rf amplitude, frequency and phase, and electron source control. In most cases, hard-wired closed-loop controllers (Ref. 6) are used to compensate for perturbations, and the set points determine the operating level or value. These set points may be adjusted directly by the operator using thumbwheel switches, or as with the beam transport magnets, using the computer as a control multiplexor from another assignable control knob.

(b) Active Control Loops

(i) Structure Temperature Control

The resonant frequency* of the ETA accelerating structures changesby 14 kHz per °C change in temperature. During normal operation, rf power dissipation in the structures may be varied from 0 to 100 kW inducing temperature perturbations which are limited to about ± 1°C by the computer-controlled cooling system. A single task, WATER, is activated by SCHED every 15 seconds (thermal time constants for the structures are of the order of tens of seconds) to control the temperature of both structures. During start-up, it works as a temperature controller, ensuring a smooth transition from room temperature to the desired operating temperature (commonly 35°C). During beam operation, both structures are excited from a single master oscillator, and for each structure a hard-wired resonance controller drives a fast acting mechanical tuner to keep the structure resonant at the master oscillator frequency. Here WATER works as a feedback controller on the tuner position, adjusting the

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* The resonant frequency referred to is that frequency at which the structure is resonant in the $\pi/2$ mode.

cooling rate to limit excursions of the tuner from its rest position. ETACON is well adapted for this type of slow control function. An algorithm including linear, integral and differential terms is used, but with insignificant Central Processing Unit (CPU) usage due to the slow response required.

(ii) Structure Start-up

In readying the structures for the beam, the accelerating fields must be brought up to the desired level and the resonant frequencies matched to that of the master oscillator. Facilities do not now exist for the computer to reset tripped relays in the interlock chains so a fully automatic start-up is not possible. The operator must reset the tripped relays (after, of course, supplying the missing service or correcting the faulty equipment) and bring the system (which now has about 40 reset switches) to reach an 'RF ENABLE' or 'BEAM ENABLE' state. Operationally in a large machine this inconvenience would become intolerable and all resets should be accessible from the computer. The remainder of the start-up is completely controlled by ETACON and the procedure for a single structure is as follows.

With the rf drive to the klystron disabled, the field set point is read from thumbwheel settings to determine the desired operating field level and WATER is instructed to begin stabilizing the temperature. From the measured temperature, the resonant frequency is calculated and the start-up oscillator for that structure is adjusted accordingly. Then about 1 kW of rf power is turned on and the frequency of the oscillator is varied until resonance, as indicated by minimum reflection coefficient, is found. The hard-wired resonance controller keeps the oscillator frequency matched to the resonant frequency of the structure (Automatic Frequency Control or AFC mode), while the rf power is increased in steps until the desired accelerating field level is reached. Because the hard-wired controller can only accommodate 20% of the normal frequency shift during start-up, the computer must add an additional offset signal to the oscillator during this period. The field level is then maintained for about 5 minutes to roughly stabilize the temperature (and hence the resonant frequency). At this time resonance control is switched to the mechanical tuner (Automatic Mechanical Control or AMC mode) and WATER is switched to AMC mode. The oscillator frequency is then adjusted to match within 1 kHz that of the master oscillator. This operation may also take several minutes because of the slow response of the cooling system. The rf power is then reduced, the drive source is transferred from the start-up to master oscillator, and the former power level is quickly restored. At this time, the structure is ready for the beam, and the start-up task terminates.

(iii) Electron Source Control

The ETA electron source is a 100 kilovolt, 200 milliampere triode electron gun. Separate power supplies (controlled by ETACON) determine the cathode potential relative to the grounded anode (0 to -100 kV), cathode heater current (0 to 1.5 A) and bias electrode potential relative to the cathode (0 to 15 kV). The latter two supplies are in a high voltage terminal at the cathode potential. Originally a mechanical servo system with insulating shafts was used to provide the required 100 kV isolation, but it proved too slow and unreliable for useful computer control. This system has now been replaced by optical links using light pipes and voltage-to-frequency and frequency-to-voltage converters.

