CRYOGENICS CONTROLS IN THE ISAC-II SUPERCONDUCTING RF ACCELERATOR

R. Nussbaumer, D. Dale, T. Howland, H. Hui, R.Keitel, K. Langton, M. Leross, J. Richards, B. Shaw, E. Tikhomolov, TRIUMF, BC, Canada.

Abstract

The TRIUMF ISAC-II superconducting heavy ion linear accelerator is composed of eight cryomodules containing a total of 40 superconducting radio frequency cavities. This paper describes the control system for delivery of liquid Helium and liquid Nitrogen, and quench protection of accelerator components. We discuss integration of the ISAC EPICS-based control system with the control systems for two turn-key Helium refrigerators, details related to the delivery system and its interface to other accelerator elements. Anticipated and ongoing control system upgrades are described.

OVERVIEW

The last stage of the ISAC Radioactive Beam Facility at TRIUMF [1] consists of a heavy ion linear accelerator which uses superconducting technology (SCLINAC).The cryogenics system is used to provide cooling of radio frequency (RF) cavities and superconducting focusing solenoid magnets in the accelerator.

The first stage of the SCLINAC was built in 2004-2005 with five cryomodules each containing four RF cavities. A cryogenics system was installed to serve this accelerator stage. In 2007-2008, an additional refrigeration plant, identical to the original, was installed, in preparation for the second accelerator stage. At the time of this writing, three new cryomodules are being installed and commissioned, with an additional twenty cavities. Cooling for these cryomodules will be served from the combined capacity of the two refrigeration plants.

The ISAC facility at TRIUMF is controlled using an EPICS-based [2] control system. Seamless integration with the existing control system infrastructure is considered essential for operation of the cryogenics system.

PRINCIPAL COMPONENTS

Turn-key Liquid Helium Production Plant

Gaseous Helium is liquefied by two Linde Kryotechnik AG [3] refrigeration plants each comprised of a Model TCF50 refrigerator cold box, a main recycle compressor, an oil removal and gas management system, and a control system. A single recovery compressor is used. Up to 860 l/hr of liquid helium can be produced by each plant, exceeding original design specifications. The liquefied helium is stored in buffer dewars for delivery to the accelerator cryomodules.

Cold Distribution and Gaseous Helium Recovery System

The delivery infrastructure including piping, valves, pumps, and monitoring apparatus was supplied and installed by private contractors. These components are used to deliver liquid helium and liquid nitrogen to the accelerator components, and to return the warm and cold Helium back to the refrigeration plant.

Recovery and storage of Helium gas is performed when the refrigeration plant is shut down or in the event of emergency.

Vacuum spaces are used for thermal insulation purposes. These vacuum spaces are managed using standard vacuum controls employed in ISAC beamlines. The same standard PLC-based controls subsystem model performs control of the cold distribution system and helium recovery systems.

Related Devices

Purity of the helium returning to the refrigeration plant is monitored by a commercial online nitrogen analyzer. An interface to the EPICS-based ISAC control system is used to provide remote monitoring and control of the device.

An offline test stand uses liquid Helium from the ISAC-II refrigeration system, and extraction of the liquid helium is controlled via the ISAC standard control system. The test stand includes a commercial Throttling Butterfly Valve. Controls for this device are presently being developed, using EPICS.

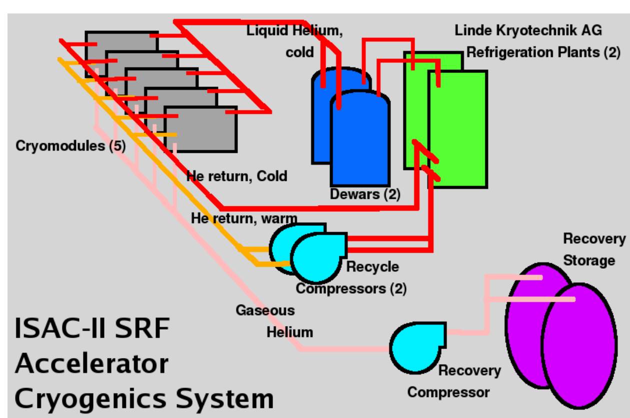

Figure 1: ISAC-II Cryogenics system block diagram. Liquid Nitrogen delivery not shown.

CONTROLS AND INTEGRATION

Turn-key Liquid Helium Production Plant

The refrigeration system supplied by Linde uses a proprietary control system based on a Siemens [4] S7-400 Series Programmable Logic Controller (PLC). The ISAC-II accelerator uses two such identical systems, and each is equipped with a MS-Windows hosted operator interface based on the Siemens Simatic software package. The standard refrigeration system also includes a touch-panel user interface that is mounted on the door of the cabinet that houses the PLC and related wiring and equipment.

