LANSCE CONTROL SYSTEM FRONT-END AND INFRASTRUCTURE HARDWARE UPGRADES

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Abstract

The Los Alamos Neutron Science Center (LANSCE) linear accelerator drives user facilities for isotope production, proton radiography, ultra-cold neutrons, weapons neutron research and various sciences using neutron scattering. The LANSCE Control System which is in part more than 40 years old provides control and data monitoring for most devices in the linac and for some of its associated experimental-area beam lines.

In Fiscal Year 2011, the control system went through an upgrade process that affected different areas of the LANSCE Control System. We improved our network infrastructure and we converted part of our front-end control system hardware to Allen Bradley ControlsLogix 5000 and National Instruments Compact RIO programmable automation controller (PAC). In this paper, we will discuss what we have done, what we have learned about upgrading the existing control system and how this will affect our future plans.

BACKGROUND

LANSCE is the proposed site for Los Alamos National Laboratory's (LANL) future signature facility Matter-Radiation Interactions in Extremes (MaRIE). This experimental facility will be the first in a proposed new generation of scientific facilities for the materials community to meet 21st century national security and energy security challenges [1].

Currently different efforts are under way to prepare the facility for its future mission. One effort is based on the LANSCE Linac-Risk Mitigation (LL-RM) project that focuses on risk mitigation of programmatic equipment — components and equipment directly related to the acceleration of the particle beam. Other efforts are focused on parts of the facility that are not directly related to the acceleration of the particle beam.

Despite these different efforts that are mostly driven by different funding sources, there is an overarching strategy for the instrumentation and controls system:

- Replacement of obsolete Controls Hardware
- Installation of new Timing System (in 2013)
- Improvement of Controls Infrastructure

The scope of the work ranges from integration of commercial-off-the-shelf components to complete substitution of obsolete and non-maintainable systems and equipment. For the most part, the projects are self-performed by LANL's Accelerator Operations and Technology - Instrumentation and Controls (AOT-IC) group, which provides maintenance and support of the injector, accelerator, beam transport, and target control system (CS) at the LANSCE User Facility (LUF).

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PROJECT EXECUTION CONSTRAINTS

To execute any scope of work, while maintaining 3000h/year beam operation requires the integration of the upgrade projects into the (LUF) operation schedule [2].

The LUF operates cyclically. It typically operates for several months a year to meet commitments to programmatic customers. Run cycles are interspersed with intra-cycle maintenance breaks of a few days to a week for the purpose of recycling the H- ion source and conducting emergent or time-sensitive maintenance. Run cycles are followed by months-long outage; during which scheduled and more extensive maintenance is conducted.

The LANSCE Control System (LCS) which is based on the Experimental Physics and Industrial Control System (EPICS) is critical to operations. Even during intra-cycle maintenance breaks the CS is often needed. Any major upgrade or modification needs to be addressed during the months-long outages. Traditionally this annual outage starts in January and ends in April. During the four month outage in 2011 AOT-IC executed several major projects:

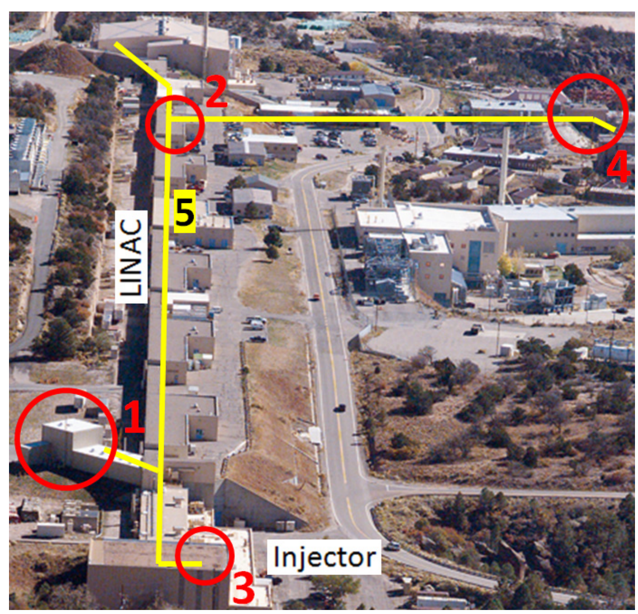

Figure 1: LANSCE User Facility.

