ARIEL CONTROL SYSTEM AT TRIUMF - STATUS UPDATE

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Abstract

The Advanced Rare Isotope & Electron Linac (ARIEL) facility at TRIUMF has now reached completion of the first phase of construction; the Electron Linac. A commissioning control system has been built and used to commission the electron gun and two stages of SRF acceleration. Numerous controls subsystems have been deployed including beamlines, vacuum systems, beamline diagnostics, machine protect system interfaces, LLRF, HPRF, and cryogenics. This paper describes some of the challenges and solutions that were encountered, and describes the scope of the project to date. An evaluation of some techniques that had been proposed and described at ICALEPCS 2013 are included.

SCOPE OF CONTROL SYSTEM

The e-Linac was to include a total of 3 stages consisting of 2 cavities per stage except for the first stage, which has only one, of Superconducting Radio Frequency (SRF) acceleration. The performance of the installed cavities has allowed postponing the third cryomodule. With the installation of the third cavity greater than 30MeV will be achievable. The second accelerator stage is planned for upgrade to 20MeV acceleration in one year from this writing. Deployment of the control system has been performed in subsystems, with the intention to isolate interaction between the subsystems, as well as to dedicate personnel to the various subsystems. Different broad control system technologies are used in each subsystem, and this allows personnel to focus on smaller classes of methodologies.

Numeric Facts and Figures

Devices under control	1160
Discrete IO Points	11155
EPICS IOCs	22
IOC Hosts	16
EPICS Device Support types	24

Figure 1: Scale of the control system at this writing

DEPLOYMENT STRATEGIES

A stated goal of the e-Linac control system was to re-use as much existing design and methodology as possible. The TRIUMF Controls Group has a significant body of work and methodology that was built up from prior projects. This includes a system of tools to build EPICS runtime databases, EPICS Operator Interface (OPI) screens, consistency checking in PLC interlock programming, and development of a consistent look and feel of control room consoles.

Part of the technology deployed in earlier TRIUMF control systems was based on consistent device styles chosen by other groups, especially vacuum, power supplies, and beam diagnostics groups. Despite the intent to develop no new methods and technologies, the style of control system interfaces used by equipment specialists from other disciplines did not accommodate the controls group strategy, and considerable re-work of existing methods was required. This paper will focus on some details of methods not previously included in control systems deployed at TRIUMF.

CONTROLS SUBSYSTEMS

Vacuum Systems

A new strategy for interface to vacuum systems was required when the vacuum group chose to introduce the concept of portable pumping carts. In this system, a small number portable carts containing turbo pumps, backing pumps, vacuum gauges and related valves was fabricated. These carts are arranged to pump down vacuum spaces at 26 discrete locations along the beamlines, according to stages of commissioning and following maintenance procedures requiring vacuum breakage.

Each turbo pumping cart is equipped with a small PLC drop that contains sufficient Input/Output support to drive and read the vacuum devices contained on the cart. A central vacuum controls PLC provides the program logic and EPICS interface for supervisory control and display. Asynchronous connection and disconnection of the central PLC is successfully accomplished by exploiting the ability of the Schneider[1] Quantum PLC to perform IO scans. IO scanning allows the PLC program to detect connect events and disconnect events seamlessly, and to map IO registers to beamline location-specific process variables.

The PLC reads dedicated loopback cables at each pumping cart and connection port, in order to permit the location of each connected cart to be tracked. This information is used to allow OPI displays to reflect the connection status of each cart and each beamline connection port in real time.

The ability to seamlessly connect and disconnect field IO at runtime has resulted in estimated saving of CDN $28000 in PLC hardware by removing the need for redundant dedicated PLC IO hardware. In addition, the reduction in cabling, estimated at 10000 metres, served to relieve the constraint of cable routing space availability to the Electron Hall where the accelerator and beamlines are

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located. This strategy is now considered a significant success.

