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LCLS-II CRYOMODULE AND CRYOGENIC DISTRIBUTION CONTROL*

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Abstract

LCLS-II is a superconducting upgrade to the existing Linear Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory. Construction is underway with a planned continuous wave beam rate of up to 1 MHz. Two cryogenic plants, a distribution system, and 37 cryomodules with superconducting cavities will operate with liquid helium at 2.2K. The process is controlled with networked Programmable Logic Controllers (PLC) and the Experimental Physics and Industrial Control System (EPICS) as an integrated system that work in concert for controlling valves, pressure, flow, and temperature. Interlocks and critical process information are communicated with the low level radio frequency (LLRF), vacuum, and magnet systems. Engaging the controls community proved vital in advancing the controls architecture from a conventional design to a centralized, reliable, and cost-effective distributed platform. The date for first light is in 2020.

INTRODUCTION

Two cryogenic plants, designed by the Thomas Jefferson National Accelerator Facility, supply helium to the LCLS-II linear accelerator (LINAC) cryogenic control system. SLAC is responsible for the LINAC control system and the EPICS integration to the plant [1]. The controls design includes:

- EPICS Supervisory Control of the cryogenic plant, distribution system, and cryomodules.
- 2 sets of centralized, redundant PLC processors and EtherNet/IP modules for cryomodule and distribution system.
- PLC 1 GB/s interface to EPICS.
- Device-level Ring (DLR) communication with Distributed I/O and LLRF Input/Output Controller (IOC) Servers.
- Profibus Decentralised Peripherals (DP) communication to temperature monitors.
- Profibus Process Automation (PA) communication to valve positioners.
- Over 100 devices distributed over 4 rings.
- Interfaced systems: LLRF, Magnet, Vacuum.
- Interfacing and controlling: cryogenic valves, pressure transducers, liquid level monitors, temperature monitors, and heaters.

CONTROLS ARCHITECTURE

The system controls and monitors instrumentation in the cryomodule and distribution system; the instrumentation quantities are shown in table 1 below [2].

Table 1: Instrumentation Signal Count

Instrument	Quantity
Pressure	106
Temperature (sensor)	1500
Liquid level	74
Valves	84
Heaters	520
Voltage Taps (conditioned)	315

Collaborative feedback from fellow laboratories helped build the architecture for controlling the LCLS-II cryomodule and distribution system. This lead to the adoption of centralized processing and commercially available off-the-shelf hardware.

Centralized Redundant Processing

The cryogenic plant supplies helium through two distribution boxes. One distribution box supplies the upstream 17 cryomodules and one distribution box supplies the downstream 20 cryomodules. The controls architecture mirrors this mechanical design by having the PLC processing located in two centralized locations. These centralized processing locations have the complete PLC programs that support the control functions for the instrumentation described in this document. Figure 1 shows one of the two sets of redundant chassis architecture. Two chassis contain the same Rockwell ControlLogix hardware: PLC 1756-L83E processor, Ethernet modules, and redundancy control modules are located near both distribution boxes. The primary chassis fails over to the secondary chassis when a fault occurs in one of the modules located in the chassis. The EtherNet/IP modules support communications to the DLR and the PLC's in the cryogenic plant. The 1 GB/s interface on the PLC CPU supports communication to the EPICS IOC.

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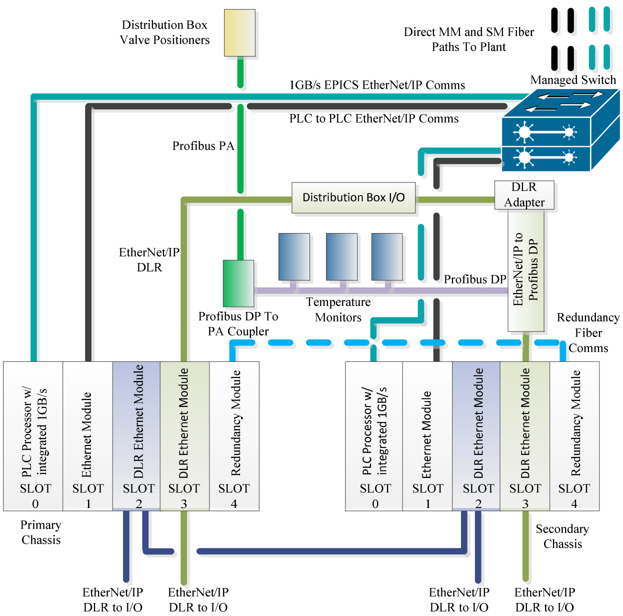

Figure 1: Centralized, redundant, PLC chassis.

Device-level Ring Communications

The DLR offers many benefits. In a largely accessible network, many accidental changes in the system can cause communication outages or interruptions in the network, such as:

- Adding a device with a conflicting IP
- Adding a device that broadcasts data in an unmanaged area of the network
- Reconfiguring part of the network that adversely affects communication with other subsystems

To reduce the likelihood of these occurring, the DLR I/O network is the choice, isolated from outside network influence in order to maintain reliability. A DLR is a fault-tolerant network, but multiple failures may isolate devices contained between multiple failed communication links. The mitigation for this is immediate personnel response to troubleshoot and resolve an initial failed link on the network. Each DLR does not exceed manufacturer design recommendations [3].

Figure 2 below shows the typical device architecture on a cryomodule rack. This diagram shows the integration of the DLR to Profibus DP and Profibus PA.

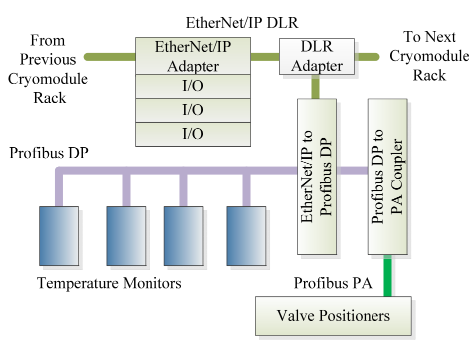

Figure 2: Typical networked controls hardware per cryomodule rack.