Unlike the structure start-up program, which is a single task written in FORTRAN (two tasks if WATER is included as part of the start-up) the electron source is controlled by several interacting tasks. Separate tasks written in assembly language are provided to control each of the three supplies and other tasks look after fault identification and correction, communication with the operator, source start-up and conditioning, and emission control. These tasks communicate with each other by means of the Executive (RTOS) and Task Common.

There are important reasons for the different programming approaches taken in the two cases. The structure start-up is basically a step-by-step procedure, completed or aborted within about ten minutes, and a single task is both sufficient and easier. By contrast, the electron source control, even for start-up, may require intermittent action over several hours (for the case of a new cathode), and emission control is a continuing operation. Here a multi-task structure is superior for several reasons. Implementation is easier since the tasks may be checked out individually. The group of interacting tasks make much more efficient use of computer facilities, particularly memory, than a single task, because only the start-up or emission control tasks need be resident in the memory. Program development is also easier because usually only a single small task must be changed and it can often be added and tried out during operation by simply instructing the Executive to use the new version in place of the old.

Emission control has been one of the more difficult operations attempted to date with ETACON, and 100% reliability has not yet been achieved. The electron gun was designed for space-charge limited operation, with the current controlled by the bias electrode potential. However, in many cases only a few milliamperes are required, and at this level it has been found necessary to operate in the emission limited mode (current determined to first order by the cathode temperature). In this mode other effects such as ion bombardment and cathode poisoning strongly influence the emission and cause instabilities that complicate the control problem. Emission control with the present system may therefore only be possible for currents greater than about 10 mA where the gun behaviour is much more predictable.

7. Role of a Computer in Accelerator Safety

The ETACON computer system was never intended to assume the responsibility for machine or personnel safety. It was felt that only a mature and well-understood system could contribute in an area where 100% reliability was required. For this reason all safety systems and interlocks are hard-wired and most lie outside the computer domain. This is unfortunate as it has now been shown that the computer has a part to play in accelerator safety.

Full computer-controlled shutdown would require the computer to respond within 30 μs and take shutdown action according to the nature of the fault. Our experience with ETA shows this to be both impractical and unnecessary. There are few parallel systems in the interlock chain of a high power linear accelerator and all pertinent services must be operable before rf or beam operation is permitted. This leads to extremely simple trip and interlock logic and the present system of using latching relays for this purpose is both economical and reliable. The disadvantage of the system is that recovery from a momentary fault is not possible.

With ETA, pressure bursts in the vacuum system or a beam disturbance causing a radiation spike shuts off the beam. Excess reverse power to a klystron will trip the rf causing the accelerator structure to cool down, increasing its resonant frequency such that it can no longer be excited by the master oscillator. We have introduced fast hardware logic to be more selective in closing down the rf supply but rf shutdowns are still total. Somewhat more choice is available for the electron source. Very excessive beam spill to any of the beam scrapers triggers fast hardware logic which crowbars the main power supply for the electron source. However, at some lower but still abnormally high level the computer is informed by a hardware interrupt and can sometimes take corrective action to prevent a total shutdown. Similarly vacuum deterioration may be detected by the limit check task in time for the source to be turned down before the hard-wired trip occurs. From our experience with this subsystem it is evident that if the computer had more access to the safety and interlock systems it could play a major role in also determining the extent of other shutdowns. For instance the complete accelerator could be placed on a stand-by level rather than always returning to the starting point or the computer could determine whether such things as the water control valves should be closed, the rf level should be reduced but not turned off or the beam current should be reduced.

There are limits to the reliance that can be placed on a single processor computer system like ETACON. If problems which occurred in the first months following installation are omitted, the ETACON computer has been very reliable (one or two hardware failures per year). In addition to these however, power failures, operator errors, software faults and electrical noise cause loss of service for 3 seconds or longer on a weekly basis*. Such computer failures could be greatly reduced with the present hardware configuration, but only by making it more difficult to implement changes and certainly not to the point where 100% reliability was assured. (For this, the minimum requirements would probably be for a dual processor system with each checking the other and shutdown initiated by any disagreement.) Therefore with a system like ETACON the primary responsibility for machine and all responsibility for personnel safety should continue to be independent of the computer system. Conversely, expansion of ETACON's supervisory and corrective role is both feasible and desirable.

