HIGH LEVEL EXTENSIONS TO THE TRIUMF CENTRAL CONTROL SYSTEM

D.A. Dohan and M.M. Mouat
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3

Abstract

The TRIUMF central control system "CCS" consists of a system of 16-bit minicomputers connected to cyclotron equipment by means of a multi-branch parallel highway CAMAC system. Because these computer "sources" are programmed primarily in assembler language, there are difficulties in carrying out complex or precise numerical algorithms. Recently, a limit to the maximum number of sources with access to the CAMAC hardware has been removed and several VAX computers have been added. The configuration has very conveniently allowed independent development of data acquisition and analysis software, and has permitted the implementation of mature accelerator physics software developed elsewhere. The new VAX sources incorporate the use of sophisicated system software, multiple high-level languages, graphics, networking and an independent CAMAC highway. A separate serial CAMAC highway supports cyclotron development without compromising the on-line duties of the existing central control system. This paper describes the new configuration and the implementation of the data acquisition and analysis software.

Introduction

The control system which began in the early 1970's was instrumental in bringing out TRIUMF's initial cyclotron beam. At the time of its inception, this system was one of the first to fully exploit the CAMAC interface standard. At that time, 16-bit minicomputers were just becoming available; they did not come equipped with sophisticated, multi-user, multitasking operating systems and they typically had little support for efficient high level languages. As a result of these historic restraints, the control system software at TRIUMF evolved around a simple supervisor to manage a number of concurrent routines written entirely in assembler.

After the basic machine control and safety requirements were met and the first extracted beam was achieved, emphasis shifted toward providing more detailed and explicit operator information, both for routine operation and for specific complex operations such as beam energy changes. More recently, while the original design specifications for the cyclotron have been met, new requirements in beam quality, multiple beams, and extraction of H- beams for tests of TRIUMF as an injector for a proposed KAON factory have emerged. Recent developments in beam diagnostics and complicated tuning algorithms are available but require advanced computer techniques. The design and architecture of the TRIUMF control system has allowed for a very convenient expansion of the system to accommodate the cyclotron development needs described above, without compromising the existing system and operation. Further developments and specialized equipment and laboratories not directly connected to the operating cyclotron also require the use of sophisticated computer techniques. A common, well supported computer/user interface allows better software and hardware support and faster implementation in the developments at these. The following paper describes these extensions, and some of the developments in tuning and diagnostics that the new system has provided.

The TRIUMF Control System

TRIUMF's central control system has been built around a GEC Elliott "executive suite" interface[1] that arbitrates between a number of sources attempting to access cyclotron parameters through a set of 7 parallel highway CAMAC branches. Several years ago, the number of cpu's needed to meet the cyclotron control requirements exceeded the maximum allowable number of computer interfaces, due to bus loading problems. Active extension of the executive crate bus has allowed a large increase in the maximum number of sources and has provided an opportunity for developments in areas other than cyclotron supervision and control. Examples in beam physics and diagnostics will be discussed.

The original layout contained only Data General 16 bit mini-computers sources, interconnected with a high speed DMA multi-processor communications adapter "MCA". A multi-port memory "MPM" based data base structure provides these computers with access to cyclotron device information including CAMAC geographic addresses, data conversion, scaling, and acquisition routine parameters. The central control system computer software can be split up functionally into three areas; diagnostics/high level applications, software development and dedicated real-time operations. The diagnostics and high level applications are run under Data General's Advanced Operating System (AOS) in Eclipse S130's and are coded mostly in Fortran and Basic. These programs have the ability to acquire data base information from the MPM and to access the CAMAC system. Unfortunately, there is no hardware or software support for graphics, colour, hardcopy plotting or high level interactive data analysis. Very little beam physics software such as beam transport or rf field codes has been developed on this type of computer.

Software development is performed on an off-line Eclipse S130 and the linked code is downloaded to the target processor via the MCA. Real-time supervision and control is done by a group of six Nova 4's. Each cpu is given specific tasks to perform, including operator console supervision, cyclotron scans for analog and digital changes, error logging, data acquisition for display routines, remote console supervision, cyclotron protection scans, and cyclotron status and control display. CAMAC LAM interrupts are handled in real-time by the processor that has the appropriate interrupt service routine. It is common for a single LAM to interrupt more than one computer. In this case, the other processors wait until the appropriate cpu clears the LAM.

