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**APS Superconducting Test Undulator (SCU0) Control System**

**Functional Requirements Document**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| |  |  |  |  | | --- | --- | --- | --- | | **APS AES/CTL**  **Specifications Document #** | **Superconducting Test Undulator (SCU0) Control System** | **Revision** | **1.0** | | **Functional Specification for SCU0 Control System** | | | |  |  |  |  | | --- | --- | --- | | Martin Smith |  |  | | Controls Engineer (Author) | Signature | Date | |  |  |  | | Matt Kasa |  |  | | Magnetic Devices Engineer (Author) | Signature | Date | |  |  |  | | Chuck Doose |  |  | | Magnetic Devices Engineer (Author) | Signature | Date | |  |  |  | | Yury Ivanyushenkov |  |  | | SCU Technical Leader | Signature | Date | |  |  |  | | Richard Farnsworth |  |  | | Controls Group Leader | Signature | Date | |  |  |  | | Boris Deriy |  |  | | Power Supply Engineer | Signature | Date | |  |  |  | | Ju Wang |  |  | | Power Supply Group Leader | Signature | Date | |  |  |  | | Efim Gluskin |  |  | | Magnetic Devices Group Leader | Signature | Date | |  |  |  | | Vadim Sajaev |  |  | | Accelerator Physicist | Signature | Date | |  |  |  | | Michael Borland |  |  | | ASD Associate Division Director | Signature | Date | |  |  |  | |

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| 00 | All | Initial Document Release | Martin Smith | Jan 24, 2011 |
| 0.1 | All | Added interlocks and warnings, numbered requirements, removed unused sections and more. | Richard Farnsworth | April 5, 2011 |
| 0.2 | All | Added pressure sensor diagram (Figure 2), temperature sensor diagram (Figure 3), and general formatting changes. | Martin Smith | April 6, 2011 |
| 1.0 | All | Reviewed all content changes, added summary table for requirements, and figure appendix | Martin Smith | June 28, 2011 |

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# INTRODUCTION

A control system for a Superconducting Test Undulator (SCU0) designed and operated by the Advanced Photon Source (APS) is required to provide remote control and monitoring of the system in a manner consistent with other control systems at the APS project.

## Purpose

This document describes the functional design requirements of the Superconducting Test Undulator control system to be constructed and operated at the APS [1]. The SCU0 is a fixed gap superconducting electromagnetic insertion device which will be installed in the APS storage-ring located at sector 6-ID in the downstream position [2,3]. The system is comprised of a cryomodule that includes a superconducting magnet cooled with liquid helium (LHe) contained in a LHe tank, a cold beam chamber cooled by two cryocoolers, two radiation shields and three pairs of current leads cooled with two other cryocoolers. The magnetic structure consists of two magnetic cores, each containing a main coil and two correction coils. Each coil is powered by a DC current power supply. The cryomodule is instrumented with voltage taps, temperature sensors, pressure sensors, a level sensor and electrical heaters.

## Scope

This control system is the first of its kind at this facility and therefore many of the components that the system will be comprised of may also be one of a kind at the APS project. In order to maintain control system consistency for the APS project, the control system design will be based on the EPICS software toolkit. Since many of the system components have already been chosen for this project the control system will be designed with these specific components in mind.

## Background

The Magnetic Devices Group is responsible for the measurement of magnetic devices at the APS which produce the x-rays to be used by the beamline scientists. The insertion devices must be designed in such a way as to minimize storage-ring particle beam perturbations. The initial draft of this document was written by Martin Smith of the APS Controls Group in order to provide an outline of the control system features for the purpose of control system design.

## References

[1] Ivanyushenkov, Y. (2009, December 16). *Superconducting Undulator Development Status - Yury Ivanyushenkov* . Retrieved from https://icmsdocs.aps.anl.gov/docs/groups/aps/@apsshare/@ald-pa/documents/presentation/aps\_1308844.pdf

[2]Trakhtenberg, E. (2010, February 5). *Superconducting undulator installation*. Retrieved from https://icmsdocs.aps.anl.gov/docs/groups/aps/documents/presentation/aps\_1404301.pdf

[3] Harkay, K. (2011). *APS-U Superconducting Undulator Physics Requirements Document.* Accelerator Systems Division, Accelerator Operations Group, Argonne.