Cryogenics Systems

The SRF accelerator modules rely on the use of liquid helium cryogenics, and sub-atmospheric pumping to establish operation at 2 degrees Kelvin of the accelerating cavities. To accomplish this, a hybrid of commercial and in-house cryogenics system has been developed. Initially, the strategy was to model the prior work in the TRIUMF ISAC-II facility. In this arrangement, a commercial turnkey helium liquefaction plant would be augmented by an in-house cold-distribution system. Air Liquide Advanced Technologies[2] (ALAT) was chosen as the vendor of the helium liquefaction system (cold box). An interface to TRIUMF equipment and signalling was defined, allowing some aspects vital to operation of the cold box, to be provided and installed by TRIUMF, and signals provided to the ALAT PLC.

The cold delivery system and sub-atmospheric pumping system are composed of various valves, pressure, temperature and pressure monitors, as well as four Busch[3] (model here) mechanical pumps. These are controlled by one Schneider Quantum PLC with IO drops at three different geographic locations.

The convention used to deploy control systems heretofore by TRIUMF controls has been a strictly device oriented system. In this arrangement, there is little coupling of device control, except in ways that are well defined where devices provide status information that is used in machine protection interlocks. Automation of processes has been implemented in only very limited ways.

As a departure from this, there is a requirement to provide some level of autonomous behaviour. The intention is to remove or reduce the need for human operator interaction with the cryogenics system, as well as to improve system performance by exploiting the faster response time capability of a PLC. This level of automation is expected to be accomplished as a new layer of logic, which can be used independently of the machine protection and remote control role of the control system. Strategically, this is intended to allow a segmented roll-out and commissioning of the automation portion of the control system. Experts from the Cryogenics Group are collaborating closely with the Controls Group to define what form this will take.

Initially, there was a clear intention to use the ALAT cold box as a turnkey-only package. Due to the dedication and expertise of one PLC expert in the Controls Group, some modifications to the delivered system have been identified and proposed. These include improvements to the way the ALAT system interfaces to two Kaiser Helium compressors, and segmentation of some PLC controls to reflect geographic separation and functional relationships between elements of the ALAT cold box. These enhancements will also facilitate the aforementioned automation efforts, and the interface to the supervisory EPICS controls.

Beam Optics Systems

Beam optics in the e-Linac uses conventional electromagnets for steering and focusing the electron beam. The control system, then, is responsible for control of power supplies. As a departure from prior work at TRIUMF, the magnet power supplies used in the e-Linac are mostly equipped with built-in Ethernet LAN interfaces, and support a SCPI style of command and query language.

These power supplies are controlled directly from EPICS IOCs, using the combination of EPICS asyn and streamDevice support packages. The system of EPICS records used to control power supplies through analog and digital interfaces was duplicated, using the streamDevice over asynDriver/TCP EPICS devices support. This was successful in creating user interfaces and behaviours that closely resembled prior implementations. In addition to the LAN/SCPI interfaces, three power supplies were purchased from BiRa[4] Systems. These are conventional off-the-shelf power supplies that are augmented with a closed loop stability controls system, and are driven by a proprietary EPICS device support layer.

Monitoring of power supply parameters requires continuous polling, which introduces high volumes of network traffic. In order to isolate the effect of the beam optics traffic from the rest of the control system network, dedicated EPICS IOCs with dual Ethernet interfaces were used to control the power supplies. The strategy is to use one Ethernet LAN as a field bus for the power supplies, while the other network interface provides a conventional TCP/IP interface to the IOC host, including the EPICS Channel Access protocol traffic.

For reasons of economics, the power supplies chosen were of a unipolar nature, even though most beamline requirements dictated bipolar operation in order to support magnet degaussing. In-house polarity switches were built, and these are controlled by the EPICS IOCs using VME based digital IO to drive and monitor the state of the polarity switches. EPICS record logic to support these polarity switches has been successfully implemented.