The existing control system in the ISAC facility uses Schneider Electric Modicon [5] PLCs and the original intent was to leverage the experience and standardization within the ISAC Controls group by requesting a cryogenics control system based around Modicon PLCs. Although a quote was tendered for use of the Modicon PLC as requested, the high additional cost was not deemed acceptable.

The two refrigeration systems were supplied in stages approximately four years apart. Integration of the first delivered system with the ISAC Control system was performed through a small set of prescribed hardwired contacts, which permitted basic control functions to be initiated through an ISAC-II Modicon PLC. Additionally, a small set of read-only PLC variables was made available by in-situ PLC program modifications by Linde commissioning personnel.

The existing EPICS device support for Modicon PLCs was modified to enable the read-only PLC variables to be read into an EPICS Input-Output Controller (IOC). This provides a usable degree of integration with the rest of the ISAC control system, especially the in-house delivery system controls.

At the time the second refrigeration system was delivered in 2007, development of a full EPICS device support package had been undertaken, and with the cooperation of Linde, a map of key PLC process variables was acquired. The EPICS device support software uses the documented Siemens S5 communications protocol over standard IP/ethernet LAN infrastructure. Siemens S5 fetch-write protocol allows read-write access of arbitrary process variables within the PLC.

Through an Internet search, a terse description of the S5 protocol was located, without which development of the software interface would have been extremely difficult. Once understood, the protocol is very easy to implement using a standard UNIX sockets interface. Initial experience with the protocol was gained using a Perl script that reads and writes messages between a Linux PC and a network connected PLC. This initial training tool served as a reference model for development of the final product, and consists of less than 200 lines of Perl code.

The software architecture was derived from the modbus device support package written by Mark Rivers [6] at the Argonne Advanced Photon Source. Modbus uses the EPICS Asyn package as a standard underlying layer. Upgrade of the stage-one system to the more recent control system standard is planned but as yet unscheduled.

Development of the EPICS device support software was performed off-line, using a spare Siemens PLC, and required some reverse engineering of the Linde PLC programming model. This was facilitated through the use of the Siemens Simatic/Step 7 software development package, which interfaces to the PLC through a USB-attached fieldbus adapter.

An initial concern prior to development of the EPICS interface software was whether there would be any kind of unexpected behavior of the Linde control system due to the presence of multiple concurrent sources of commands (Windows hosted GUI, Linux-hosted EPICS IOC, and Siemens touch-panel). This potential problem of conflicting masters did not occur, and all three operator interfaces have been found to operate compatibly. EPICS output records are kept in sync with PLC variables through a special database using reads from the associated PLC process variables.

Cold Distribution and Helium Recovery System

The ISAC Control system uses an implementation of Modicon PLCs supervised by EPICS IOCs. This arrangement is the standard used for vacuum controls, and has a good track record for performance and reliability. The same architecture was used to provide control of the Liquid Helium and Liquid Nitrogen delivery system.

Communication between the EPICS IOCs and the Modicon PLCs uses Modbus over IP/ethernet. EPICS device support, *modtcp*, was developed in-house at TRIUMF [7]. The cold distribution control system controls and/or monitors approximately 320 devices or data points. Control of the 3 new cryomodules will increase that number by approximately 40%. A single Modicon PLC controls the entire cold distribution system, and is supervised by one Linux hosted EPICS IOC.

The main classes of devices that are controlled are valves, pumps, compressors, heaters, and vacuum gauges. Process variable readback types are numerous temperature points monitored using a variety of transducers, Helium and Nitrogen pressures, and vacuum. Automated control functions are provided as part of the Linde refrigeration system and with PID loops on the Helium and Nitrogen proportional valves. During cool-down and in non-routine situations, the cryogenics system is controlled by operators through EPICS process displays. The PLC provides device interlocks to protect against device damage and Helium loss caused by operator error or accident. All critical elements of the cryogenics system, including controls, are powered by Uninterruptible Power Supplies and backup generator power.

Related Devices

EPICS integration of the Controle Analytique [8] Nitrogen analyzer was initially performed using an in-house device support package employing UNIX message queues and a back-end Perl script daemon. In 2008, it was replaced with a more generic StreamDevice-based [9] EPICS interface that parses the output of the instrument's embedded HTTP server.

Control of the Throttling Butterfly Valve in the 1.3 GHz Cryostat Test-stand uses EPICS StreamDevice over RS-232 to control the valve. The valve has a built-in controller with upstream and downstream pressure sensors that allow it to self-regulate a pressure drop across the valve. Setpoints can be sent and feedback received through the EPICS interface. Implementation of these controls is under way at this writing.

Standardization

A standardized user interface using the EPICS edm display manager is deployed throughout ISAC, including the cryogenics control system. In addition, EPICS allows partitioning of access rights between system experts and general operations personnel. This allows routine monitoring, without control capabilities, by standard operations staff, while experts can gain full access to all components.

