SHMS Q2Q3Dipole Acceptance Test Plans Operations and Lessons Learned

Paul Brindza

Q2Q3D ERR Oct. 12, 2016

Outline Q2Q3D Testing

- Magnet assembly testing
- Acceptance Test Plan and matrix
- Acceptance Criteria
- SHMS Magnet Operations
- Lessons learned for HB and Q1 testing
- Hall C magnet tests and ODH

Q2Q3D Commissioning Tests

- Initial magnet tests on SHMS after installation
  - Hipot magnet DC circuit to 500 Volts
  - Electrical checkout all instrumentation for isolation and sensor function
  - He Mass Spec Leak test of LHE and LN2 leak rate < 1 x10^-9 atmcc/sec
  - Pressure test to 6 Bar
- Intermediate magnet tests of I&C – validate all sensors and equipment
  - Connect I&C cables to PLC
  - Voltage taps (Dipole 16 plus spares, Quads 36 plus spares)
  - Thermometers, LNE(8) & LN2(8)
  - Cryogenic valve function (5 each magnet) and stroke calibration
  - Vacuum and pressure gauges (Vac, LHE, LN2)
  - Liquid level probes (LHE&LN2)

Q2Q3D Commissioning Tests

- Cryogenic tests
  - Decontamination of LHE space 1 PPM water, ~10 PPM N2
  - Connect cryo gas return lines and DC bus
  - Circulate warm He gas back to ESR typically for 24 hours to validate contamination levels
  - Connect LHE and LN2 supply U-tubes
- Cool Down First Stage
  - Target Temp < 100K
  - Use PLC controlled Helium gas coolant
  - Delta Temp in magnet < 50 K
  - He Coolant ~ 50 K < Magnet temp
  - Process uses a local PLC controlled heat exchanger to make any temperature He gas between 250 K and 80 K by blending 80 K Helium gas with 300 K He gas

Q2Q3D Commissioning Tests

- Cool down second stage
  - Require Magnet temp < 100K
  - Introduce LHe to magnet thru “Bottom fill” manifold in coil
  - Reduce temperature to 4.4 K
  - Fill magnet and CCR reservoir with Liquid Helium
  - Transition to cold return
  - Transition to “top fill”
  - Regulate liquid level (LHE & LN2) with PLC

Q2Q3D Commissioning Tests

- Low power tests
  - Check out I&C at 4.2 K
  - Check out cryogenic controls for stability
  - Validate all sensor functions
  - Calibrate quench detector ~ 10 milliVolt sensitivity
  - Verify DC circuit isolation
  - Operate up to ~ 400 Amps (10%) to validate DCPSU, QD, Voltage Taps
  - Verify support rod strain gauges at acceptable stress
  - Adjust magnet center if necessary
  - Magnets centers must remain within +/-3 mm of true magnetic center

Q2Q3D Magnet High Power Tests

- Progressive excitation in current steps(next table)
  - Ramp magnet to target current
  - Verify voltage taps
  - Verify support rod strain measurements
  - Verify Quench Detector sensitivity and balance
  - Ramp down and adjust coil if necessary
  - Soak at target current for one hour
  - Slow ramp down
  - Ramp up to target current and fast dump
  - Repeat at next current step

Q2Q3D High Power Test Matrix

% Iop	Itest Amps	Stored Energy	CL Mass flow	PSU Output Voltage	PSU Ramp Rate	Dump Resistor Temp (after FD)	Helium Pressure (after FD)	Magnet Temp (after FD)
	Amps	MJoules	SLPM	Volts	A/sec	C	ATM	K
0	0	0	138					
10	345	0.16	144					
25	863	1.00	154					
50	1725	4.00	170					
75	2588	9.00	186					
100	3450	16.0	201					
103	3554	17.0	203					

SHMS Dipole Test Matrix

% Iop`	Current	Stored Energy (SE) % of MOP	CL Mass flow Setting	PSU Output Voltage	PSU Ramp Rate	Dump Resistor Temperature (after FD)	Helium Pressure (after FD)	Magnet Temperature (after FD)
	Amps	MJoules	SLPM He gas	Volts	A/sec	C	ATM	K
0	0	0	138					
10	366	0.10	145					
25	915	0.63	155					
50	1830	2.50	172					
75	2745	5.63	189					
100	3660	10.0	205					
109	4000	12.0	212					

SHMS Q2Q3 Test matrix

Acceptance Criteria Q2Q3D

- Magnets shall meet design requirements(see table)
- Magnets shall operate with
  - Acceptable current **(103 % dipole, 109% Q2Q3)**
  - Acceptable Heat Leak **(QHe < 40w , QLN2 < 100w)**
  - Acceptable insulating vacuum leak rate **(LR <10^-9)**
  - Acceptable magnetic multipoles (see table)
  - Acceptable Instrumentation function (see table)
  - Acceptable magnetic center (< 3mm)
- No requirement for training quenches
- No requirement for PLC, DCPSU, QD, QP, CCR

Design requirements

Nominal DIPOLE Maximum Field	**T**	**4.25**
Required field orientation		Horizontal
Required Integral Field Strength	T-M	12.3
EFL(nominal RD)	m	2.90
Required Coil Radius (cold)	m	0.36
Required NI Total	Kilo Amp-Turns	3,918
Required Reservoir hold time	time	1 hour
Required cool down time	time	10 days
Coil voltage isolation	volts	500 V

Nominal Q2Q3 Gradient Max	**T/m**	**14.4**
Required Field orientation		Normal
Nominal EFL	m	1.61
Required coil Radius (cold)	m	0.36
B(r=pole)	T	5.184
Required Integral Grad strength	T/M -M	23.2
Required NI Total	Kilo-Amps-turns	7,940
Required Reservoir hold time	time	1 hour
Required cool down time	time	10 days
Coil Voltage isolation		500 V

Multipole tables

Maximum Integral Harmonics Dipole		
$\int B_{(1)}$	Dipole	100 %
$\int B_{(3)}/ B_{(1)}$	Sexapole	+ 2.0 %
$\int B_{(5)}/ B_{(1)}$	Decapole	- 1.0 %
$\int B_{(7))}/ B_{(1)}$	Tetradecapole	+ 0.5 %
$\int B_{(9)}/ B_{(1)}$	Octaadecapole	-0.5 %
$\Sigma \int B_{(n>9)}/ B_{(1)}$	All Others	|0.1 %|

Maximum Integral Harmonics Q2Q3		
$\int B_{(2)}$	Quadrupole	100 %
$\int B_{(3)}/ B_{(2)}$	Sexapole	0.10 %
$\int B_{(4)}/ B_{(2)}$	Octapole	-0.05 %
$\int B_{(6)}/ B_{(2)}$	Dodecapole	-0.3 %
$\int B_{(8)}/ B_{(2)}$	Hexadecapole	0.01 %
$\int B_{(10)}/ B_{(2)}$	Icosapole	-0.10 %
$\Sigma \int B_{(n>10)}/ B_{(2)}$	All Others	|0.05 %|

