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PLC BASED VACUUM CONTROLLER UPGRADE AND INTEGRATION AT THE ARGONNE TANDEM LINEAR ACCELERATOR SYSTEM

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Abstract

The installation of a new Electron Beam Ion Source (EBIS) to the Argonne Tandem Linear Accelerating System (ATLAS) at Argonne National Laboratory requires a vacuum system capable of providing pressures in the region of 1e-10 Torr. Historically, vacuum interlocks have been provided via analog logic chassis which are difficult to upgrade and maintain. In order to provide sufficient interlocks to protect high voltage components of the EBIS, a new programmable logic controller (PLC) based Vacuum control system has been developed and integrated into the rest of the accelerator supervisory control system. The PLC interfaces not only with fast acting relay based interlock signals but also with RS-485 based serial devices to monitor and control lower priority parameters such as pump speeds, vacuum pressure readout and set points, run hours and more. This work presents the structure and interface logic necessary to communicate with a range of vacuum gauges, turbo-molecular pumps and ion pump controllers. In addition, the strategy to interface vacuum control with the rest of the accelerator control system is presented.

INTRODUCTION TO ATLAS

The ATLAS accelerator is located at the United States Department of Energy's Argonne National Laboratory in the suburbs of Chicago, Illinois. It is a National User Facility capable of delivering ions from hydrogen to uranium for low energy nuclear physics research in order to perform analysis of the properties of the nucleus. As a result of the wide variation of beams delivered [1], re-tuning of the entire machine is necessary on a near weekly basis. After a series of upgrades, ATLAS will consist of two possible ion source lines, a common injection and beam transport line, and 8 different target areas. This wide range of possible machine configurations combined with the thousands of individual devices which support them present a very real challenge to operators to arrive at a final tune quickly.

Historical Vacuum Chassis

For several decades the ATLAS Vacuum Control System has been implemented via in-house custom built hardware chassis utilizing a combination of analog logic circuitry and complex programmable logic device (CPLDs). Several different versions of these chassis exist, depending on their intended purpose (Table 1). For example, some chassis do not provide a remote vacuum pressure reading while others may or may not control a turbo molecular pump, causing additional effort to integrate into the control system.

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Table 1: Variations of Vacuum Chassis at ATLAS

Rev #	Comments	Turbo?
1 A-D	Original Design, Built in 1984	No*
2 A-C	For Targets, No Remote Pressure	Yes
3 A-C	For Cryostats, No Remote Status	Yes
4A	Proposed, Full Remote Status	Yes

* Turbo control and monitoring added later

These chassis utilized silk-screen type front panels which must be re-spun for any change in device layout. An example of the current interface is below (Figure 1).



Figure 1: Example of silk screened front panel.

VACUUM PROJECT MANAGEMENT

A first order problem which was considered during a change in system design philosophy is how to define the scope of the project. Requirements of a basic vacuum interlock system, the range of possible vacuum component vendors, and interfaces with the final customers needed to be considered and documented. Limiting the possible component vendors supported by ATLAS was accomplished via a publicly accessible website containing a list of vendors and equipment supported. (Figure 2) [2].

Category	Manufacturer	Model/Type	Order Info	Supplier	Details
Cryo Pump	BROOKS CTI-CRYOGENICS	CRYO-TORR 8	8033351G002	Vacuum One	CF flanged, Vapor Pressure Gauge, Temp Probe, 1.33 CF Accessory port
Heater Blanket	BROOKS CTI-CRYOGENICS	Kit	8080002K012	Vacuum One	Used for Regeneration of CT 8 Pump, 120VAC
Temp/Controller 1	BROOKS CTI-CRYOGENICS	196443 Microprocessor Based	211998-0001	Vacuum One	10' cable, 2 Set Point Control, Digital Display, 3U chassis mount
Temp/Controller 2	BROOKS CTI-CRYOGENICS	196443 Microprocessor Based	211998-0002	Vacuum One	35' cable, 2 Set Point Control, Digital Display, 3U chassis mount
8200 Compressor	BROOKS CTI-CRYOGENICS	CRYO-TORR 8200	8032549G002	Vacuum One	208VAC 1PH, 1 CT8 pump operation, 1 year absorber life

Figure 2: Example of supported vacuum equipment.

