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DESIGN OF VESSEL AND BEAMLINE VACUUM AND GAS CONTROL SYSTEM FOR PROTON RADIOGRAPHY*

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Abstract

A new capability for conducting explosively-driven dynamic physics experiments at the Proton Radiographic (pRad) facility at Los Alamos National Laboratory (LANL) is in development. The pRad facility, an experimental area of the Los Alamos Neutron Science Center (LANSCE), performs multi frame proton radiography of materials subjected to an explosive process. Under design is a new beamline with confinement and containment vessels and required supporting systems and components. Five distinct vacuum sections have been identified, each equipped with complete vacuum pumping assemblies. Inert gas systems are included for backfill and pressurization and supporting piping integrates the subsystems for gas distribution and venting. This paper will discuss the design of the independent vacuum control subsystems, the integrated vacuum and gas control system and full incorporation into the Experimental Physics and Industrial Control System (EPICS) based LANSCE Control Systems and Networks.

OVERVIEW

Proton Radiography at LANSCE

The proton radiography capability at the LANSCE Area C pRad facility has been advancing materials science for over 20 years [1, 2]. High energy protons, provided by the LANSCE proton accelerator, are used to produce multi frame radiographs of materials during dynamic experiments. The new beamline will extend pRad capabilities in terms of material size and types, explosive dynamics and imaging. The design incorporates a nested vessel network to contain and observe the dynamic experiment, a beamline to transport and focus the proton beam, a vacuum and gas handling system to provide the necessary environment, and a control system to operate all of it.

New pRad Beam Line Vacuum System

Vacuum performance and isolation requirements resulted in five major isolatable sections of beamline and vessels [3]. To support independent operation of the five sections, and to comply with project assembly/disassembly requirements, five identical vacuum pump carts will be used, each with separate but coordinated control equipment. Various vacuum pumps, isolation valves, vacuum gauges, check valves and other devices are included in the system design.

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CONTROL SYSTEM DESIGN

Mechanical Design

The beamline components include the upstream beam pipe, the containment outer vessel, the confinement inner vessel, and the downstream beam pipe. An assortment of valves allow for the sections to be isolated and to permit independent vacuum pumping, gas handling, and operation. Not all valves, piping and assorted other vacuum components are depicted on Fig. 1 which illustrates the beamline and vessels and associated vacuum carts.

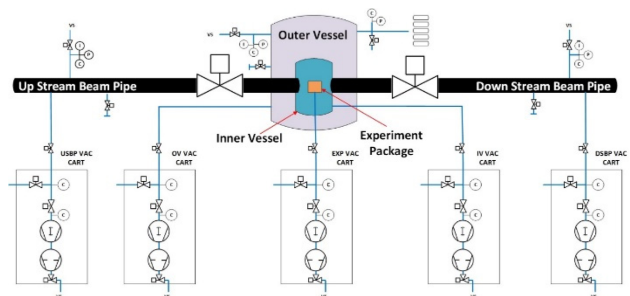

Figure 1: Beamline vacuum components.

The number of vacuum isolation valves totals to 45 of which 12 are gate valves and the remainder are right angle or globe valves. The two largest valves are the beam pipe isolation valves on either side of the outer vessel. For measuring vacuum and/or pressure there are 18 Convectron vacuum gauges, 8 ion gauges and 12 pressure gauges. The target vacuum base pressure is 50mTorr and the design pressure for post-experiment is 97,807 Pag (14.0 psig). Each vacuum cart contains one roots blower and one rotary vane pump. All of these components are read and/or remotely controlled solely by the control system, to work within requirements that during alignment operations with proton beams the beamline area is evacuated of personnel.

Instrumentation and Controls

Valves included in this design vary in sizes and types but all are air actuated and commanded by 24 volt binary signals. Limit switches are used for open/closed indications. Software will monitor travel times and consistency and validity of open/close signals and issue faults when required. All valves fail closed on loss of signal or air.

Rotary vane pumps back roots blowers which in combination, are required to rough out the system to 50 mTorr in 30 minutes.

For vacuum measurements, a number of Convectron and ion gauges are located throughout the system. The ion gauges are used specifically during high vacuum leak checking prior to main operation. Also included are a few

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pressure sensors for use during set up, post-experiment diagnostic and special procedures. Assorted non-controlled/monitored devices like check valves, filters, expansion tanks, etc. are included to complete the design.

An assortment of non-vacuum related measurements are also included for diagnostic purposes.

The National Instruments (NI) compact RIO (cRIO) programmable controllers will provide automated control system functionality. The cRIO provides 4 or 8 slots for I/O modules, an FPGA tightly coupled to the I/O modules and a real time Linux based controller with several network ports. The real-time controller and FPGA are programmed using NI LabVIEW.

