Chapter 14

Ring Instrumentation and Controls

This chapter describes the technical design of the g-2 cryogenic and vacuum control system and other process systems supporting the experiment. This control system will be a copy of the typical Siemens S7-400 PLC (Programmable Logic Controller) control system as deployed by the Fermilab PPD/Mechanical Department. The g-2 cryogenic and vacuum system will be located on the Muon campus in the MC1 building and Muon g-2 experimental hall. This area is classified as ODH Class 0 area and has several large cryogenic and gas components. Cryogens include Liquid Helium and Liquid Nitrogen. This cryogenic system has approximately 600 electronic input sensing devices and 100 output devices. Input devices include temperature sensors, pressure transmitters, vacuum gages, level probes, and strain gages. Output devices include solenoid valves, control valves, and vacuum valves and pumps. All electronic and electrical control system equipment is air cooled and does not require any forced air cooling or water cooling. Cabinet air vents are provided for certain devices where appropriate. The control system equipment components are all commercially available products which are UL listed. The cryogenic control system has been designed and will be built following all the required rules and standards such as the NEC and NFPA 70E. All premises wiring is to be installed by Fermi Electrical contractors and licensed electricians.

14.1 Cryogenic/Vacuum Control System

The G-2 process controls also known as the slow controls will have a Siemens S7-400 PLC with S7-300 associated I/O modules as the master control system. There will be sub systems controlled by other PLCs that will report to the Master PLC. The Master PLC will also provide system data and interlocks to these subordinate PLC systems. The DAQ control system known as MIDAS will also be provided data and interlocks from this S7-400 master PLC. See the Control System Architecture drawing shown in figure 14.1.

14.1.1 Piping and Instrumentation Diagram

The piping and instrumentation diagram is shown in figure 14.2.

