THE TRIUMF CONTROL SYSTEM

J.V. Cresswell and D.R. Heywood
TRIUMF, Vancouver 8, B.C., Canada

D.P. Gurd
University of Alberta, Edmonton, Alta., Canada

R.R. Johnson
University of British Columbia, Vancouver 8, B.C., Canada

W.K. Lacey
Dilworth, Secord, Meagher and Associates Ltd., Toronto, Ont.

ABSTRACT

The TRIUMF cyclotron will be controlled by a computer-driven CAMAC-based system. Data is acquired, displayed and logged automatically at preset intervals while operator commands to modify a machine parameter are serviced in response to interrupts. Branch drivers, branch extenders and control modules have been designed and manufactured. The major features of the system have been implemented and tested on CRM-ISIS and installation is proceeding on the main machine.

1. INTRODUCTION

The TRIUMF control system performs two basic tasks: data acquisition and set-point control. Initially there will be no attempt to close the loop between input and output other than by operator intervention. However, all data passing to and from the control console is directed by computers through a CAMAC branch highway system so that portions of the system can be automated when they are well understood. Personnel and machine safety are assured by a hard-wired system distinct from the control system described herein.

2. GENERAL SYSTEM OBJECTIVES AND CONCEPTS

Conceptual design of the TRIUMF control system began over three years ago. At that time it was estimated that approximately 300 power supplies would have to be remotely programmed, 1200 analogue signals measured and 2000 digital states monitored on a regular basis. Power supplies and signal sources would be separated from the control room by distances of up to 300 ft. Furthermore, details of the system would have to evolve as the details of other machine subsystems were fixed.

It was decided that the best way to achieve the required complexity while retaining flexibility was through the use of digital computers coupled to a universal digital transmission system. Space does not allow for a detailed defence of the decision to "go digital". Suffice it to say that all the usual arguments for and against computer control were raised and debated before the decision was reached.

Of more significance at this time are the reasons why the system was configured around several mini-computers (Datagen Supernovas) rather than one large computer and why CAMAC was chosen as the digital transmission system. Once again the over-riding consideration for both decisions was the need for flexibility.

2.1 Multiple CPUs

Consider first the multi-CPU approach as it applies to the present pre-commissioning phase of activity. The machine subsystems are being developed by groups in physically separate locations, i.e. CRM-ISIS in the central region model lab, RF in the main building, beam transport at the University of Victoria. Simultaneously, controls software and hardware are being developed and debugged in the controls group laboratories. Because we have six computers, development can proceed with a minimum delay on all fronts at once. Moreover, specifically adapted software may be used for each task. Thus the programming system is run under a disc operating system (DOS), hardware debugging uses BASIC, and prototype control systems run under our own executive.

During and after commissioning, the CPUs will be reconfigured, probably as shown in Fig. 1, to control the total system.

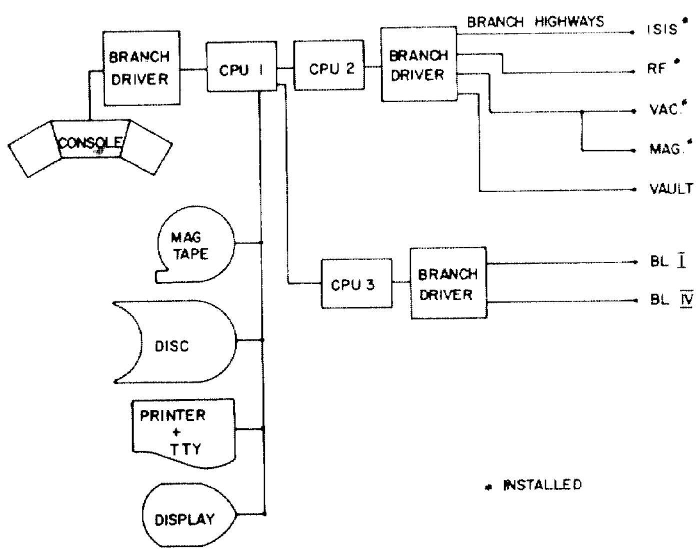

Fig. 1. Control system configuration

One CPU drives the main control console, CRT display and major data-logging peripherals. Two others service the 6 branch highways dedicated to cyclotron and beamline controls. Current plans call for the CPUs to be interconnected via Datagen Multiprocessor Communication Adaptor,* but the option does exist to multi-source the branch drivers. There will still be CPUs dedicated to CRM, software development and hardware development so that additions or modifications to the control system can be tested off-line. At that time the following additional advantages of the multi-CPU concept will become significant:

a) By dedicating one CPU to console and logging tasks, and the others to control and monitoring, the complexity of the scheduling problem in each CPU is reduced.

b) Multi-CPUs clearly provide more instruction cycles per second than could a single machine of comparable speed. In periods of intense controls activity the extra time could prevent task queues from filling up.

c) The mean time to repair (MTTR) the system in the event of CPU failure will be minimized because a stand-by CPU can be substituted and the faulty one repaired off-line.