Q2Q3D instrumentation Table

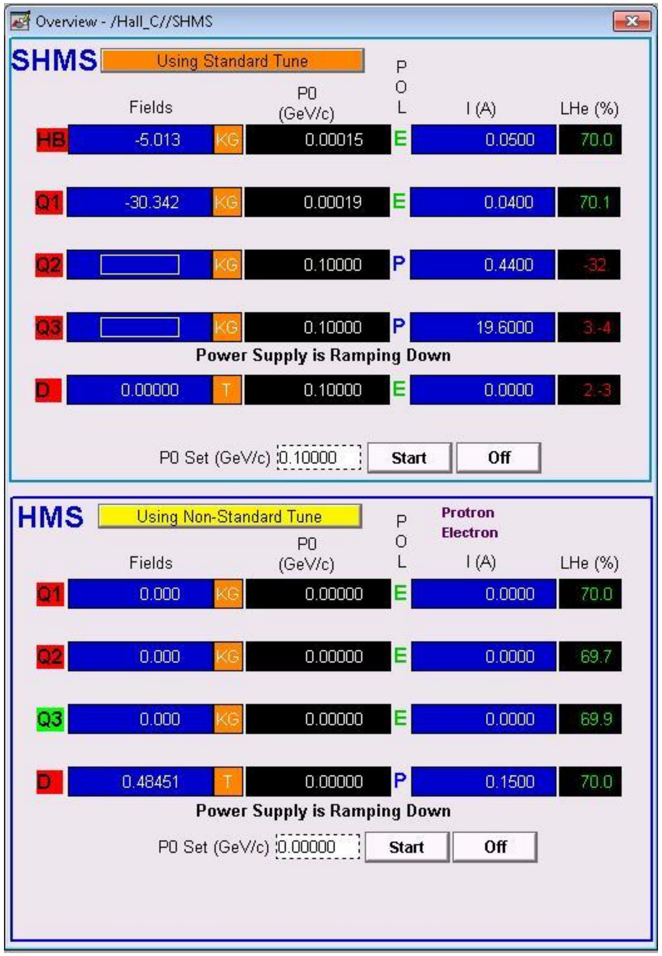
	Dipole	Quad	D spares	Q spares	type
Voltage taps	8	18	8	18	
HE temp sensors	4	4	4	4	Cernox
LN2 Temp sensors	4	4	4	4	PT100
Strain Gauges	8	8	8	8	2 axis

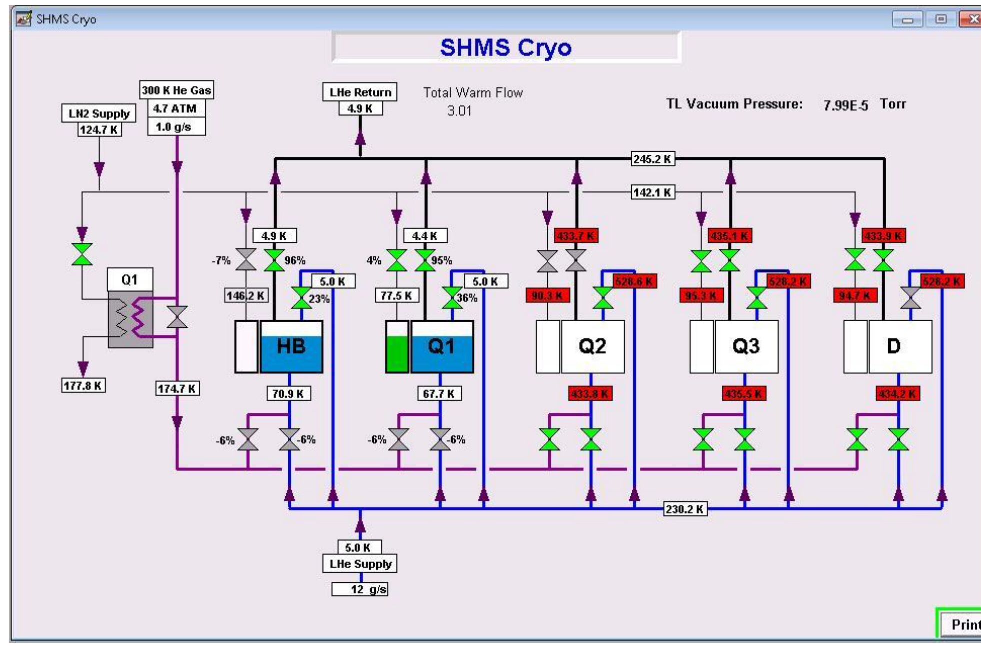
Note: CCR instrumentation by JLAB

SHMS Magnet Operations

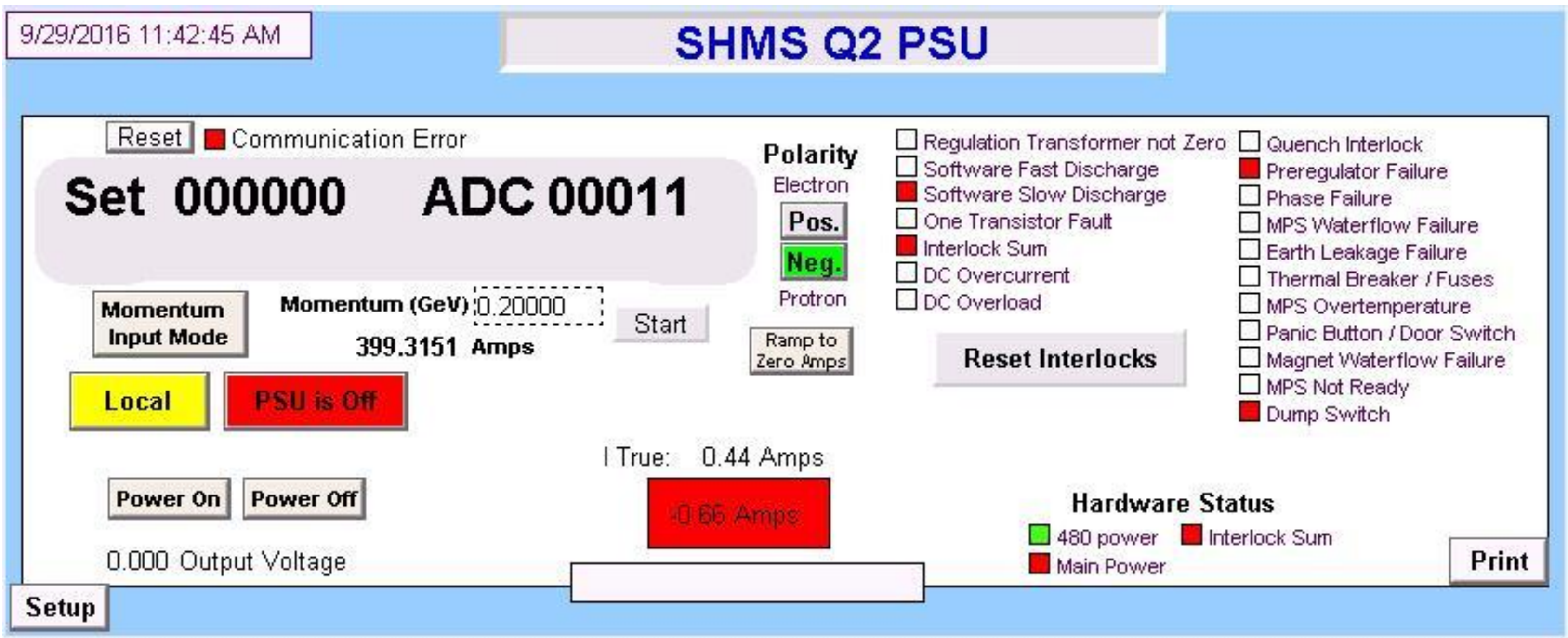
- Magnet Testing uses the same control system as routine operations for Experimental Physics
- PLC control is used on HMS (15 years) and SHMS (2 years)
- PLC executes operators commands
- PLC displays, logs and graphs temp, strain, voltages, pressures, vales, liquid level
- PlC reacts to and logs interlocks
- Quench Detection is analogue and digital


