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LCLS-II CRYOMODULE ISOLATION VACUUM PUMP CART*

S.C. Alverson†, D.K. Gill, S. Saraf, SLAC National Accelerator Lab, Menlo Park, California, U.S.A.

Abstract

The Linac Coherent Light Source II (LCLS-II) Project is a major upgrade to the lab's Free Electron Laser (FEL) facility adding a new injector and superconducting linac. In order to support this new linac, a pumping scheme was needed to isolate the liquid helium lines cooling the Radio Frequency (RF) cavities inside the cryomodules from outside ambient heat as well as to exhaust any leaking helium gas.

New carts were built consisting of a mechanical backing pump, turbo-molecular pump, and several vacuum valves and gauges for this purpose. These were designed to both automate the process of pump down for the technicians via remote and local control, as well as be portable enough to be able to be moved to different locations as needed depending on the state of the vacuum in the cryomodule strings (Fig. 1).

Figure 1: Photo of LCLS-II L0B cryomodule string.

BACKGROUND

The primary concerns for the LCLS-II [1] cryomodule isolation region are buildup of gasses that can transfer heat to the circulating cryogenic lines as well as formation of ice which can build up causing damage [2].

- It is almost impossible to completely avoid all leakage of helium gas within the cryomodule, so it must be continuously pumped out.
- If the cryogenic lines start warming up due to heat transfer to outside atmosphere, the cryogenic fluids will expand creating more gas leakage into the isolation vacuum.
- If temperatures increase too much, a quench [3] will occur shutting off the machine and lead to downtime.

SOLUTION

To avoid these issues, we designed a pump cart system with automated pump down sequences and interlocks. As much electronics as possible were installed remotely outside of the tunnel to avoid radiation damage and allow access for troubleshooting. Design is intended to be turn-key such that pump down and recovery operations are largely hands-off, governed by the system logic. Carts and support infrastructure are designed to be as portable as possible in case it needs to be relocated to areas with higher leak rates.

Hardware

In order to keep the cart portable, it was designed in-house [4] to be as compact as possible so it could be easily moved to different locations in the tunnel depending on where the worst vacuum is detected. All hardware was mounted on a metal frame with casters as well as adjustable legs and brackets that can be utilized for bracing to the tunnel floor.

Cart Devices The cart interfaces to the crymodule isolation vacuum volume via a VAT manual valve installed on the side of the cryomodule feed cap. Care had to be taken during installation as the cryogenic beamline is a particle-free area [5]. Hardware mounted within the cart itself (Fig. 2) consists of the following devices:

- MKS 3170037SH Convectron (Pirani) Gauge (x2)
- MKS 4220014 Cold Cathode Gauge
- VAT 09140-PE24-X Pneumatic Gate Valve
- VAT 26428-KE21 Pneumatic Angle Valve
- Pfeiffer TP1 HiPace 300 Turbo Pump
- Kashiyama NeoDry 36-12 Roots Pump

A passive supplementary air reservoir was also installed on the cart to ensure that if the site air supply goes down, enough air will still be available to facilitate closing the valves.

Controls and Infrastructure To avoid failures due to radiation damage, all discrete electronics had to be installed in the support building high above the tunnel (Fig. 3). Spare long haul cables were installed periodically along the cryomodule strings ready to be plugged in if a cart needs to be moved. These lead up to the controls racks contained in each sector alcove where the Programmable Logic Controller (PLC) and device controllers are installed consisting of the following:

- Allen-Bradley ControlLogix® PLC
  - 1756-L83 Controller
  - 1756-EN2T Ethernet
  - 1756-IF16 Analog Input
  - 1756-OF8I Analog Output
  - 1756-IB32 Digital Input
  - 1756-OB16I Digital Output

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† alverson@slac.stanford.edu

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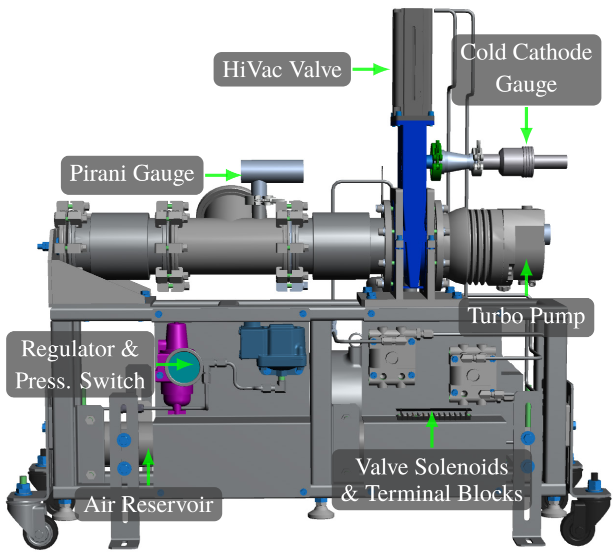
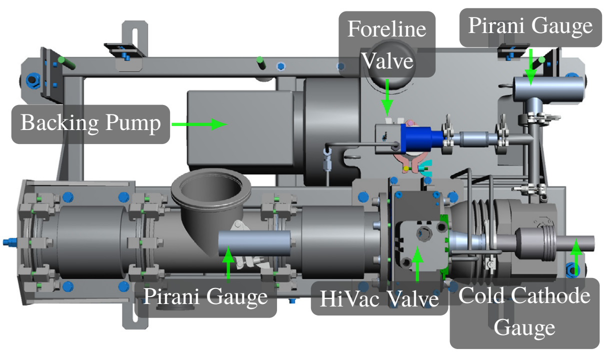


