Design of Vessel and Beamline Vacuum and Gas Control System For Proton Radiography*

P. S. Marroquin, J. D. Bernardin, J. G. Gioia, D. A. Hathcoat, H. J. Sandin, W. W. Winton, A. Llobet,
Los Alamos National Laboratory, Los Alamos, New Mexico, USA

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.

Proton Radiography at LANSCE

The proton radiography capability at the LANSCE Area C pRad facility has been advancing materials science for over 20 years. 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.

Design of pRad Beamline Vacuum System

Vacuum performance and isolation requirements resulted in five major isolatable sections of beamline and vessels. 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 (see Fig. 1). Various vacuum pumps, isolation valves, vacuum gauges, check valves and other devices are included in the system design.

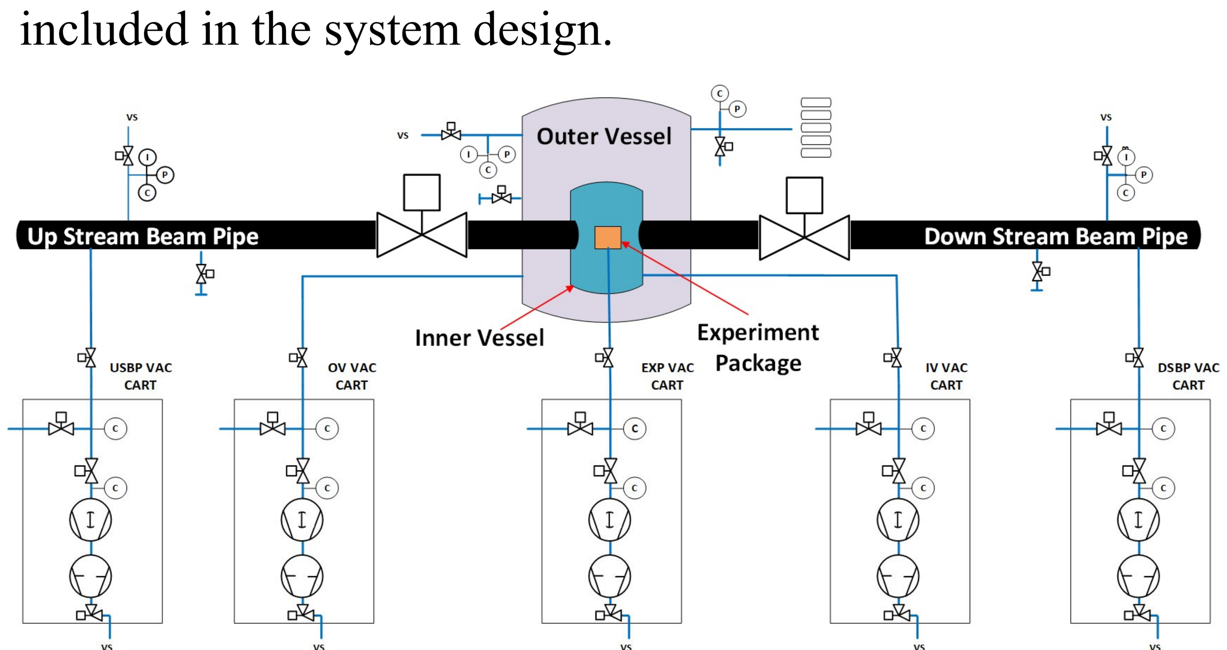

Figure 1: Beamline vacuum components

Mechanical Design

Beamline components (Fig. 1): up stream beam pipe, containment outer vessel, confinement inner vessel, and downstream beam pipe.

Number of vacuum isolation valves: 45 (12 gate valves plus right angle and globe valves). The two largest valves are the beam pipe isolation valves on either side of the outer vessel.

Vacuum gauges: 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).

Vacuum cart pumps: one roots blower and one rotary vane pump.

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 monitors travel times, consistency and validity of open/close signals and issue faults when required. All valves fail closed on loss of signal or air.

