Jefferson Lab

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HALL B PROCEDURE NO.:
B000000400-P001 Rev H

TITLE: **Hall B Solenoid Power-Up and Power-Down Procedure**

BY: R. Fair

DATE: 01 / 24 / 2017

Intended Checker and Approvers:
CHK: P. Ghoshal
1. APP: R. Rajput-Ghoshal
2. APP:
3. APP: 3rd Approver (if necessary)

H		Update MPS control screen	R. Fair	P. Ghoshal	R. Rajput-Ghoshal		05.28.20
G		Update with new interlock screen	R. Fair	P. Ghoshal	R. Rajput-Ghoshal		10.29.19
F		Updated energization steps to include 'Turn ON MPS' and tidied up text for the other steps.	R. Fair	P. Ghoshal	R. Rajput-Ghoshal		02.07.19
E		Updated MPS EPICS screenshot as two hall sensors are now 'dead'. Added step in energization process to check that all SOE timestamps have been 'zeroed' and updated Appendix A accordingly. Added section on solenoid key parameters.	R. Fair	P. Ghoshal	R. Rajput-Ghoshal		01.24.19
D		Added ramp-down rate	R. Fair	P. Ghoshal	R. Rajput-Ghoshal		08.08.18
C		Included charts showing times to ramp to target currents and information on E-Stops and QD resets	R. Fair	P. Ghoshal	R. Rajput-Ghoshal		08.06.18
B		Ensure magnet is ramped to zero Amps before reversing polarity. Updated SME contact names.	R. Fair	P. Ghoshal	R. Rajput-Ghoshal		12.12.17

A		Updated to reflect changes made during commissioning and for normal operation	R.Fair	P. Ghoshal	R. Rajput-Ghoshal		09.26.17
REV.	ECO#	DESCRIPTION	BY	CHK.	APP.	APP.	DATE
SUMMARY OF CHANGES FROM PREVIOUS REVISION:							

Contents

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1. Hall B Solenoid Key Parameters

CLAS12 HALL B SOLENOID – REQUIRED AND MEASURED PERFORMANCE PARAMETERS

Performance parameter	Broad Specification	Actual measured
B_0	5T	5.0 T
$L = B_0^{-1}.\int B.dl$ (B_0 field at the center (0,0,0) of solenoid)	L = 1 to 1.4 m	1.41 m
Field Uniformity in Target Area	$\Delta B/B_0 < 10^{-4}$ in cylinder 0.04 mm length x 0.025 mm (100 ppm)	318 ppm *(to be improved using superconducting corrector coils around the target)*
Field at HTCC PMTs location	B < 35 Gauss - for the four HTCC PMT locations	B = 6-22 Gauss
Field at TOF PMTs location	B < 1200 Gauss - for the two TOF PMT locations	B = 43-1041Gauss

CLAS12 HALL B SOLENOID - MAGNET PARAMETERS

PARAMETER	DESIGN VALUE SOLENOID
Number of Coils	**4 + 1**
Coil structure	Layer wound
Total Number of turns	5096 (2 x 840 + 2 x 1012+1392
NbTi Rutherford cable	SSC 36 strands
Nominal current (A)	2416
Central field (T)	5
Conductor Peak Field (T)	6.56
Field homogeneity in ϕ25mm x L40 mm cylinder	1 x 10-4
Inductance (H)	5.89
Stored Energy (MJ)	17
Warm bore (mm)	780
Total weight (KG)	18800
Cooling mode	Conduction cooled
Supply temperature (K)	4.5
Temperature margin	1.5
Stabilized conductor	W17 mm x T2.5 mm copper channel
Turn to Turn Insulation	0.004” Glass Tape ½ Lap
Heat Shield Cooling	Helium boil-off

2. Scope and Requirements

This document describes the power up and power down procedure for the Hall B CLAS12 Solenoid superconducting magnet.

This document is organized as follows:

- ‘Shift Workers Guide for Regular Physics Operation’ for the magnet/power supply, based on the commissioning experience
- An appendix containing the Power-up sequence followed during 12 GeV commissioning, at the conclusion of which the project transferred operational responsibility to Hall B
- Power-up sequence for post-commissioning phase (but prior to regular operations) as envisioned during commissioning (but open to modifications based on Hall B priorities)
- An appendix summarizing the observed individual coil temperature rise during ramping which was then used to guide the selection of the final ramp rates for normal operation

3. Shift Workers Guide for Regular Physics Operations

Introduction

This section summarizes the power up (energization) and power down (de-energization) procedure for the Hall B CLAS12 Solenoid superconducting magnet. It is primarily a guide for shift workers.

Emergency Contact Names

Should the need arise, first call the 'ENGINEER ON CALL' – his/her name and contact telephone number should be on the white board in the Hall B Counting Room.

The ENGINEER ON CALL will then (if necessary) call in the relevant Subject Matter Experts (SME).

Table I – Contact Names

Sub-System	SME
Magnet Power Supply	Denny Insley, Krister Bruhwel, Sarin Philip
Magnet Fast Dump / Quench	Ruben Fair, Probir Ghoshal, Renuka Rajput-Ghoshal
Cryogenics System	Denny Insley, Dave Kashy
Vacuum System	David Anderson
Instrumentation and Control	Nick Sandoval, Brian Eng, Pablo Campero-Rojas

Pre-Energization Checklists

The following checks should already have been completed.

IF IN DOUBT PLEASE CONTACT THE 'ENGINEER ON CALL'

1. *B000000400-P003 Hall B Solenoid Pre-Power-Up Instrument Checkout Procedure*
2. *B000000402-P002 Hall B Superconducting Magnets Power Supply Maintenance Turn-On Checklist (incl. Solenoid)*
3. *B000000402-P001 Hall B Superconducting Magnets Pre-Power-Up Power Supply Internal Interlock Checklist (incl. Solenoid)*
4. *B000000400-P007 Hall B Solenoid Pre-Power-Up Water-Cooled Leads Checkout Procedure*
5. *B000000400-P008 Hall B Solenoid Pre-Power-Up Vapor-Cooled Leads Checkout Procedure*
6. *B000000400-P004 Hall B Solenoid Pre-Power-Up Quench Detector Tuning Procedure*
7. *B000000400-P005 Hall B Solenoid Pre-Power-Up Interlock Checkout Procedure*
8. *B000000400-P002 Hall B Solenoid Operations Power Up Checklists*

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Magnet Operation

The Operator controls the Magnet Power Supply (MPS) for the magnet and monitors the magnet and its sub-systems via a PLC using a series of EPICS screens. Bringing the Solenoid to operating field is done in a series of current steps at differing current ramp (or slew) rates. Each time the operator establishes the desired current on the EPICS screen and clicks anywhere outside the 'Set point' box, the power supply automatically begins the ramp to the set point current at a pre-programmed slew rate (Ramp rate). This slew rate is set within the PLC code and is not accessible to the operator.

Shift workers will typically operate the magnet using the Magnet Power Supply (MPS) Control Screen shown in Figure 1 below.