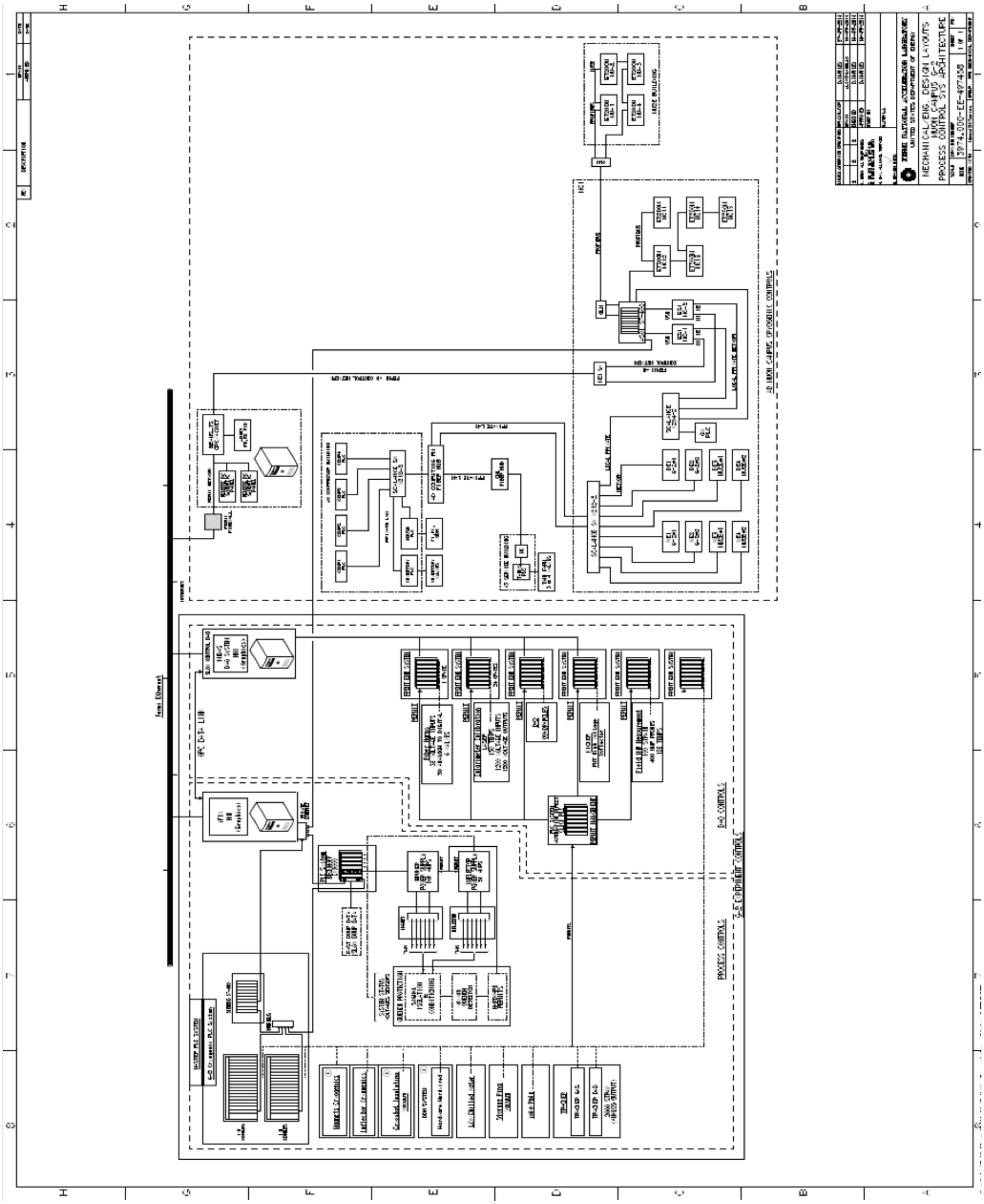

Figure 14.1: G-2 Controls System Architecture.

14.1.2 Programmable Logic Controller

The g-2 cryogenic/vacuum system will be controlled by a Siemens S7-400 PLC with S7-300 associated I/O modules (or equivalent industrial controls system) networked on a Profibus