0.0 MeV
0.00 uA
Login
Rotation
Status
PSU
Valves
LHe
LN2
Voltage
SHMS HB
SHMS Q1
SHMS Q2
SHMS Q3
SHMS Dipole
PSU
Valves
LHe
LN2
Voltage
Forces
Interlock

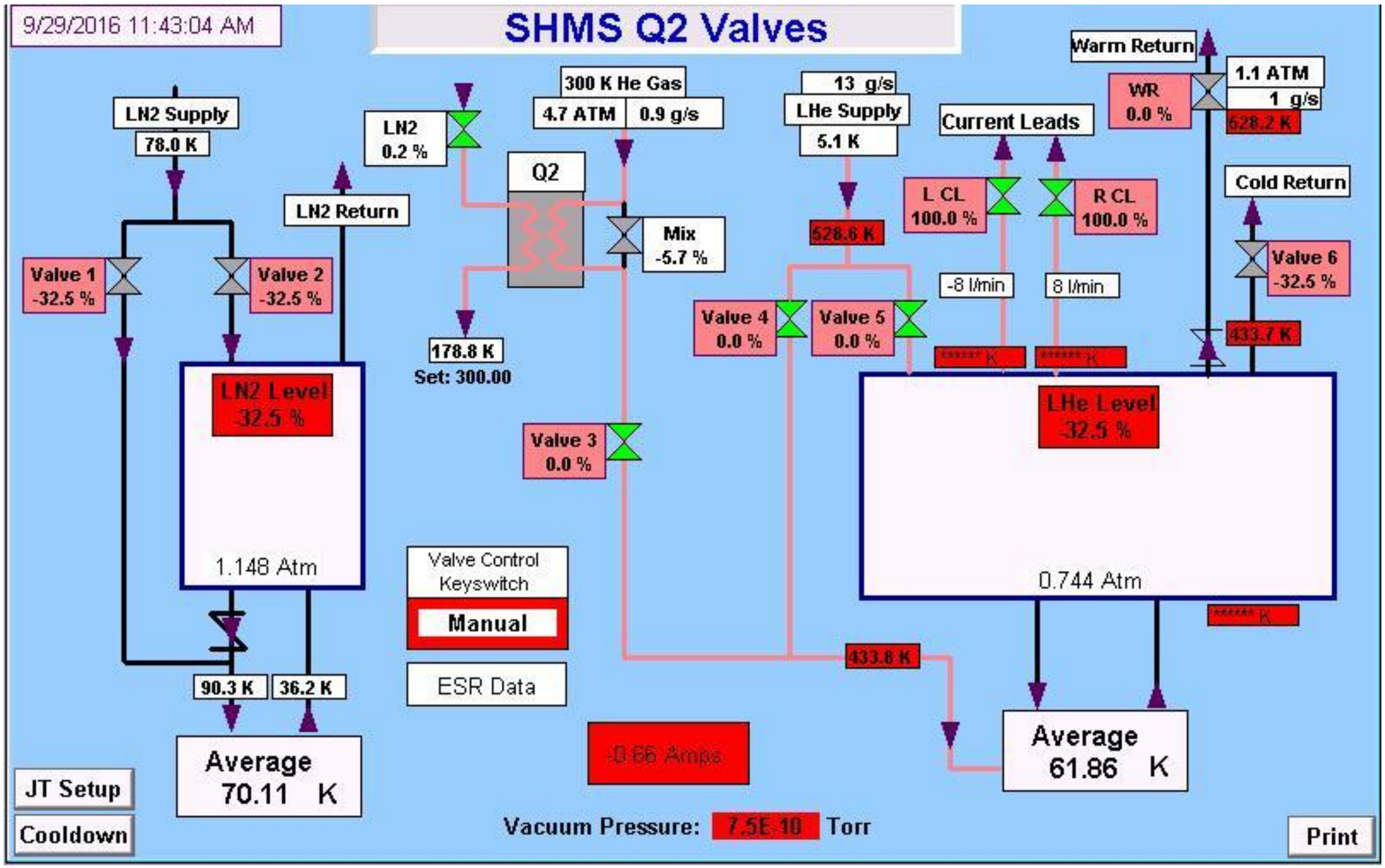

Overview - /Hall_C//SHMS
SHMS
Using Standard Tune
Fields
P0 (GeV/c)
POL
I (A)
LHe (%)
HB -5.013 KG 0.00015 E 0.0500 70.0
Q1 -30.342 KG 0.00019 E 0.0400 70.1
Q2 KG 0.10000 P 0.4400 -32
Q3 KG 0.10000 P 19.6000 3.4
Power Supply is Ramping Down
D 0.00000 T 0.10000 E 0.0000 2.3
P0 Set (GeV/c) 0.10000
Start
Off
HMS
Using Non-Standard Tune
Protron
Electron
Fields
P0 (GeV/c)
POL
I (A)
LHe (%)
Q1 0.000 KG 0.00000 E 0.0000 70.0
Q2 0.000 KG 0.00000 E 0.0000 69.7
Q3 0.000 KG 0.00000 E 0.0000 69.9
D 0.48451 T 0.00000 P 0.1500 70.0
Power Supply is Ramping Down
P0 Set (GeV/c) 0.00000
Start
Off


SHMS Cryo
SHMS Cryo
LN2 Supply
124.7 K
300 K He Gas
4.7 ATM
1.0 g/s
LHe Return
4.9 K
Total Warm Flow
3.01
TL Vacuum Pressure: 7.99E-5 Torr
245.2 K
142.1 K
Q1
HB
Q1
Q2
Q3
D
177.8 K
174.7 K
70.9 K
67.7 K
230.2 K
5.0 K
LHe Supply
12 g/s
Print