## Assumptions and Constraints

### Assumptions

Before the control system design can begin the functional requirements document must first be completed and all interested parties must agree to the information contained herein.

Functional testing of the control system hinges on the completion of the superconducting test undulator (SCU0) and will require two to three weeks to assemble and test with the device being operational as well as at the disposal of the control system design engineers at the time of testing. Such a preliminary test of the control system can be performed during the undulator standalone cold test before installation of the undulator on the storage ring.

Complete tests of the undulator and the control system will be performed once the undulator is installed in the storage ring and operational, and is time limited by the length of the APS accelerator shutdown and installation schedule.

### Constraints

There will be a SCU0 cold test between January and March of 2012 so there must be a fully functional stand alone control system in place by that time.

The installation in the storage ring sector 6 is scheduled for the May 2012 shutdown at which time the control system to be used must be operational.

## Document Overview

A summary table of functional requirements (FRQ) is first presented with all requirements being numbered; these FRQ numbers will not be changed from this point forward. If there is an FRQ that is not needed it should be noted in the table as well as within the part of the document describing the requirement.

The design methodology will be briefly described before presenting the details of the functional requirements. A section for other requirements will be presented.

The appendices include a glossary of terms used throughout this document as well as various system diagrams. These appendices are included at the end of the document for reference.