National Instruments (NI) compact RIO (cRIO) programmable controllers will provide automated control system functionality. The real-time controller and FPGA are programmed using NI LabVIEW.

Two 8 slot NI cRIO 9048s (see Fig. 2 and 3) provide control and measurement for all beamline and vessel instrumentation.

Control Chassis 1

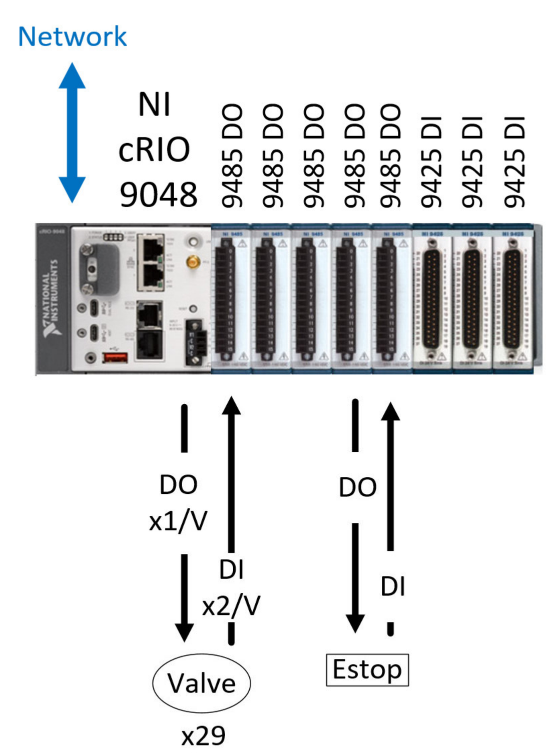

Figure 2: cRIO Control Chassis 1

Control Chassis 2

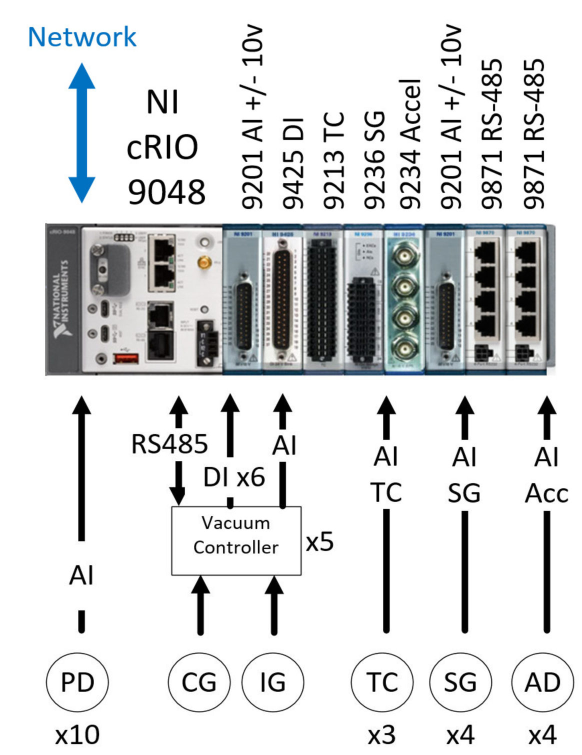

Figure 3: cRIO Control Chassis 2

Each of the five vacuum carts will be controlled by individual NI cRIO 9041s (see Fig. 4).

Touch screens for local displays and operator input are installed on each cRIO, for set up, leak checking and diagnostics.