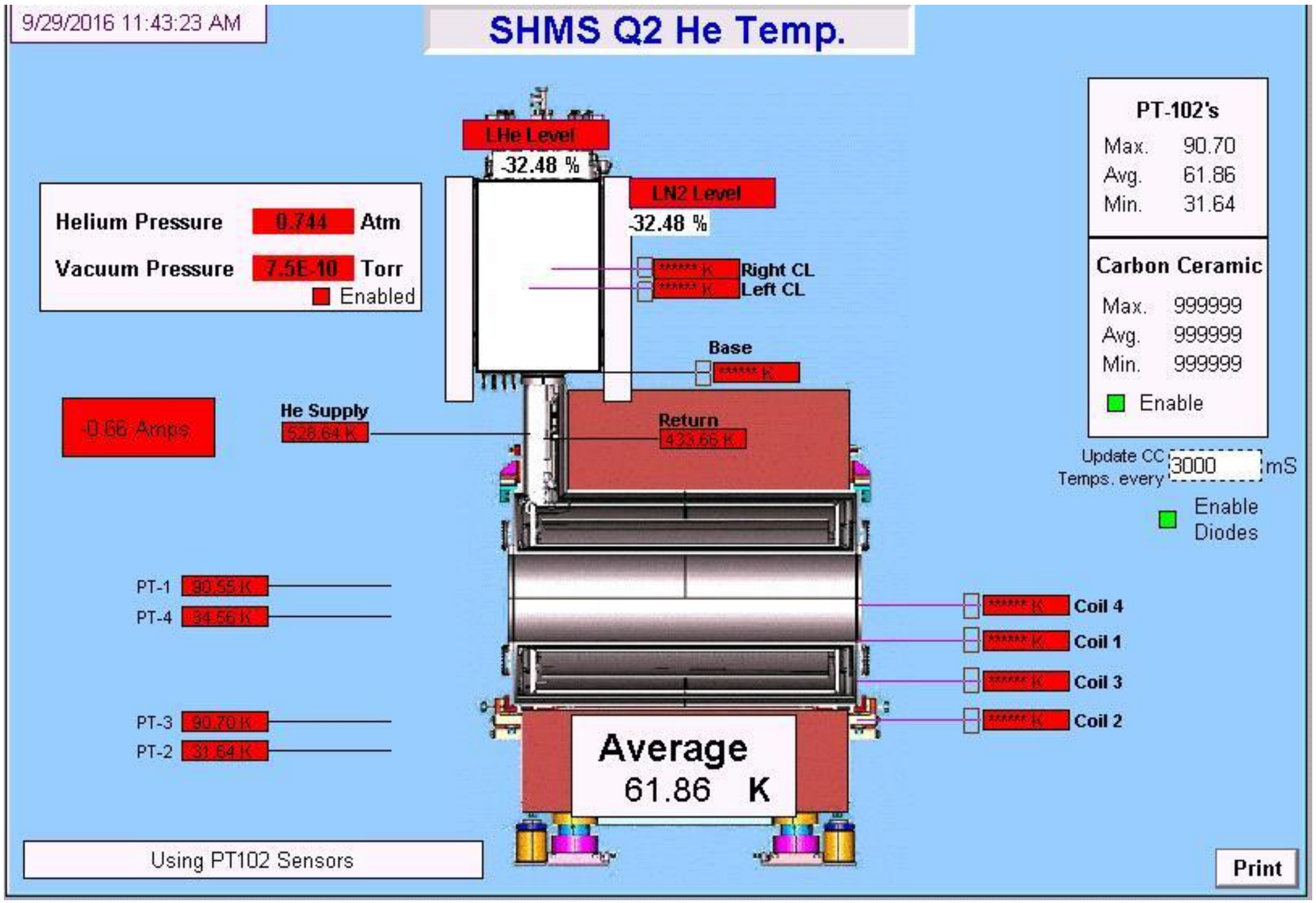
Q2 PSU Control Screen



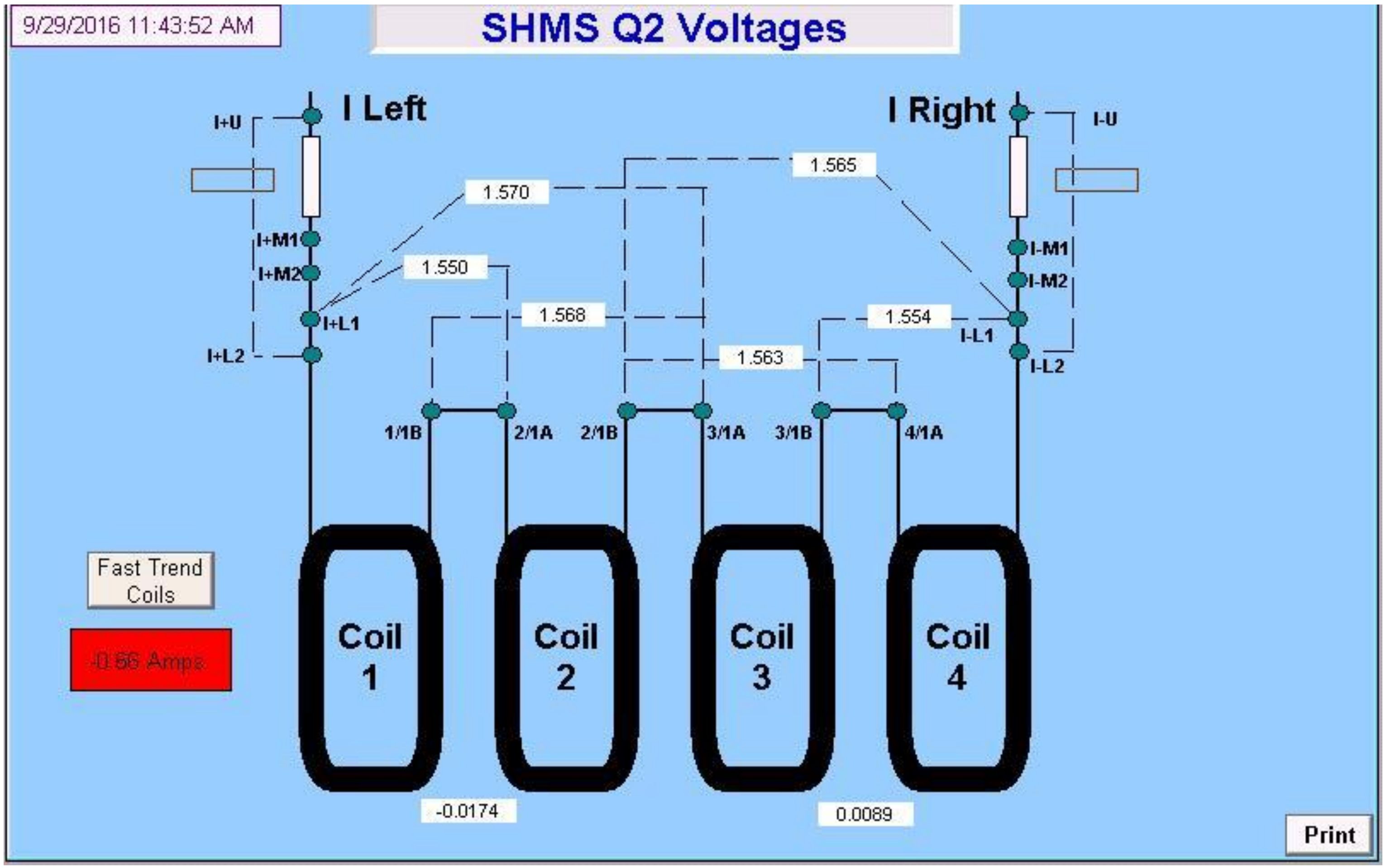
SHMS Q2 Cryogenic Screen



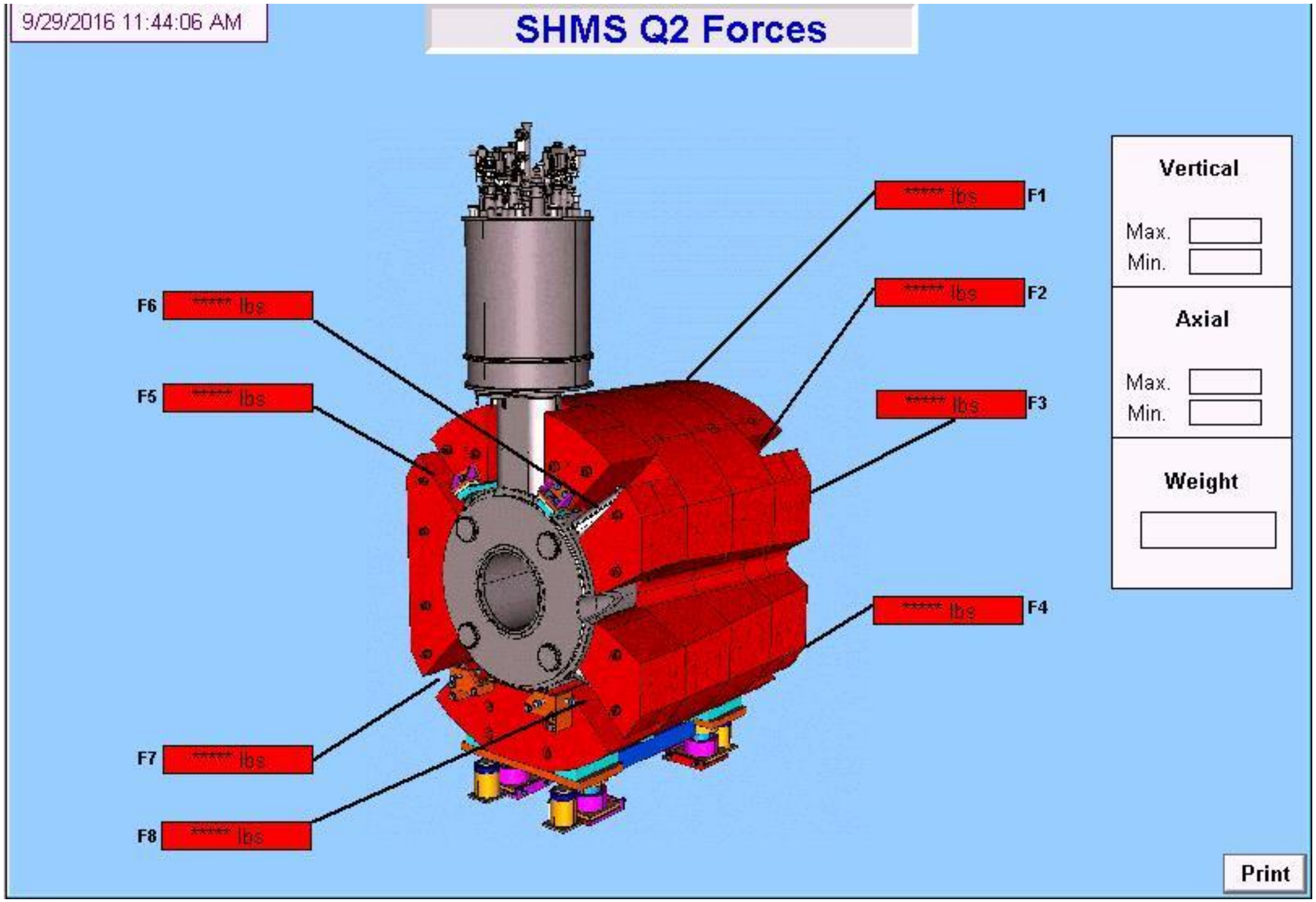
SHMS Q2 Helium Temp Screen



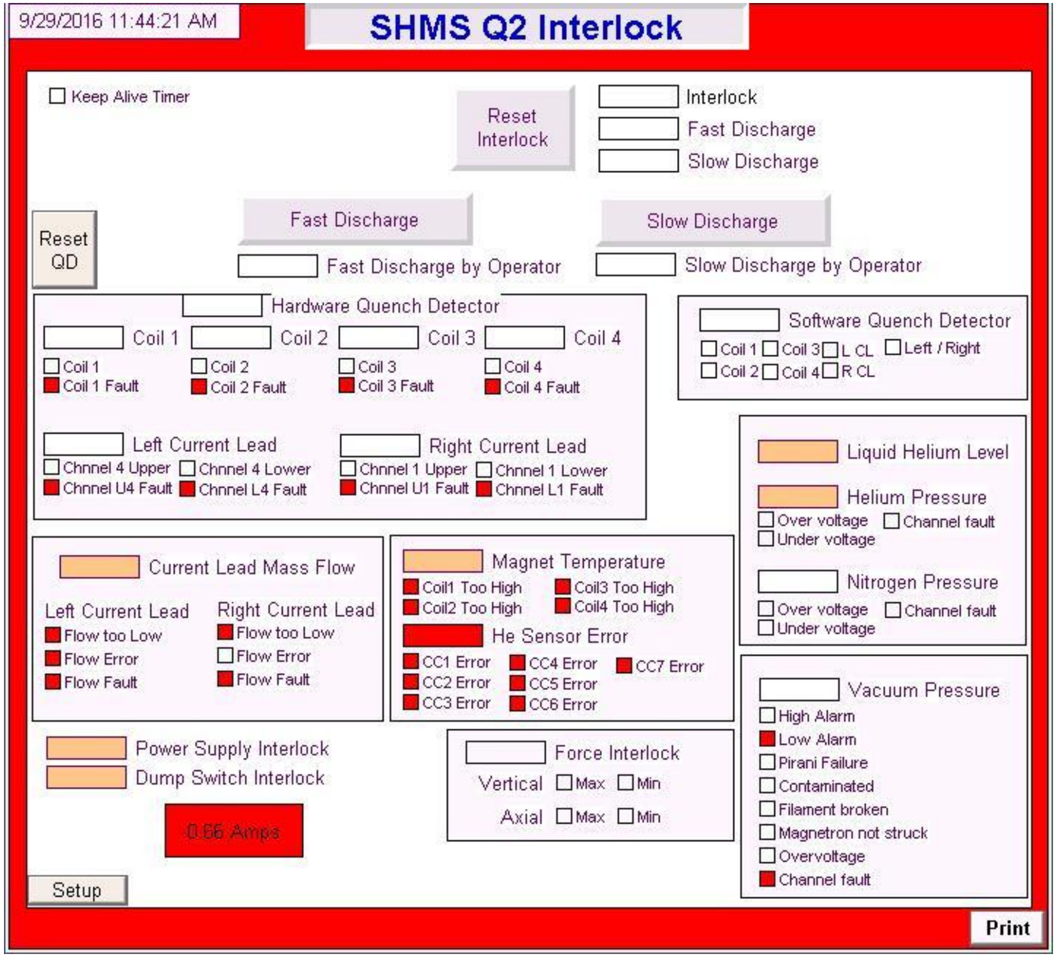
SHMS Q2 Coil Voltages



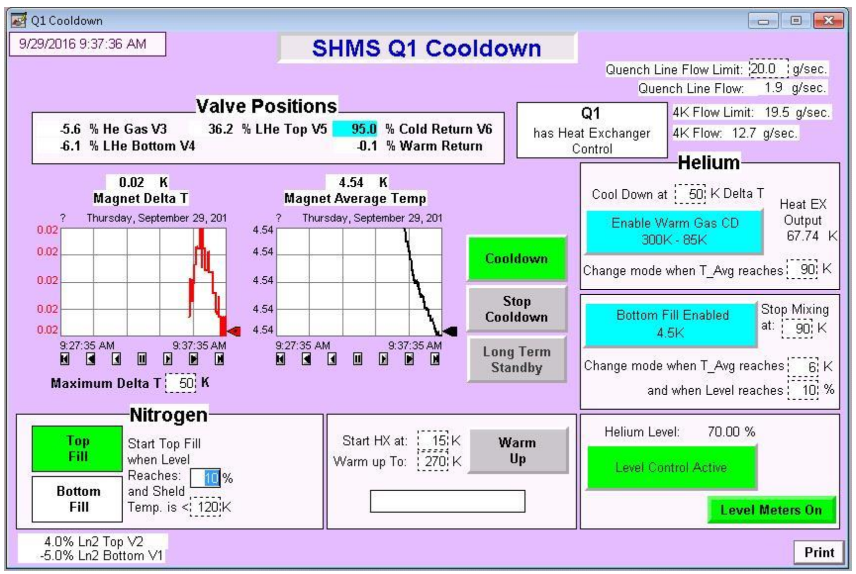
SHMS Q2 Suspension Link Screen

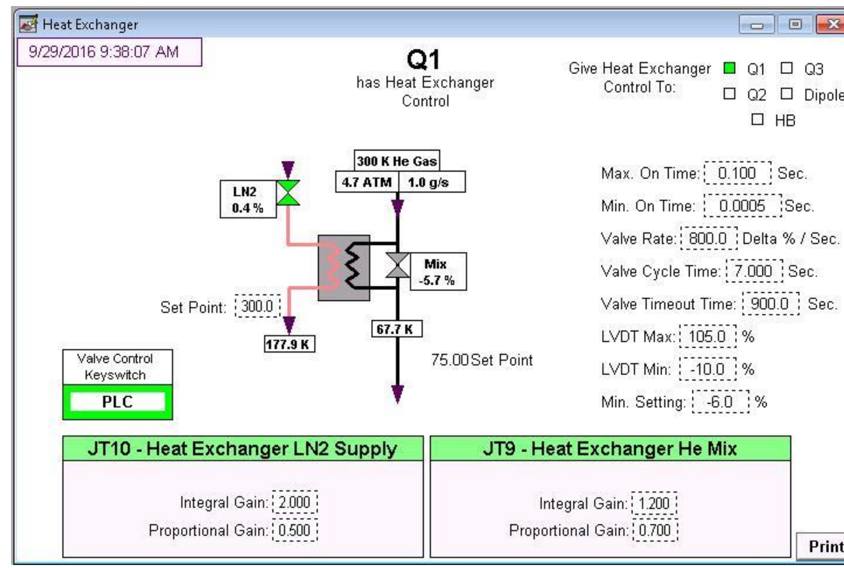


SHMS Q2 Interlocks



SHMS Cool Down Control





Lessons Learned So Far-Q1

- Q1 Testing was routine up to 3000 Amps(110%)
  - Q1 never quenched
  - Q1 arrived with a small vacuum vessel leak that was fixed after testing
  - DCPS, QD, QP worked OK
  - PLC worked well- some software bugs fixed
  - Cryogenics worked well
  - Cooldown uncovered a transfer line bug- fixed

Lessons Learned so Far - HB

- HB tested OK and trained up to 4000 Amps(102%)
  - Shield Eddy Current issue required a crusade
    - Progressive testing campaign
    - Special fast data acquisition
    - Lots of detailed analysis
    - Modified operating plan- floating shield- reduced dump resistor
  - Big surprise was that the Dump Switch was very slow @ 900 mSec- fixed now at 35 mSec
  - Testing took one year and ~ 35 training quenches
  - Another surprise – HB Quenches were non events ie. very low energy deposited in the HB and fast recovery
  - All DCPS dump switches are now fast