Table 1: Summary of functional requirements

| **Requirement Parameter** | **Value** | **Unit** | **Ref.** |
| --- | --- | --- | --- |
| **Main power supply meeting requirements below** | 19” Relay rack mount |  | SCU1.0 |
| Remote communications interface conforming to IEEE communication standards | Preferred interface RS232 or Ethernet TCP/IP |  | SCU1.0.1 |
| Remote and local enable/disable capability |  |  | SCU1.0.2 |
| Remote hardware reset capability |  |  | SCU1.0.3 |
| Output power supply voltage range | 0 – 5 | VDC | SCU1.0.4 |
| Remote and local output voltage read back | 0 - 5 | VDC | SCU1.0.5 |
| Remote and local adjustment of over voltage protection set point | 0.12 – 5 | VDC | SCU1.0.6 |
|  |  |  |  |
| **Remote and local current control** |  |  | SCU1.1 |
| Output current range | 0 – 850 | Amps DC | SCU1.1.1 |
| Remote and local current read back | 0 - 850 | Amps DC | SCU1.1.2 |
|  |  |  |  |
| **Remote controlled current ramping** |  |  | SCU1.2 |
| Ability to provide up/down current ramping | Lesser value between what the APS storage-ring will permit during beam operations and 10 | Amps/sec | SCU1.2.1 |
|  |  |  |  |
| **Corrector power supply(s)** | 19” Relay rack mount meeting all of the requirements below for SCU1.3 |  | SCU1.3 |
| Corrector power supply(s) output | Coordinated with main power supply output |  | SCU1.3.1 |
| Output current range | 0 – 100 | Amps DC | SCU1.3.2 |
| Remote and local current read back | 0 - 100 | Amps DC | SCU1.3.3 |
| Output power supply voltage range | 0 – 10 | VDC | SCU1.3.4 |
| Remote and local output voltage read back | 0 - 10 | VDC | SCU1.3.5 |
| Remote and local adjustment of over voltage protection set point | 0.12 – 10 | VDC | SCU1.3.6 |
|  |  |  |  |
| **Cryogenic Temperature Monitoring** | Meeting all specifications listed below for SCU1.4 |  | SCU1.4 |
| Maximum Number of Temperature Sensors | 32 | Each | SCU1.4.1 |
| Temperature Range | 4 - 300 | Kelvin | SCU1.4.2 |
| Temperature Measurement Resolution | 0.1 from 4 – 150, 1 otherwise | Kelvin | SCU1.4.3 |
| Temperature Measurement Speed | Approximately 1 for each sensor provided | Readings/Second | SCU1.4.4 |
| Temperature Measurement Accuracy | ±0.3 from 4 -150, otherwise best effort | Kelvin | SCU1.4.5 |
| Parallel Measurements | Best effort |  | SCU1.4.6 |
| Remote and local temperature read backs | IEEE standard communication interface |  | SCU1.4.7 |
| Hardware Alarm Outputs | High Temperature alarm for each input | TBD | SCU1.4.8 |
|  |  |  |  |
| **Liquid Helium Level (LHe) Monitoring** | Measurement | cm | SCU1.5 |
| Level Monitoring Accuracy | Appropriate for device providing monitoring |  | SCU1.5.1 |
| Level Monitoring Resolution | Appropriate for device providing monitoring | cm | SCU1.5.2 |
| Remote and local level read backs | IEEE standard communication interface for remote monitoring |  | SCU1.5.3 |
| Hardware Alarm Outputs | Low level alarm threshold TBD | cm | SCU1.5.4 |
| Maximum number of devices used | 2 | Each |  |
|  |  |  |  |
| **Main Coil Current Transducer** |  | TBD | SCU1.6 |
| **Main Coil Current Transducer Commmunication** | GPIB/Analog 0 - 1 | TBD | SCU1.6.1 |
|  |  |  |  |
| Voltage tap read backs | 0 – 10 | VDC | SCU1.7 |
| Heater Current Supply | 20 VDC @ 2A |  | SCU1.8 |
| **Beamline User Control** | Energy controlled | eV | SCU1.9 |
| **Machine Physicists and other users** | Current control of correctors and main coil | Amps | SCU2.0 |
| User display | MEDM or CSS BOY | None | SCU2.1 |
|  |  |  |  |
| **Interlocks** | Provided as specified below |  | SCU3.0 |
| Magnet Overheat | (TT19 or TT20) > Tmax2  (Tmax2 TBD) | Kelvin | SCU3.1 |
| Quench | Power supply over voltage limit (TBD) | Volts | SCU3.2 |
| LHe Tank | Level < Lmin2 (Lmin2 TBD) | cm | SCU3.3 |
| **Current Leads** |  |  | SCU3.4 |
| 100A-1 Lead 1 | TT09 - TT02 > T1max2 (TBD) | Kelvin |  |
| 100A-1 Lead 2 | TT10 - TT02 > T1max2 (TBD) | Kelvin |  |
| 100A-2 Lead 1 | TT13 - TT04 > T1max2 (TBD) | Kelvin |  |
| 100A-2 Lead 2 | TT14 - TT04 > T1max2 (TBD) | Kelvin |  |
| 500 A Lead 1 | TT11 - TT04 > T2max2 (TBD) | Kelvin |  |
| 500 A Lead 2 | TT12 - TT04 > T2max2 (TBD) | Kelvin |  |
|  |  |  |  |
| **Warnings** |  |  | SCU4.0 |
| Beam Chamber Hot | TT21 or TT22 or TT23 > Tbc max | Kelvin |  |
| Magnet Coils Warm | TT19 or TT20 > Tmax1 | Kelvin |  |
| **Coil Current Leads** |  |  |  |
| 100A-1 Lead 1 | TT09 – TT02 > Tmax1 | Kelvin |  |
| 100A-1 Lead 2 | TT10 – TT02 > Tmax1 | Kelvin |  |
| 100A-2 Lead 1 | TT13 – TT04 > Tmax1 | Kelvin |  |
| 100A-2 Lead 2 | TT14 – TT04 > Tmax1 | Kelvin |  |
| 500 A Lead 1 | TT11 – TT04 > Tmax1 | Kelvin |  |
| 500 A Lead 2 | TT12 – TT04 > Tmax1 | Kelvin |  |
|  |  |  |  |
| 60 K Radiation shield | TT24 > TT24max | Kelvin |  |
| 20 K Radiation shield | TT25 > TT25max | Kelvin |  |
|  |  |  |  |
| LHe Tank level is low | LI1 < Lmin2 | cm |  |
| LHe Tank level is low | LI2 < Lmin2 | cm |  |
| LHe Tank Pressure is high | PT2 > PT2max |  |  |
| Recondenser temperature is high | TT15 > TT15max | Kelvin |  |
| Tank temperature is high | TT16 > TT16max | Kelvin |  |
|  |  |  |  |
| Insulating vacuum is poor | PT1 > P1max |  |  |
|  |  |  |  |
| Cryocooler DS TOP – 1st stage | TT01 > TT01max | Kelvin |  |
| Cryocooler DS TOP – 2nd stage | TT02 > TT02max | Kelvin |  |
| Cryocooler US TOP – 1st stage | TT03 > TT03 max | Kelvin |  |
| Cryocooler US TOP – 2nd stage | TT04 > TT04 max | Kelvin |  |
| Cryocooler DS BOT – 1st stage | TT05 > TT05max | Kelvin |  |
| Cryocooler DS BOT – 2nd stage | TT06 > TT06max | Kelvin |  |
| Cryocooler US BOT – 1st stage | TT07 > TT07 max | Kelvin |  |
| Cryocooler US BOT – 2nd stage | TT08 > TT08 max | Kelvin |  |
|  |  |  |  |
| Compressor DS TOP | CI1 = High |  |  |
| Compressor DS TOP | CI2 = High |  |  |
| Compressor DS TOP | CI3 = High |  |  |
| Compressor DS TOP | CI4 = High |  |  |
| Compressor US TOP | CI5 = High |  |  |
| Compressor US TOP | CI6 = High |  |  |
| Compressor US TOP | CI7 = High |  |  |
| Compressor US TOP | CI8 = High |  |  |
| Compressor DS BOT | CI9 = High |  |  |
| Compressor DS BOT | CI10 = High |  |  |
| Compressor DS BOT | CI11 = High |  |  |
| Compressor DS BOT | CI12 = High |  |  |
| Compressor US BOT | CI13 = High |  |  |
| Compressor US BOT | CI14 = High |  |  |
| Compressor US BOT | CI15 = High |  |  |
| Compressor US BOT | CI16 = High |  |  |