1. Isotope Production Facility: Proprietary Control System changed over to an Allen Bradley based Control System
2. LINAC – Sector H: One module of the original "RICE" (Remote Instrumentation and Control Equipment) system was changed over to a National

Instruments cRIO based Control System at the end of the 800MeV Linac
3. PSR – Mechanical Equipment Building: Two CAMAC crates were changed over to a National Instrument cRIO based Control System.
4. H- Injector: CAMAC changed over to an Allen Bradley based Control System
5. Network: Installation of a Fiber Optics back bone communication infrastructure that connects the major areas of the LANSCE Accelerator Facility

These projects will be discussed in turn blow.

ISOTOPE PRODUCTION FACILITY

The Isotope Production Facility (IPF) which produces medical isotopes is part of the LUF. The original IPF Target CS was a stand alone system utilizing non-LCS standardized controls software and hardware components. Due to the fact that the CS was designed, installed and maintained by a non LANL, out of state contractor any maintenance or repair event was time consuming and costly. As a result, IPF management decided to replace the proprietary IPF CS with LCS standardized technology.

The stringent IPF production schedule, as well as the pre and post production requirements, limited the CS upgrade work to 2 1/2 weeks. This included time to take the old CS hardware out, to install the new one, and to test and commission the CS system. In order to accomplish such a daunting task the controls team had to prepare and optimize their approach.

In a process which started 3 months before the actual upgrade work, the old CS was examined during the inter-cycle maintenance breaks. In combination with old CS requirements documentation the system was re-engineered and a suite of process control charts that reflected the operational behavior were developed. These process control charts went through a rigorous review process where operators and expert users verified and validated the new design documentation with requirements and their experience of the old CS. Furthermore, a full CS prototype was developed and tested prior to installation.

For this application an Allen Bradley (AB) ControlLogix 5000 PLC was chosen since the previous system was a PLC as well, though from a different brand. An "EtherIP" driver/device support module interfaces to the AB ControlLogix 5000 PLCs via Ethernet to EPICS IOCs under EPICS R3.13 or R3.14. The software driver (EtherIP) is available through the EPICS collaboration [3].

To accommodate the required Input/Ouput (I/O) points we installed two PLC chassis in the Master-Slave configuration. This saved the project one controller module on the slave side. The Master chassis hosts the AB 1756-L61 ControlLogix 2MB 5561 Processor with an onboard flash memory card that holds the ladder logic program for cases when the internal memory could lose its process application. That same chassis holds all Analog I/O modules of types Spectrum Controls 1756sc-IF8u and AB 1756-OF8. The slave hosts all digital modules of type AB 1756-IB32 and AB 1756-OW16I. The AB's 1756-ENBT ControlLogix EtherNet/IP Module serves as interface between the AB control chassis as well as interface between the EPICS IOC and the AB Master P

The installation and commissioning were successful. However, despite many design reviews, a prototype, and our best effort, some of the requirements surfaced just after the system was installed.

LINAC – SECTOR H

The CS for the 201.25 MHz and 805 MHz linac is based on RICE (Remote Instrumentation and Control Equipment) which was installed in the early 1970's when the facility was built. With more than thirty year old technology come many problems. Many of the discrete components in RICE electronics can no longer be purchased, supplies of spares are dwindling and plastic connectors are becoming brittle. Calibration capabilities were not built-in, raising questions about year-to-year comparability of settings. Lack of any vendor support means all maintenance and repair must be done in-house. Non-standard electronics means all in-house maintenance people must receive extensive RICE-specific training on technology that was installed 40 years ago. The current architecture and implementation is shown below [4].

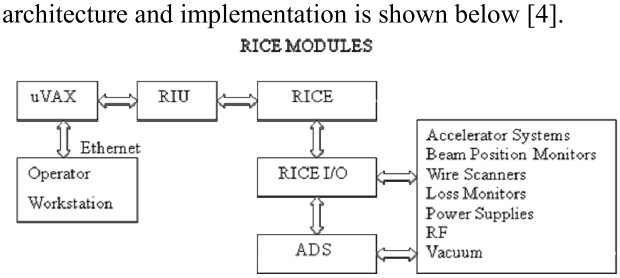

Figure 2: Block Diagram of the RICE System.

