THE SNS VACUUM CONTROL SYSTEM UPGRADE FOR THE SUPERCONDUCTING LINAC*

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Abstract

The superconducting linac of the Spallation Neutron Source (SNS) has 23 cryomodules whose vacuum system is monitored and controlled by custom built hardware. The original control hardware was provided by Thomas Jefferson National Accelerator Facility (JLab) and contained a variety of custom boards utilizing integrated circuits to perform logic. The need for control logic changes, a desire to increase maintainability, and a desire to increase flexibility to adapt for the future has led to a Programmable Logic Controller (PLC) based upgrade. This paper provides an overview of the commercial off-the-shelf (COTS) hardware being used in the superconducting vacuum control system. Details of the design and challenges to convert a control system during small windows of maintenance periods without disrupting beam operation will be covered in this paper.

INTRODUCTION

The original hardware provide by Thomas Jefferson National Accelerator Facility consisted of a custom built chassis housing a variety of custom boards that use gate logic (Figure 1). A total of 8 separate control chassis were used to provide monitoring and control for the Super Conducting Linac (SCL) vacuum system.

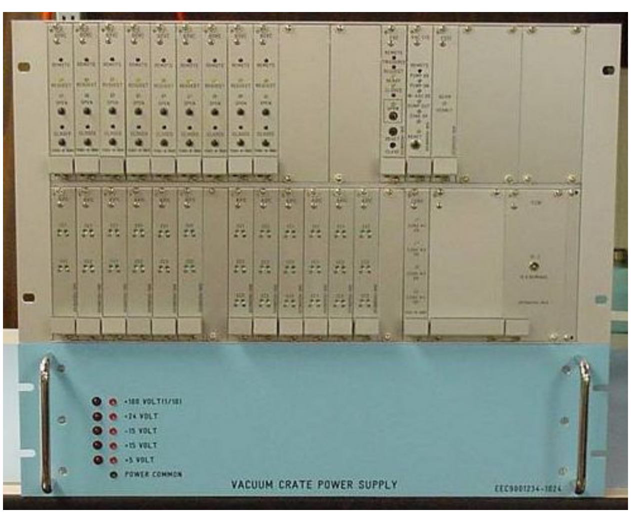

Figure 1: JLab vacuum chassis and power supply.

Several different boards were used in each chassis to monitor vacuum gauges, ion pumps, beam line gate valves, and fast valves. Some boards monitored signals within a chassis and provided status to the upstream and downstream control chassis for interlock logic between vacuum rack locations. All of the interlock logic and control was achieved by this custom built system and could act as a stand alone system without any integration to Experimental Physics and Industrial Control System (EPICS). The JLab vacuum chassis also required a custom built power supply chassis that included 5 different voltage supplies for the required voltages use in the integrated circuitry.

Varian ion pump and MKS gauge controllers [1] [2] were chosen as the SNS standard for vacuum systems and are used on the SCL section of the machine. The JLab chassis uses custom-built cables to interface with the vacuum controllers that connect to the chassis with circular style connectors (Figure 2).

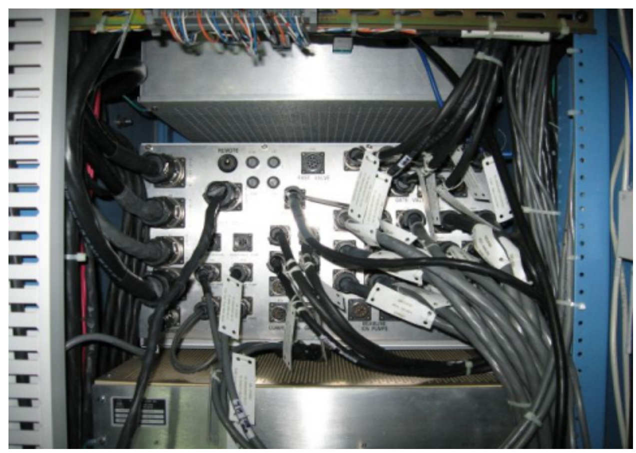

Figure 2: Rear view of chassis with interface cables.