# DESIGN METHODOLOGY

This document was developed through communications with members of the Magnetic Devices Group. The information contained herein was provided in particular, by Matt Kasa and Chuck Doose who are currently working hands on with the device prototype. Information was also obtained from ICMS.

# FUNCTIONAL REQUIREMENTS

# User Requirements

There are several different types of users from the standpoint of the control system and they include machine physicists, beamline users, and maintenance personnel. All of these users will generally have the same requirements, differences will be noted.

SCU1.9 Beamline user control shall be in units of energy (eV)

SCU2.0 Machine physicists and SCU0 team shall have control over main coil in (Amps)

SCU2.1 User display shall be either MEDM or CSS BOY to comply with APS standards

## Main Power Supply

SCU 1.0 Main power supply requirements:

SCU 1.0.1 Remote communications interface.

This will allow for remote control/monitoring of the main power supply

Shall use an IEEE standard communication protocol.

(Preferred interfaces RS232 or Ethernet TCP/IP)

SCU 1.0.2 Remote and local enable/disable of power supply output.

This feature will likely be used for maintenance and storage-ring operations for to disable device operation during studies and possible maintenance periods.

SCU 1.0.3 Remote reset capability.

The control shall provide a reset for over voltage conditions which can ocurr due to superconductor quenching

SCU1.0.4 Output Voltage Range

The output voltage to the main coil of the device shall have a remote and locally adjustable range of 0 – 5 VDC.

Analog voltage used to program current output

SCU1.0.5 Remote and local voltage read backs

The power supply shall have both remote and local readbacks for the output coil voltage of 0 – 5 VDC.

SCU1.0.6 Over Voltage Protection

The power supply shall have an output over voltage protection which can be adjusted both locally and remotely between 0.12 – 5 VDC

SCU1.1 **Current Control**

The main coil power supply shall have an adjustable current control which can be adjusted both locally and remotely.

SCU1.1.1 Output Current Range

The main coil power supply shall have an output current range of 0 – 850 Amps DC.