(a) Side View



(b) Top View

Figure 2: Pump cart mechanical CAD model.

- Allen-Bradley PanelView™ 15” touch panel
- MKS 937B Combination Gauge Controller
- Pfeiffer TCP-350 Turbo Pump Controller
- Phoenix Contact 277-5055-ND Current Sensor
- Digi ConnectPort TS 16 MEI Terminal Server

Figure 3: Example of sector controls rack installations.

In order to save costs, it was decided for the pump cart logic to share PLCs and infrastructure with the general beamline vacuum controls. This allowed us to use fewer modules and reduced the overall required rack space. Hardware wiring is designed to be fail safe such that any loss of power will automatically insert the valves.

Software

Software for controlling the pump cart comes in two types. All logic and local control is handled by the PLC for reliability and can safely run the cart even without SLAC network services being online. Remote monitoring and control is then handled by the Experimental Physics and Industrial Control System (EPICS). The EPICS interface is only capable of reading and writing certain registers (tags) to the PLC and does not make any command decisions itself. The PLC has ultimate authority on what operations can be facilitated under the given circumstances.

PLC Logic Code was developed in Allen-Bradley’s proprietary Studio5000® software suite. Mostly written using ladder logic, structured text is also utilized for clarity in routines where it made sense. In order to maintain consistency and portability between installations, the logic is designed around generic templates accepting input parameters for various I/O connections and device names.

A single main program contains all of the control logic and interlocks and several Add-On Instructions (AOIs) were created for common operations. User Defined Types (UDTs) were created as common containers for device-type data. For example the SlowValve UDT contains data on the valve position, open and closed limit switches, air line pressure state, interlock summary, control mode, etc., allowing an easy way to keep related signals organized. Since the code was isolated in its own program, it was easy to add as many instances to the common PLC as needed for the carts installed in that area.

Several operational modes were specified [6] correlating to different running conditions of the cart as seen in the following table (Table 1).

Table 1: Operational Modes

Mode	Condition
Running	All valves open and pumps running. Interlocks are active and clear.
Pumpdown	Run through a full pumping sequence from high pressure.
Idle	Initial state after power up or fault reset. Do nothing and wait for Operator action.
Shutdown	Close all valves and turn off pumps in sequence.
Fault	Hard trip interlocks and Shutdown cart. Must be manually reset by an Operator.

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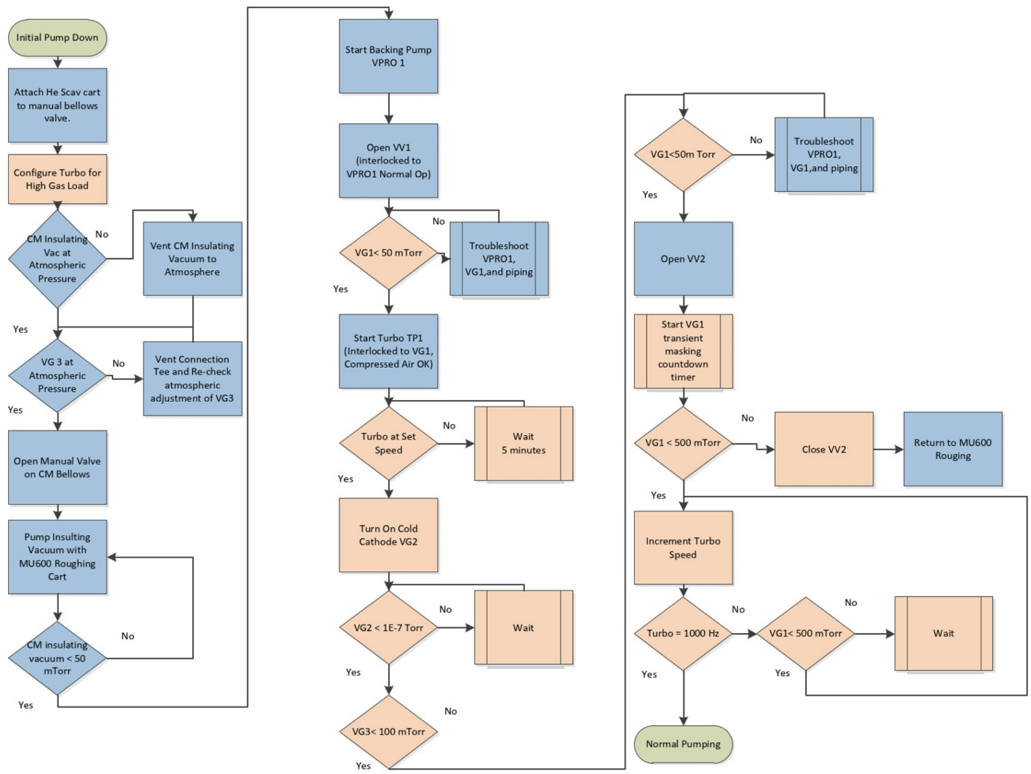