The parallel highway is a large, mature CAMAC system. There are seven branches in the executive crate, the maximum number supported, with a total of 45 crates. Long branches require differential branch extenders (DBE's), which incur a delay penalty due to transmission and buffering. DMA transfers have not been implemented.

The Expanded System

The executive crate described above has recently been redesigned to allow for more sources. To overcome the bus loading problems incurred in a passive extension of the executive, an active extender/arbitrator[2] has been designed and installed which has allowed the original executive crate to be supplemented by two more crates. There is now enough room to house the current needs and additional active extenders can be employed if it becomes necessary. With this ability to add new computer sources, a unibus system interface to the executive crate was purchased and installed on a VAX 11/730, and a microVAX II with a Qbus interface has recently been added for secondary beamline control. This has permitted VAX/VMS access to the entire set of parameters relating to cyclotron operation. The executive system environment permits the central control system (CCS) and the VAX 11/730 system to operate essentially independently of one another. The expanded layout is shown in Fig. 1. Whereas the CCS parallel CAMAC hardware remains operational essentially all the time, the operation of the CCS computers or the VAX system may be interrupted either because of software bugs or because of maintainence, updating and testing reasons. Routine CCS computer maintainence and updating often requires that these computers be inoperative during scheduled maintainence days. It is precisely during these times that many groups needing to work on their equipment carry out maintenance and development and require the CCS computers to complete their work. The independence of the VAX system during these maintenance periods has allowed testing of new diagnostic devices and unusual system operational conditions, in particular the rf system.

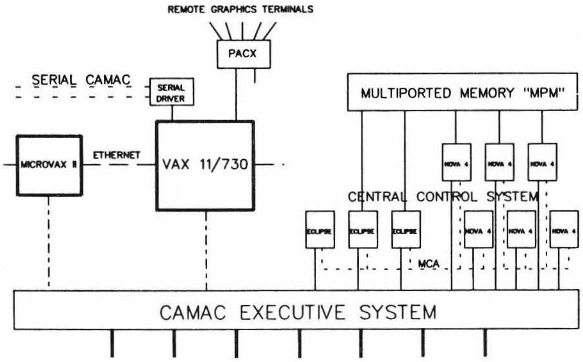

Fig. 1. The TRIUMF control system, showing the MCA, MPM, executive suite and the VAX extension.

Although the CCS computers and the VAX system can operate independently, there are areas of conflict. One of the largest problems in a multi-source system is the issue of device ownership. Within the CCS the most common system for device reservation is a busy module with defined reservation bits which must be cleared after the parameter is no longer needed. Conflicts very rarely occur and on these occasions they have been solved by word of mouth. The VAX system does not have a well defined path to the MPM data tables. A procedure has been developed whereby a copy of the MPM tables may be transfered to the VAX. However, a full set of data acquisition, conversion and scaling subroutines are also needed to supplement the tables. A more comprehensive data base system is planned for the VAX to accommodate these needs. In the meantime, changes in CAMAC device addresses or characteristics must be made directly in the VAX code. Fortunately most of the cyclotron development work has involved established parameters which have been stable during this period.

The VAX Hardware Description

The VAX 730, which has a direct interface to the central control system, is networked to in excess of 15 other VAX computers on site, including a VAX 780/8600 cluster. Users anywhere on site have access to the Cyclotron Development VAX via DECNET or by means of a terminal network PACX system, permitting remote acquisition and display of cyclotron data. The VAX software, however, does not allow write access to the CCS CAMAC hardware except from selected terminals in the vicinity of the control room. The movement of data across the network to more powerful computers is becoming increasingly more common as the applications become more sophisticated and as the VAX 11/730 becomes more heavily used.

The VAX 11/730 system is configured to be fairly autonomous, containing most of the devices needed for independent operation. In addition to the networking already mentioned, there are almost six hundred megabytes of disk and a tri-density tape drive. Both monochrome and colour graphics terminals are available, two multi-pen color plotters, and a laser printer that supports graphics and text for low volume, high quality output.