SCU1.1.2 Current Read Back Values

The main coil power supply shall have current read backs available both locally and remotely with a range of 0 – 805 Amps DC.

SCU1.2 **Current Ramping Control**

The main coil power supply shall have remote current ramping capability.

SCU1.2.1 Up/Down Current Ramping

The main coil power supply shall have the capability of providing remote current ramping using analog voltage control.

The main coil power supply shall have a slew rate of the lesser value between what the APS storage-ring will permit during beam operations and 10 Amps/second. This will insure not only minimal storage-ring beam disturbance but also that the main coil magnet does not quench; this can occur in about 10 ms. [3]

Note:

Existing power supply is Agilent 6680A which only has a GPIB interface, output voltage range of 0 – 5 VDC, output current range of 0 – 875 amps, programming accuracy of voltage 0.04% + 5mv and current of 0.1% + 450ma, 1.5mv rms ripple and 10mv pk-pk. There is a desire to use this power supply due to a low ripple current.

SCU1.3 **Correction Power Supply**

SCU1.3.1 Corrector Power Supply Synchronization

The corrector coil supply(s) shall be sychronized to the main coil power

supply according to lookup table provided my Magnetic Devices group.

SCU1.3.2 Corrector Supply Output Current Range

The corrector power supply has an output current range between 0 – 100

Amps DC.

SCU1.3.3 Corrector Supply Current Readbacks

The corrector power supply shall have both local and remote current

readbacks in the range of 0 – 100 Amps DC.

SCU1.3.4 Corrector Supply Voltage Output

The corrector power supply shall have a voltage output range of 0 – 10

VDC.

SCU1.3.5 Corrector Supply Voltage Readbacks

The coorector supply shall have both local and remote readbacks in the

range of 0 – 10 VDC.

SCU1.3.6 Overvoltage Protection

The corrector supply shall have an adjustable overvoltage protection

setpoint range between 0.12 – 10 VDC which can be adjusted locally and

remotely.

SCU1.4 **Cryogenic Temperature Monitoring**

The cryogenic temperature monitoring system must meet all requirements within this section SCU1.4.

SCU1.4.1 Maximum Number of Temperature Sensors

There shall be a maximum of 32 temperature sensors located in various places within the cryogenic chamber. These locations can be found in Figure 3 in Appendix B at the end of this document.

SCU1.4.2 Temperature Range

The temperature range to be measured is between 4 – 300 Kelvin

SCU1.4.3 Temperature Measurement Resolution

The control system shall have a 0.1 Kelvin measurement resolution

between 4 – 150 Kelvin otherwise 1 Kelvin

SCU1.4.4 Temperature Measurement Speed

The control system shall provide a minimum of one reading per second

per sensor

SCU1.4.5 Temperature Measurement Accuracy

All temperature measurements shall have an accuracy of ±0.3 Kelvin

between 4 – 150 Kelvin, otherwise best effort.

SCU1.4.6 Parallel Measurements

All temperature measurements can be performed 8 at a time in parallel

from each of up to 4 temperature monitor devices.

SCU1.4.7 Remote and Local Temperature Read Back

Local temeperature read backs shall be available for local operation of the

SCU0 ID. Remote temperature read backs shall be available using a

standard IEEE communication protocol with RS232 being preferred.

SCU1.4.8 Hardware Alarm Outputs

High temperature hardware alarm outputs must be provided for each

temperature sensor

Note:

Currently using the [Lakeshore Model 218s](https://icmsdocs.aps.anl.gov/docs/groups/anl/@apsshare/@magneticdevices/documents/manual/aps_1418321.pdf) (APS\_1418321) temperature monitor which could have GPIB, IEEE-488 or RS232 interface with over temperature alert for each sensor.

SCU1.5 **Liquid Helium (LHe) Level Monitoring**

Liquid helium level shall be maintained for device cooling with the monitoring

being performed by a hardware device with an RS232 or Ethernet IEEE standard

interface to the control system for value readback

SCU1.5.1 Level Monitoring Accuracy

The control system shall provide accuracy of level monitoring appopriate

for the hardware device providing measurements.