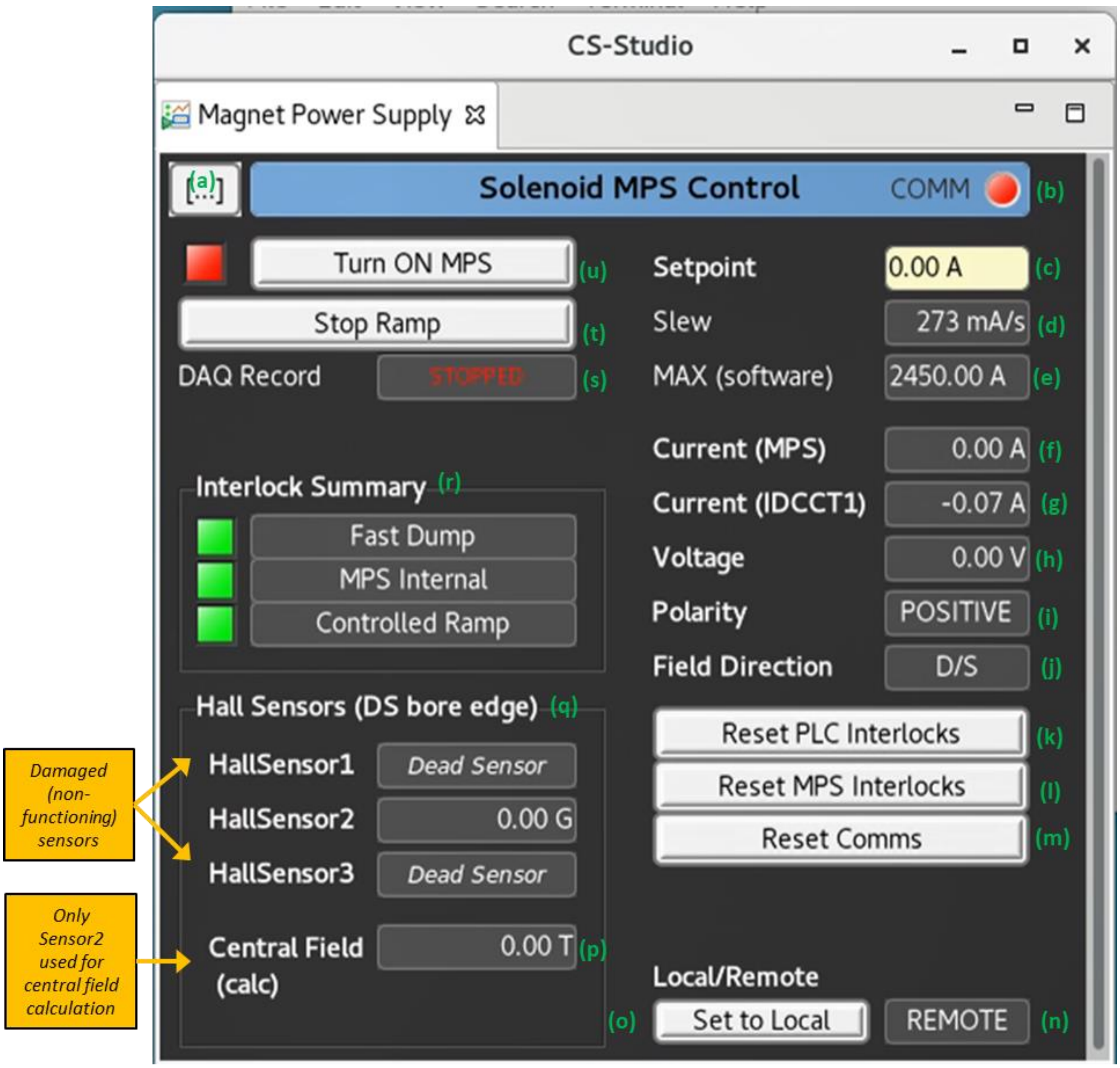

Figure 1 - JLab MPS Control – EPICS (Ref. Table II)

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Table II – Definition of items on MPS EPICS Control Screen *(Ref. Figure 1)*

	Description	Expected value
(a)	Launches 6 additional windows: (i) Interlock Status (ii) Fast DAQ recording control (iii) Fast DAQ live data (iv) Current Mismatch Alarm Settings (v) SOE Timestamps (vi) Trigger Fast Dump (**Note: Initiates a fast dump of the magnet current through the dump resistor**. On clicking this button, the user will be prompted to confirm the action.)	N/A
(b)	Ethernet to RS232 communication between Solenoid PLC, 435NBX, and Magnet Power Supply	GREEN
(c)	Desired target current. User types value into the field shown and presses enter. Use a negative value if ramping to a negative polarity. User only needs to enter a number (no units are required). If the user enters a number greater than the software limit (see (e) below), the target current (c) will automatically be set to (e). **NOTE: WHEN CHANGING POLARITY, ALWAYS RAMP TO ZERO FIRST, WAIT 5 MINUTES AND THEN TYPE IN THE NEW CURRENT SET POINT.**	User Defined
(d)	Slew rate (ramp rate) set within the PLC. The rate will automatically be altered depending on target current set by the user.	Pre-defined within code
(e)	Software (SW) magnet current limit set within the PLC.	2450 A
(f)	Magnet current read back from magnet power supply, A/D 16 bit	N/A
(g)	Magnet current read back from buffered analog output of control crate (through cRIO)	N/A
(h)	Magnet Power Supply output voltage	N/A
(i)	Magnetic field direction (and therefore magnet current polarity).	Downstream (D/S) or Upstream (U/S)
(j)	Magnetic field direction. Positive field direction is D/S when looking downstream.	N/A
(k)	Resets only the PLC internal interlocks	N/A
(l)	Resets only MPS interlocks	N/A
(m)	Resets only communications between the magnet power supply and PLC	N/A
(n)	Read back of MPS control state: will display 'LOCAL' in local mode, and 'REMOTE' in remote mode. Must be set to 'REMOTE' to allow changes on the MPS EPICS screen to affect the power supply.	N/A
(o)	Used to switch between local and remote mode on the MPS display unit	N/A
(p)	Calculated central field of the solenoid (Tesla) = 1.1365*[(HS2+HS3)/2]/10000 ; *HS1 is a 'dead' sensor*	N/A
(q)	Read backs from 3 hall sensors mounted on the downstream end of the solenoid inner bore vacuum jacket. Positive readings signify that the magnetic field vector is pointing downstream (DS) and that the magnet is in POSITIVE polarity.	42038 Gauss @ 2416 A
(r)	Sum status of the three sets of interlocks	GREEN
(s)	Indicates whether the Fast DAQ system is writing data to disk. Always ensure this is 'RECORDING' before energizing the magnet	RECORDING
(t)	Pauses the ramping of the magnet by EPICs changing the set point to a value close to the current read back	N/A
(u)	Button to turn on MPS after communications has been established (Enables output). On clicking this button, the user will be prompted to confirm the action.	ON

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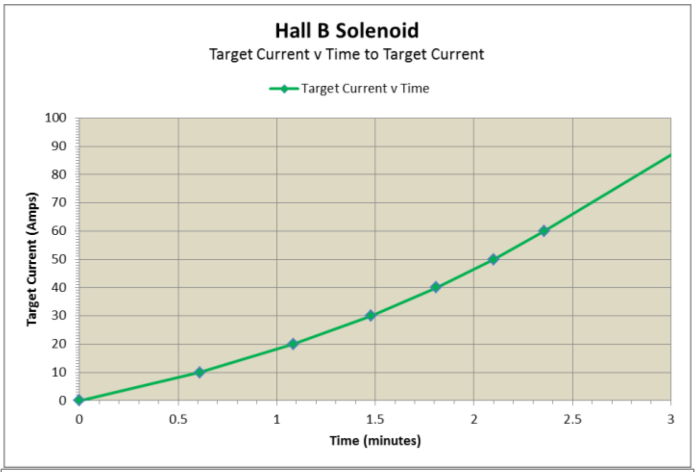
Power Up

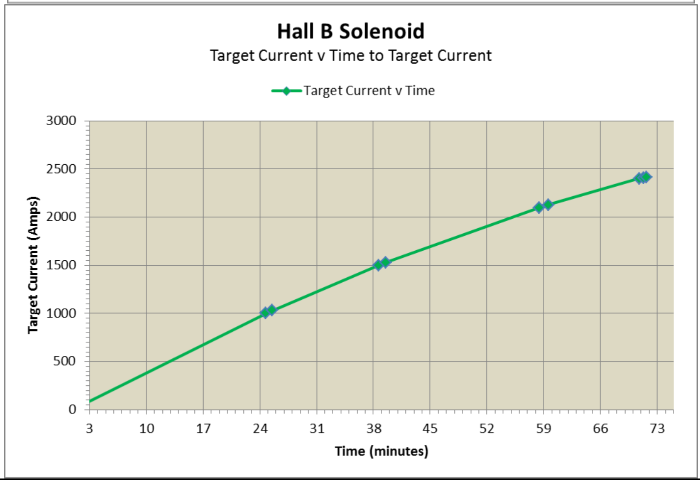
Reference should be made to Figure 1 and Table II.