Lessons Learned Summary

- Hall C Cryogenics , PLC Controls, DCPSU, Quench Detection, Quench Protection and Cool Down System rely on old tested systems that all worked extremely well- albeit with a few bugs
- All five DCPS upgraded with fast Dump Switch
- Hall C Engineering now has the skill and resources for a fast high accuracy data acquisition system if needed thanks to HB Eddy Current crusade.
- System bugs all worked out on Q1 the 1st magnet tested

Q2Q3D Magnet Testing and ODH

- Quench Training of the Q2Q3D is likely especially for the dipole
- Dipole helium inventory ~ 1000 LL helium
- Expelling the entire inventory of 1000 L results in a Hall C ODH rating of 0 except for above the crane rail where ODH 1 is reached.
- See Hall C ODH analysis in ERR documentation

Acceptance Test Summary

- Dipole Q2Q3 are designed to spec. Passed
- Factory Electrical tests - Passed
- Max. Current, Heat Leak, Leak rate, Multipoles, Coil Isolation, Sensor function to be tested at JLAB
- PLC Control will be used to execute the Test Plan
- Test Plan procedure will permit safe testing of the Q2Q3D
- Your comments please?

Appendix –Addressing the charge

1. Mechanical & cryogenics:

- Pressure vessel ratings of each vessel in the magnets- Brindza & Porheil Presentation, JLAB Tech Spec's