SCU1.5.2 Level Monitoring Resolution

The control system shall provide a monitoring resolution appropriate for

the hardware device providing measurmemnts and measurements shall be

in cm.

SCU1.5.3 Remote and Local Level Read Backs

LHe level read backs shall be present both locally and through a standrad remote interface in compliance with SCU1.4.7.

SCU1.5.4 Hardware Alarm Outputs

To be provided to the control system by the monitoring device with the

threshold value to be determined

SCU1.5.5 Maximum Number of Devices

There shall be a maximum of 2 LHe level monitors to be used in the

system

Note:

Currently using [American Magnetics Model AMI-135-2K](https://icmsdocs.aps.anl.gov/docs/groups/anl/@apsshare/@magneticdevices/documents/manual/aps_1418323.pdf) (APS\_1418323) with the following specifications:

* resolution of 0.1%, 0.1cm, or 0.1 inches
* Hi/Lo alarm relay outputs rated at 30 VAC or 60 VDC up to 0.5 amps max
* Sample and hold time from 0.1 to 600 minutes or hours
* Analog output of 0 – 10 VDC 16-bit resolution with an error of ±1.1% and a voltage drift of 100ppm per degree C.
* 4 – 20ma analog output at 24 VDC and a resoultion of 16-bits with an error of ±0.25% and current drift of 75ppm per degree C.
* Input power requirement of 90 – 132 VAC
* 19-inch rack mounted

SCU1.6 **Main Coil DC Current Transducer**

Currently using an obsolete [Ultrastab 860R](http://www.gmw.com/electric_current/Danfysik/860_862/860.html) manufactured by Danfisyk and it is unclear which exact model is going used if any. These units have status, interlock, and analog output connectors. This would be used to monitor output current from both the main and the correector power supplies.

A current transducer may not be used at all but rather a analog output from the power supplies could be used to provide the current output feed back required for control of the main coil supply.

SCU1.6.1 Main Coil Current Transducer Communications

The communications shall be IEEE standard compliant or analog.

The exisitng device has a GPIB interface as well as 0 – 1 VDC analog

output voltage that is proportional to the current being measured.

SCU1.7 **Magnet Voltage Tap Read Backs**

Remote read back of magnet voltage taps shall be provided; the range is 0 – 10

VDC

SCU1.8 **Heater Current Power Supply**

The power supply for the heater current shall provide 20 VDC output at a

maximum current of 2 Amps.

SCU1.9, SCU2.0, and SCU 2.1 were previous discussed in this document.

SCU3.0 **Interlocks**

All deivce interlocks shall be performed using hardware optionally being

processed by a microprocesor for decision making if necessary. This section

describes the types of interlocks required by the system.

SCU3.1 Magnet Interlocks

The following table provides information on magnet interlocks

|  |  |  |  |
| --- | --- | --- | --- |
| **Sub-system** | **Event** | **Signal** | **Action** |
| Magnet | Magnet overheat | (TT19 OR TT20) > Tmax2 | Start current ramp down |
|  | Quench | Power supply over-voltage trigger | Start current ramp down |
|  | Main coil voltage increase | (V7) or (V8) > Vmax1 | Start current ramp down |
|  | Corrector coil voltage increase | VT9or VT10 > Vmax2 | Start current ramp down |

Table 2: Magnet Interlocks

SCU3.3 LHe Tank Level

When the liquid helium level is less than Lmin2 (TBD) ramp main power

supply to zero amps. LI1 or LI2 < Lmin2.