Figure 4: Pump down procedure flow chart, including manual response.

After initial boot of the PLC, the cart will be set in the Idle mode with all valves inserted (0 V to solenoid), pumps offline (permits removed), and interlock summaries broken pending a reset by an Operator. This is considered the safest default state as it guarantees the valves will not be open while the pumps are not running. The valves also start up in Local mode (no Remote or PLC-driven Auto operation) on power up as an additional measure to guarantee they will not open unexpectedly. An Operator must switch them to Auto before the PLC is allowed to have autonomous control.

Once the interlocks have been reset, the cart can be transitioned into Pumpdown (Fig. 4) where the valves are automatically opened in sequence with the pumps coming up to full speed. First a relay is closed to send 208 VAC to start up the backing pump. Once the current sense coil verifies that the pump is running, the fore line valve will open. Only once the fore line Pirani gauge sees the pressure drop below 5×10^{-2} Torr will it then send the permit for the turbo pump to spin up. In order to verify that the turbo pump is running properly, a run-up test is performed with the HiVac valve closed first to verify that the Cold Cathode pressure drops below 1×10^{-7} Torr. As a protection for the Cold Cathode, the high voltage is held off by the PLC until the turbo pump has reached a minimum of 700 Hz. Once the turbo has been proven to function and has reached its top speed of 1 kHz, the HiVac valve will open to begin pumping on the cryomodule isolation volume. If the HiVac Pirani gauge reads the pressure to be lower than 2×10^{-1} Torr, the pump down process is considered complete and the cart will transition to the Running state.

There are a variety of interlocks being monitored while the cart is running, from gauge pressure readings to pump current and speed. As long as the turbo and backing pumps are running, the pressure interlocks work on a “five strikes” system. If a pressure interlock is tripped, the HiVac valve will be inserted and a High Load timer will start allowing the pumps a chance to try and expel any gas. At the end of the timer, the pressure interlocks are temporarily bypassed with a second timer so that the valve can open and pull in more gas from the cryomodules. If the pressure is still high after the Bypass timer expires, the valve will close again and the High Load timer will start once more. This process can continue a maximum of five times within the span of one hour. If the pressure is still not below the threshold by the fifth trip the cart will Fault, transitioning to Shutdown and notifying an expert for intervention.

EPICS Database Remote monitoring and operation of the pump cart was accomplished using SLAC’s EPICS based distributed control and data archiving system. Read back of pressures, pump currents and speeds, interlock and operational modes, as well as timer counts are all available remotely to Operators. Controls consist of pressure setpoints, interlock reset, Pumpdown/Shutdown mode requests, and valve operation (as long as valves are not in Auto mode). As mentioned previously, commands issued through the EPICS interface are just requests, the PLC ultimately decides if those requests are allowed to be fulfilled. All data histories are preserved via SLAC’s Archiver appliance.

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Databases are built around standard EPICS collaboration modules:

- EtherIP to connect to PLC via Ethernet
- Asyn and StreamDevice for RS232 connection (via terminal server) to gauge and pump controllers
- Calc records used for translating operational states into user friendly formats

User Interface Interfaces are provided both for EPICS via the Extensible Display Manager (EDM) as well as locally at the PLC with a touch panel Human Machine Interface (HMI) running Allen-Bradley's Studio5000 View Designer®.

EPICS EDM displays (Fig. 5) are intended to adhere as closely as possible to standard vacuum controls displays used at SLAC for consistency and ease of use by Operators. Display files are based on common templates used for all carts identified via passed macro values. Pressure, interlocks, and mode states utilize EPICS severity states and the LCLS Alarm Handler for notifications. Alarm states "bubble up" from the low-level device specific displays to the top-level "Home" displays being actively monitored. Email notifications are also sent out to experts automatically for certain major Alarms.