RICE controls can be divided into two main categories.

- Industrial Controls: Consists of command and readback of two-state devices, along set-point generation and analog readback of devices.
- Timed-and-Flavored Data: Consists of data taken with a specific relationship to the beam-type (flavor) and timing.

As part of the LL-RM project, a design has been developed to replace the Industrial Controls of the RICE system. The major component of this system are Programmable Automated Controllers (PACs) built by National Instruments. The controller is called CompactRIO (cRIO) and is a reconfigurable control and acquisition system. – An architecture already supported by EPICS [5].

The controller is a cRIO–9024 a Real-Time Controller: 800MHz, 512MB DRAM, and 4GB of Storage. The removable cRIO controller sits in an NI cRIO-9118 chassis with additional 8-slots, Virtex-5 LX110 reconfigurable chassis. The most noticeable advantage is its high performance and reliability, high performance FPGA, and hot swappable modules. For our application the cRIO is hosted in a commercial BiRIO rack mount chassis which interfaces to commercial BiRIO interface boards that in turn provides interfaces to the device field wiring. This configuration promises in many cases a simple chassis swap during 24-7, on-call operations support while the diagnostic and repair would occur in the electronics laboratory setting.

Figure 3: cRIO in BIRO chassis.

For our analog signals we use the NI cRIO-9205, 16-Bit Analog Input module. The NI cRIO-9474 Digital Output Module is used to create 5 V, 50us wide pulses for stepper motors. For our digital signals we use the NI cRIO-9425 Input Module and the NI cRIO-9477 Digital Output module. A block diagram of the new system is shown below:

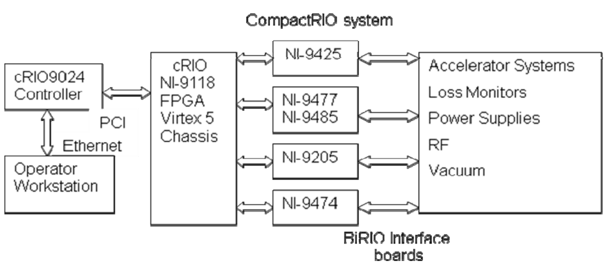

Figure 4: Block Diagram of the cRIO System.

While the controls replacement work was a success the new control wiring needs improvement. Since we replaced only the Industrial Controls I/O of the Rice system the rewiring of the intermixed signals created an eye sour. For the future, any controls rewiring will be done for both the time flavored and industrial control data at the same time. This will minimize any rewiring of the time flavored system when it will be installed in 2013.

H- INJECTOR

The former H- injector CS was based on 1980's Computer Automated Measurement And Control, (CAMAC) technology. It is a modular data handling system and its primary application is data acquisition. Individual crates are controlled by slave or intelligent controllers. The controllers are tied together with a parallel Branch Highway that ends in a Branch Driver. The Branch Driver is interfaced directly to a data acquisition computer; in our case an EPICS VME IOC.

With technology that was installed in the 1980's comes a host of problems. Often the documentation for individual modules is unavailable, spare inventory is limited, many modules are not available anymore and repair of modules is difficult or impossible due to lack of suitable spare parts.

Modern Ethernet enabled data acquisition technology is capable of replacing the CAMAC functionality. Based on our positive experience with AB we did choose the rugged Control Logix5000 PLC for this job in which 80kV arc downs are part of the daily routine.

For this project we did install 2 AB PLC systems, one for the 670kV another for the 80kV section of the Injector. Despite the fact that these PLC were only about 6 feet apart from each other, due to the voltage difference and the required process control communication, a fiber optics network link between the PLCs had to be installed.

The information exchange was implemented through AB ControlLogix producer and consumer tags. Unfortunately, AB's PLC consumer tags do not recognize if the communication to the producer has failed. It just keeps the last know state. Since the communication link between the two PLCs is critical for Run Permit and interlocks, we installed a watch-dog timer that alerts the system and operator if the information link is broken.