Beam Diagnostics Systems

Several classes of beam diagnostics devices not previously implemented in a TRIUMF control system have been introduced. These include a Fast Wire Scanner (FWS), several viewscreen systems allowing beam physicists to visualize the electron beam, and a non-intercepting RF-Shield used to measure beam current in real time, and in-house designed and fabricated Beam Position Monitors (BPMs).

As well as new device types, the convention previously used to control stepping motors has been changed from the now obsolete Oregon Micro Systems (OMS) VME based motor controllers to Galil[5] controllers. In a previous endeavour at TRIUMF, crafting device support code to augment the EPICS Motor Record interface to the

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Galil controllers was found to be unsuccessful by. New motion control for beam diagnostics devices uses streamDevice EPICS support to communicate with the Galil motor controller on a dedicated Ethernet LAN. Control system logic mimicking the function of the EPICS Motor Record was developed, in order to maximize compatibility with prior work, and with a view to later successful implementation of motor record code to support the Galil controller.

There exists in certain instances, the possibility of moving beam diagnostics devices to collide in space within the beamline. A dedicated Schneider PLC has been implemented with the sole purpose of redundant protection against such collisions.

Viewscreens using the EPICS asyn-based Area Detector package were created by a University based partner, and provided to TRIUMF as turnkey packages. These use the same Galil model motor controllers as other beam diagnostics devices. The original delivery provided EPICS IOC hosts that were configured with Ubuntu Linux, and booted from spinning magnetic media. The operating system and filesystem structure for these has been replaced with the diskless booting system that is now a standard in EPICS based controls at TRIUMFBeam Position Monitors (BPMs) were developed by the Beam Diagnostics group, in collaboration with the Controls Group. Communication with the BPMs is via TCP/IP using EPICS streamDevice to write commands and read query replies.

RF Controls

Low Level RF (LLRF) controls are produced by the LLRF Group at TRIUMF. This permits a system of fast feedback control of the LLRF system, while interfacing to the e-Linac EPICS control system on a supervisory basis. For the e-Linac Control System, a new EPICS interface was developed by the LLRF Group, enabling the use of conventional streamDevice interfacing, and replacing a legacy system that had become inconsistent with current practice.

The SRF cavities receive High Power RF (HPRF) energy from two Ampegon[6] Klystron power supplies. These are turnkey systems containing embedded Siemens[7] PLCs. The principle control system interface to HPRF equipment is via these embedded PLCs, using an in-house EPICS device support package.

HOST SYSTEMS AND NETWORKING

A small variety of EPICS IOC host types have been deployed in the e-Linac Control System. VME based IOCs are used where direct hardware interfaces are required. This strategy is inherited from prior work. Other alternatives were contemplated briefly, however there were too many elements that either required VME, such as the Machine Protect System Long Ion Chamber detector interfaces from Thomas Jefferson Laboratory, or would require replacement of in-house designs that had already been done for the VME form factor.

Other EPICS IOC hosting has been implemented using small form factor commodity PCs equipped with Intel Atom processors and dual ethernet interfaces. Because of the heavy use of EPICS streamDevice over Ethernet TCP/IP, commodity off-the-shelf hosts are deemed suitable, as long as they are capable of running Linux as an Operating System. These are also used to communicate with PLCs, both in-house programmed Schneider PLCs, as well as Siemens PLCs that are embedded in the turnkey cryogenics system as well as two turnkey high power Ampegon Klystron power supplies

Dell server class x86 computers are used as fileservers to host all EPICS binaries, runtime databases, configuration files, and to store user data. These are running Debian Linux, which has been adopted as the standard for fileserver and development host applications in the TRIUMF Controls Group.

The front-end IOC hosts use a version of Linux that was tailored in-house for use in EPICS IOC hosts. The OS is booted over the network using the industry standard PXE protocol. Both the Linux kernel and a customized RAM based root filesystem are downloaded from TFTP servers are boot time, and the hosts run disklessly, mounting fileserver NFS shares for non-volatile storage. The custom root filesystem inherits startup arguments from the PXE configuration file, so that specific applications can be centrally assigned to specific hosts.