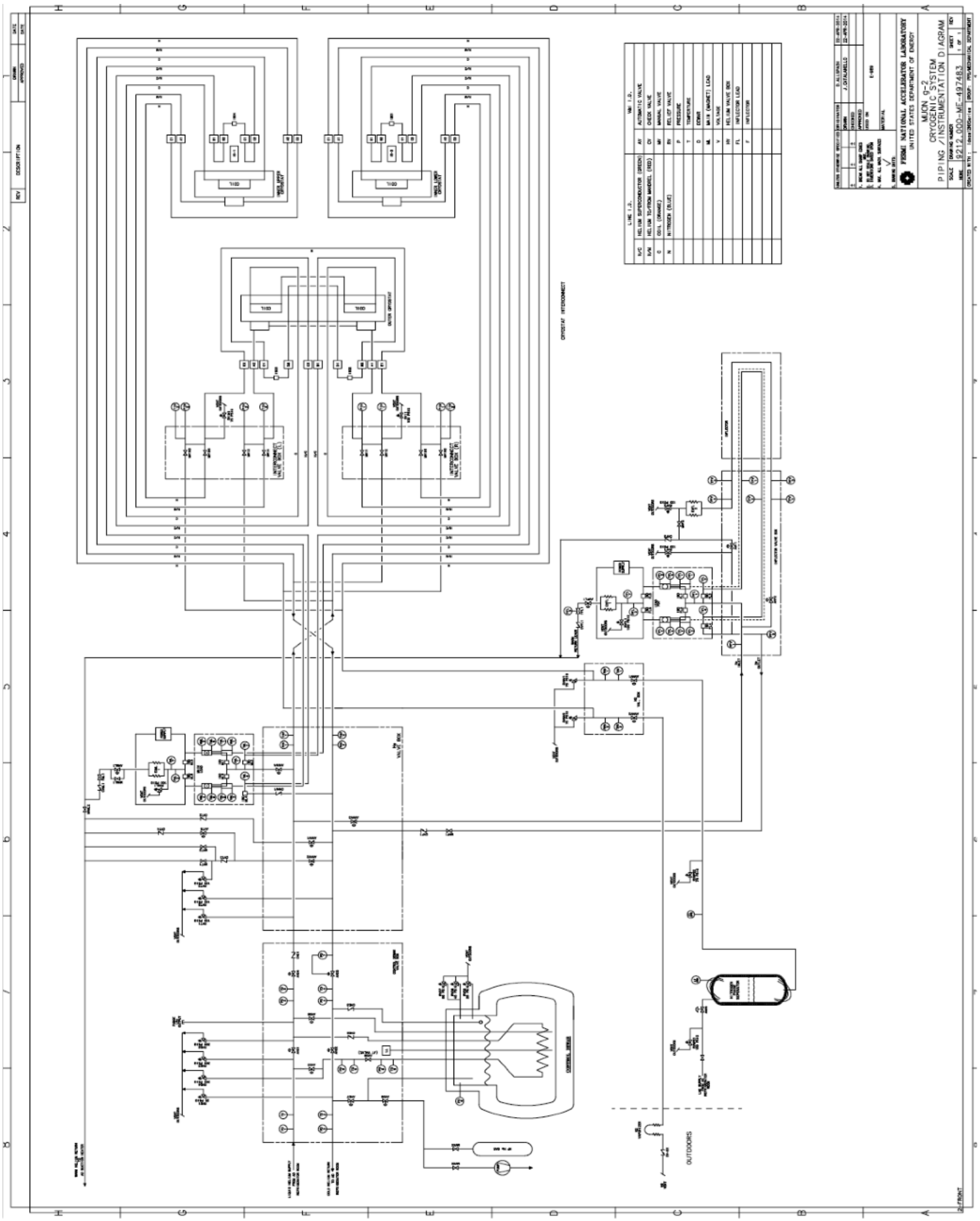

Figure 14.2: The G-2 Piping and Instrumentation Diagram.

network. This PLC system will be programmed using the Siemens S7 engineering programming software (or equivalent software meeting IEC 61131-3 standard). Siemens S7-400 PLC systems are currently in use at several Fermilab projects: LAPD, LBNE 35 Ton, Super CDMS, Microboone, and NML/CMTF.

14.1.3 Instrumentation

The g-2 cryogenic/vacuum system instrumentation will consist of commercial transducers, transmitters, valves, positioners, strain gauges, and thermometers. These commercial devices will have conventional signals that conform to the normal PLC module input and output signal ranges. The locations of these devices are given in reference [1]. PSIG, PSIA, and differential pressures will be measured by commercial transmitters that provide a 4-20 mA signal when available. A voltage range of 0-10 VDC will be an alternate range. Temperature will be measured by a Platinum 100 ohm RTD when possible, because the PLC system can read them directly. There are a number of Silicon diodes in the detector which will be measured by a Lakeshore temperature transmitter that provides a 4-20mA output to the PLC system. Any Cernox RTDs will also be measured with a Lakeshore temperature transmitter that provides a 4-20 mA signal to the PLC.

14.1.4 Strain Gauges

G-2 has strain gauges (full bridge style) mounted on the straps and radial stops, which are inside the cryostats and so are at cryogenic temperatures. Room temperature strain gauges are also mounted on the outer cryostat pushrods. Strain gauges will be used during commissioning to make sure that the forces agree with expectation. It is not necessary to read out all these strain gauges during regular experiment operation.

All strain gauges (4 wires per gauge) will be connected to a patch panel in the control room. A select subset of strain gauges will be read out with 2 Vishay D4 units, which will be connected to a Windows PC via USB.[1] Each Vishay D4 unit can read out 4 full-bridge strain gauges. A full description can be found in reference [2].

14.1.5 Vacuum Pump Control

Vacuum Pump stations are used to maintain various vacuum systems. These stations can be controlled by the Master PLC system using discrete I/O. Each pumping station also has isolation control valves. The vacuum pumps for the ring cryostats and beam vacuum chambers are described in tables 14.1.5 and 14.1.5.

The pump station remote control interface is shown in figure 14.3.

14.1.6 Programmable Logic Controller Input/Output

The g-2 cryogenic/vacuum system will be controlled by a Siemens S7-400 PLC with S7-300 associated I/O modules (or equivalent industrial controls system) networked on a Profibus

[1] Any strain gauge can be read out by manually plugging it into one of the Vishay D4 units.

Table 14.1: Summary of vacuum pumps for the ring cryostats. The Turbo Molecular Pumps (TMPs) pump helium and air to maintain the cryostat insulating vacuum pressure at less than 1E-4 Torr.

Pump Type	Location
Roots Blower	Lead Pot 1
Backup to Roots Blower	Upper 11 Position
TMP	Upper Lead Pot 2
TMP	Upper 7
TMP	Lower 7
TMP	Lower 11
TMP	Outer 7
TMP	Outer 11
TMP	Lower 3

Table 14.2: Summary of vacuum pumps for the ring beam vacuum chambers. The Turbo Molecular Pumps (TMPs) pump helium and air to maintain the cryostat insulating vacuum pressure at less than 1E-7 Torr.