The use of EPICS device support for control and monitoring of the turn-key PLCs permits a seamless integration of the cryogenics controls with the control system of the overall project. The use of Windows based computers within the control system is discouraged, and with a full range of cryogenics control provided within the ISAC control system, the need for the proprietary Windows hosted GUI is reduced or eliminated. EPICS operator displays and other minor functionality can be customized using standard EPICS tools.

In ISAC, PLCs are supervised by Linux hosted EPICS IOCs. All IOCs are at EPICS revision level 3.14.x. A standard PLC programming model has been adopted, as well as standard methods for producing EPICS IOCs, EPICS databases, and EPICS operator displays [10, 11,12]. Collectively, these processes are an efficient means of producing control systems that are reliable, consistent in composition, and consistent in behavior.

CONCLUSION

Control of the cold distribution system was accomplished using a combination of PLC and EPICS tools. A high degree of reliability of such a system has been demonstrated. The specifications set forth by cryogenics system designers and other experts have been met.

Consistent use of implementation standards results in efficiencies in implementation, as well as consistencies in the end-use behavior. Use of EPICS standard software rather than locally developed software layers speeds implementation and leverages the experience of a broader community of developers which results in a product that can be more readily expanded and improved.

Industrial Outsourcing

While the use of a PLC with programming model matching existing TRIUMF standards would have resulted in a more consistent and less complex system, it was possible to interface to turnkey products and still maintain end-user compatibility with prior work. Our experience shows that full functionality can be achieved with the cooperation of equipment vendors.

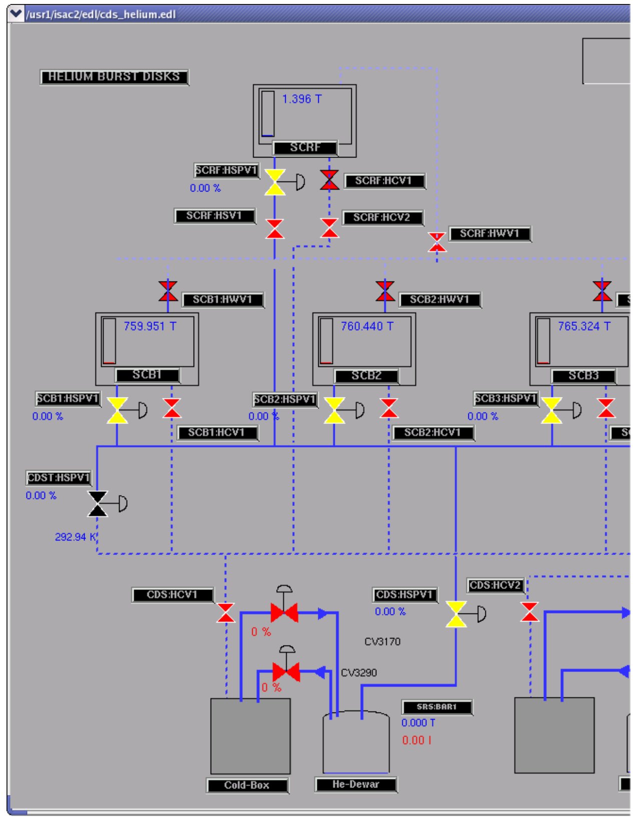

Figure 2: EPICS EDM Synaptic Display of Cold Distribution System (2 cryomodules cropped for clarity)

REFERENCES

[1] R. Keitel, et al., 'The ISAC Control System – Phase II', ICALEPCS05, Geneva, Switzerland, October, 2005

[2] Experimental Physics and Industrial Controls System, http://www.aps.anl.gov/epics/

[3] Linde Kryotechnik AG, http://www.linde-kryotechnik.ch/1259/1260.asp

[4] Siemens AG, http://w1.siemens.com/entry/cc/en/

[5] Schneider Electric, http://www.schneiderelectric.com/sites/corporate/en/home.page

[8] M. Rivers, http://cars.uchicago.edu/software/pub/

[7] R. Keitel, http://isacwserv.triumf.ca/epics/modtcp/TRIUMFmodtcp.html

[8] Controle Analytique. Thetford Mines, Quebec, Canada

[9] D. Zimoch, http://epics.web.psi.ch/software/streamdevice/

[10] R. Keitel, 'Generating EPICS IOC Databases from a Relational Database – a Different Approach', ICALEPICS01, San Jose, CA, USA, November, 2001

[11] R. Keitel, R. Nussbaumer, 'Automated Checking and Visualization of Interlocks in the ISAC Control System', ICALEPCS01, San Jose, CA, USA, November, 2001

[12] R. Keitel, 'EdlBuild – Display Generation for the EPICS EDM Display Manager', ICALEPCS05, Geneva, Switzerland, October, 2005