The AB PLC is basically the same that we used for the IPF system upgrade with one exception. We introduced an AMCI 5274 High Speed Inspection Module that operates as a stand-alone module with continuous reporting of status information to the AB 1756 system. It can take analog samples at known points; defined by position, time, or digital input, and compare the measured values to a programmed profile and determine the pass/fail of the inspection. We used the AMCI module as a triggered ADC to read the pulsed signals that were previously read by a sample and hold chassis to measure two current monitor signals as well as the current signals of High Voltage and Arc Power Supply.

Unfortunately, operations of the AMCI modules within the arc prone environment caused the module to lock up. Attempts to improve the situation within the high voltage H- Injector Dome environment failed. Even with good vendor costumer support we were unable to find a solution to reset the module without having to reboot the whole PLC.

Since this was not practical solution to this problem we installed the PLC AMCI module in Injector Control Room and connected the signal to the AMCI through fiber optics cables. This solution has proven to be reliable even though it was not our preferred solution.

MECHANICAL EQUIPMENT BLDG

The Mechanical Equipment Building (MEB) hosts a variety of beam line control devices that help transport and diagnose the beam to the different experimental areas (1L and WNR). Part of the in 1980's installed CAMAC system was replaced by a NI cRIO system of the same type as used for the LINAC Sector-H. Leveraging the development and prototyping effort that was done for the LL-RM, project the controls team was able to replace 2 out of 4 CAMAC crates at minimal incremental cost.

For the maintenance outage in 2012 we do expect to replace the remaining two CAMAC systems freeing up more spares for other CAMAC systems still in use.

NETWORK UPGRADE

The communication network upgrade is the first LL-RM scope element that has been delivered. The new network is the foundation for most other system upgrades that will be installed over the next 5 years.

Since the early 1980's, our old LCS network has grown in a piece-by-piece fashion from no network at all to network in many areas. At its core it has a 100Megabit switch and some of the edge switches have only 10Megabit. In many cases we have unmanaged switches in place which makes maintenance, troubleshooting, and performance monitoring inefficient or impossible. Furthermore, the historically grown structure has little to do with modern network topologies. In fact it consists of a multi star configuration where one edge switch functions as a "core switch" for many other new edge switches. Many of these switches were connected via single or multi-mode fiber or CAT5 twisted pair cables.

Our new installed fiber optics network has 10 gigabit (Gb) capabilities at the core switches and 1 Gb at the edge switches. Near the Central Control Room (CCR) we installed five Nortel-5530 core switches. Each switch has 12x1Gb fiber optics ports, 24 x 1Gb twisted pair, and 2x10Gb fiber ports (Note: After installation we learned that 12 of the 1Gb fiber ports and 12 of the 1Gb twisted pair ports are using overlapping resources. The use of one fiber optics port reduces the availability of one twisted pair port.

The new communication network is a true star configuration. In total, 451 fiber optic strands all originating near the CCR were installed. Each of our 42 primary drop off locations has anywhere from 12 to 24 fiber strands. In total 12,800 feet of single mode fiber was installed throughout the accelerator facilities. At each primary drop off location either a Nortel-5510 or 5520 edge switch was installed. Both have 24x1Gigabit twisted pair ports and 2 or 4x1GBit fiber ports respectively. (Note: The Nortel-5520 switch has Power over Ethernet). Near these switches we ran between 12 to 48 CAT6A twisted pair patch cords to secondary drop off locations. These patch cables can be connected back to the edge switch as needed. Under this regime 21,000 feet CAT6A twisted pair cable was installed for this project.

Currently we are in the process of developing a centralized configuration and monitoring schema. The related work including the transition from the old to the new network will start during our next planned maintenance outage in 2012.

CONCLUSION

Commercial off-the-shelf hardware can replace purpose-built hardware with a customized I/O system that interfaces directly with modern standardized control software. RICE controls for two accelerator modules and, a few CAMAC crates in one beam line and injector have been successfully replaced with 8 cRIO Industrial I/O and Allen Bradley systems with more to follow.

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