	Instruction	Action
CHECKS AND INITIAL SETTINGS ON THE MPS CONTROL SCREEN BEFORE ENERGIZING MAGNET		
1	Set the *(c) Setpoint* to 0 (zero) A. [This is to avoid any unintentional current ramps before all checks have been completed].	• Type '0' (i.e. zero) in the field *(c)* and hit the *Enter* key on the keyboard. • If the control screen does not allow you to do this, call the ENGINEER ON CALL
2	Check that *(b) COMM* is GREEN	• If it is RED, click *(m) Reset Comms* • If it does not turn GREEN, call the ENGINEER ON CALL
3	Check that *(e) MAX sw* (software) limit is set to a value higher than the final target current.	• If it isn't, call the ENGINEER ON CALL
4	Check that *(n)* is displaying REMOTE.	• If it isn't, click *(o) Set to Remote* to set it to REMOTE • If it does not switch to REMOTE, call the ENGINEER ON CALL
5	Check that all the *(r) Interlock Summary* indicators are GREEN.	• If any of the indicators are RED, call the ENGINEER ON CALL • From the pull-down menu: Select *Interlock Status* • This will bring up another window (*Solenoid MPS Interlock Status - PLC*). • Report to the ENGINEER ON CALL which indicators are RED. • Go back to the MPS Control screen
6	Check that the 'SOE Timestamps' are all zero	• Click on *(a)* (upper left of screen). • From the pull-down menu: Select *'SOE Timestamps'.* • This will bring up another window (*Solenoid and Torus SOE Timestamps*). • Ensure that all the timestamps are zero. • If any cells are non-zero, go back to the MPS Control Screen and click on *(k) Reset PLC Interlocks*. • Re-check the SOE Timestamps window again *[Note: you may have to wait a few seconds for the changes to register. Click (k) once more if necessary]*
7	Turn ON the Magnet Power Supply	• Click on *(u)* to 'Turn ON MPS' (upper left of screen)
8	Check that *(s) DAQ Rec* is displaying RECORDING	• If it says STOPPED, click *(a)* (upper left of screen). • From the pull-down menu: Select *Fast DAQ Recording Ctrl.* • This will bring up another window (*Solenoid Fast DAQ ROOT File*). • Click the 'Start Recording' button. • Check that a filename is displayed below and that the file size is increasing before continuing with magnet energization. • Go back to the MPS Control screen

ENERGIZING (POWERING UP) THE MAGNET	
9	The following ramp rates and target currents to power up the magnet to full field (2416 A) are pre-programmed in the PLC. Simply type in the 'Target Current' in the *(c) Setpoint* field and either hit *Enter* on the keyboard or click anywhere outside the field to start the ramp up. The ramp rates have been selected to minimize eddy current heating of the coils and also to minimize voltage over-shoot at the end of each ramp step.

From Current (A)	To Target Current (A)	Slew rate (mA/s)	Time Steps (Mins)	Time – accumulated (mins)
0	10	273	0.61	0.61
10	20	350	0.48	1.09
20	30	426	0.39	1.48
30	40	503	0.33	1.81
40	50	571	0.29	2.10
50	60	648	0.26	2.36
60	1000	699	22.41	24.77
1000	1030	648	0.77	25.54
1030	1500	597	13.12	38.66
1500	1530	554	0.90	39.57
1530	2100	503	18.89	58.45
2100	2130	452	1.11	59.56
2130	2400	401	11.22	70.78
2400	2410	324	0.51	71.30
2410	2416	273	0.37	71.66





10	If there are any trips (magnet, cryogenics, control, communications etc), one of more of the *(r) Interlock Summary* indicators will turn RED and the magnet will either Fast Dump or initiate a Controlled Ramp Down. If this happens call the ENGINEER ON CALL.

Power Down

Table III provides the nomenclature for the various magnet discharge modes.

Table III – Definition of Magnet Discharge Modes

Type of discharge	Definition	Discharge time
Normal ramp down	Discharge following the prescribed maximum ramp rate at a given current, through the Power Supply	~ 4219 sec (70 min) from full current (2416 A)
Controlled ramp down	Discharge following the prescribed maximum ramp rate at a given current, through the Power Supply	~ 4219 sec (70 min) from full current (2416 A)
Fast Dump	Discharge (emergency) through the Dump Resistor (dump switch) – this is also the discharge mode during a magnet quench	145 sec from full current (2416 A) to zero (29 sec time constant)

Note: Solenoid Magnet inductance = 5.8 Henries, Dump resistor = 0.2 Ohms

Reference should be made to Figure 1 and Table II.

	Instruction	Action
DE-ENERGIZING (POWERING DOWN) THE MAGNET		
1	The following ramp rate, which is used to power down the magnet from full field (2416 A), is pre-programmed in the PLC. Simply type in the ‘Target Current’ in the *(c) Setpoint* field and either hit *Enter* on the keyboard or click anywhere outside the field to start the ramp down.	
2	If there are any trips (magnet, cryogenics, control, communications etc), one of more of the *(r) Interlock Summary* indicators will turn RED and the magnet with either Fast Dump or initiate a Controlled Ramp Down. If this happens call the ENGINEER ON CALL.	

From Current (A)	To Target Current (A)	Slew rate (mA/s)
2416	0	700

Reversing Polarity

Reference should be made to Figure 1 and Table II.

	Instruction	Action
REVERSING POLARITY		
1	• Note that POLARITY is defined as follows : Axial field pointing DOWNSTREAM = POSITIVE POLARITY (Hall sensor readings are positive) Axial field pointing UPSTREAM = NEGATIVE POLARITY (Hall sensor readings are negative) • Typing a POSITIVE number in *(c) Setpoint* will cause the magnet to ramp in POSITIVE POLARITY MODE • Typing a NEGATIVE number in *(c) Setpoint* will cause the magnet to ramp in NEGATIVE POLARITY MODE • Note: If the magnet is in POSITIVE POLARITY MODE and you wish to run it in NEGATIVE POLARITY MODE, do the following: ○ Type zero (0) Amps into the set point field (c) ○ Wait till the magnet power supply (MPS) current read back (f) reads zero or is as close to zero as it is going to get. ○ Wait at least 5 minutes for it to settle. ○ Now type in the negative current set point into the set point field (c) • Do the reverse if ramping from NEGATIVE POLARITY to POSITIVE POLARITY – i.e. always ramp to zero Amps first. • Additional Note: If any of the Quench Detection (QD) units trip while carrying out the polarity reversal procedure described above, do the following: ○ Turn OFF the MPS (u) ○ Reverse polarity by typing in either a negative current or positive current in the set point field (c) should clear the QD fault. If this does not work, call the ENGINEER ON CALL who may have to go down into the hall to clear the QD fault locally on the power supply remote control crate.	
2	If there are any trips (magnet, cryogenics, control, communications etc), one of more of the *(r) Interlock Summary* indicators will turn RED and the magnet will either Fast Dump or initiate a Controlled Ramp Down. If this happens call the ENGINEER ON CALL.	

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Emergency Stops

There are 3 Emergency Stop buttons (E-Stops) for the Solenoid Magnet.