2.2 CAMAC

Before CAMAC was chosen as the transmission system for TRIUMF, several other approaches were studied and compared on the basis of capital cost, reliability, flexibility and development time. The cost of a CAMAC-based system was estimated between that of a complete in-house data transmission scheme of less complexity and that of a system purchased from a consultant or computer firm. The CAMAC system was judged to be potentially more reliable than any in-house scheme because critical modules and mechanical assemblies are available from firms practising reliable manufacturing and quality assurance techniques. Furthermore, in the key area of flexibility, CAMAC by its very nature surpasses all less complex data transmission systems considered. Finally, because all relevant CAMAC standards were frozen at the beginning of development, TRIUMF's relatively small engineering staff could devote its energies to designing the console and special interface modules required to control TRIUMF equipment.

2.3 Basic Tasks Performed by the Control System

The basic tasks performed by the control system are most easily understood by considering the interactions between a machine operator and a group of typical programmable power supplies (see Fig. 2). The operator is provided with at least[1] a device select switch, a set of lighted ON/OFF push-buttons to control and indicate the state of the power supply, a shaft encoder or slew buttons to set the output level of the power and a numerical display to confirm that level. In a CAMAC crate near each power supply there is a TC0441 module that

* Datagen of Canada Ltd., Hull, P.Q.

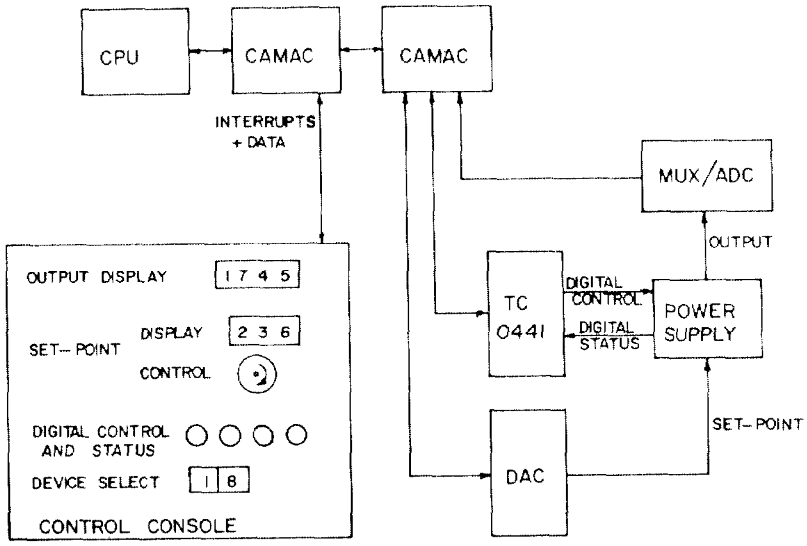

Fig. 2. Typical control tasks

issues digital control pulses to the supply and senses its status; and a digital-to-analogue converter (DAC) module that controls its output level. One channel of a multiplexed analogue-to-digital convertor (MUX-ADC)[1] measures the output level.

In the absence of any control action by the operator, the only task performed by the control system on this part of the system is to regularly measure the output level, compare it to alarm limits and display or log it as required. The time between measurements is normally 1/3 sec for console displays. Otherwise, the point is included in one of several scan groups measured at 10 sec, 1 min or 5 min intervals.

When the operator wishes to change the state or output of the power supply he first thumbs the selection switch to the appropriate device address. This interrupts the computer and causes the current set-point to be read from the DAC memory and loaded into the console shaft encoder register to ensure "bumpless" control. The level being controlled is placed on 1/10 sec scan to provide display feedback within human response time. Movements of the shaft-encoder or depression of a push-button generate further interrupts at a maximum rate of one/100 msec. These cause new control data to be read from the console and sent to the DAC or digital controller after appropriate scaling or bit manipulation. Simply stated, the control system software consists of an interrupt activated console driver along with a number of display, logging, plotting and scanning tasks running asynchronously on the basis of software interval timers. Programs to handle these tasks are coded in assembly language and are executed under the supervision of the real-time executive NATS.*

3. TRIUMF-DESIGNED HARDWARE

In spite of the wide variety of commercially-available CAMAC equipment, it was necessary at the outset to design a Supernova branch highway driver,[2] a differential branch extender and several special purpose control modules. Six branch drivers were manufactured and are currently in use. However, those on the control system will soon be replaced by a software compatible version of the more sophisticated GEC-Elliott Executive Suite.[3] The differential branch extenders are also now supplied by GEC-Elliott who completed our design and undertook all production engineering. The various control modules described briefly below are all being manufactured by local subcontractors to TRIUMF specifications.