Cavity Heaters

The cavity heaters are 46.3 Ohm (nominal) polyimide strip heaters affixed to the bottom of the vessel bath. There are a total of 8 cavity heaters per cryomodule. The heaters are driven by a fan-less, programmable, regulated (0-50 VDC) linear power supply. The maximum voltage is below 50 VDC to reduce the hazardous voltage in the tunnel. The PLC analog output is a 0-10 VDC linear to the 0-50 VDC output of the power supply. To monitor the current draw of each heater, current shunts are placed in series with the power supply to the heaters. As current fluctuates, the shunt produces 0-50 mV which is amplified by a signal conditioner to the PLC analog input.

The LLRF EPICS server sends the gradient of each cavity to the cryo control PLC. Each server is located at one set of racks per crymodule and communicates to the PLC over the DLR. The PLC uses the gradient as part of the calculation to vary the power to the heaters.

The PLC controls the AC source to the DC supplies in sets of four. This allows sets of 4 at a time to be powered on during startup to reduce the risk of tripping circuit breakers. It also allows the PLC to remove sourced AC power to the power supplies of the feedback from the power supply does not match the command after a defined amount of time.

End Can Heaters

Two cartridge heaters are located in each cryomodule. Regulated 0-50 VDC, programmable, switched-mode power supplies power each of these heaters. These supplies have an internal Current Transducer (CT) that provides a current reading to the PLC with a 0-10 VDC feedback.

Valves

The pneumatic valves in the tunnel require a positioner to regulate the air to the actuator. By working through FermiLab engineering and the valve manufacturer, we learned of hardware used in similar applications at LHC. Based on the feedback received from LHC, we chose the same positioner design used for a number of years in the tunnel at CERN [4]. Each rack-mount positioner chassis contains 15 positioners. There are 6 chassis located above ground, away from damaging radiation; the piezos and feedback potentiometers reside in an enclosure on the valve body. Each chassis communicates via Profibus PA [5].

Pressure

Each cryomodule has 2 pressure transducers in the tunnel; one ranged from 0-100 PSIA and one ranged from 0-100 Torr. These transducers are expected to be affected by radiation over time. The placement of these sensors are in areas that have less radiation exposure than other locations around the cryomodule.

Additional pressure sensors for diagnostics on the end caps are strain gauges, a recommendation from the cryogenic controls team at Oak Ridge National Laboratory. These gauges, without microprocessors, are more resistant to damaging radiation.

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Liquid Level

The liquid level probe connects to a monitor customized by the manufacturer (AMI) to limit the excitation voltage to less than 50 VDC, reducing the electrical hazard in the tunnel. The monitor sends a 4-20 mA signal to the PLC to indicate the liquid level. One probe is located in the upstream portion of the cryomodule and the other is on the downstream. The 0.5% slope (Figure 3) in the SLAC tunnel creates a challenge for managing the liquid helium level in the cryomodule to bathe all cavities without overfilling into the Helium gas return pipe [6].

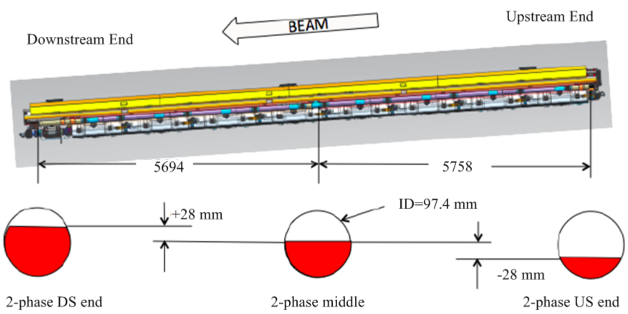

Figure 3: Liquid level for single LCLS-II cryomodule [6].

Temperature

Initial research on Resistance Temperature Detector (RTD) monitors proved challenging in processing overhead and cost when integrated in centralized control. Ethernet enabled devices were available at reasonable scale, but centralized processing with the number of monitors needed proved to cause communication overhead concerns.

DESY engineers developed their own cryogenic RTD and level monitoring hardware to bridge this gap and integrate with the control system by using Profibus DP [7]. This innovative design reduces the communications footprint by reducing the number of Ethernet devices. Implementing this monitor requires calculating the RTD value by solving polynomials. This was the chosen device type until Lakeshore recently released the 240-8P, a Profibus DP temperature monitor that runs the polynomials and holds the configuration files in the temperature monitor on-board memory. This removes the overhead required for polynomial calculations in the PLC processor.

Cable Plant and Connectors

Cable plant for an accelerator requires a tremendous amount of coordination efforts by working closely with all subsystem design engineers and supporting departments. Cables in the cryogenic control system design that run from the gallery through penetrations into the tunnel are nearly all multi-conductor with the following properties: shielded, twisted-pair, low smoke zero halogen, cross-linked Polyolefin (XLPE) insulated.

Connectors on the cryomodule are pins and the interface plug connectors utilize cups. This makes the connectors touch-safe to reduce the risk of a person experiencing an electric shock.

For the cryo control subsystem, the design of nearly every device generating voltage is below 50 VDC, with the exception of vacuum monitoring.

OUTLOOK

Having one PLC program for each set of cryomodules is expected to simplify programming techniques and decrease the time required to make programming enhancements. Centralized control loops for heaters and liquid level control in two PLC locations should ease programming.

An isolated I/O network utilizing the DLR topology is expected to reduce issues commonly experienced with star networks.

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