How Many E-Stops?	Where is the E-Stop located?	What does it do?
1	Counting Room, on the rack inside the electronics room	Fast Dumps the magnet : (+/-) 2416 Amps to 0 Amps in 2.5 minutes*
1	Outside of power supply cabinet, Level 1 in the hall	Fast Dumps the magnet : (+/-) 2416 Amps to 0 Amps in 2.5 minutes*
1	Outside of remote Control Crate, Level 2 in the hall	Runs the magnet down via the transistor bank and the TH1 thyristor : (+/-) 2416 Amps to 0 Amps in 5.5 hours*
ALWAYS OBTAIN CONFIRMATION FROM THE ON-CALL ENGINEER BEFORE RESETTING THE EMERGENCY STOPS		

** - theoretical times*

What to do after a Fast Dump or Quench

- ❑ Always contact an engineer from the Magnet Group (i.e. whomever is 'On Call'):
  - Ruben Fair
  - Probir Ghoshal
  - Renuka Rajput-Ghoshal
  - Dave Kashy
- ❑ On the 'phone to the magnet engineer, please have the following information ready:
  - Status of Magnet Power Supply EPICS screen
  - Status of interlock screen – Click on (a) (see Figure 1) and select 'Interlock Status'
  - Cryogenic status and any other information you feel is relevant
- ❑ Re-setting the Quench Detector (QD) units remotely
  - Note that this reset of the quench detectors (i.e. to clear their fault status) should only be done AFTER consultation with either the ON-Call Engineer or the Magnet Group. This is so that the engineer can confirm that the acquired voltage data has been reviewed and all is still well with the magnet.
  - The 'QD Hard Reset' button can found on the same EPICS screen as the Interlocks. Click on button (a) (See Figure 1) and select 'Interlock Status'. The reset button is at the bottom right of the screen.

Appendix A – Magnet Power Supply Control Screens (EPICS)

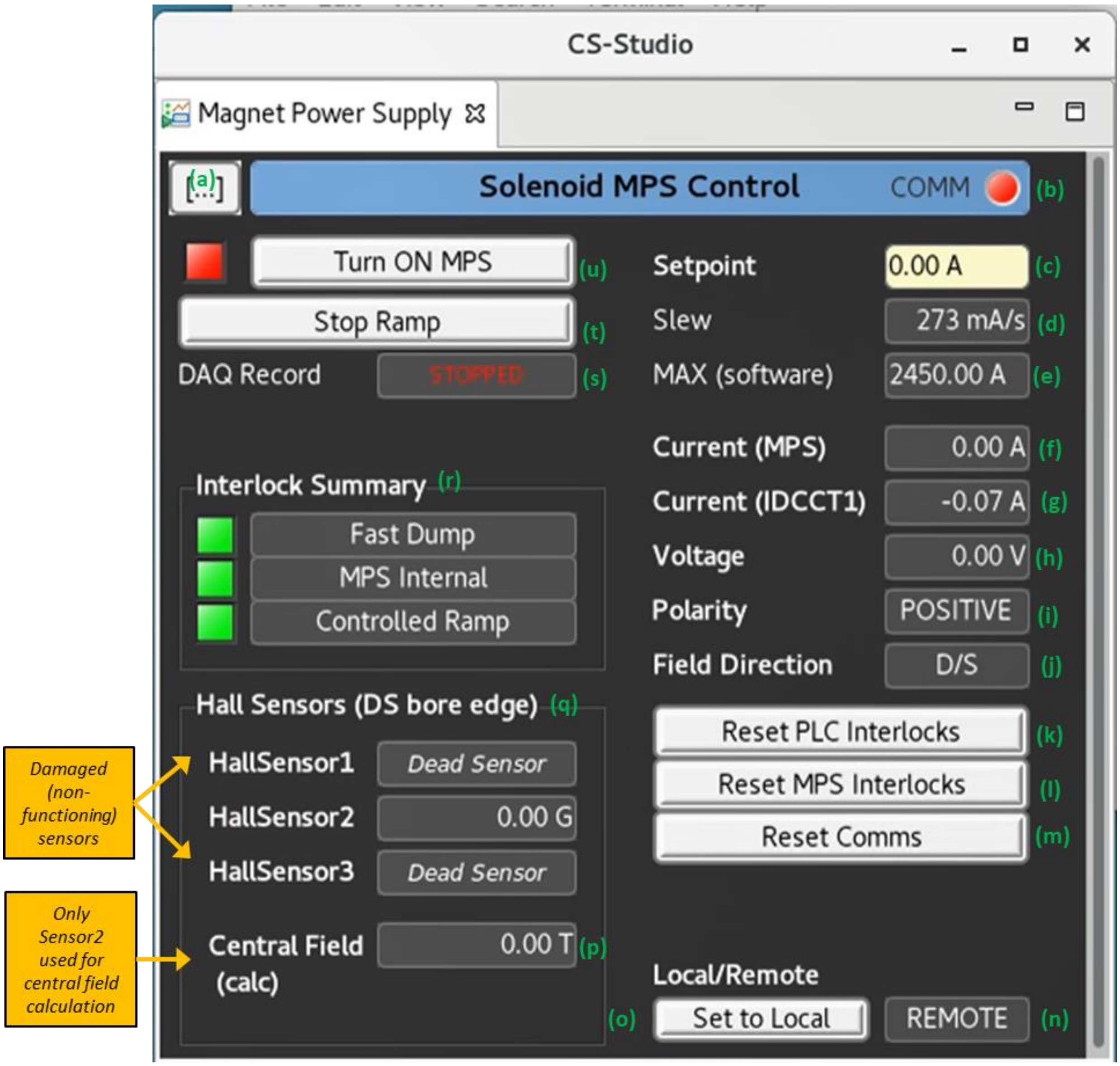

Figure A.1 - JLab MPS Control – EPICS

Clicking on Item (a) (Figure A.1), will provide the user with access to six further EPICS screens as follows, (of which only 3 may be relevant for a shift worker):