Vacuum Cart Control

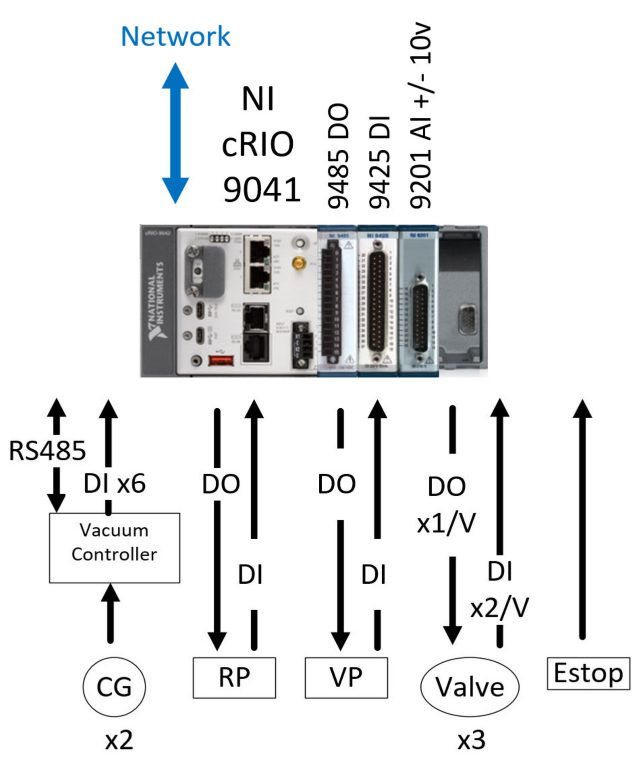

Figure 4: Vacuum Cart cRIO Control Chassis (5 each)

Network

Communication from cRIO controllers to operators in the control room are via the LANSCE accelerator controls network (see Fig. 5).

EPICS Channel Access (CA) is the network process variable communication protocol selected. Each cRIO on the network hosts both server and client services for a highly robust and top performing control variable distribution solution.

Figure 5: Network Layout

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 cRIO chassis 1.

EPICS Input Output Controller (IOC) 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. The LANL/EPICS lvPortDriver utility is used for EPICS IOC to LabVIEW interfacing.

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.

Control Modes

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.

