UPDATE ON THE CENTRAL CONTROL SYSTEM OF TRIUMF'S 500 MeV CYCLOTRON

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Abstract

The Central Control System of TRIUMF's 500 MeV cyclotron was initially commissioned in the early 1970s. In 1987 a four year project to upgrade the control system was planned and commenced. By 1997 this upgrade was complete and the new system was operating with increased reliability, functionality and maintainability. Since 1997 an evolution of incremental change has existed. Functionality, reliability and maintainability have continued to improve. This paper provides an update on the present control system situation (2011) and possible future directions.

INTRODUCTION

The Central Control System (CCS) has been running almost continuously since 1974 when the first beam was extracted. Since those early days, and still ongoing, there has been a constant, incremental evolution of the CCS. These advances are punctuated periodically by more major changes. Even during major changes of the control system, which may occur during multi-month shutdown periods for the cyclotron, the scheduled off time for the CCS has been limited to durations of not more than a few days because many groups on site require CCS functionality even when beam is not being delivered. Instances of shutting down the CCS rarely occur now.

Evolution of the CCS has been shaped in part by constraints such as the need for availability and accommodating these constraints has presented interesting challenges. An example of this evolution is the emergence of two, symmetric, computer clusters, one for software development (and diagnostics) and one for production operation. The Development Cluster can provide all of the functionality of the Production Cluster. During a major, multi-month, site shutdown, disruptive upgrades such as that of the fibre channel storage system on the Production Cluster can proceed while the CCS software runs with full functionality in the Development Cluster. This is an important redundancy.

Almost all applications in the CCS use the X Window protocol to display their output. Two more clusters of computers (the Display Clusters) are dedicated for display purposes. Within the Display Clusters, 16 multi-headed workstations are used simply to receive output from the servers, display the X window on monitors, and allow keyboard and mouse input from the user. These workstations do not run applications.

During the life of the CCS, its computers have evolved from the initial 16 bit processors, through 32 bits to the present blend including multi-core, multi-processor 64 bit computers. Disk storage changed from the original fixed head devices, through removable cartridge styles, to multi-access DSSI drives, to early fibre channel, and now virtualized fibre channel is being installed. There was a time with no network, then the network started with collision-based 10 Mb/sec simplex thickwire, and moved through thinwire, to FDDI, to 10/100 Mb/sec switched Ethernet, and presently to the 1 Gb/sec configuration.

There are a number of general goals that most controls systems will strive to meet, characteristics such as reliable operation (low downtime), ease of new developments and maintenance, a high level of functionality, longevity while providing the required functionality, simplicity of use, and the like. The experience of TRIUMF's Cyclotron Controls Group is that to identify and understand the goals takes a cooperative approach with the end users, within the Controls Group itself, and with management. The end users are typically cyclotron sub-system groups (Vacuum, RF, Magnets, etc) and especially the Cyclotron Operations Group, but include a number of other groups such as Beam Development and ISAC Operations.

HARDWARE STRUCTURE

The present hardware configuration is a natural evolution from the initial design, which was destined to be very effective. This design employed CAMAC as a data acquisition and control bus with multiple, hardware arbitrated, computer connections (the GEC Elliott Executive crate). The configuration is referred to at TRIUMF as multiporting. This concept of multiporting continues to be a major characteristic and powerful advantage within the CCS architecture. Having multiple computers able to independently, efficiently, and (effectively) simultaneously have access to almost all CCS device channels, largely eliminates the need, overhead and complexity of passing commands and data between computers (IOCs and servers). The CCS does not have IOCs. There are only servers and these servers are capable of quickly accessing parameters across the breadth of the cyclotron from the ion source to the beam dump. This allows functionality such as quick, high level interlocks that otherwise would be difficult to provide.

CAMAC is a set of well defined, open, standards with many useful features such as a simple inter-crate bus system, interrupt handling, multiple topologies, locally arbitrated intelligence in a crate, etc. CAMAC is now seen by many people as an old technology (of approximately the same age as VME). At TRIUMF the CAMAC continues to function very well. The CCS's CAMAC was incrementally expanded to the present configuration, which has multiple, independent systems running in parallel, with each system capable of supporting up to seven parallel or serial branches. Each of these systems is capable of interfacing multiple computer connections, presently providing between three and eight computer connections.