Schematic Representation

Once an approved list of devices was defined, a detailed schematic representing each device in the new system was created (Figure 3). This schematic was used not only to physically place the new device in the system, but also to define device labels, device types, and interconnections.

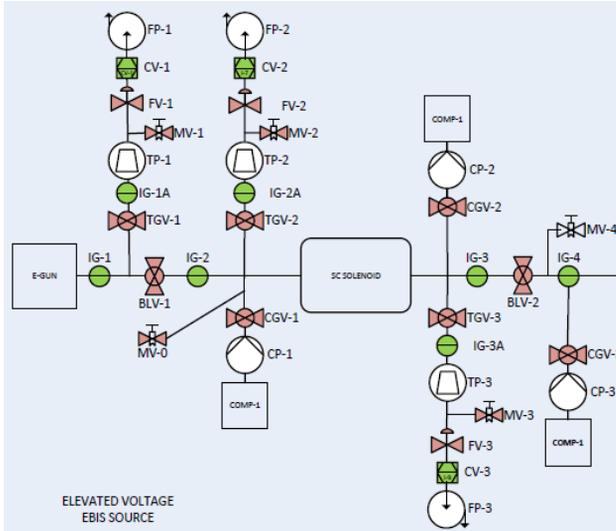


Figure 3: Schematic representation of vacuum system.

Vacuum Interface Tracking

The final steps of documenting vacuum system requirements was to create a list of devices based on the schematic representation and link them to the desired type of interface (Figure 4). We define 2 basic types of interfaces based mostly on speed and reliability: safety or interlock signals should be fast and simple, while low priority information can be slower and use more complex communication methods. This overall list of interfaces would in turn drive the requirements for the PLC itself.

NEW SYSTEM ARCHETECTURE

As a programmable vacuum solution is new to ATLAS, the Control System group was responsible for initial selection of a vendor for the PLC system. The specific vendor would be responsible for supporting not just programmable logic, but also the Human Machine Interface (HMI) via touchscreen systems and even potentially digital stripchart functionality. Finally, large consideration was given to integration into the rest of the ATLAS

4	5	6	7	8	9	10	11	12	13	14	15	16	# RS-485 # RS-232 CONTACTS 24V INPUT			
													Controller & Details	Interface	15	0
	Description	Manufacturer	Model #	1st Controller Pt# 370501-B1B-T1 (CH.A)	RS485	0	0	0	0							
	Gauge-CV1	Granville-Phillips	GP - 370 Stabil-Ion	2nd Controller Pt# 370501-B1B-T1 (CH.A)	RS485	0	0	0	0							
	Gauge-CV2	Granville-Phillips	GP - 370 Stabil-Ion	3rd Controller Pt# 370501-B1B-T1 (CH.A)	RS485	0	0	0	0							
	Gauge-CV3	Granville-Phillips	GP - 370 Stabil-Ion		RS485	0	0	0	0							
	Gauge-CV4	Granville-Phillips	GP - 275 Mini Convectron Module	Pt # 275534-EU ref. manual	RS485	1	0	2	0							
	Gauge-CV7	Granville-Phillips	GP - 275 Mini Convectron Module	Pt # 275534-EU ref. manual	RS485	1	0	2	0							
	Gauge-CV8	Granville-Phillips	GP - 275 Mini Convectron Module	Pt # 275534-EU ref. manual	RS485	1	0	2	0							
	Gauge-CV9 LEBL	Granville-Phillips	NOT PURCHASED	Pt # 275534-EU ref. manual	RS485	0	0	0	0							
	Gauge-CV10	Granville-Phillips	GP - 275 Mini Convectron Module	Pt # 275534-EU ref. manual	RS485	0	0	0	0							
	Gauge-CV11	Granville-Phillips	GP - 275 Mini Convectron Module	Pt # 275534-EU ref. manual	RS485	0	0	0	0							
	Gauge-CV12	Edwards	APG100-XM Pirani	TIC#03970100 (CH.#1)	?	0	0	0	0							
	Gauge-CV13	Edwards	APG100-XM Pirani	TIC#03970100 (CH.#2)	?	0	0	0	0							

Figure 4: Example of vacuum PLC interface tracking spreadsheet. The first four columns document each device in the system and their make and model. Then, the right four columns are used to track each interface method for the PLC.