Pump Type	Location
TMP	Chamber 6
TMP	Chamber 12
TMP	Chamber 8 (contains straw tracker)
TMP	Chamber 10 (contains straw tracker)
TMP	Chamber 2 (contains trolley drive)
Cryo Pump	Chamber 3
Cryo Pump	Chamber 9

network. The I/O modules convert digital PLC values to the field instrumentation and visa-versa. Table 14.1.6 summarizes the input/outputs.

14.1.7 Human Machine Interface

Human Machine Interface (HMI) controls will be provided through GEFANUC's iFIX software. iFIX connects to the S7-400 through Private Ethernet using an Industrial Gateway Server (IGS) driver included with the iFix software. iFIX will handle all operator security, computer alarming, and remote operator controls via the PPD-iFIX server. iFIX will also provide historical data through the PPD-iFIX historian. This historical data will be viewable in iFIX picture displays or on the web through the iFIX Proficy portal server. An example of an HMI for the LAPD experiment is shown in figure 14.4.

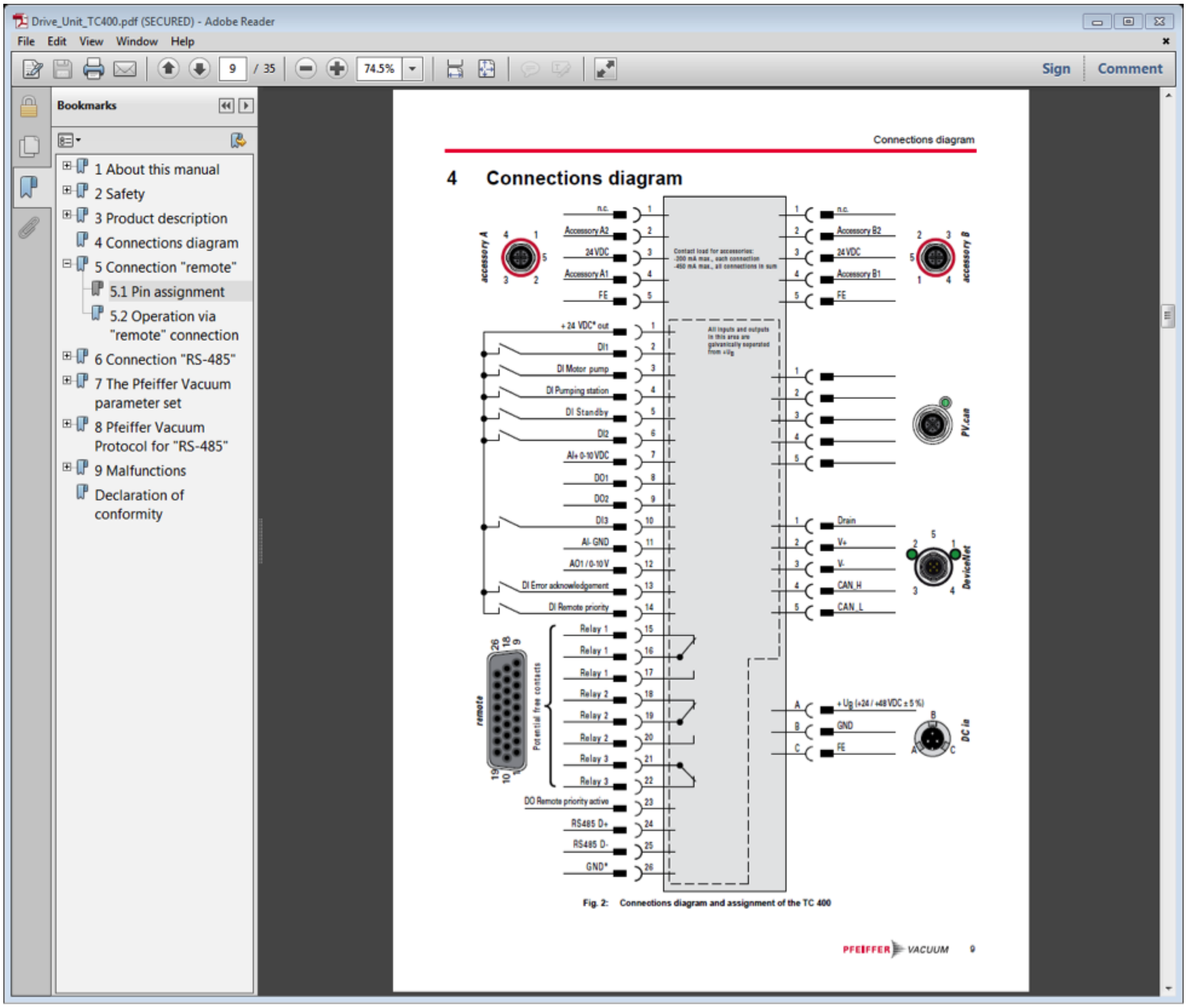

Figure 14.3: The Pump Station Remote Control Interface.