SCU3.4 **Current Leads**

The following table provides information about the current leads to the

magnets of the device.

|  |  |  |
| --- | --- | --- |
| HTS current lead overheat: |  |  |
| 500A HTS lead 1 | (TT09 – TT02) > T2max2 | Start current ramp down |
| 500A HTS lead 2 | (TT10 – TT02) > T2max2 | Start current ramp down |
| 100A-US HTS lead 1 | (TT13 – TT04) > T1max2 | Start current ramp down |
| 100A-US HTS lead 2 | (TT14 – TT04) > T1max2 | Start current ramp down |
| 100A-DS HTS lead 1 | (TT11 – TT04) > T1max2 | Start current ramp down |
| 100A-DS HTS lead 2 | (TT12 – TT04) > T1max2 | Start current ramp down |
| HTS current lead overvoltage |  |  |
| 500A HTS lead1 | VT1 > Vmax3 | Start current ramp down |
| 500A HTS lead2 | VT2 > Vmax3 | Start current ramp down |
| 100A-DS HTS lead1 | VT3 > Vmax4 | Start current ramp down |
| 100A-DS HTS lead2 | VT4 > Vmax4 | Start current ramp down |
| 100A-US HTS lead1 | VT5 > Vmax4 | Start current ramp down |
| 100A-US HTS lead2 | VT6 > Vmax4 | Start current ramp down |

Table 3: Current Lead Interlocks

SCU4.0 **Warnings**

The following table shows the warning information that the control system shall provide.

|  |  |  |  |
| --- | --- | --- | --- |
| **Sub-system** | **Event** | **Signal** | **Action** |
| Beam chamber | Beam chamber is hot | (TT21 OR TT22 OR TT23 ) > Tbc max | Start warning image on control panel (SWI) |
|  |  |  |  |
| Magnet | Coils are warm | (TT19 OR TT20) > Tmax1 | SWI |
|  |  |  |  |
| Current leads | HTS current lead overheat: |  |  |
|  | 500A HTS lead 1 | (TT09 – TT02) > T2max1 | SWI |
|  | 500A HTS lead 2 | (TT10 – TT02) > T2max1 | SWI |
|  | 100A-US HTS lead 1 | (TT13 – TT04) > T1max1 | SWI |
|  | 100A-US HTS lead 2 | (TT14 – TT04) > T1max1 | SWI |
|  | 100A-DS HTS lead 1 | (TT11 – TT04) > T1max1 | SWI |
|  | 100A-DS HTS lead 2 | (TT12 – TT04) > T1max1 | SWI |
|  |  |  |  |
| Radiation shields | Shield is hot: |  |  |
|  | 60K shield | TT24 > TT24max | SWI |
|  | 20K shield | TT25 > TT25max | SWI |
|  |  |  |  |
| LHe tank | LHe level is low | LI1 < Lmin2 | SWI |
|  | LHe level is low | LI2 < Lmin2 | SWI |
|  | Pressure is high | PT2 > PT2max | SWI |
|  | Recondenser temperature is high | TT15 > TT15max | SWI |
|  | Tank temperature is high | TT16 > TT16max | SWI |
|  |  |  |  |
| Cryostat vessel | Insulating vacuum is poor | PT1 > P1max | SWI |
|  |  |  |  |
| Cryocoolers | Stage is hot: |  |  |
|  | Cryocooler DS TOP – 1st stage | TT01 > TT01max | SWI |
|  | Cryocooler DS TOP – 2nd stage | TT02 > TT02max | SWI |
|  | Cryocooler US TOP – 1st stage | TT03 > TT03 max | SWI |
|  | Cryocooler US TOP – 2nd stage | TT04 > TT04 max | SWI |
|  | Cryocooler DS BOT – 1st stage | TT05 > TT05max | SWI |
|  | Cryocooler DS BOT – 2nd stage | TT06 > TT06max | SWI |
|  | Cryocooler US BOT – 1st stage | TT07 > TT07 max | SWI |
|  | Cryocooler US BOT – 2nd stage | TT08 > TT08 max | SWI |
|  |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| Cryocooler compressors |  |  |  |
|  | Compressor DS TOP | CI1 = High | SWI |
|  | Compressor DS TOP | CI2 = High | SW1 |
|  | Compressor DS TOP | CI3 = High | SW1 |
|  | Compressor DS TOP | CI4 = High | SW1 |
|  | Compressor US TOP | CI5 = High | SWI |
|  | Compressor US TOP | CI6 = High | SWI |
|  | Compressor US TOP | CI7 = High | SWI |
|  | Compressor US TOP | CI8 = High | SWI |
|  | Compressor DS BOT | CI9 = High | SWI |
|  | Compressor DS BOT | CI10 = High | SWI |
|  | Compressor DS BOT | CI11 = High | SWI |
|  | Compressor DS BOT | CI12 = High | SWI |
|  | Compressor US BOT | CI13 = High | SWI |
|  | Compressor US BOT | CI14 = High | SWI |
|  | Compressor US BOT | CI15 = High | SWI |
|  | Compressor US BOT | CI16 = High | SWI |