Control System which uses a third-party software solution called VSystem [3] by Vista Controls Inc. This software provides low level handler calls to user-written routines, therefore any standard communications protocol should be able to be integrated.

PLC Vendor

With a comparatively small group of Control System Engineers, preference was given to PLC systems for which the group was already familiar. The Cryogenics group within ATLAS had already utilized Schneider Electric Modicon M340 PLCs to support increased automation (Figure 5). It was desired to leverage economies of scale and cost, and therefore the M340 line of PLCs was selected to be the vacuum system vendor as well.



Figure 5: Example of Schneider Electric M340 PLC.

The Modicon line of PLCs utilizes Schneider Electric's Unity Pro line of software to develop PLC code. Possible programming languages include IEC 61131-3 Ladder Diagram, Structured Text and Function Block Language [4]. In addition there is a wide range of possible Input/Output (IO) modules available for the M340 backplane including Analog (4-20ma, 0-10V, etc.), Digital 24V sourcing and contact inputs, Serial (RS-232 and RS-485) as well as application specific modules like thermocouple or SSI encoder modules.

Finally, the Modicon line of PLCs provide ModBUS/TCP ports in order to communicate with Magelis Touchscreens and provide maximum integration between PLC and Touchscreen to manage process variables and addresses between systems. These systems can access PLC I/O port data directly without any middle translation.

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Analog and Digital Signal Distribution



Figure 6: Range of signal distribution options considered, from hand-wired terminal blocks to fully custom PCBs.

The selection of signal distribution methods was perhaps the most complex part of the project. Several solutions were considered, from hand wired terminal blocks to completely custom printed circuit boards (PCBs) handling necessary signal routing and combinations (Figure 6). For example, several devices have a single DB-15 connector which combines power, 24V digital logic, and RS-232 or RS-485 serial communication in a single connector.



Figure 7: Example of fore pump/ion gauge interface (middle) and PLC distribution (top and bottom). The PLC distribution has rear terminal block connections.

The final interface hardware between the PLC and devices was designed in house (Figure 7). There are several interface designs for different devices. The first basic function is sending converted 24V signal from the device to the PLC for information such as device status, relay status, etc., or vice versa for controlling. It also provides an RS-485 connection bus for more advanced readout and controlling. Finally, it has some local control functions for convenient local control or device testing during startup.

For example, one design is for connection between Granville-Phillips series 390 Micro-Ion® ATM vacuum gauge, Edwards nXDS15i scroll pump and the PLC. It provides local control such as turning on/off the gauge or the pump, adjusting the speed of the pump and running a degas cycle of the 390 vacuum gauge. It also provides RS-485 connections and sends all interested relays' status to the PLC. The other designs follow the same requirement for other different vacuum devices.

PLC LOGIC AND SOFTWARE

At least two requirements of a vacuum control system are: 1.) Protect and operate the vacuum system and components, and 2.) To provide information to the end users and allow for control, monitor, and tracking. There has been a large body of work [5, 6] dedicated to centralizing databases of vacuum system information and utilizing this information to automatically generate PLC code templates. This can lead to much lower development times and higher reliability for large, complex machines. As ATLAS is a small machine compared to the Large Hadron Collider for example, the advantages in speed and standardization have not outweighed the development effort necessary to improve automation. PLC projects are still written manually, however code blocks are reused often.

Fast Control Sections

Fast controls for vacuum interlocks and machine safety are written in Ladder Logic for simplicity and speed (Figure 8). Currently, the fast sections are set to run in a round-robin scheme at a preprogrammed period of 10 milliseconds. This is considered fast enough for valves which can take hundreds of milliseconds to close. In addition, a watchdog time of 100 milliseconds is enabled to catch any undefined behaviour. Any fault will cause the PLC outputs to return to their 'safe' states.

The code takes a "valve-centric" view, in that each section is responsible for determining if a valve should be in the "open" or "shut" states. The input to these sections is the corresponding set of alarms which affect a valve. The concept of an "alarm" is related to either binary or integer setpoint, and the alarm condition is triggered if the input is equal to the alarm setpoint, and the alarm is "enabled".