An important addition is a Kinetics 2053 CAMAC interface that is capable of supporting both a CAMAC serial highway and a CAMAC parallel highway. The VAX 11/730 currently has a 12 crate serial highway system that provides access to many of the cyclotron operation and development areas, as shown in Fig. 2. This serial highway provides a CAMAC system independent from the CCS although many areas are serviced by both systems. An interesting and useful new development is the crossover of the VAX serial highway with a crate in the CCS. This crate has an L2 serial crate controller giving serial highway access. The parallel highway uses a new, auxillary crate controller that also functions as an A2 controller handling the parallel highway needs. The arbitration uses the auxillary control bus's ACL signal. This cross over of systems provides a very easy way to pass data from one system to the other. The serial highway which is run at five megahertz byte serial supports DMA in both block mode and list mode. This provides a faster data VAX transfer than through the parallel highway which does not have DMA transfers implemented.

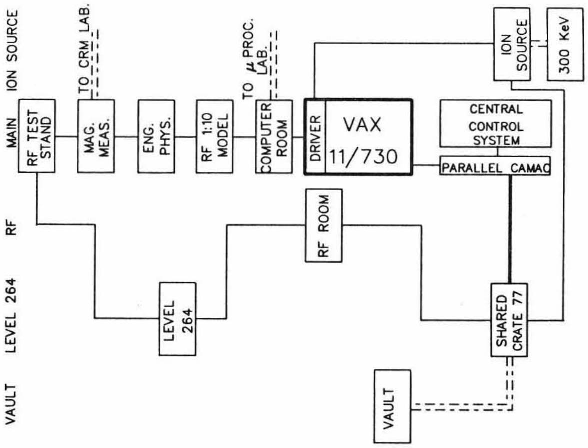

Fig. 2. The serial CAMAC highway system. The laboratory areas which are serviced by the serial highway are indicated. Crate 77 has shared access by both the CCS parallel highway and the VAX serial highway.

The Software Interface

When new additions in computer technology are made to an existing, mature system, perhaps of greater concern than the actual cost of the hardware is the difficulty and expense incurred in providing an adequate software interface to the existing equipment. This must be done with minimal interference to the operation of the existing system. For example, the existing CCS software is structured to respond quickly to LAM's and other random events. The structure has not been designed to support computers that do block transfers which tie up the entire CAMAC system and prevent other computers from timely handling of random events. Although the VAX 11/730 can be set up to do block transfers and this would be useful, such transfers would cause rather undesirable effects in the CCS computers. Access conflicts must be resolved, both among different users on the new computer hardware and between users of the new and original systems. These conflicts are resolved in hardware where possible, and care must be taken that no software "race" conditions or other bus tie-ups occur.

When designing the software interface for the VAX there were a number of considerations. The speed of the CAMAC call was important, especially since only programmed I/O calls were to be implemented. To prevent inadvertent modification of critical cyclotron parameters, it was felt that CAMAC write operations should be restricted in some fashion. There was also a feeling that to aid in preventing multiple user conflicts some type of CAMAC device reservation scheme was needed.

To address these features, a privileged shared image "GECSHR" was created^{3}). This image provides both IEEE standard calls (including cfsa and cdreg) and non standard subroutine calls. In addition optional subroutine calls at program initiation will permit CAMAC write operation only from a privileged set of terminals to ensure that inadvertent writes are not performed. Parameter reservation has been implemented. To meet the need of fast CAMAC calls in a programmed I/O environment, the procedure of using a formal software device driver with the VMS QIO call structure was not used. Instead, a simple approach was taken in which the I/O page is mapped during the CAMAC access. Thus, a user Fortran CAMAC call takes about 650 µs on a VAX 11/730 or about 220 µs on a microVAX II. The nonreentrant code is protected by disabling the interrupts during the CAMAC I/O which ensures that multiple user calls are correctly completed. The time deviation during which the interrupts are off is not a significant factor. All of the subroutine calls support DEC's common language interface so it is possible to use a variety of languages with these calls. Presently at TRIUMF there are Fortran, C and Assembler programs that use these CAMAC subroutines.

To provide as fast a CAMAC call as possible, a similar approach was implemented on the VAX 11/730 for the Kinetics serial highway. Although the cycle time is considerably longer at about 1500 µs, this is still much faster than the equivalent QIO call that takes almost 10 milli seconds on the VAX 11/730. Because of the independence of the serial highway from the CCS and the capability of both block mode and list mode transfers on the Kinetics driver, a formal device driver was sought. A superlative package was obtained from ORNL^{4}). This software fully supports all of the Kinetics hardware features and includes a system of assigning logical names to CAMAC geographical addressing. This package is a well documented and thorough public domain product.