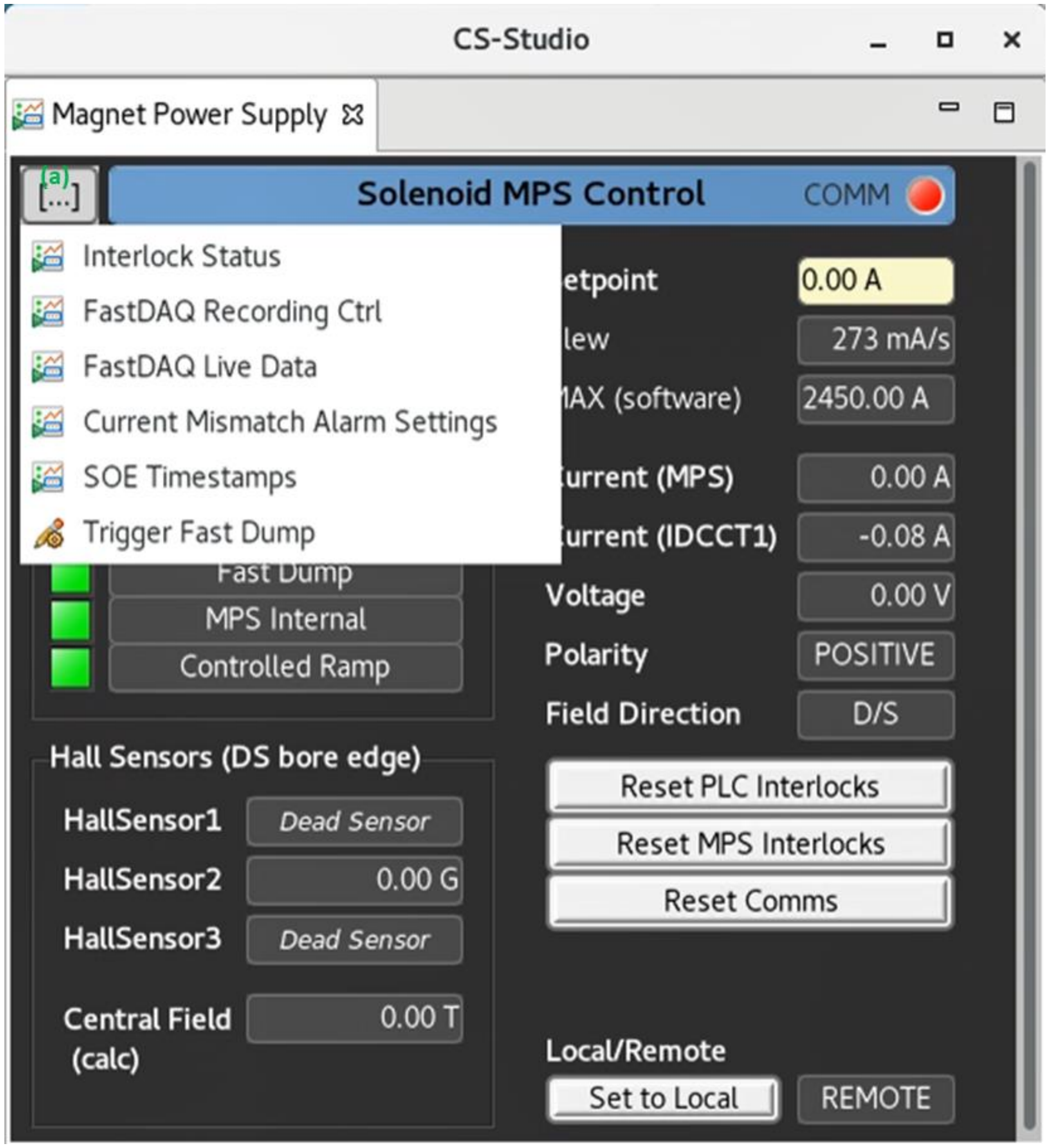

Figure A.2 - Clicking on (a) produces a pull-down menu with selections for 6 additional screens

Interlock Status

All interlock indicators should be GREEN before start of magnet energization

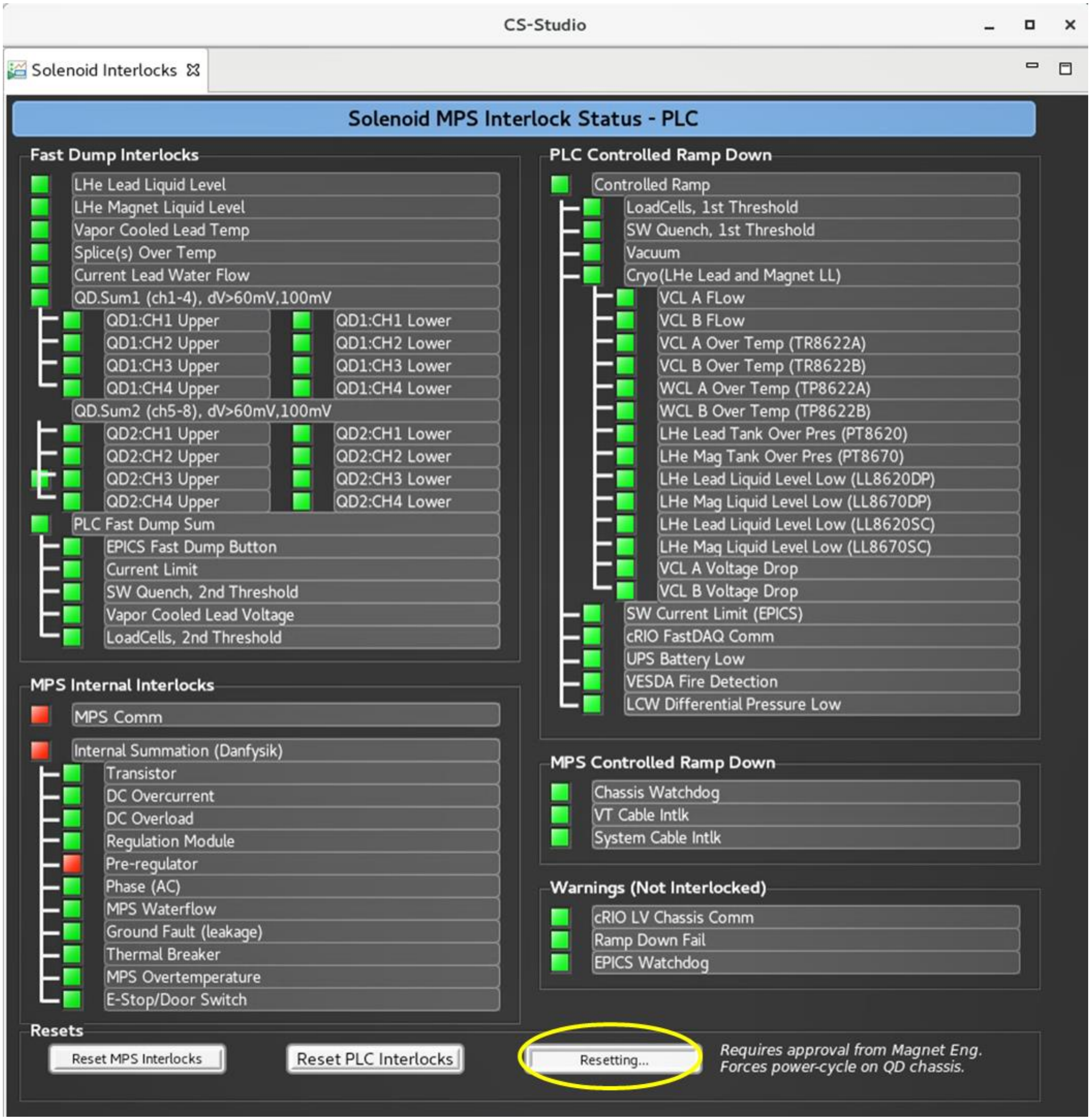

Figure A.3 Interlock Status Screen

<u>Note</u>: The 'QD Hard Reset' (bottom right of the Interlocks Status screen should only be pushed once confirmation has been received from either the ON-Call Engineer or the Magnet Group

Fast DAQ Recording Status

The Recording Status should be RECORDING before start of magnet energization. Click the 'Start Recording' button if necessary. Check that a filename is displayed below and that the file size is increasing before continuing with magnet energization.

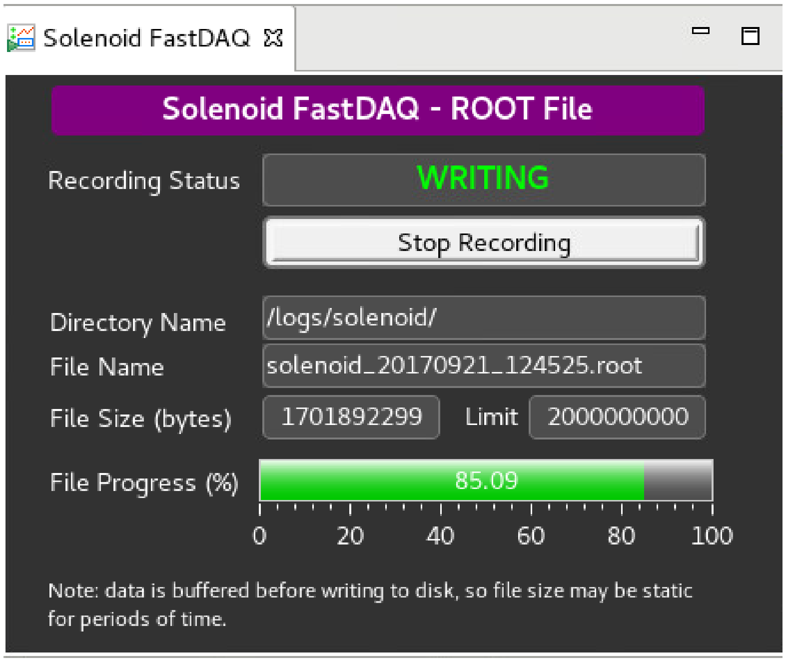

Figure A.4 Fast DAQ Recording Screen

Fast DAQ Live Voltage Data

This displays live voltage tap data for all the voltage channels as well as the magnet current IDCCT1 – i.e. as read by the Fast DAQ National Instruments cRIO modules.

The screens below (without the magnet in operation) are an indication of the noise levels to be expected for each of the voltage channels. Noise levels typically vary from ±10 mV to ±60 mV for individual channels and can be as high as ±170 mV across the whole magnet.