To provide signals from the JLab chassis to EPICS, Beckhoff remote I/O was added to the vacuum rack. The Beckhoff BK9000 [3] Ethernet coupler with digital input and output modules provided the discrete signals from the vacuum chassis. Later, to provide the analog signals for pressure readings, a second BK9000 was added with analog modules. These remote I/O interfaced with the chassis using custom cables with the circular connectors.

LOGIC CHANGE ISSUES

Requests for logic changes to the original JLab vacuum system came early in the startup and commissioning of the SCL. The use of custom integrated circuit boards made logic changes impossible without redesigning the circuitry. In order to have both the ion pumps and cold cathode gauges interlock the Low Level Radio Frequency (LLRF) System, external "AND" gate modules were added to the control system. This change was made to provide additional protection against window arcing and beam line vacuum pressure spikes during commission of the cavities. Another logic change required temporary bypasses for cold cathode gauges monitoring window

* SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy
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vacuum. External "OR" gates with Beckhoff I/O were installed to achieve this capability.

Pressure set point changes could be made on the custom boards using the provided potentiometers and measuring the voltage on the comparator circuits for the various interlocks. One drawback with making a setpoint change was that the power had to be removed from the JLab chassis and the board pulled and placed on an extender card. This meant RF power to four cryomodules had to be turned off to make a setpoint change.

NEW DESIGN FOR SCL VACUUM SYSTEM

A new PLC-based system was implemented to replace the JLab chassis, additional I/O hardware, and custom power supplies. The primary motivations were to reduce the probability of failures and to effectively manage spare parts.

All of the original custom hardware was replaced using commercial off-the-shelf (COTS) hardware. The SNS standard Allen-Bradley ControlLogix5000 PLC [4] is used to provide all interlocks and control for the SCL vacuum system. The PLC uses EtherNet/IP [5] to communicate to the EPICS Input/Output Controller (IOC) and Linux workstations provide the operator interface.

One COTS 100 Watt 24VDC power supply is used to provide digital input and output signals for interlocks, gate valves, and fast valve controls. This one power supply took the place of the custom power supply chassis with the various voltages.

The Low Energy Differential Pump (LEDP) region and High Energy Differential Pump (HEDP) region both have VAT fast valves. These fast valves were originally controlled by the JLab custom-built fast valve boards. The upgrade utilizes a VAT 75 series controller [6] to control and trigger the fast valves using VAT pressure sensors. The VAT controller signals are monitored and controlled with the PLC.

Serial to Network Solution

To reduce the number of PLC I/O connections, a Digi PortServer [7] is used to interface with the MKS Series 937A and Varian controller's serial communication cards. The Digi provides RS-232 and RS-485 serial-to-Ethernet connectivity to allow full read and write capability. Commands to turn high voltage on/off, change setpoints, and to monitor pressures are accomplished through the Digi PortServer using the asyn/StreamDevice solution [8] [9].

The original hardware to provide this function was VME 64x analog and digital I/O modules with industry pack 8 channel ACD cards. The commercial VME hardware would cause the IOC to lock up after running for several months due to a memory stack issue when the I/O was continuously polled for data. The hardware would also hang during IOC rebooting; requiring the power to be cycled several times before a successful reboot. These were the major reasons to upgrade to the Digi PortServer solution.

CONVERTING A CONTROL SYSTEM IN A SHORT MAINTENANCE WINDOW

The challenge to converting or upgrading any control system in a short maintenance window is to be as transparent to operations as possible and to maintain the design integrity for protecting the equipment.

The logic of the JLab system was well documented with drawings of each board type and setpoint values to act as a road map to convert into PLC ladder logic. The PLC code was written to match the JLab logic exactly with added features for bypassing cold cathode gauge interlocks. Keeping the logic the same was very important to maintain the protection JLab designed into the original system. The same test procedures that were used during the initial installation were slightly modified to verify the logic was the same in the PLC.