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* The computer normally sends a reset pulse to an external three-second timer every second. If more than two such pulses are missed, the accelerator is automatically shut down. The accelerator can tolerate shorter periods of computer inaction.

8. Conclusions

An effective and versatile accelerator control and data acquisition system has been developed using mainly commercial process I/O hardware and software. The availability of such fully integrated systems with powerful operating systems and support of high-level language permits accelerator physicists and engineers to participate directly in applications software development. The hardware and software protection features inherent in a system such as ETACON permits program development to safely time-share with real-time control and data acquisition jobs.

Although the system is now well developed, its capabilities have not been fully utilized and further evolution is contemplated. Gun-current control requires further effort, and klystron collector voltage control as a means of improving klystron efficiency has been proposed. The role a computer can play in personnel and machine safety is another topic that merits further investigation.

Original plans called for all application programming to be in FORTRAN, but this has not proved to be practical for many of the real-time control and data acquisition tasks because of memory and control bandwidth limitations. For ease and speed of programming, FORTRAN or some other high-level language is, in general, essential for a system such as ETACON. However, with an operating system such as RTOS, I/O can be coded almost as easily in assembly language and operations such as bit manipulation are actually easier. Thus it is expected that even in systems without the memory and control bandwidth limitations of ETACON, some assembly coding would be desirable.

References

1. Fraser, J.S., Kidner, S.H., McKeown, J. and McMichael, G.E., "The Chalk River Electron Test Accelerator", Proc. 1972 Proton Linear Accel. Conf., Report LA-5115, Los Alamos, New Mexico, p. 226.
2. Schriber, S.O., Fraser, J.S., and Tunnicliffe, P.R., "Future of High Intensity Accelerators in Nuclear Energy", Atomic Energy of Canada Limited, Report AECL-5903 (1977).
3. McMichael, G.E., Kidner, S.H., and Fraser, J.S., "Computer Control of the Beam Transport System of the Chalk River Electron Test Accelerator", Atomic Energy of Canada Limited, Report AECL-5544 (1977).
4. "Real Time Operating System (RTOS) Reference Manual", Publication Number 29-240R07, Interdata Inc., Oceanport, New Jersey (1974).
5. Belshe, R.A., Elischer, V.P., and Van Jacobson, "The Feasibility and Advantages of Commercial Process I/O Systems for Accelerator Control", 1975 Particle Accelerator Conference, IEEE <u>NS-22</u>, no. 3, 1036 (June 1975).
6. McKeown, J., Fraser, J.S., and McMichael, G.E., "Field Control in a Standing Wave Structure at High Average Beam Power", Proc. 1976 Proton Linear Accel. Conf., Atomic Energy of Canada Limited, Report AECL-5677 (1976).