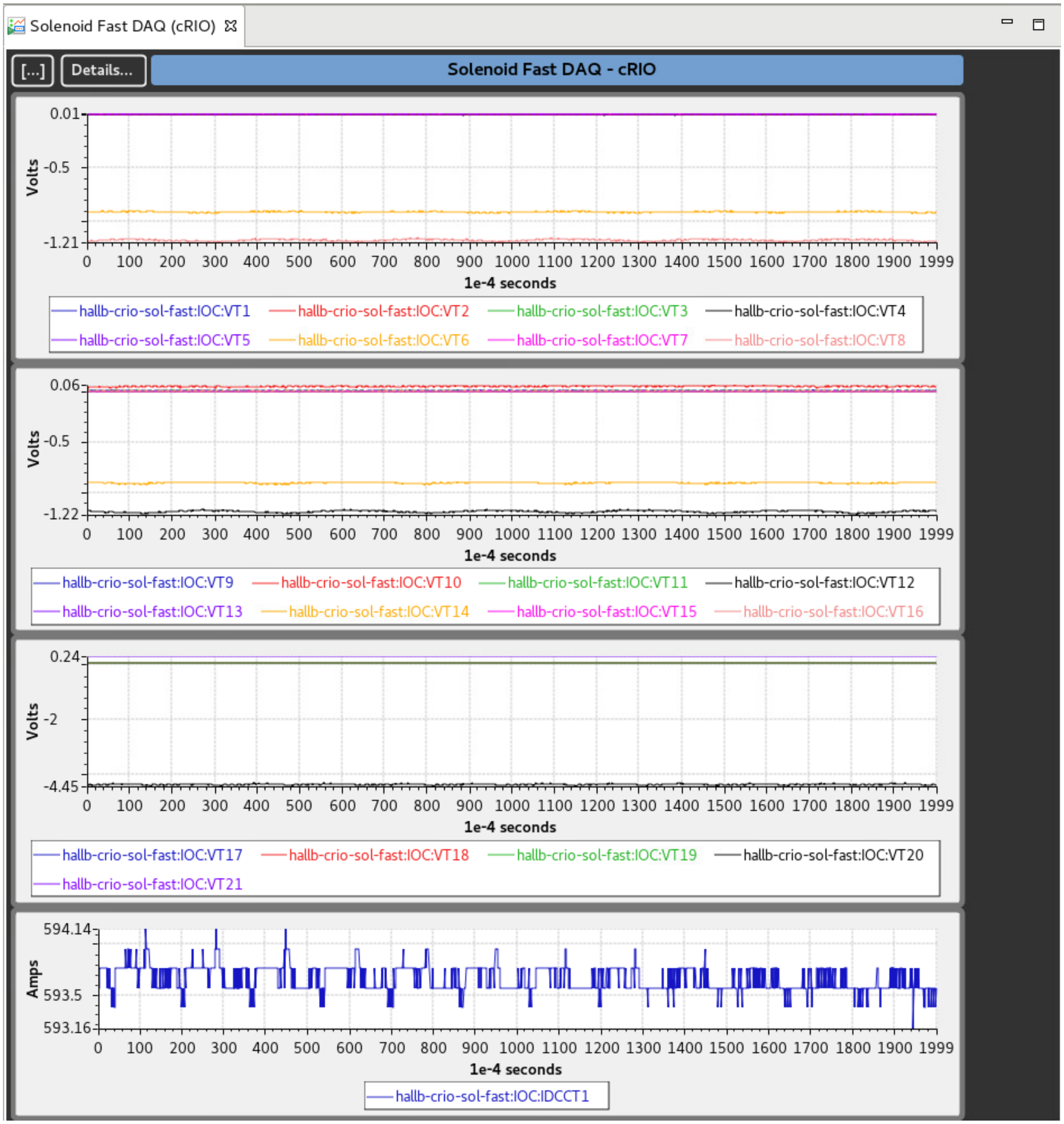

Figure A.5 Fast DAQ Live Voltage Data Screen

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SOE Timestamps

This displays the timestamps for all the SOE (Sequence of Events) relays. If an 'event' occurs (for example a fast dump of the magnet), the user can refer to this screen to review the timestamps to determine which relay triggered first. This helps with diagnosis as to what may have initiated the event.

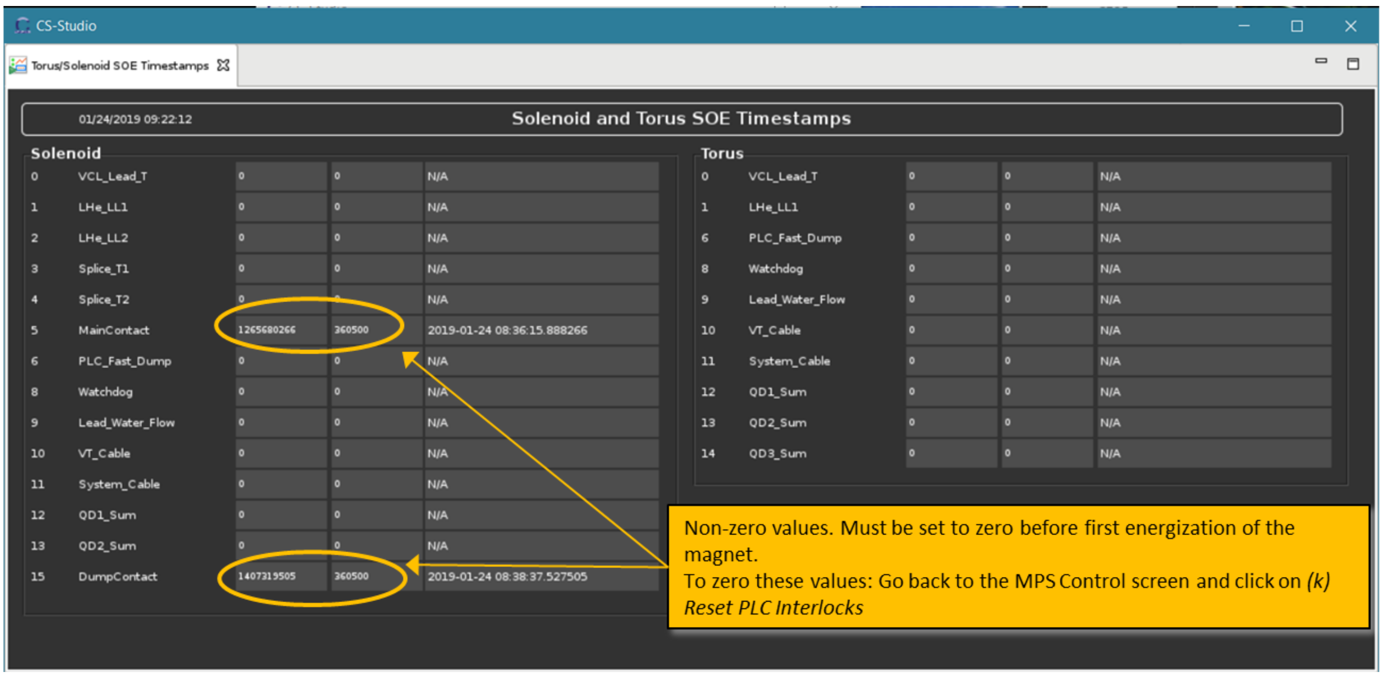

Figure A.6 SOE Timestamps Screen

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Appendix B - 12 GeV Commissioning Power Up & Power Down

This is the procedure followed for magnet commissioning.