Two 8 slot NI cRIO 9048s provide control and measurement for all beamline and vessel instrumentation, see Fig. 2 and Fig. 3. Central coordinated control of the entire system will be implemented within the primary control cRIO.

Each of the five vacuum carts will be controlled by an NI cRIO 9041, see Fig. 4. Supervisory remote control of the carts by the primary cRIO is always enabled. Local control is permitted by selection of the appropriate diagnostics mode. Touch screens are provided for local displays and input for set up and diagnostics. Software implemented control sequences for all devices are kept local to the individual cart's cRIO.

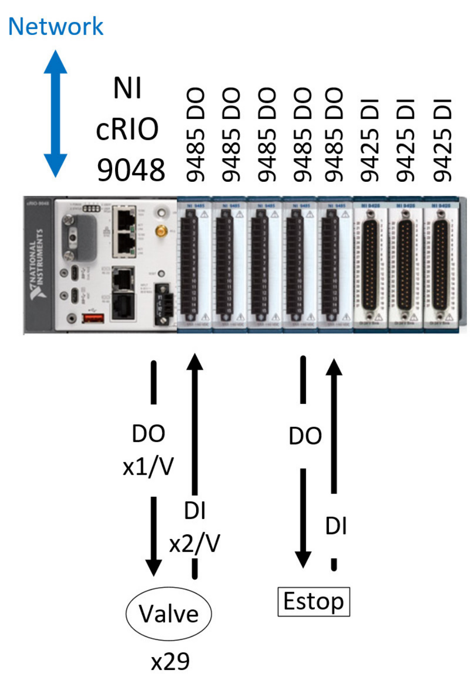

Figure 2: cRIO Control Chassis 1.

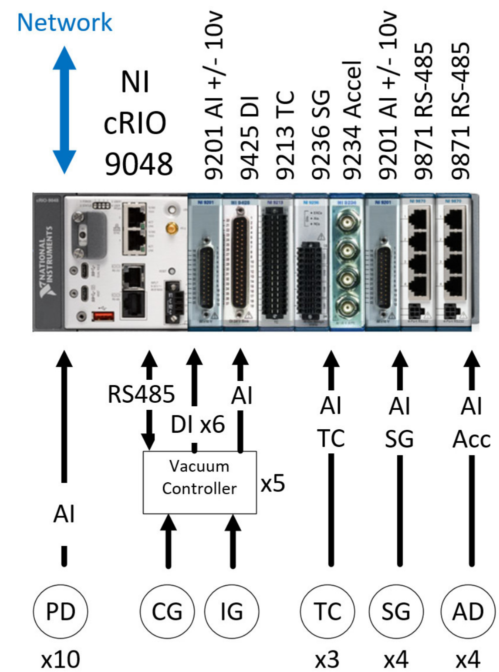

Figure 3: cRIO Control Chassis 2.

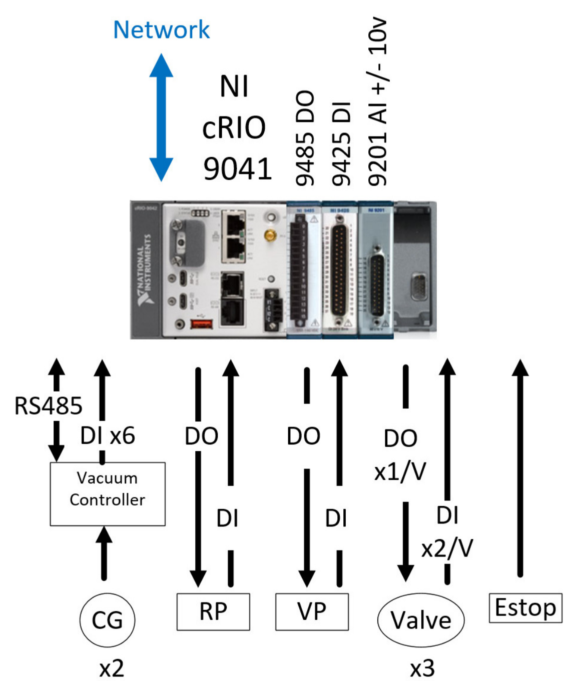

Figure 4: cRIO Vacuum Cart Control chassis.

Network

Data communication between the cRIO controllers and operators in the control room uses a subnetwork of the LANSCE accelerator controls network [4]. Network components consist of multiple rack mounted fiber connected switches with connections to end devices via shielded CAT 6 twisted pair cables, see Fig. 5.

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EPICS Channel Access is the primary network process variable protocol with each network component offering both server and client services for a highly robust and top performing control variable distribution solution [5].