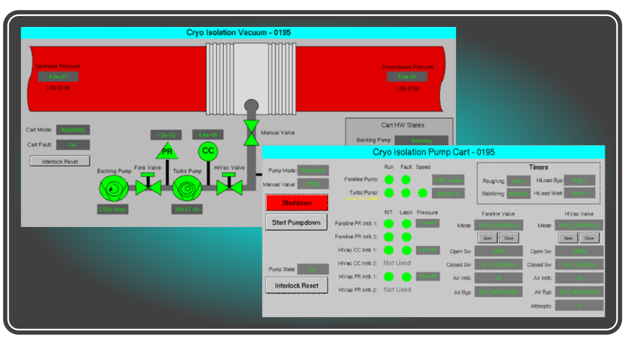

Figure 5: Example of EPICS EDM screens.

Similarly, the PLC HMI (Fig. 6) is designed around standardized template files with properties. All controls are made consistent with the beamline vacuum controls and Alarms propagate up to the top level screen. Controls are also password protected to avoid unintended state changes.

Figure 6: Example of PLC HMI screens.

All code and display files are backed up in file versioning systems. The PLC code and displays are currently using the older Concurrent Versioning System (CVS) while the EPICS application has been ported over to Git. Eventually all files will be moved to Git as part of SLAC's general upgrade path. Checkout documents are stored in CVS in a common repository with the PLC code in order to stay in sync with any changes to the logic.

INSTALLATION

A total of nine pump carts were deployed (Fig. 7) across the four different cryomodule strings (L0B, L1B, L2B, and L3B). The original plan called for a single cart in L0B as it consists of only a single cryomodule, but all other areas had at least two carts to handle the gas load. L3B in particular is the longest of the strings and was installed with a vacuum break in the middle, dividing the vacuum into two volumes. Each half of that string was given two carts each. Non-interlocked Commercial Off The Shelf (COTS) pumping stations were used initially to pump out and maintain the cryomodules' vacuum while the carts were being brought online and tested one at a time.

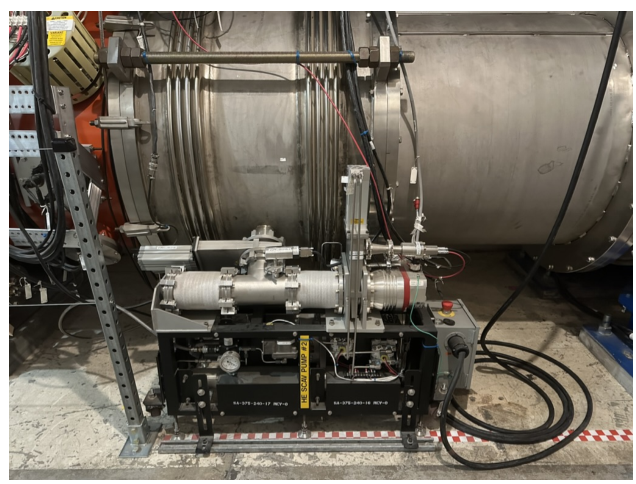

Figure 7: Pump cart as installed on cryomodule.

COMMISSIONING

A detailed test plan was written for fully exercising the system in production while the local COTS backup pumps were installed. This allowed the team to uncover flaws in the logic that would have been difficult to encounter during normal running. Minor issues with the PLC logic, sticky valve solenoids, and a noisy current transducer were observed during the process of commissioning. All issues encountered were able to be corrected and the carts have been running stably for over a year now.

After running at 2 K, larger than expected helium leaks were discovered in L3B. One cart each was moved from L1B and L2B to add supplemental pumping where the highest pressures were observed. The move was accomplished very smoothly as designed and gas loads have since been well

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within specifications. These issues aside, the commissioning went quite quickly with no real major problems. Once commissioning was completed and successful checkouts completed for all carts, the temporary back-up pumps were removed from operation.

CONCLUSION

All carts have been online and running continuously now for more than a year and the performance has proven to meet all specifications. It was originally thought that once the cryogenic system was cooled down to 2 K the RF cavities and fluid lines themselves would act as cryopumps maintaining the low pressure passively. The carts could then be valved off from the cryomodules and removed in order to preserve their lifetime (both from radiation and for routine maintenance on the mechanical parts). In practice this has so far been unrealistic as the helium leakage rate in some areas continues to necessitate the additional pumping provided by the carts. There have been several events to occur post-commissioning where the isolation vacuum was under high scrutiny (site power outages, cryo plant going offline for maintenance or repairs, etc.) and each time the carts have performed well. Thus far this system has proven to be reliable, low maintenance, and relatively simple to operate and change as needs arise.

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