The electronics in the CAMAC varies from the original (1970s), to the very recent (2011). Many of the new CAMAC modules (ADCs, DACs, etc.) are newer in fabrication, of a more recent design, of better function, higher resolution, and of better performance than our new PLCs, and at a lower cost per channel. Although design and fabrication of CAMAC electronics is easy by today's standards and witnessed by recent modules, industry support of CAMAC is in sharp decline.

Other data acquisition and control connections are also supported, including links such as Ethernet to PLCs, Ethernet to other processors, Ethernet to terminal servers (for serial ASCII), Ethernet to specific devices (such as an arbitrary waveform generator), Ethernet to web servers (such as a weather station), and VME.

PLCs are being increasingly used in the CCS because of their ease in interlock implementation, modularity, and widespread acceptance. There are still more than 10, old, microprocessor-based, local control and interlock systems that communicate with the CCS and are in need of replacement. Refurbishing each of these systems represents a significant amount of monetary, staff and time resources, all of which are in short supply. Projects such as replacing the main tank vacuum microprocessor system continue to be deferred. The original systems run with remarkable reliability, although two years ago a microprocessor failed and integrated circuit chips were found with chip leads corroded away.

The CCS network expansion has a variety of characteristics including aspects such as in the number of connections, in bandwidth and latency performance, in functionality, in complexity of management, in the resources required for maintenance and development, and in the resources required for security. To help address security, a security-in-depth (layered) approach is taken. This includes items such as firewalls, multiple VLANs, individualized computer security filtering, and monitoring. Diagnostic devices such as the Fluke OptiView Series III network probe has proven to be particularly useful in characterizing network activity and in diagnosing network problems (such as to identify multiple use of an IP address).

Hardware diagnostics have increased significantly, especially in specifically targeted areas. Each CAMAC crate is now equipped with a specially designed diagnostic module (60 in all), which is queried every six seconds to identify early signs of power supply issues, temperature issues (ambient and fan failure), and in the future other potential problems will be monitored.

The widespread expansion of Uninterruptible Power Systems (UPS) within the CCS has boosted reliability and uptime. Although various sub-systems suffer during power issues, normally the CCS now runs through these events and helps to identify and analyze the consequences. This is particularly helpful for Operations.

The main console has been tailored to work efficiently for the Operations Group. Approximately 35 dedicated CCS monitors of varying sizes from 18 to 42 inch are driven by two clusters of multi-headed workstations. Twelve of the workstations are in the main console.

In addition to workstations, the console still provides knobs, buttons, and analogue meters to enhance the tuning ergonomics. These devices come in both dedicated and assignable instances and the underlying software support provides a number of enhanced features such as configurable beam current run-up characteristics to take a beam-off situation to the desired beam current.

SOFTWARE (DEVELOPMENT & PRODUCTION) ENVIRONMENTS AND FRAMEWORK

The Central Control System software was first created (early 1970s) using the recently developed NATS (Nova Asynchronous Tasking Supervisor) realtime operating system. The control system software was written in assembler and distributed across a number of Data General Nova computers. These Nova computers ran, with daily reboots due to application bugs, for many years until the completion of an upgrade project that was initiated in 1987. The choice was made to move to Digital Equipment Corporation VAX computers running the VMS (also called OpenVMS) operating system but to maintain the data acquisition hardware infrastructure, which was predicated on CAMAC. Due to the constraints of the upgrade, the conversion was not completed until December 1996. Although the Cyclotron Controls Group also supports Linux, Microsoft Windows, and Solaris, VMS is the operating system underlying the cyclotron's production software. VMS runs efficiently and reliably. As the computer hardware evolved from 32 bit VAXes to 64 bit Alphas and then Itaniums, the necessity arose to simultaneously support applications and software infrastructure on multiple hardware architectures. The OpenVMS development and runtime environments make this issue straightforward. There is only one code base for the CCS and users are unaware of the hardware they are running on. Now, only Alphas and Itaniums are supported but adding another architecture should be simple.

Programming, debugging and software testing is done on the Development Cluster. When the software is deemed to be running correctly it is moved to the Production Cluster for deployment.

A master Oracle database is used to maintain device and acquisition information. From the master database a single, static, runtime database with all necessary device and acquisition information is extracted and normally moved to each of the computers doing data acquisition and control. Configuration management is effectively eliminated because there is only one current configuration and normally all of the computers have it. A new version of the runtime database can be installed on the fly, without needing to reboot or stopping any applications that are running. Only newly started applications will dynamically link to the new version, thus multiple versions may simultaneously be active in each computer.