To properly exploit the various CAMAC drivers, a number of software tools have been developed or obtained from other laboratories. The major component in the whole system is the VAX VMS operating system which although sometimes bulky and slow, provides an immense amount of utilities for tailoring and controlling the user environment.

Applications Software

Application routines using the VAX facilities described above are for the most part written by the cyclotron physicists and engineers who are involved in the commissioning of new diagnostics or tuning techniques. This effort has been greatly enhanced by the availability of an extremely powerful utility OPDATA^{5}), a user friendly interactive data analysis and graphics package. The data may be in the form of single value scalers such as the rf voltage, or one-dimensional arrays or vectors such as probe scans. This general purpose utility developed at TRIUMF allows the user to manipulate and plot machine data, either interactively or by means of a command file for repetetive analysis. A set of GPIB calls has been written to access and control devices on the CCS or the serial highway. Some application programs are described below.

Internal Beam Phase Profile

The internal beam phase history as a function of radius in the cyclotron is measured using a general probe data acquisition utility (PSU), and the data is analyzed and displayed using the OPDATA utility. A short pulse of beam (typically a few tens of µs) is injected into the machine, and the time to reach an internal probe is measured as the probe is moved. This time-of-flight vs radius information is processed by OPDATA to derive the energy gain per turn as a function of radius. Deviations of this function from the expected uniform energy gain are used to calculate the product $V*\cos(\phi)$. Fig. 3 shows a plot of the raw time-of-flight data, and the $V\cos(\phi)$ function. These curves are then used by operators to improve the machine isochronism.

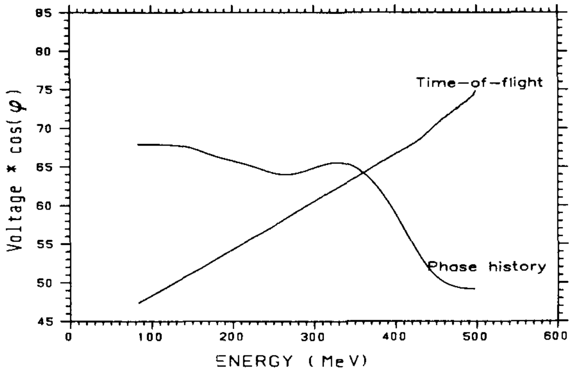

Fig. 3. Internal beam phase history extracted from time-of-flight measurements on an internal probe.

Emittance

An apparatus for measuring the emittance of ion source and injection line beams has been developed and tested at TRIUMF. Slit motor drives and deflection plate controls are interfaced to the VAX by means of the serial highway described above. Since the source is usually operated in a high voltage terminal, a fibre optic section of the serial highway is used to bridge the high voltage. Commercially available u-port modules are used to convert the byte parallel stream to bit serial on the optical fibre and vice versa. By

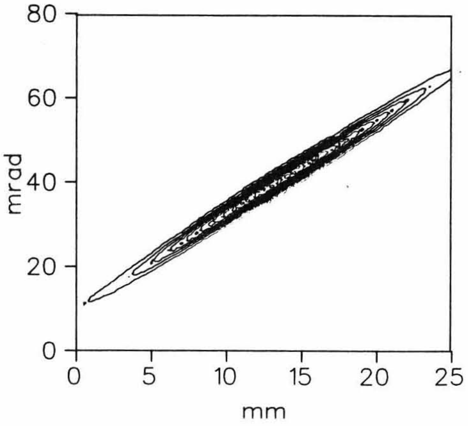

Fig. 4. CAMAC based emittance contours from the cusp ion source.

measuring the divergence of slit selected beams, a composite of the emittance is obtained. A contour plotting utility is used to produce contours of equal beam intensity in the x,x' and y,y' planes, as shown in Fig. 4.