3.1 Quad DAC module 4 DA 10+5

The 4 DA10+5 is a double width CAMAC module containing 4 10-bit digital-to-analogue convertors based upon an NAL design.[4] The unit contains 4 10-bit latches that can be loaded from the dataway with a F(17)A(i) command and echoed with an F(1)A(i) command. The contents of each latch and the contents of a free-running 10-bit counter are continuously gated by a digital comparator to form pulse-width-modulated signals whose DC component is the desired analogue output. AC components are removed from the signal by low pass filters and a buffer amplifier provides a low output impedance. The DAC response time is greater than 10 msec. This is advantageous in two ways. First, it prevents shock excitation of power supplies with long servo time constants. Secondly, it allows time for a dynamic echo check, and if necessary a correction, of the transmitted set-point before the output slews significantly.

3.2 TC044 Digital Controller

The TC0441 is a special purpose quad 4-bit input/output gate housed in a double-width CAMAC unit. It is designed to drive isolated 24 V relay windings with 200 msec long pulses and sense digital status from isolated relay contacts. Three significant features of the module are illustrated in Fig. 3. Firstly, the DE-ENERGIZE output driver is normally on; all others are normally off. Secondly, the 24 V relay power is bussed through the module independently of the CAMAC power system. Together these features allow a fail-safe DE-ENERGIZE command to many devices to be controlled by a manual "PANIC" button. The other noteworthy feature is the facility to read back the latches. As with the DAC it is possible to make a dynamic echo-check to correct transmission errors before any relay has time to respond.

3.3 CAMAC Stepping Motor Controller

Stepping motors will be used to position stripping foils and probes. To control them a CAMAC stepping motor controller has been designed which

*Nova Asynchronous Tasking Supervisor - MacDonald, Dettwiler and Associates Ltd., Vancouver, B.C.

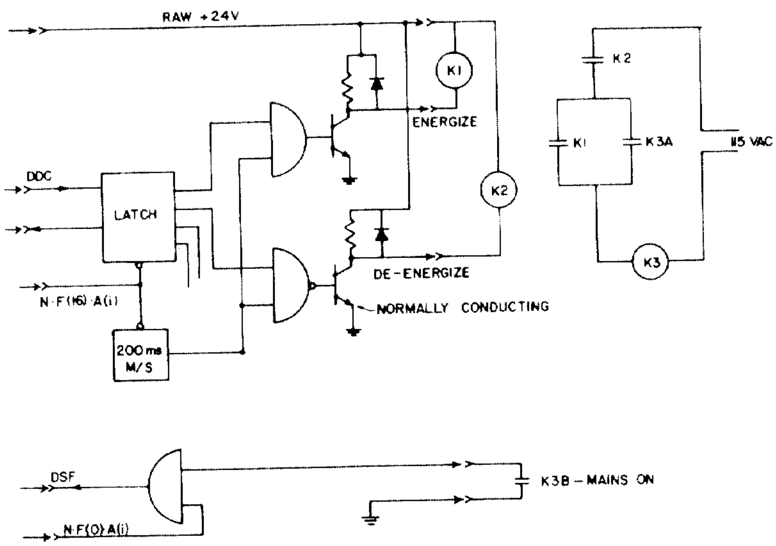

Fig. 3. Digital control interface

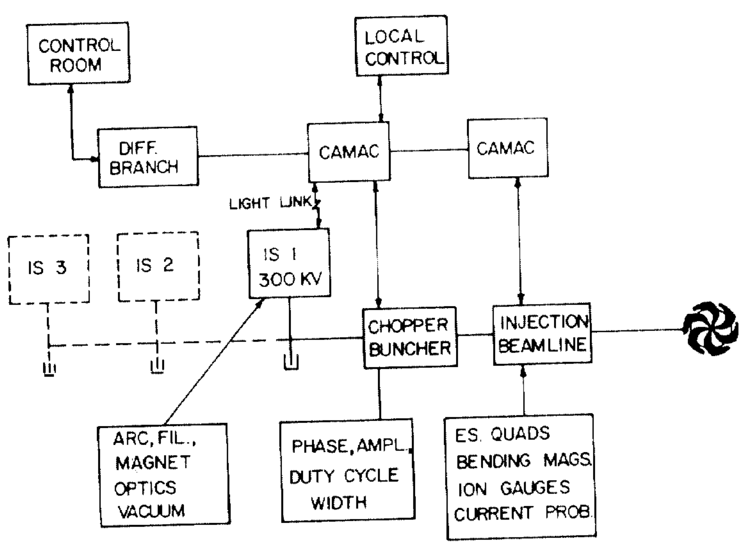

Fig. 4. ISIS controls

has the following features:

1) Open loop control of stepping motors
2) Closed loop control, with either incremental or absolute (parallel) shaft encoder position feedback
3) Programmable speed selection
4) Limit switch stops (at ends of travel)
5) Slew to limit switch locations on command
6) Programmed insertion or deletion of an intermediate limit or indexing position
7) Optical isolation from motor translator power supply circuits
8) 16-bit resolution, expandable to 24-bit by addition of an adjacent module with 8-bit registers

The module contains a destination register which can be loaded from CAMAC and a position register. In the open loop mode the position register is incremented or decremented by the motor stepping pulses, while in the closed loop mode it is either incremented by directional pulses from a shaft-encoder or parallel loaded with a word from an absolute encoder.

A comparator using the destination and position registers as inputs then determines the directional information to be sent to the motor until a null is reached, at which point stepping pulses are inhibited. An interrupt may be sent to the computer indicating the destination has been reached. The position and destination registers as well as the limit switch status may be read at any time.

3.4 No-break Power System

To isolate the control system from line transients and to allow orderly shutdown in the event of a power failure, all computers and CAMAC crates derive power from a no-break source. 24 V Ni-Cad battery packs are deployed in the controls area. Each is designed to provide a seven-crate branch or three computers with 15 min of uninterruptible power. Raw 24 V is bussed to the crate (or computer) where DC-DC (DC-AC) converters generate the other raw voltages required. Series regulators mounted on the rear of the crate maintain the voltage within the CAMAC specification.

4. ION SOURCE AND INJECTION (ISIS) CONTROL

In order to unify the above discussions of system concepts and module design, the ISIS control configuration will now be described briefly. ISIS is a suitable example because it utilizes nearly all features of the control system.

To control ISIS[5] it is necessary to control one (later three) ion sources biased at 300 kV, a chopper-buncher and a 130 ft long injection line (see Fig. 4). Primary control will originate in the control room but local control will be available to allow off-line run-up of the system prior to commissioning and during periods of maintenance. To avoid conflict between control stations, a key interlock system will be used. It will allow the on-line ion source to be controlled from the control room only and ensure that beam stops are in place on the off-line sources.

Control information passes between the ISIS area and the control room via a differential branch highway (see Fig. 4). A serial fibre-optic light link interfaces CAMAC crates in the high tension cage to a special module in a crate at ground potential. This module, currently under development, will take parallel CNAF + (DATA) words from the crate backplane, serialize them and transmit them to the cage. Upon receipt of a word the terminal in the cage will perform the required function, then return a status (+DATA) word. Completion of bi-directional transmission is indicated by a LAM request. At a 0.5 megabit rate the longest CAMAC cycle will be complete in less than 150 μsec.

Within the cage, four quad DACs will be interfaced to the arc, filament, magnet and optic element power supplies. Ten TC044ls will control the digital status of the power supplies and the pumps and valves of the vacuum system. A 64-channel MUX-ADC will measure the various analogue signals.

At ground potential CAMAC quad DAC modules control the phase, amplitude, duty cycle and width of the beam pulses from the chopper-buncher. Beam intensity monitors are multiplexed and digitized onto CAMAC, while the beam pulse structure is monitored in real-time on broadband CRT display. Fifteen quad DACs coupled to unity gain inverters control some 60 electrostatic quadrupoles along the injection beam line, while a further ten DACs control miscellaneous steering and bending elements. Outputs of all power supplies, ion gauges and beam current monitors are measured by MUX-ADCs. In keeping with the controls concept all parameters are scanned on a regular basis, compared to preset limits, and displayed or logged on demand. Modification of a setting is initiated from a control console by operator command.

All portions of the ISIS control system except those in the cage have been installed and are operating on CRM-ISIS. Experience gained there has produced sufficient data that the first phase of automation, an automatic run-up sequence for the injection beam line, is now being programmed.

REFERENCES

1. H. Dollard, D.R. Heywood, D. Marquardt, D.P. Gurd and R.R. Johnson, Paper N9 this conference
2. W.K. Lacey and D.P. Gurd, private communication (1971)
3. The Elliott Executive Suite - a modular approach to controllers for CAMAC systems, GEC-Elliott Process Instrument Limited, Century Works, Lewisham, U.K.
4. CAMAC computer interface type SI-N - interface for Nova and Supernova computers. GEC-Elliott
5. L.A. Klaisner, private communication

DISCUSSION

BARDIN: What is the overall budget for this system?

HEYWOOD: I would ask the head of the control group, Dick Johnson, to answer that.

JOHNSON: The total estimated cost in 1970 was $1.2 M. That is an estimated cost. We are on a yearly budget.