14.1.8 Helium Refrigerator Controls

The Helium liquefier system controls were designed and built by the Accelerator Division cryogenic department. This control system also consists of a Siemens S7-400 PLC as the core controller. This system will easily interface with the G-2 experiment master Siemens S7-400. The AD cryo S7-400 and the G-2 S7-400 PLC will share a private network. This private network will allow PLC variables to be shared in either direction and also allow the iFIX HMI to control the Helium refrigerator components.

14.1.9 System Communication and Data Sharing

Data will need to be shared between multiple systems outside of the Siemens master PLC system. There are a number of methods and protocols that allow data sharing such as OPC, MODBUS TCP/IP, SQL, and others. The Helium refrigerator communication will be

Table 14.3: Summary of types of input/outputs connections to the PLC

Subsystem	4-20mA 0-10 VDC Analog inputs	Silicon Diode inputs	RTD (PT100's) inputs	Discrete (digital) 24 VDC inputs	Discrete (digital) 24VDC outputs	24 VDC Analog outputs
Magnet Cryo	23	68	10	20	8	7
Inflector Cryo	10	10	10	10	10	4
Cryostat Vacuum	10	0	10	40	40	2
ODH	10	0	2	10	6	2
LCW/Chilled Water	10	0	10	10	10	4
Storage Ring Vacuum	7	0	7	30	30	4
Yoke/Pole	10	0	10	10	10	10
Tracker	10	0	10	10	10	10
DC System	10	0	10	10	10	4
Subtotal	100	78	79	150	134	47
Total	588					

through the private network that links the G-2 Master S7-400 PLC and the AD cryogenic control system S7-400 PLC. The DAQ system HMI is known as MIDAS. The most likely communication path between the G-2 Master Siemens S7-400 PLC and MIDAS will be OPC over Ethernet, but SQL is also possible. The magnet DC control system will be run by a Beckhoff CX5000 PLC. The Beckhoff CX 5000 PLC will be linked to the G-2 Master Siemens S7-400 PLC through PROFINET which is an industrial protocol supported by both systems

14.2 Life Safety and System Reliability

ODH System

The ODH system will utilize six MSA O2 heads. Two O2 heads will be located near the ceiling of the g-2 experimental hall, with another four O2 sensors located near the floor of the hall. There will be an ODH warning horn and strobe lamp. These will be centrally located in the hall. There will be two ventilation fans used to maintain the ODH risk class zero status in the g-2 hall. One fan will exhaust air out of the g-2 hall at the ceiling venting it outside. The second fan will supply fresh air to the building near the floor outside of the rings. These fans are controlled by the S7 PLC and can also be run locally using a switch mounted at the fan controls. The ODH system is hardwired to both fans such that during an ODH alarm both fans run. The O2 Sensors are MSA model A-UltimaX-PL-A-14-03D2-0000-100 and have a span of 0-25%. Each O2 sensor is to be wired to an MSA electronic controller