Figure 1. ETACON Computer System

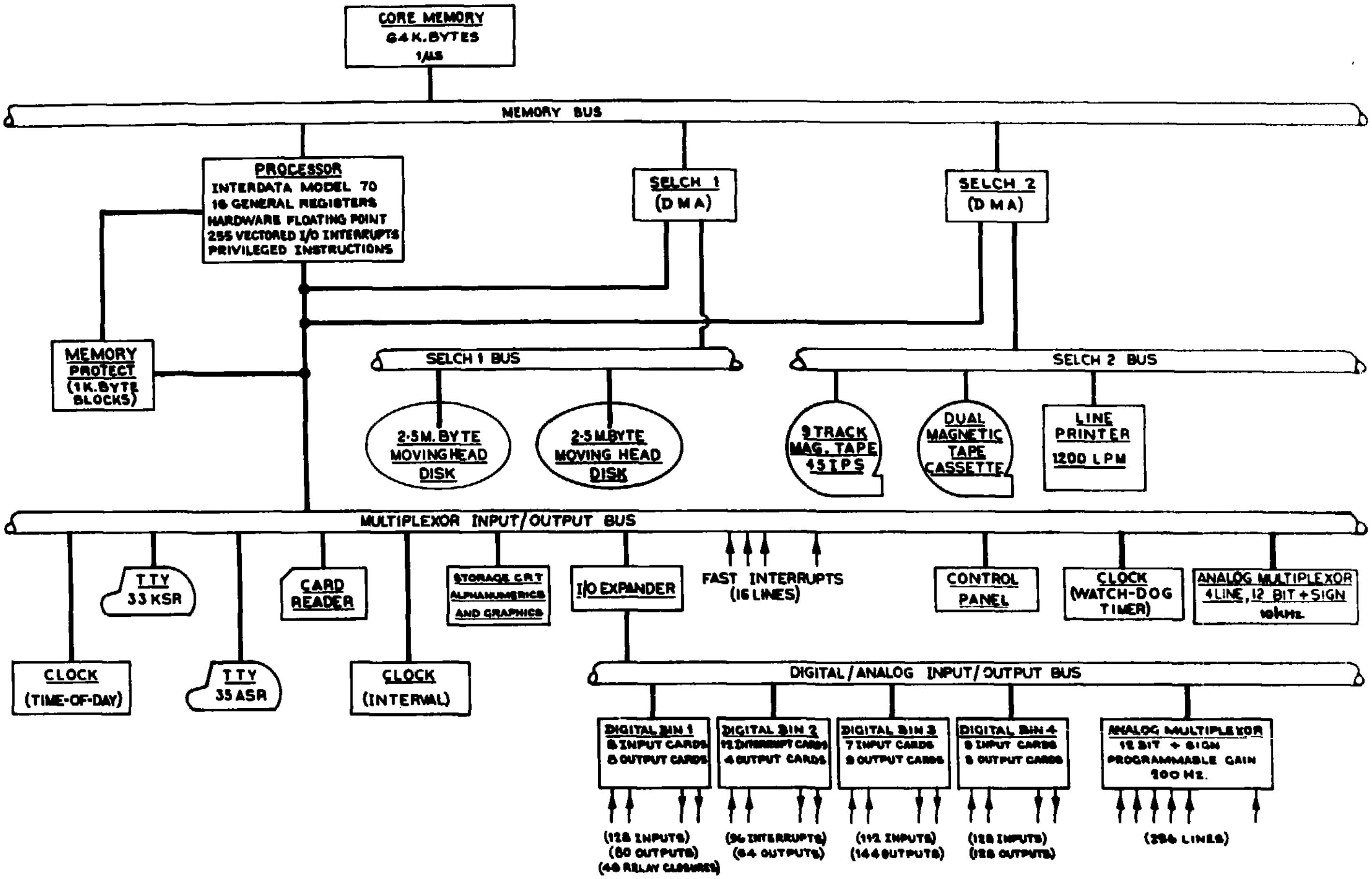

Figure 2. ETACON Computer System Block Diagram

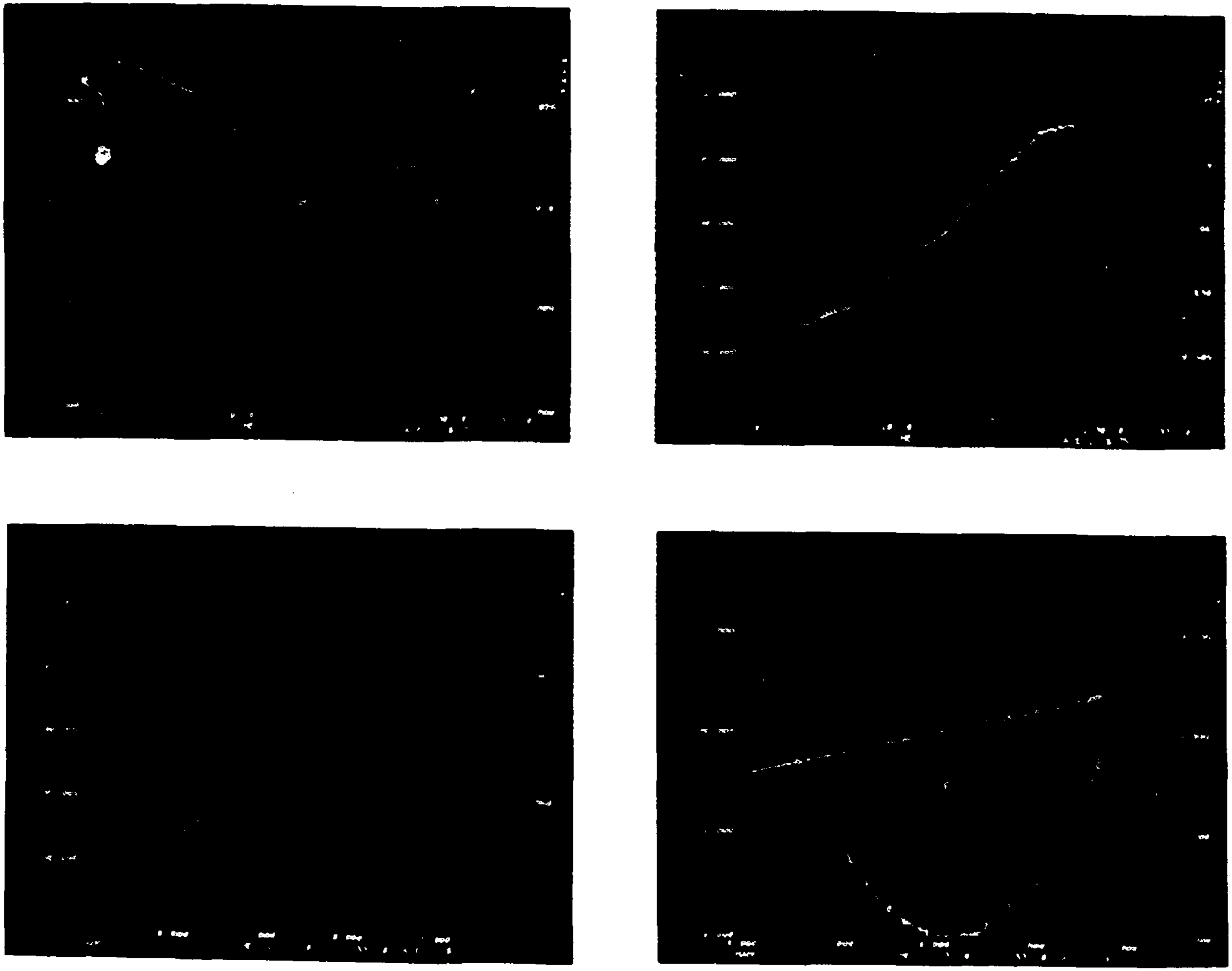

Figure 3. Time History and X-Y Data Displays

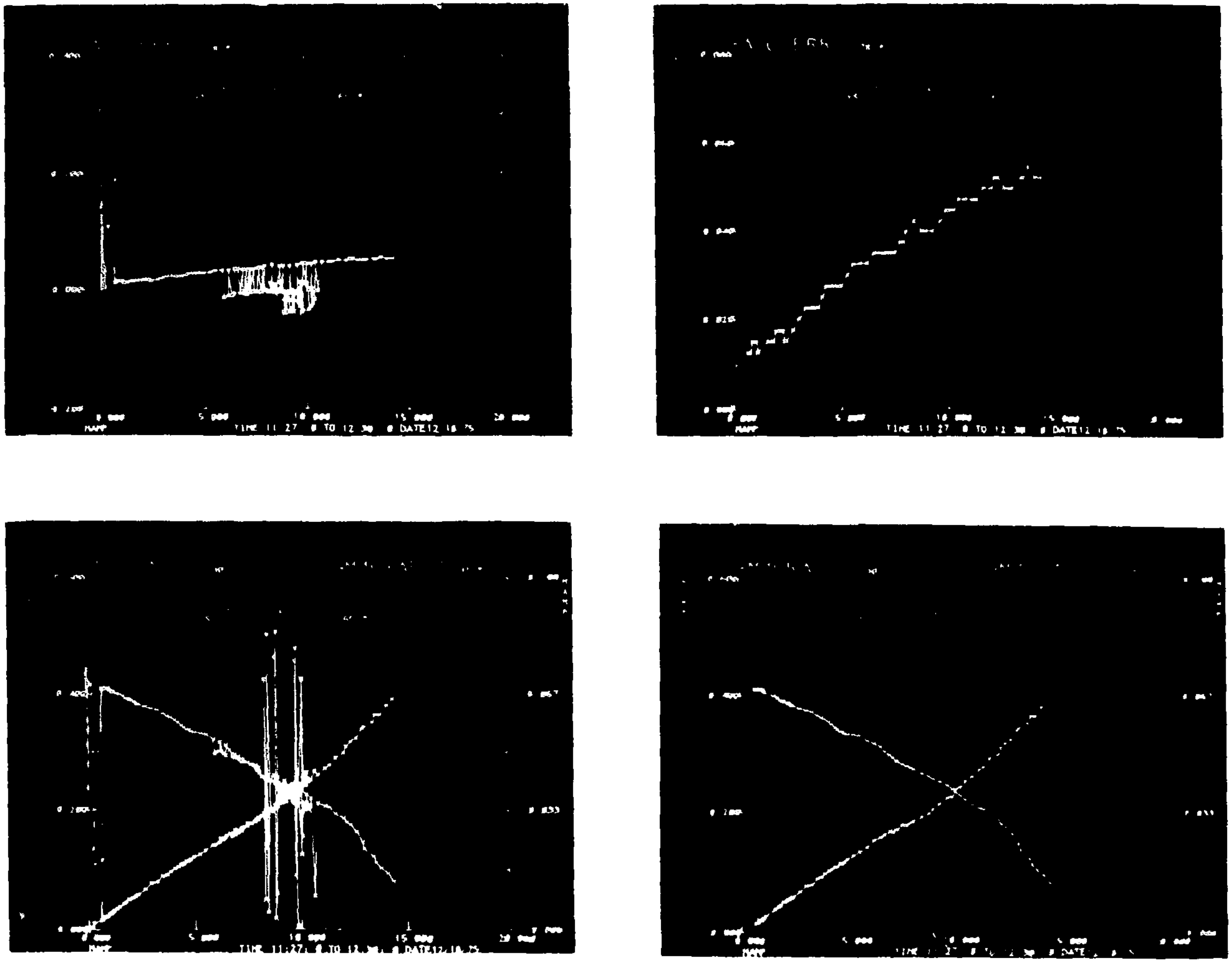

Figure 4. "Gated" Data Displays

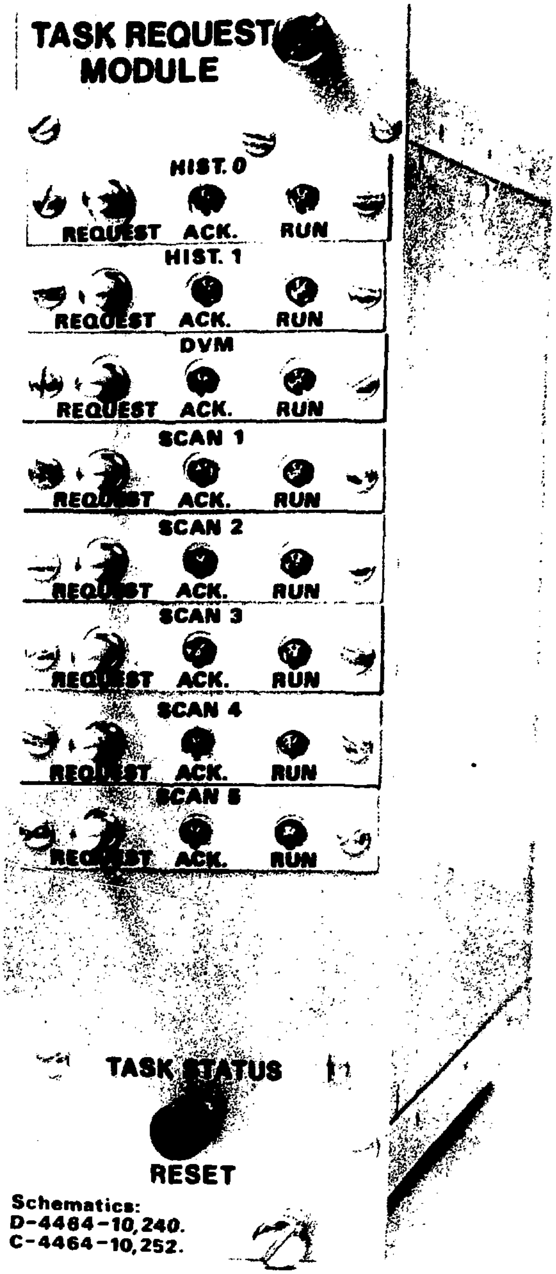

Figure 5. ETACON 8-line Task Request Module

APPENDIX A

SUMMARY OF RTOS FEATURES

- Multiple application tasks[*] can be operated concurrently with interleaving.
- Up to 16 levels of priority can determine the task execution sequence.
- Tasks can share time on the same priority level, thereby insuring equal distribution of system processing time.
- A "watchdog" timer protects against endless program loops.
- Modular structure so that system elements can be added or deleted easily, thereby assuring the user of a compact, tailored RTOS environment.