Wire Scan

Vertical and horizontal profiles of the high energy beam are usually measured with harp scanners consisting of typically 16-32 wires with 3 mm spacing. Because of the coarseness of the harps, and because of variations in the collection efficiencies of the wires, a new scanning utility has been written, in which the beam is swept across selected wires in the harp by upstream bending magnets. The improved resolution of the scan is shown in in Fig. 5. To remove the dependence of steering magnet sensitivity on the profiles, calibrating procedures are built in. The system permits the measurement of beam profiles that are wider than the harp width.

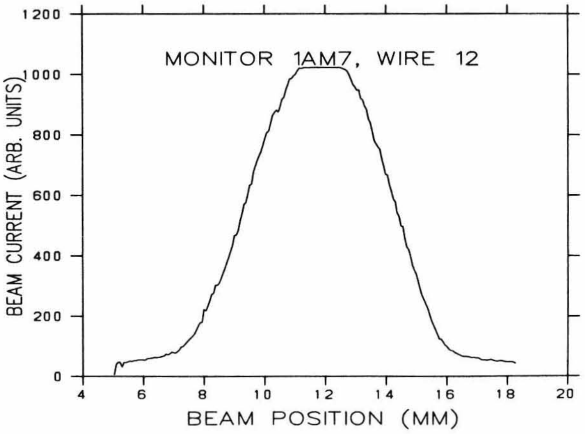

Fig. 5. Precise wire scan measurements obtained by scanning an upstream bending magnet across stationary wire monitors.

Network and Spectrum Analyzer Support

Laboratory and main machine measurements of rf cavities and components have been greatly simplified by the use of fft, network, and spectrum analyzers, all of which are equipped with the IEEE-488 bus. A GPIB-CAMAC translater module permits VAX access to this equipment in any location serviced by the serial CAMAC or the central parallel CAMAC highways. A set of low-level routines has been written from which specific data aquisition programs are built for each of these instruments. These programs are linked with device-independent graphics software developed by the Beam Development Group to provide the facilities for the storage, analysis and plotting of data from these instruments.

Present Limitations and Future Improvements

The user friendly environment of the VMS operating system, combined with a great deal of utilities has permitted the rapid development of applications programs. At present, user interaction is carried out by means of color graphics terminals. These have the advantage that they may be located conveniently throughout the laboratory. They do however lack the speed and versatility of modern display devices. To alleviate some of the speed requirements, a VAX workstation has been acquired for installation in the control room. A more general console, with superknobs, trackballs, etc awaits development. A more serious limitation in the present structure is the 730 processor speed. During periods of cyclotron development in particular, the computer throughput is impeded by heavy demand. Some of the cpu load can be shared by other processors in the Ethernet network. Another approach that has been initiated is to have the CAMAC data acquisition carried out by a "front end" processor, residing within the executive. Also being assessed is the potential of new hardware, such as VME-bus with embedded intelligence (68000 processors) to serve as the data acquisition layer). To increase the cpu speed, a more powerful VAX cpu is being considered as a replacement for the 730.

For general program development, the system described above lacks an efficient, maintainable database from which the programmer can extract the necessary information which will enable him to obtain any cyclotron data. The control database developed for the SLAC[6]) accelerator complex is being assessed as a model around which to build such a general database, to serve the requirements of beam physicists, rf engineers, safety personnel, as well as the machine operators and cyclotron physicists. Thus the database would contain information such as location and strength of magnets as well as DAC and ADC addressing information. Physical sizes and locations of new equipment installed in the cyclotron tank may be incorporated into the database.

In conclusion, effective advantage has been taken of commercially available hardware, and of the sophisticated VMS user interface, with a minimum maintainence load. A large pool of mature user software and utilities, particularly graphic aids have been exploited to aid in the solution of many real-time and semi off-line cyclotron physics problems. A natural extension in applying recent commercial developments is the area of artificial intelligence and expert systems.

Acknowledgements

The authors are grateful to the Electronics and Controls groups at TRIUMF for the help and discussions. Particular acknowledgements are due to Luc Durieu for his work in extending the control system.

References

1. D.P. Gurd, Proc. of 9th Int. Conf. on Cyclotrons and app'n, GAEN, 565 (1981).
2. L. Durieu, private communication (1985).
3. Y. Miles, private communication (1985).
4. E.T. Blair, private communication (1984).
5. C. Kost, private communication (1984).
6. SLAC Design Handbook, SLAC, Stanford University (1984).