This flexibility allows new versions to be tested while the latest commissioned version continues to run.

OpenVMS, like Linux and Unix, employs the X Window protocol for display purposes. The vast majority of display processes use X Windows but web based applications are supported. Web based programs such as Oracle forms and a Safety System program for testing gamma and neutron monitors are frequently used.

The main Operations console hardware is tied into the CCS via interrupt driven CAMAC signals that go to the OpenVMS servers. Software detects device selection and parameter modification (such as an increment via button press) so that dedicated applications can quickly and appropriately adjust the accelerator equipment and the X window displays. Input via X windows is also available.

The CCS framework has mostly been developed in house but there are some commercial products such as the graph widgets and message bus infrastructure.

A communications link exists between the CCS and the Central Safety System (CSS). In the CCS a touch panel and associated monitor provide Operations and others an interface with the CSS. This system has 39 display pages. In addition, there are a number of other display pages showing CSS data, such as neutron monitor levels displayed as vectors, which change colour depending on their value as compared to the trip and warning levels.

A recent addition to the Cyclotron's control system is the implementation of EPICS for a part of the ion source and injection line's vacuum equipment. This work has been structured to follow the standard EPICS implementation as used in ISAC, a radioactive ion beam (RIB) facility at TRIUMF. The Cyclotron Controls Group has previously been involved in implementing and supporting EPICS on secondary beamlines for experimental facilities.

Access directly from an application in a server to production equipment connected to the CAMAC takes approximately twenty microseconds (depending on computer, command, and location of the equipment). The hardware component varies between three and eleven microseconds (with an average of five uS). A new hardware interface, which is in design, should lower the access times in both hardware and software. The effective bandwidth is also increased because there are multiple CAMAC systems and computers running in parallel.

Graphical displays in the Main Control Room that are generated from CCS applications can be roughly placed into one of two categories, displays that run continuously in a specific location for all operational shifts (the vast majority), and displays that change from shift to shift and are started and used dynamically as the need arises. Many LCD monitors have multiple application displays of the first category running on them. All of these applications normally run on just one server and if a full startup is requested, approximately 180 applications (and displays) are created during the startup period. A full startup has been slowed down (to about five minutes) to provide programmed delays for sequencing the window startups. The displays are positioned and sized to nicely tile the monitors' screens. If the Controls Group wants to shutdown the active display server, with one command executed on another server all of the applications/displays can be started and run simultaneously to those on the first server. The previously existing displays will be covered over by a new copy of the application's output and the first server can be shut off without Ops losing any displays. The configuration of displays is handled by Ops.

APPLICATIONS

The CCS has five primary applications that play major roles in cyclotron operation: XTpages, Xstrip, Histograms, Scans, and Elog. The key application is called XTpage (originally for X window Terminal Pages). This is more a framework with a common user interface for what is currently 325 display pages. Each display page is an application on its own. Emittance scans, target scans, control of probes, individual device control, loading injection line tunes, viewing and controlling sub-system parameters, bypassing PLC interlocks, control system diagnostics, and many other activities are interfaced via XTpages. In addition, each page has a user customizable help page. XTpages follows the CCS colour rules and provides a standardized user interface.

Xstrip is a heavily used strip chart tool. On each instance, the user can retrieve up to ten years worth of logged data on up to twenty parameters and plot the data. The tool will let the user then go into active mode and append current data in realtime at up to 20 hertz. Xstrip has received, and continues to receive, a significant amount of ongoing development to add features. Many users and especially Operations have contributed to its characteristics and success. By right clicking on an active parameter on an XTpage, you can start an Xstrip application, automatically retrieve/plot that parameter's logged data, and then start gathering active data.

The Histograms are a family of vector plot applications. Plothist, Plotcross, Complex Plot, etc will allow users to represent parameters as vectors in realtime.

The Scans is a server based package of event handling software that loads pre-defined scripts and then runs in realtime. There are two basic forms, event handling that provides messages only, and event handling that provides messages and device interlocking. Because of the CCS architecture, the Scans can quickly read parameters across the breadth of the CCS, draw conclusions and take actions. The Scans are modelled on PLC operation but provide the power and flexibility expected in a server.

The Elog is a web based, database backed, electronic log application. Other CCS applications have been modified to support saving graphical displays for inclusion in the Elog.