- Number of tasks allowed at any one time is limited only by the amount of memory available.
- Tasks need not be totally memory resident but can be segmented and overlayed from a mass storage device.
- An extensive set of operating commands is provided for system control, interrogation, and initialization (Appendix B).

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[*] A task consists of a single program (as a main program and associated subroutines and overlays) and a Task Control Block containing information pertinent to overall system operation.

- Background tasks may be rolled out to provide memory space for other non-resident tasks.
- Calendar and time of day maintained by the RTOS system, as well as interval timing.
- Tasks can communicate with other tasks, i.e. request their activation and cancellation.
- Tasks and the operator can communicate by passing parameters.
- Core-resident re-entrant subroutines (e.g. the FORTRAN formatter) may be used by any task and thus a separate copy is not required for each task.
- Both memory and mass storage devices are allocated and protected by the RTOS executive, thereby preventing program errors from harming total system performance.
- Input/Output operations are device independent allowing device allocation without having to alter existing software.
- Input/Output operations are easily programmed by issuing a Supervisor call (SVC) which passes appropriate parameters to the RTOS executive (Appendix C).
- Interrupts are automatically handled by the RTOS executive.
- Debug options allow on-line program development and testing in a background mode while servicing real-time events in the foreground.
- A task common area may be allocated for storage of data common to several tasks.

APPENDIX B

SUMMARY OF ETACON OPERATOR COMMANDS

ALLOcate fnpa, ssss, eeee, wprp	File number and device address, start cylinder, end cylinder, write protect and read protect pattern
LIST pa	Device address of mass storage device for which files are to be listed
RELease fnpa	File number and device address for file being released
DATE mm/dd/yy	Set current date
TIME hhmmss	Set current time
RDDAte	Read current data
RDTIme	Read current time
BIAS xxxx	Set bias to xxxx for open and replace commands
OPEN xxxx,xxxx,...,xxxx	Open up to eight locations
REPLACE xxxx,yyyy,...,yyyy	Replace contents of up to eight locations starting at xxxx
CHANGE xxxx,yyyy,...,yyyy	Replace contents of up to eight locations in user area starting at xxxx
MAP	Print system map
PROTect	Put system in protect mode
TCOMom xxxx	Set TSKCOM size
BKSP pa	Backspace one record on device pa
BSFM pa	Backspace to file mark on pa