This procedure:

- Picks up where the power supply and power-up checklists end (B000000400-P002 and all previous checklists)
- Ends when magnet is brought to operating current and is ready for field mapping
- Distinguishes between "first ramp up" (commissioning), pre-operational ramps done after 12 GeV project commissioning but prior to regular operation, and subsequent ramp ups during regular operations
- During first ramp up (12 GeV commissioning):
  - Going up in current in steps
  - Reversing after each ramp to observe behavior of instruments
  - Exercising the fast dump capability of the power supply at least once (at partial current)
  - Reverse the magnet polarity (at partial current) to ensure instruments and controls, power supply, and other systems, can operate in reverse polarity
- A sub-procedure (checklist) to be followed in the event of quench

Pre-Energization Checklists

In the Intervening time between start of cool-down and complete helium fill, many of the system operation controls as well as interlocks can be tested and verified using the following set of checklists:

1. *B000000400-P002 Hall B Solenoid Operations Power Up Checklists*
2. *B000000402-P002 Hall B Superconducting Magnets Power Supply Maintenance Turn-On Checklist*
3. *B000000402-P001 Hall B Superconducting Magnets Pre-Power-Up Power Supply Internal Interlock Checklist*
4. *B000000400-P007 Hall B Solenoid Pre-Power-Up Water-Cooled Leads Checkout Procedure*
5. *B000000400-P008 Hall B Solenoid Pre-Power-Up Vapor-Cooled Leads Checkout Procedure*
6. *B000000400-P003 Hall B Solenoid Pre-Power-Up Instrument Checkout Procedure*
7. *B000000400-P004 Hall B Solenoid Pre-Power-Up Quench Detector Tuning Procedure*
8. *B000000400-P005 Hall B Solenoid Pre-Power-Up Interlock Checkout Procedure*

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12 GeV Commissioning Power Up & Power Down

The Operator controls the Magnet Power Supply (MPS) for the magnet and monitors the magnet and its sub-systems via a PLC using a series of EPICS screens. Bringing the Solenoid to operating field is done in a series of current steps at differing current ramp rates.

Each time the operator establishes the desired current on the EPICS screen and clicks anywhere outside the 'Set point' box, the power supply begins the ramp to the set point current at the specified slew rate (Ramp rate).

The power supply can either be controlled via its own remote control interface (mounted in a rack within the hall itself), see Fig. B.1 below; or via a JLab-developed EPICS screen, see Fig. B.2.

Figure B.1 - Danfysik Remote Control Crate

Figure B.2 - JLab MPS Control – EPICS
(slew rate input is accessible to user during commissioning phase – the EPICS screen will need re-programming to re-enable this feature)

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For the power-up procedure, the following nomenclature will be used for a magnet discharge:

Table B.I – Definition of discharge mode

Type of discharge	Definition	Discharge time
Normal ramp down	Discharge following the prescribed maximum ramp rate at a given current, through the Power Supply	~ 4219 sec (70 min) from full current (2416 A)
Controlled ramp down	Discharge following the prescribed maximum ramp rate at a given current, through the Power Supply	~ 4219 sec (70 min) from full current (2416 A)
Fast Dump	Discharge (emergency) through the Dump Resistor (dump switch) – this is also the discharge mode during a magnet quench	145 sec from full current (2416 A) to zero (29 sec time constant)

Note: Solenoid Magnet inductance = 5.8 Henries, Dump resistor = 0.2 Ohms

Power-Up Sequence (12 GeV Commissioning)

During commissioning ramp-up certain parameters will be monitored and recorded (aside from the EPICS logs). Values are to be monitored and compared during the stops between ramps to ensure behavior is as expected before moving on to the next step.

The commissioning power-up will start with the magnet connected in the ***negative*** polarity. [NOTE: COMMISSIONING STARTS WITH THE "LEAST" USED POLARITY. IF MAGNET IS TO BE USED MOSTLY IN POSITIVE POLARITY, START WITH NEGATIVE. IDEA IS TO "TRAIN" MAGNET IN MOST USED POLARITY)

The steps to follow during commissioning power-up are:

STEP 1a

Purpose:

- To check on inductance of coils and magnet
- To allow 'tuning' of quench detector circuits
- To check for signs of eddy-current heating in coils, fingers, and thermal shields
- To verify correct Gauss/Amp for the magnet
- To verify integrity of coil splices
- To check for hysteresis in instrumentation

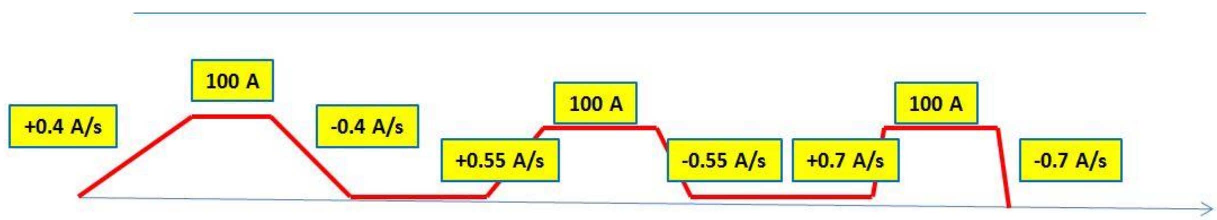

Figure B.3 - Ramp-up schedule for Step 1a

(1) Pre-Power-Up Checklist complete

(2) Verify magnet polarity is negative (i.e. field direction is UPSTREAM, U/S)

(3) Ramp up current from 0 to 100A, stay at 100A at least 10 minutes, and then decrease back to zero at the same ramp rate. Repeat three times at increasing ramp rates (0.4, 0.55, and 0.7 A/s) and staying at 0 A at least 10 minutes each time

(4) During ramp up or ramp down monitor:

  a. Voltages across coils (and entire magnet)

  b. Voltages in current leads (and stop ramping if abnormal)

(5) During stay at 100A check, record and evaluate:

  a. Load cells

  b. Hall probes

  c. Coil and shield temperatures

  d. Splice voltages (especially when we are at high current)

  e. VCL voltages

(6) Upon cycles completion, check for consistent behavior, signs of hysteresis in the instrumentation

STEP 1b

Purpose:

- To verify all instruments and controls, power supply, and magnet, can operate in reverse polarity
- To verify that all the checks done on Step 1a are still valid in reverse polarity mode

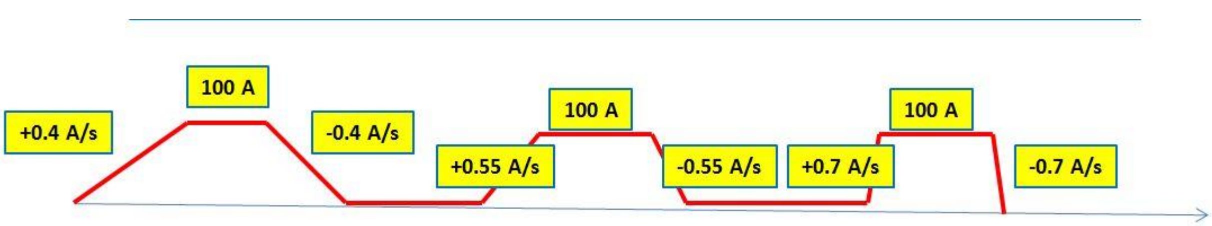

Figure B.4 - Ramp-up schedule for Step 1b

(7) Reverse polarity to ***positive*** (i.e. field direction is DOWNSTREAM, D/S)

(8) Verify all instruments and controls are operational

(9) Proceed with a similar ramp and same steps as in Step 1a (but now in reverse polarity)

(10) Ramp up current from 0 to 100A, stay at 100A and then decrease back to zero at the same ramp rate. Repeat three times at increasing ramp rates (0.4, 0.55, and 0.7 A/s)

(11) During ramp up or ramp down monitor:

a. Coil and shield temperatures

b. Voltages across coils (and entire magnet)

(12) During stay at 100A check, record and evaluate:

a. Load cells

b. Hall probes

c. Coil and shield temperatures

d. Splice voltages (especially when we are at high current)

e. VCL voltages

(13) Upon cycles completion, check for consistent behavior, signs of hysteresis in the instrumentation

(14) Compare findings of Step 1b with those of Step 1a and check for consistency

For all the next steps, the polarity of the magnet is NOT changed, it remains ***positive***.