NEW/INCREASED FUNCTIONALITY

Only a few of the developments since the last Status Report [1] will be mentioned here. The targets in RIB facilities are important and need stable incident beams. Because beam over current and position errors may cause machine protection issues, beam trips are periodically initiated. To enhance beam stability, beam current (amplitude) feedback, and beam position feedback loops have been implemented [2]. The feedback loops have significantly reduced these trips. In addition, a procedure referred to as “soft trips” is now used [2], which allows the beam current to be quickly and iteratively reduced to avoid the trip situation as opposed to just turning the beam off. This “soft trip” is much easier on the targets, and probably other equipment such as extraction foils. In another ISAC related development, an application was setup to rotate the proton beam in a circle on the RIB target to assist in beam and target development.

There have been a variety of enhancements to existing applications (XTpage, Xstrip, Scans, and Histograms). In the cases of emittance and target scans, isolated applications were incorporated into XTpages. Online diagnostics have been enhanced. One major step forward, as described earlier, was the deployment of a specially designed diagnostic module and initial software support. In what is an ongoing project, the Oracle X window based forms are being replaced by web based forms.

RELIABILITY, PERFORMANCE, MAINTAINABILITY

The Central Control System runs reliably. Figure 1 shows that since the upgrade was started in 1987, the control system downtime has been decreasing to the point now where it varies according to the (small) number of hardware failures. Equipment is normally spared at an appropriate level, which helps maintainability. And most failures can be analyzed rather quickly with the aid of improved diagnostics. Online diagnostics and daily checks often show problems before downtime occurs.

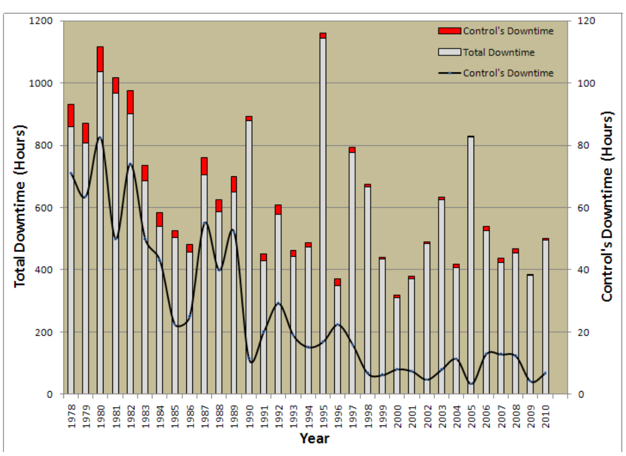

Figure 1: Cyclotron Total and CCS Downtime.

Reliability, performance and maintainability have all benefited from new designs and new electronics. New DACs and ADCs have been deployed in the last few years and new digital I/O is being prepared.

PROJECTS DONE, PROJECTS TO DO

The Cyclotron Controls Group inherited responsibility for the hardware of more than twenty old microprocessors. Some of these systems are obsolete and do not need replacement. Two systems, the Solid Target Facility and Beamline 2C’s vacuum system were each replaced by a PLC. There are still more than ten microprocessors, involving major systems such as the main tank vacuum and ISAC target protection, which need to be replaced. The scope of this work is daunting.

A large project involving a major upgrade of the vertical section of the ion source and injection system was recently completed. Control of the vacuum component of this work was done using a PLC and EPICS.

FUTURE

The future will continue to bring the incremental changes as seen in the past. Changes to the fibre channel storage arrays are now underway. The site network is almost always being upgraded, with significant redundancy plans established. Enhanced Scans are also underway. These changes will provide better efficiency, clarity, and flexibility. Upgrades of the microprocessor systems will occur but firm plans are still to be made, although almost certainly PLCs will be used.

SUMMARY

In summary, the Central Control System is running well, providing good functionality, performance, and reliability, while remaining efficient to support. Many of the lessons learned must be viewed knowing that TRIUMF is a lightly funded facility relative to many similar sites. The CCS has done well to stay with technologies that are reliable and that have an evolutionary path. The VMS, CAMAC and multi-access disk storage systems are good examples. The effort to recognize and remove less reliable/harder to support technologies has been rewarded. Investing in diagnostics and tools to detect problems early on before downtime occurs or more serious consequences follow, has been worth the effort. The perspective of taking ownership of the core infrastructure, to maintain adequate spares, and to follow the philosophy of don’t change for change’s sake, change to gain something, has worked well.

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