- Applicable codes & analysis- Brindza & Porheil Presentation, ERR documents, JLAB Tech Spec's
- Material test/code documentation- ERR Q2Q3D Documents, FDR documents
- cryogenic circuit: supply, return, cooling procedures- Brindza Presnentation
- relief sizing to handle a quench or catastrophic loss of vacuum- Lassiter & Porheil presentations, ERR Q2Q3D documents
- ODH analysis - worst credible release- ODH Analysis hall C
- cryogenic controls- Brindza & Lassiter presentations

2. Power & magnet protection:

- quench analysis- Porheil presentation
- power lead ratings - flow requirements, voltage drop, etc.- Brindza Presentation
- power supply characteristics/design
- magnet interlock & protection system(s)
- quantities monitored/expected thresholds/behavior logic
- failure mode and effect analysis/"what if" analysis

3. Magnet operation & documentation:

- instrumentation and controls- Brindza & Lassiter presentations
- drawings and schematics for the complete magnet system- See ERR Documents
- work rules/training requirements- See OSP 63388
- operation manual/procedures – Brindza & Lassiter presentations PLC, DCPS,QD, OSP 63388
- Integration with other magnets/systems- NIS
- identification of any special issue in the magnet system that requires special training and/or attention- See ERR Documents "Support Rod Adjustment Procedure