STEP 2

Purpose:

- As for Step 1b but at higher currents
- To test the Fast Dump process

Figure B.5 - Ramp-up schedule for Step 2

(15) Ramp up current from 0 to 120A at +0.7 A/sec, wait at 120 A (time needed to do the checks below)

(16) Proceed to 240 A at the same ramp rate, wait and record

(17) During ramp-ups monitor:

a. Coil and shield Temperatures

b. Voltages across coils (and entire magnet)

(18) During stays check:

a. Load cells

b. Hall probes

c. Coil and shield temperature

d. Splice voltages (especially when we are at high current)

e. VCL voltages

(19) From 240 A level, trip Fast Discharge (by soft or hard button). After Fast Discharge, stay discharged:

a. Collect data and look at voltages,

b. If anything trips, understand why

c. Look at all mechanical sensors (are they back to values recorded at 0 A?)

STEP 3

Purpose:

- To stress and de-stress the coils and structural members during ramp-up (training)
- To test the Controlled Ramp Down process from full operating current

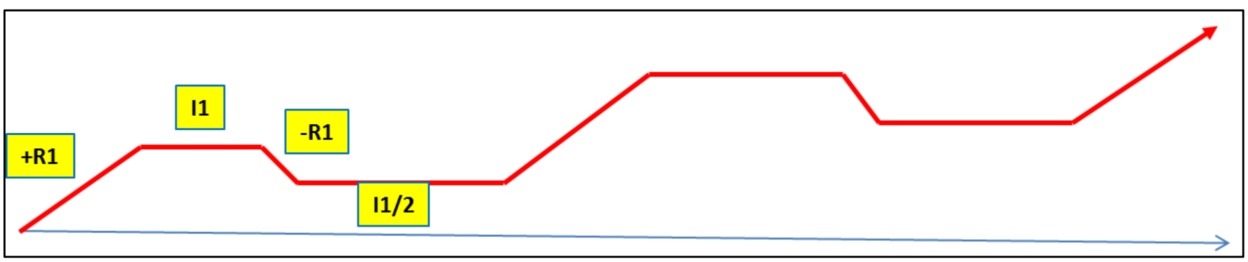

Figure B.6 - Ramp-up schedule for Step 3 (illustration)

(20) After Fast Dump checklist is complete, commence ramp-up to slightly above nominal current (2435 A) following a pattern:

1. Ramp current up to I1 at a rate +R1
2. Stay at I1 to conduct checks (30-60 minutes)
3. Decrease current to I1/2 at a rate –R1
4. Stay at I1/2 for checks (30-60 minutes)

(21) Continue this process of ramp up/wait/ramp down/wait to increasing levels of current at the appropriate ramp rates. The levels and rates are the same used during a regular ramp up, as follows:

Table B.II - Maximum ramp rate as a function of current, schedule of current ramps for Step 3[1]

Nominal ramp rates

Current (A)	Ramp rate (A/sec)
0 - 1700	0.7
1700 - 2416	0.4

Schedule for first ramp up

(A)	(A/sec)
500	0.7
250	-0.7
1000	0.7
500	-0.7
1500	0.7
750	-0.7
1700	0.7
850	-0.7
2000	0.4
1000	-0.4
2435	0.4
2417	-0.4

Stop and evaluate

(22) During ramp-ups monitor:

a. Coil and shield Temperatures

b. Voltages across coils (and entire magnet)

(23) During stays check:

a. Load cells

b. Hall probes

c. Coil and shield temperatures

d. Splice voltages (especially when we are at high current)

e. VCL voltages

(24) It is important to record and evaluate the VCL voltages during ramping-up, as values may be incorporated to the control system in the form of an alarm on deviations from expected trend

(25) At 1700A, and AFTER lowering the current to 850A, stop the process, evaluate all the data collected up to this point, and only proceed with this step if no anomalies in magnet behavior are noted.

(26) After evaluation, resume the step, and charge magnet to 2435 A (0.8% above nominal).

(27) From the final current of 2435 A, come down to nominal current of 2416 A, and then perform a Controlled Ramp Down monitoring all instrumentation – in particular temperature sensors to identify any eddy current issues (both in shields and coils).

[1] Note that these values for ramp rates were determined BEFORE the start of commissioning. Observation of thermal transients (AC losses) during magnet ramping may lead to modifications, which will be reflected in the Operations Manual

Actions in the event of training quench

1. In the event of a training quench during power up, the step will be stopped to investigate and try to localize where the quench originated, and if data permits, identify a root cause for the quench. The steps are:
    a. Analyze all temperature, pressure, mechanical, and voltage fast DAQ data to determine location, and if possible, source of the quench
    b. Check the interlock SOE (sequence of events)
    c. Attempt to isolate location and root cause of quench
    d. From the voltage tap data estimate quench propagation velocity, and use the information to validate assumptions of quench propagation modeling (in particular, if quench originates in a splice region, confirm that the quench propagates into the coils)
    e. Do a visual inspection of all magnet, power supply, and cryo systems
    f. Unless investigation uncovers a problem, then:
2. Re-start by following the cooldown check list (as per appropriate section in the Cooldown Procedure B000000900-P001)
3. Proceed to cooldown (as per appropriate section in the Cooldown Procedure B000000900-P001)
4. Go through procedure B000000402-P001 Hall B Superconducting Magnets Pre-Power-Up Power Supply Internal Interlock Checklist
5. Re-start the power up step at which the quench occurred (1a or 1b, 2, or 3), going back to the beginning of the step

Power-Up Sequence (Post-Commissioning)

After taking the magnet to 2435 A, and a Controlled Ramp Down from 2416 A, the 12 GeV commissioning phase is considered complete. Post-commissioning operation begins, and is intended to further exercise certain features prior to unrestricted operation. There are two steps in this post-commissioning phase:

(1) Exercise a reverse polarity ramp-up to high current
    a. Reverse the polarity from positive to negative
    b. Proceed to execute Step 3 from the Commissioning Power-Up, but only up to a current of 1700 A

(2) Exercise a fast Dump from high current
    a. After stopping at 1700 A and recording data, exercise a Fast Dump (via soft or hard button) from this level back to 0 A
    b. Analyze the data from the ramp-up and Fast Dump, in particular, any indication that the coils may have quenched during the Fast Dump

Approved: 6/2/2020; E-Sign ID : 417395; signed by: Ap. 1: R. Rajput-Ghoshal; C.: P. Ghoshal; D: T. Fuell

Appendix C – Determination of ramp rates from observation of coil temperature rise

The following table summarizes the observations of coil temperature rise during ramping and was used to determine the final set of ramp rates.

Data from steady ramp up			20-Sep-17											
			700mA/s		600mA/s		500mA/s		500mA/s		400mA/s	Full ramp	Steady State	
		Initial - St	1000A	Delta	1500A	Delta	1800A	Delta	2100A	Delta	2416A	(hr:min)	2416A	Delta
	Coil \ Time	8:30	8:56		9:10		9:21		9:32		9:46	1:16	11:00	
	C1	4.561	4.636	0.075	4.598	0.037	4.59	0.029	4.59	0.029	4.573	0.012	4.53	-0.031
	C2	4.575	4.653	0.078	4.608	0.033	4.587	0.012	4.58	0.005	4.555	-0.02	4.53	-0.045
	C3	4.628	4.793	0.165	4.756	0.128	4.757	0.129	4.74	0.112	4.744	0.116	4.64	0.012
	C4	4.661	4.837	0.176	4.796	0.135	4.766	0.105	4.74	0.079	4.728	0.067	4.64	-0.021
	C5	4.705	4.837	0.132	4.818	0.113	4.808	0.103	4.79	0.085	4.799	0.094	4.72	0.015
	Max Delta			**0.176**		**0.135**		**0.129**		**0.112**		**0.116**		**0.015**
	Peak Temp		**4.837**		**4.818**		**4.808**		**4.79**		**4.799**		**4.72**	

Filename: Ramp Rates_R2 stored in:

M:\hallb_eng\CLAS12\Magnets\Solenoid\Solenoid Operations\Solenoid Power Up\Ramp to field

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