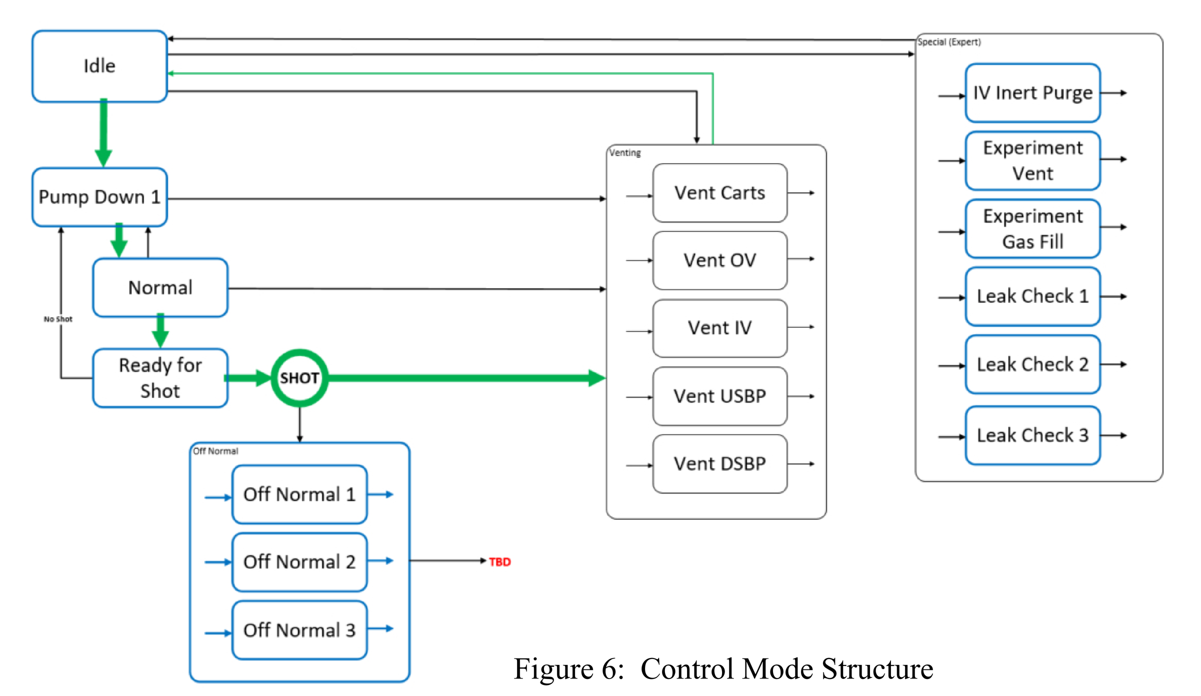

Figure 6: Control Mode Structure

Pump Down Control Logic

The Mode Pump-Down 1 logic steps are as follows (see Fig. 7):

1) Operator commands and pre-conditions are checked before starting mode
2) Selected beamline valves are opened or closed as necessary until all are in position
3) Each vacuum cart opens or closes cart valves
4) Roughing pump is started
5) When at vacuum setpoint, vacuum pump is started
6) Cart is pumping down
7) When all carts are pumping down then Pump-Down 1 mode is achieved

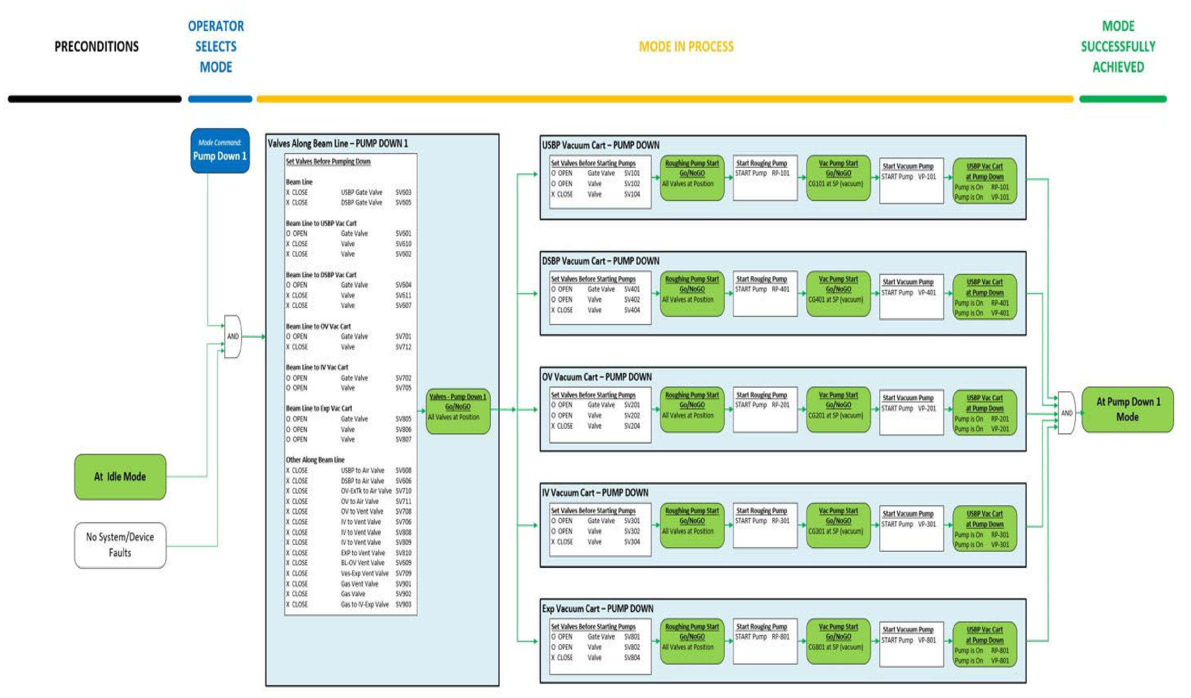

Figure 7: Logic Sequence for Mode Pump Down 1

* Supported by the US Department of Energy, Los Alamos National Laboratory. Managed by Triad National Security, LLC for the DOE National Security Administration (Contract 89233218CNA000001). LA-UR-19-29671