Charge Item 4

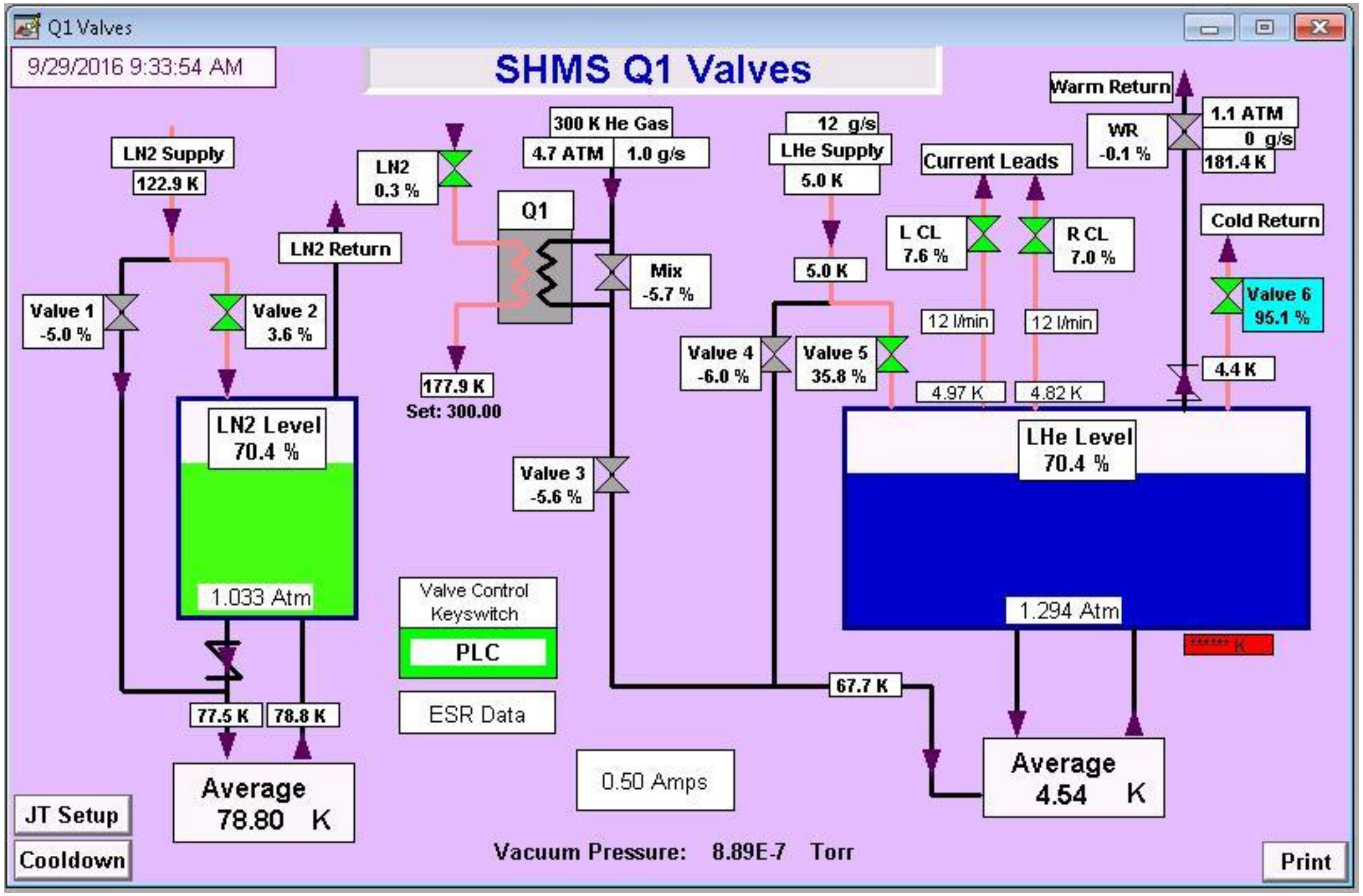
Plan toward completion and resource loaded schedule for the three magnets.