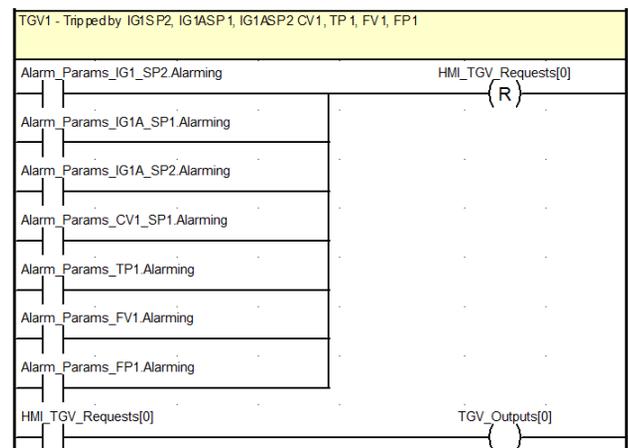


Figure 8: Ladder-logic section for turbo valve interlock.

Slow Control Sections

Slow control is primarily concerned with interrogating non-critical, non-real-time information from all devices within the vacuum system. The ATLAS Controls group has standardized on the RS-485 bus for serial communication, due to its ability to communicate via long distances with good noise rejection, and the ability to 'multi-drop' many devices on one RS-485 bus.

The slow control sections of PLC code are written in the more complex Structured Text programming language in order to leverage language tools like derived function blocks (analogous to ‘functions’ in the C language). In this way, blocks of code can be written to communicate with a single family of devices, and an internal table defines all the devices and their associated addresses. The code loops through the internal table and executes commands and monitor transactions to send or receive data from all the defined devices in order.

There is a small amount of reusability in this type of PLC code when combined with rudimentary objects. Objects here are defined as data structures inside of UnityPro. One datatype can be instantiated several times for each member of a device family, for example Edwards nXDS15i fore pumps (Figure 9). Then the code loops through a pre-defined set of commands and populates the parameters within each structure after each loop.

Name	Type
stBinaryInterlock	<Struct>
stForepumpParams	<Struct>
Device_Address	string[6]
Module_Address	string[6]
Substate_Error	INT
Value	string[32]
Alarm_Params	stRealAlarm
Command_Word_HMI	ARRAY[0..15] OF BOOL
Motor_Power	INT
stGaugeParams	<Struct>
stRealAlarm	<Struct>

Figure 9: Screenshot of fore pump parameter structure.

Human Machine Interface

The Magelis series of touchscreens from Schneider Electric has provided seamless integration to the PLC layer. A graphical editor is used to draw representative sections of beamlines and place indicators and buttons available to actuate valves or start/stop pumps. A secondary advantage is an online, real-time interface available from any Windows 8 PC running Internet Explorer ActiveX. This remote access functionality provides identical control screens as if the operator was standing in the same room as the touchscreen itself (Figure 10).

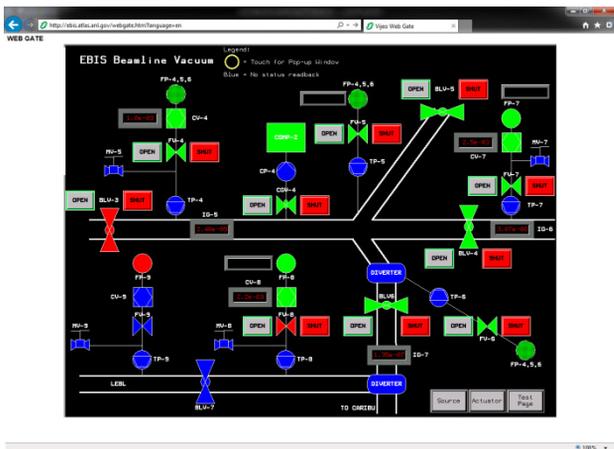


Figure 10: Internet Explorer remote access example.

CONCLUSION

The first application of this new PLC based Vacuum Control System has been installed at ATLAS for the new Electron Beam Ion Source (EBIS) platform. It has been tested to successfully operate valves and some vacuum interlock operations have been verified. Future work will soon include a second project to use PLC controls for a new ion source. By leveraging reuse of vacuum components and associated code, large economies of scale have been realized versus custom hardware chasses.

Continuing work has been allocated to the development of a standalone test rack which will include a PLC system, touchscreen and a standard vacuum pump configuration of rough pump, turbo, valves, and gauges. This way, further development can take place on an offline system, which greatly speeds development and testing.

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