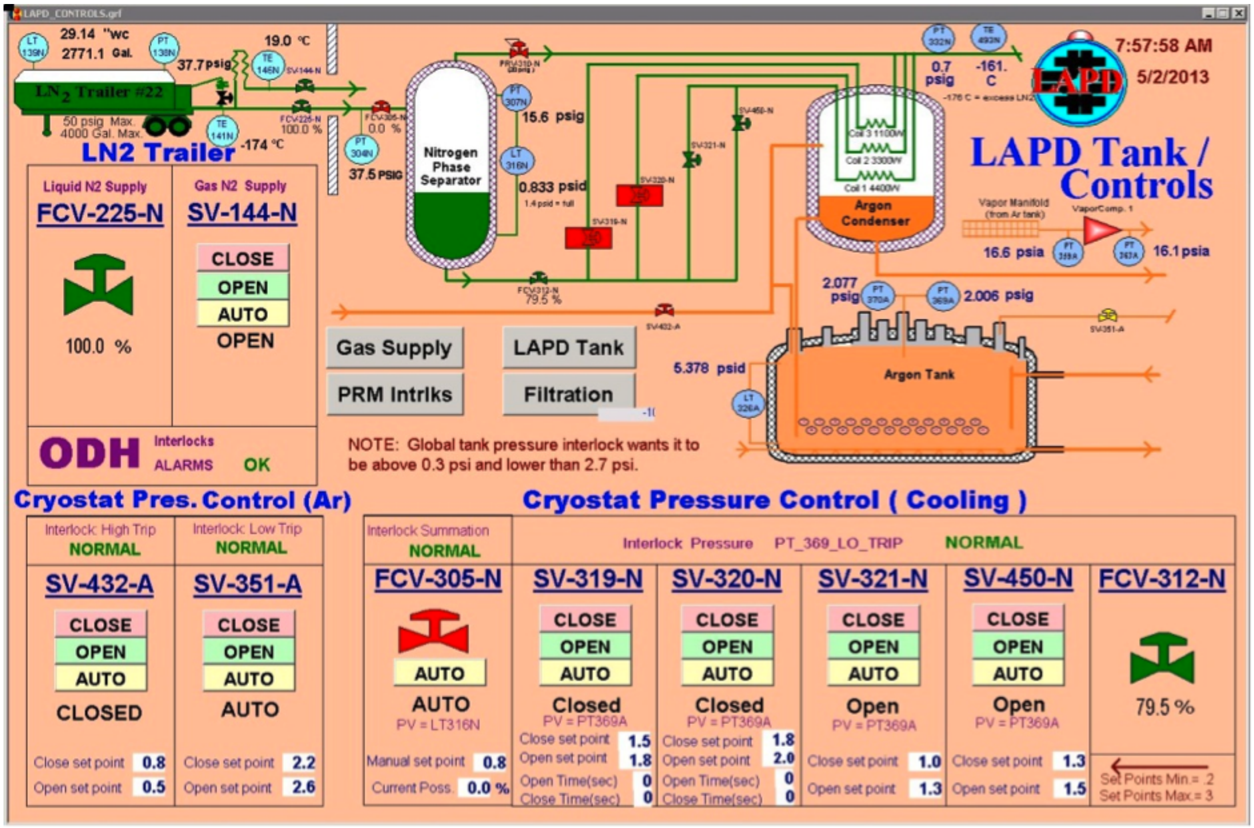

Figure 14.4: Human Machine Interface for the LAPD experiment.

which provides an analog output signal wired to the S7 PLC. This MSA electronic unit also provides relays which have three O2 level alarms thresholds, 18.5%, 18%, and 17.5%. The relay output that is set at 18.5% is wired directly to the ODH warning horns and strobe lamps located in MC1 and FIRUS. The MSA electronic unit also provides a trouble relay output which is also wired to the PLC and FIRUS. The trouble output is wired in a failsafe manner, such that loss of power or blown fuse to the ODH controls will generate a trouble alarm. The MSA equipment is wired directly to its own self-contained control circuitry in its own enclosure. This self-contained enclosure has its own power supply which is independent of the PLC control system, allowing the ODH system to function independently of the PLC control system. The power for this ODH system comes from a U.P.S. (Uninterruptible Power Supply).

14.2.1 Uninterruptible Power Supply (U.P.S.)

The control system U.P.S. is to be a commercial unit such as those manufactured by Powerware. The U.P.S. input power is fed from a premises powered outlet using the U.P.S. input line cord. This U.P.S. system will be natural gas generator backed. The diesel generator will be auto start with auto switchover on commercial power loss. There will be other loads on this generator as well. The U.P.S. has standard outlets located on the rear of the cabinet. An APC surge protector is located on the U.P.S. and its input power cord is plugged into the U.P.S output outlets. All relevant control system loads are plugged into the APC surge protector output outlets.

14.2.2 PLC Reliability and Redundancy

Siemens SIMATIC (S7 PLC and ET200M I/O modules) components meet all relevant international standards and are certified accordingly. Temperature and shock resistance are defined in the SIMATIC quality guidelines, as are vibration resistance or electromagnetic compatibility. The Siemens S7 PLC system equipment can be redundant at many different levels, from the PLC CPU (Hot Backup) to the module and instrument level. We expect to have the redundancy at the PLC level.

References

[1] Documentation of Instruments in the g-2 Cryostats, g-2 DocDB note 1653.

[2] Strain Gauge Configuration and Cost Estimate, g-2 DocDB note 861.

[3] Electrical Design Standards for Electronics to be used in Experiment Apparatus at Fermilab.

[4] EED/Infrastructure Doc. No:H011228A.