See Lassiter’s Presentation

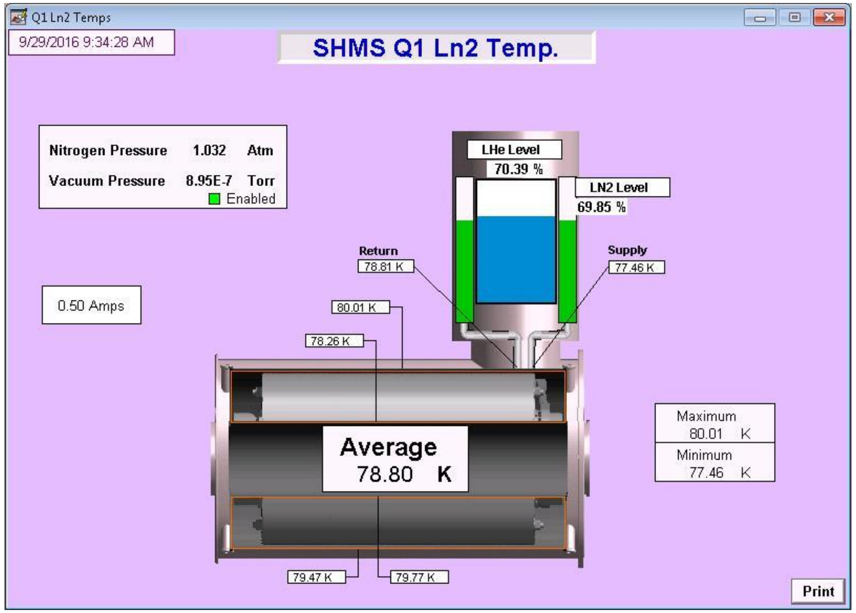
Appendix 2
Q1 screen with actual data

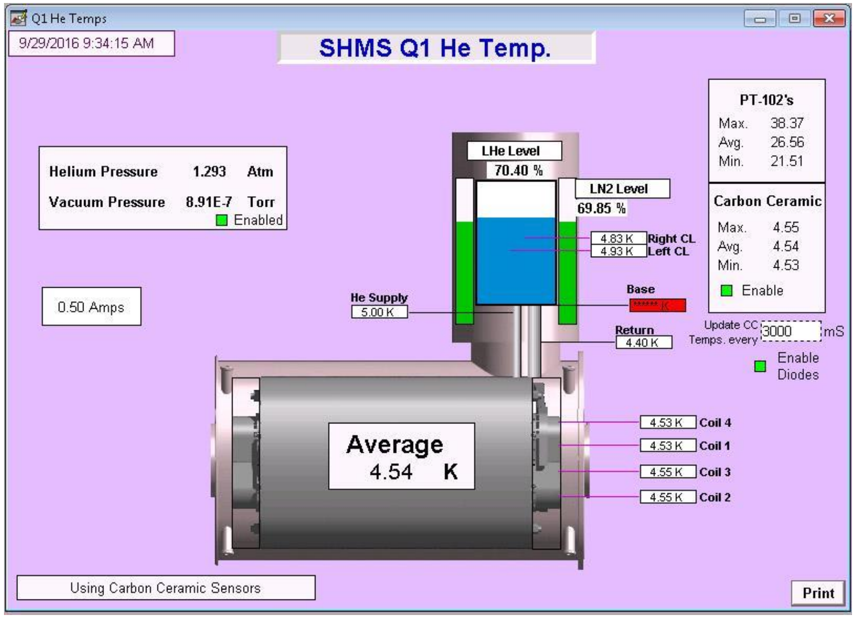
October 12, 2016

SHMS Magnet Cryogenic Screen

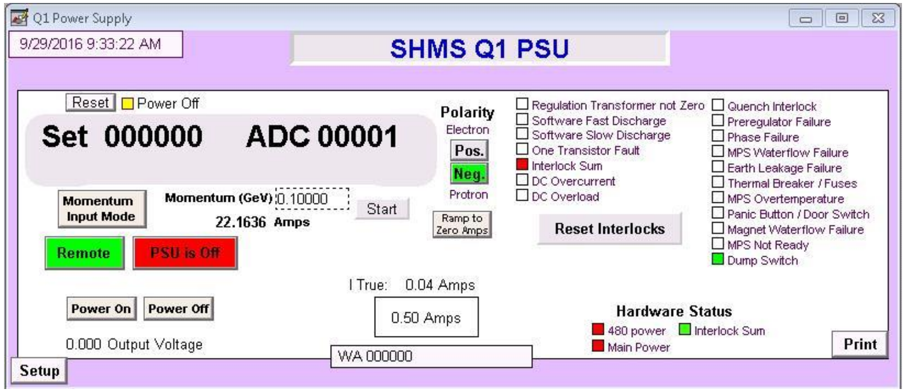


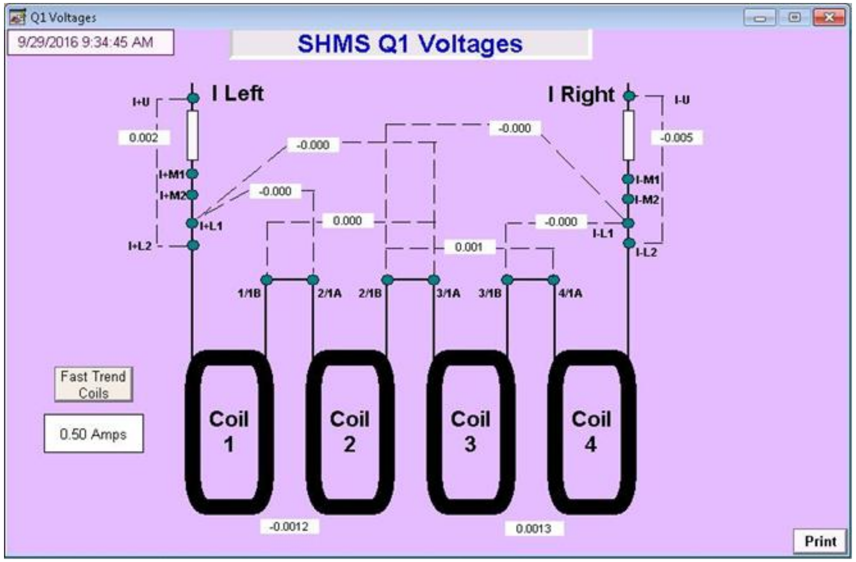
SHMS Temperature Monitoring





Power Supply and coil voltages





Appendix 3

Magnet installation activities and resources

Magnet Arrival Actions and Resources

- Magnet Arrival
  - Uncrating and Inspection at Port of Norfolk by SigmaPhi and Hall C engineering
  - Download shock recorder at Port of Norfolk
  - Magnet Delivery to Hall C floor is by contractor and is SigmaPhi's responsibility
  - Contractor is Lockwood Brothers for all three magnets
  - Delivery places the magnet on the Hall C floor
- Magnet Arrival Hall C/JLAB
  - Simple arrival tests and electrical exam by Hall C Engineering
  - JLAB alignment group – one day for fiducialization

Heavy Installation and Resources

- Heavy Installation - all activities are serial
  - Q2Q3 rigging and installation on SHMS by Hall C Tech Crew
  - Dipole due to weight has rigging onto SHMS by Lockwood Bros.
  - Yoke re-assemblies by Hall C Tech crew
  - Replace access platform around magnet CCR Hall C Tech Crew
  - Remove shipping pins and flanges Hall C Tech Crew
  - Install Vacuum blank covers and pump flanges Hall C Tech Crew
  - Install vacuum pumps and start pump down Hall C Tech Crew

Magnet Checkout and Resources

- Magnet Checkout- requires system experts
  - Leak and Pressure test – Hall C Engineering
  - Hipot coil and electrical check of sensors-Hall C Engineering
  - Install valve actuators and calibrate- Hall C Tech (1)
  - Connect I&C cables, DC bus- Spectrometer Support group
  - Check Instrumentation and controls-Hall C Engineering & Hall C Tech
  - Dry LHE space with warm N2 gas- Hall C Tech (1)
  - Connect cryogas lines- Hall C Techs (2)
  - Flow purge with He gas from ESR - Hall C Tech (1)
  - Install U-tubes ESR- Hall C Techs, ESR operator & Hall C Engineering

Dipole Only Chimney Assembly and Resources

- Dipole Chimney Assembly
  - Install platform on Dipole yoke- Hall C tech crew
  - Install shield house roof- Hall C tech crew
  - Install CCR stand & CCR and Align- Hall C tech crew
  - Close Shield roof- Hall C tech crew
  - **Splice SC Bus- SigmaPhi (1) and Hall C tech (1)**
  - **Install I&C cables- SigmaPhi (1) and Hall C tech(1)**
  - Hipot coil and elec tests- Hall C Engineering
  - Weld LHe and LN2 tubes- Hall C welder(1) & Tech (1)
  - Install MLI and shield- Hall C tech (2)
  - Install chimney vacuum can and weld- Hall C welder(1) and Tech (1)
  - Evacuate Dipole- Hall C tech (1)
  - Leak and pressure test- Hall C Engineering

Magnet Cool Down and Resources

- Magnet Cool Down-duration 2-3 weeks
  - Entire Cool Down is managed by PLC Controls
  - Cool to 80 K Requires Helium gas , LN2 & electricity
  - Humans monitor remotely – ESR operator & Hall C Engineering
  - Transition to LHE cooling at ~100K by PLC control
  - Bottom fill of Magnet by PLC Control
  - Transition to top fill by PLC Control
  - Transition to warm return by PLC Control
  - Liquid Level regulation by PLC Control
  - Tune up Liquid Level PID loops – Hall C Engineering

Magnet Testing and Resources

- Magnet Testing requires system experts
  - Verify cryogenic regulation –Hall C Engineering
  - Controls and Instrumentation check out -Hall C Engineering
  - DCPS check out -Hall C Engineering
  - Quench Detector calibration- -Hall C Engineering
  - Low power ~ 10% magnet tests – SigmaPhi & Hall C Engineering
  - Progressive excitation to higher power – SigmaPhi & Hall C Engineering
  - Adjustment of support rods as needed –SigmaPhi & Hall C Engineering
  - Celebrate - everyone