FRFM pa	Forward space to file mark on device pa
FRSP pa	Forward space one record on device pa
REWInd pa	Rewind device pa
WTFM pa	Write file mark on device pa
ASSIgn TASKID, lu,pa,...lu,pa	Assign up to eight logical units
LOAD TASKID	Load named task
START TASKID, hhmmss	Start named task at specified time
HALT TASKID	Put named task in console wait
CANCel TASKID	Cancel named task
DELEte TASKID	Cancel and delete named task from memory
CONNect TASKID pa,parm,...pa,parm	Connect named task to pa with parameter, up to eight with one command
CONTinue TASKID	Remove named task from console wait
OPTIons bbbb bbbb bbbb bbbb	Set named task's options
DISPlay TASKID	Display information from named task's TCB
TELL TASKID, message	Pass message to named task
PRIOrity xx	Set named task's priority to xx
SET	Preset core to illegal instructions before loading task or overlay
RESET	Cancel "SET" function

SUMMARY C

SUMMARY OF ETACON SUPERVISOR CALL INSTRUCTIONS

SVC	Type	Function
1		I/O
2	1	PAUSE - put calling task in "Console Wait" state
	2	GET STORAGE - provide temporary storage within task's own block of core
	3	RELEASE STORAGE - inverse of "GET STORAGE"
	4	SET STATUS - disable or enable arithmetic fault interrupts and set Condition Code
	5	FETCH POINTER - return address of unprotected task control block to caller
	6	UNPACK - convert a binary halfword to four ASCII hexadecimal characters
	7	LOG MESSAGE - send message to console teletype
	8	INTERROGATE CLOCK - return current time of day to caller
	9	REQUEST DATE - return current calendar date to caller
	10	TIME WAIT - suspend caller until a particular time of day
	11	INTERVAL WAIT - suspend caller for a specified time interval
	12	LOG MESSAGE AND AWAIT RESPONSE - send message to console teletype and wait for response from operator
	13	ALLOCATE MEMORY - dynamically obtain additional memory blocks for caller
	14	RELEASE MEMORY - release memory previously allocated

3	END OF JOB
5	FETCH OVERLAY - load and link named overlay
6	CALL TASK - allows caller to load, start, or schedule other tasks
8	SIMULATE INTERRUPT - generate a simulated interrupt from selected device
10	CANCEL TASK - terminate named task
15	BREAKPOINT - pass status and address of instruction to task and enter debug routine

APPENDIX D

FORMAT OF DATA ON ANALOG FILES

1. Sector 0

Byte Address (Decimal)	Contents
0	Data file identifier (4 ASCII characters)
4	Sequence number for next scan
6	Date of last scan (X'MDDY' - month, day, year)
8	Date file started (X'MDDY')
10	Next sector for data
12	Byte address of start of data in data sector
14	Number of scans per sector
16	Number of lines per scan
18	Final sector in this file
20	First sector for data in this file
22	Number of sectors per scan (= 1 if ≤ 112 lines)
24	Sequence number for next scan (= ADRS 4 if file not full)
26	Time of last scan((seconds after midnight) /2)
28	"Reserved" (must be -1)
30	CHECKSUM for sectors 0 and 1
32	Card/channel/gain table for first 112 lines

2. Sector 1

0	Card/channel/gain table for next 128 lines

3. Sector 2

0	Scan number in current sector	not used if scans/sector = 1
2	Print flag	
"START ADRS"	Temporary data storage	

4. Sector 3 "RESERVED"

5. Sector 4 Used by graphical display task for argument storage

6. Date Sectors

0	Data file identifier (as in sector 0)	
4	Sequence number for this data sector	
6	Year this sector completed	
"START ADRS"	Date and flag for first scan this sector (X'MDDF')	
+2	Time for scan ((seconds after midnight) /2)	
+4	Data (2 bytes per line)	
+(2*lines+4)	Date and flag for next scan Time Data	if scans/sector > 1

APPENDIX E

COMMANDS RECOGNIZED BY TASK "SCHED"

1. Add a task to the queue

```
BEGIN TASKID, SSSS, PPPP, HHH, MM
```

2. Remove a task from the queue

```
EOJ TASKID
```

3. List tasks in the queue

```
LIST
```

4. Increment next activation time

```
ADD TASKID, SSSS
```

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