This system has been updated with some new features since it was reported in ICALEPCS 2011[8]. In addition to scripting that uses kernel arguments to launch specified applications, a system of host-specific (in contrast to application-specific, since multiple EPICS IOC applications can run on a single host) configuration procedures can be launched from the central boot host. This is used for such things as installing iptables based firewall rules that allow the host to provide transparent access to PLCs on the fieldbus network interface, and to launch DHCP servers for many of the controlled devices that use TCP/IP Ethernet interfaces. In addition, a system of shared applications that were chosen not to be included in the RAM based root filesystem can be accessed at runtime for test and diagnostics purposes.

A control room dedicated to the e-Linac has been established, using conventional deskptop computers, and running the Debian version 6 Linux, and the KDE desktop framework. A total of five console computers arranged with four monitor and six monitor video configurations is serving the purpose of e-Linac commissioning, and is expected become part of a TRIUMF-wide integrated control room following completion of the ARIEL facility.

Network Structure

The network architecture used in the e-Linac controls system provides for two tiers of Ethenet TCP/IP networks. One is the general purpose Control System network which carries EPICS Channel Access traffic and other TCP/IP traffic such as NFS and SSH communications between the IOC hosts control room consoles, control

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system user hosts, and fileservers. The other tier is a system field bus oriented networks which are isolated behind IOC hosts. These carry traffic that is only related to the devices under control of the EPICS IOCs. Individual IOC hosts use their respective fieldbus networks to send and receive data between the IOC and each of the devices under control. This strategy is intended to keep overall traffic levels on the principle network low, as well as to allow isolation of any device which may become faulty and disruptive to other control system elements. In addition, it allows conservation of network IP addresses, since the field bus networks are assigned private LAN addresses from the 192.168.0.0 class.

Beyond the standard two tiers of ethernet networks, the PLCs in use in the e-Linac Control System use their own private ethernet networks. These PLC networks carry only Modbus and QEIO traffic between PLCs and their IO drops, and further segment the overall network infrastructure.

The use of a highly segmented network topology, coupled with fully functioning Linux computers as IOC hosts allows easy network diagnostics, configuration and monitoring of network traffic. Colour coding of ethernet cabling for the respective tiers promotes easier understanding of network connection and topology in the field.

CONTROLS GROUP ECOSYSTEM

In prior control system projects at TRIUMF, a system of tools and methodologies has been developed to allow for high productivity, consistent product output, and low error rates in control system production and deployment. The tools used to perform these tasks include numerous in-house scripts, libraries, and databases, and tools. These are used to generate EPICS OPI screens, EPICS runtime databases, and to generate much of the configuration data that is used in running EPICS IOCs.

Base 3.14.12.3
Alarm Handler
EDM
StripTool
Gateway
TRAR (TRIUMF Archiver)
TDCT (TRIUMF Database Configuration Tool)

Figure 2: EPICS Components.

These tools have been relied upon in roll-out of the e-Linac control system, and have been augmented in a few ways. A web-based application now generates DHCP server configuration files for all EPICS IOCs that use TCP/IP communications with the devices that they control. This allows easy configuration and rollout of field bus oriented networks. EPICS synoptic screens for beam optics and diagnostics devices are now produced by scripts, and configured through the web application and related database. This simplifies on step of producing these screens, which are dense in content, and have many details that are difficult and time consuming to produce interactively.The e-Linac Control System uses the EPICS components listed in Figure 2.

CONCLUSION

Interfacing with turnkey systems continues to be difficult in some cases. Extremely careful and detailed planning of all aspects of the vendor interface is required for a seamless integration. Much more time is required to perform integration work than is required for basic rollout of an EPICS + PLC slow controls system.

Consistent use of methodologies and tools speed deployment and produces a more consistent control system product. Building tools to produce control system software components takes up-front effort, but pays off quickly through efficiency gains and product quality improvement.

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