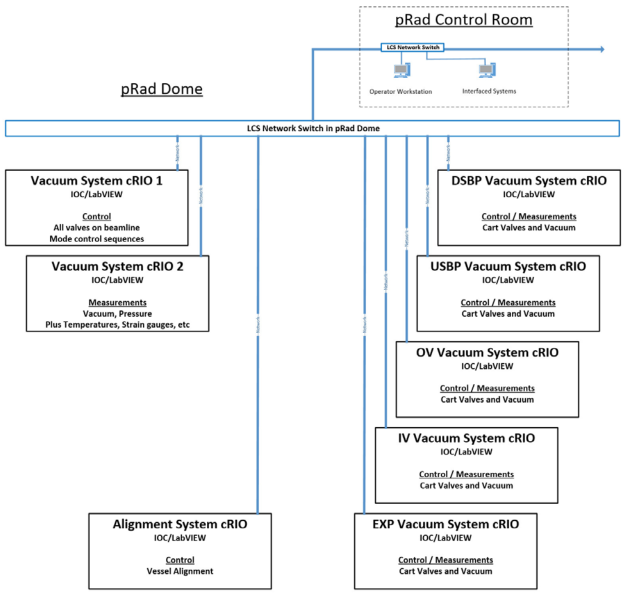

Figure 5: Network layout.

Logic and Software

Controls software is distributed over the seven cRIOs. Lower level instrument control and measurements of local devices are located on vacuum cart cRIOs while higher level sequences, mode control, fault actions and operator command interfaces are located on the supervisory cRIO.

EPICS Input Output Controller (IOC) Core systems are deployed on each cRIO which provide multiple control system functional components such as process variable definition, scan control, alarms, calculation, device interfaces, state sequences and more [6]. The LANL/EPICS lvPortDriver utility is used for EPICS IOC to LabVIEW interfacing [7].

For robust, consistent and maintainable LabVIEW software on the cRIOs, the LANL/LANSCE LabVIEW framework is employed. This framework enforces a well-engineered structure for the LabVIEW software deployed on the real time controller and FPGA.

From a top down standpoint, the pRad vacuum system control is driven by operating modes, see Fig. 6. Multiple modes have been defined. To perform a normal experiment event, a "shot", the sequence would be: pump down the beamline and vessels to the specified vacuum setpoint, stay at that vacuum level with vacuum pumps on, transition into "ready for shot" when shot is imminent (pumps are shut off, all valves but beam pipe valves are closed), perform the shot, determine success, gas vent as needed. Other modes are for set up, diagnostics, leak checks, gas fill and off-normal actions.

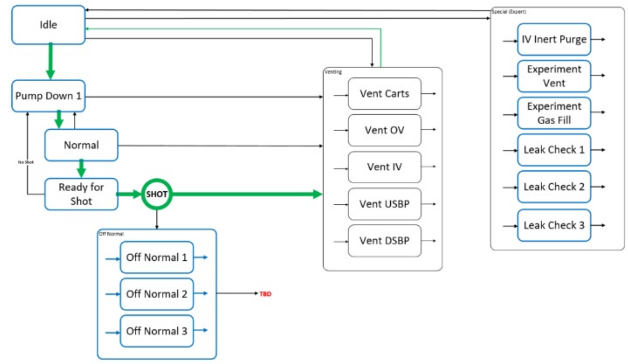

Figure 6: Control mode structure.

The Mode Pump-Down 1 logic is depicted in Fig. 7. From left to right: operator commands and pre-conditions are checked before starting mode, selected valves are opened or closed as necessary until all are in position, each cart opens or closes cart valves, roughing pump is started, when specified vacuum is reached vacuum pump is started, cart is then considered to be successfully pumping down. When all carts are pumping then Pump-Down 1 mode is achieved.

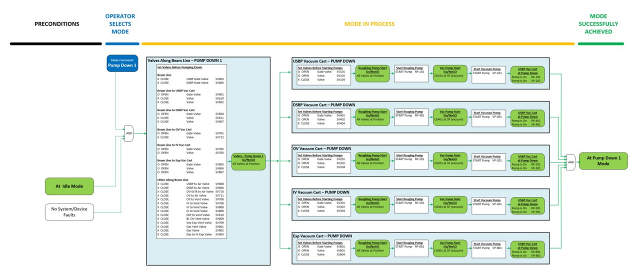

Figure 7: Logic sequence for mode pump down 1.

CONCLUSION

Design of the pRad vacuum control system is in progress and is nearing completion. Software development and system deployment is scheduled next year. This paper only briefly touched on hardware and software selections, control logic and design decisions. This system is but one part of the complex engineering and science efforts that contribute to successful proton radiography at LANSCE.

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