PLC Interface Chassis

The key to using the existing field cables to allow for hardware rollback and quick installation was the design of the PLC interface chassis (Figure 3). The new interface chassis uses the same circular connectors as the JLab chassis and was designed to allow all field cables to be used without any modifications. This enabled the old system to be removed and the new one to be installed in only 5 to 6 hours, with a fully integrated system returned to service at the end of that time. The quick installation allowed for minimum downtime of the ion pumps and vacuum gauge readings on a section of cryomodules. Testing and verifying the section upgraded took additional 6 to 8 hours.

Figure 3: Rear view of PLC interface chassis.

The PLC interface chassis has terminal blocks to connect the circular connectors to the Allen-Bradley PLC wiring harness. The terminal blocks are mounted on the front side of the chassis to allow for a technician to measure and troubleshoot every signal without interrupting or turning off any equipment. The new chassis have no custom parts; only connectors, wires, terminal blocks, and three relays used to interface with the fast valve controllers. All parts are readily available and easy to replace.

The modular design allows for a zone of vacuum or one vacuum control rack to be modified using new control chassis and still control the other vacuum zones using the old control chassis concurrently. The EPICS SCL vacuum database was written to allow for a zone of vacuum hardware to be upgraded with no change in appearance or operation of the control screens. From an accelerator operator's perspective an upgraded system was indistinguishable from the original.

Preparation and Prototype

The prototype of the PLC interface chassis was installed in the controls lab for offline testing of the upgrade before any field modification was made. A mockup of a SCL vacuum rack, IOC, and Digi PortServer with vacuum controllers allowed for testing and confirming the design prior to field installation. The prototype was designed to replace one of the middle JLab chassis. The 6 middle chassis do not have fast valves incorporated into them and were easier to upgrade first. Every field device was simulated in the lab to insure correct operation and verification of the EPICS screens, PLC logic, and test procedures.

The first vacuum zone upgrade was installed without a single issue or problem because of the extensive testing. After successfully upgrading a middle vacuum chassis the remaining chassis were built. The same process of mockup was done for the end chassis design that included interfacing with the fast valve controller and signals from upstream and downstream vacuum system.

TIME RESPONSE TO INTERLOCK LLRF

At SNS it is required that RF power to a cavity be turned off within 16 msec of a vacuum excursion (typically due to an arc). The MKS gauge controller provides an analog pressure reading and a relay digital output that can be used to sense pressure exceeding a threshold. The PLC uses both signals to interlock the RF power to a cavity. However the analog signal is processed much slower than the relay digital input.

The Allen-Bradley Logix 5000 programming software will allow a periodic task to interrupt the continuous task to perform critical interlocks. Several factors must be considered in order to achieve the required response time of 16 msec.

The time for the MKS controller to respond to a vacuum increase above the relay setpoint and output a signal to the PLC is ~13 msec. By using a periodic task with a scan rate of 2 msec and by limiting the amount of logic in that task, the Allen-Bradley 1756-L62 processor response time is less than 2 msec. Also, the scan rate for the digital input module has to be set at a fast scan rate to achieve the desired PLC response time.

The overall response time for a vacuum pressure to increase above the interlock limit and for the PLC to output a 24VDC signal to the LLRF system to turn off RF power to a cavity is ~15 msec (Figure 4).

Figure 4: Overall time response to interlock LLRF.

The response test setup used a millivolt simulator for the input to the MKS controller to simulate the ion current. The oscilloscope was triggered by the ion current simulator. Measurements were taken of the MKS relay output signal going to the PLC and the output signal from the PLC that interlocks LLRF. The measurements were repeated several times with results only varying ~100 usec. These measurements were consistent with a study done on the 1756-L55 processor response time earlier in the SNS commissioning.

CONCLUSION

All 8 zones of the SCL vacuum control system have been successfully upgraded with (COTS) hardware. The PLC based system has proven to meet the interlock response time requirements and to allow the flexibility in logic changes. The reduction of hardware components provides a more robust control system and spare parts that are standard with the other SNS vacuum systems.

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