(Threshold parameters to be defined)

Table 4: SCU0 Warnings Provided

# OTHER REQUIREMENTS

# Hardware Interfaces

A power supply controller is being developed by the Power Supply Group. The controller will be responsible for synchronizing the corrector coil power supplies with the main coil power supplies as well as providing electronic level interlock logic. The preferred device interface is either RS232 or Ethernet, although the currently selected main power supply only has a GPIB interface available.

For the RS232 type devices the communication could be over Ethernet to a Moxa box (Ethernet to serial port converter) and be monitored and controlled via a soft Input Output Controller (IOC) running on a workstation or laptop computer.

The main power supply which has a GPIB interface (if used) would most likely be an Ethernet to GPIB converter which could also be monitored and controlled via a soft IOC.

It is not clear at this time that a VME crate would be required for actual hardware input/output since the devices currently in use typically have an external interface and are commercially available off the shelf (COTS).

# Software Interfaces

Currently there is not an interface control document which specifies the software interfaces but for APS all interfaces would be compatible with other APS project applications and would use the EPICS software toolkit which would be developed, deployed, and maintained by the AES Controls Group.

# Communications Interfaces

This control shall be capable of communicating information to and from the system via the LAN using the EPICS Channel Access (CA) communication protocol.

# Hardware/Software Requirements

If a soft IOC were to be used then the system would require an already existing workstation for the IOC to run on; however, if other hardware I/O were to be required then the hardware platform would most likely be the standard APS VME64x rack mounted crate manufactured by Dawn VME Products. The workstation would likely be running Red Hat Linux Enterprise operating system while the VME crate would run the vxWorks operating system; both are compatible with EPICS.

# Operational Requirements

This control system must be operational 24/7 during APS beam time.

# Security

Standard Channel Access Security (CAS) is to be used to control which users have access to the control system operation and when. This is typical for other APS control systems.

# System Reliability

1. Magnet quenching which can occur in as little as 10ms could cause stored beam to be inadvertently dumped and should be avoided whenever possible.
2. Since the device is cooled with a closed liquid He system there exists the possibility of the vessel pressure going to a high level which should also be avoided.

# Recoverability

The foreseen failure modes of this system are related to hardware, software, and computer issues; including PV gateway problems. In the event that the system is unavailable to the user due to system failure either hardware or software system recovery must be performed in a timely manner consistent with APS call-in procedures for system recovery and repair.

In the event of a power outage all systems should be powered on with the power supply currents at zero amp output.

A clear role of system component responsibility must be conveyed to those that will be responsible for the equipment required to operate the device.

# Error Handling

Any system errors should be handled automatically by the control system in a failsafe way whenever possible.

# Validation Rules

SCU3.0 System validation shall be performed after every shutdown to insure proper device operation. A clear understanding of personnel responsible for device testing should be conveyed.

# Conventions/Standards

All data formats and communication interfaces shall be IEEE compliant.

# APPENDIX A - GLOSSARY

SCU0 – Superconducting Undulator Test Insertion Device

EPICS – Experimental Physics Industrial Control System

CA – EPICS Channel Access

CAS – EPICS Channel Access Security

LHe – Liquid Helium

MEDM – Motif Editor Display Manager (Standard APS EPICS Display Screens)

CSS BOY- Control System Studio, Best Operator Interface Yet (Updated version of MEDM)

# APPENDIX B - Figures



Figure 1: SCU ID Electrical Connections

Figure 2: SCU ID Pressure Sensor Connections



Figure 3: SCU ID Temperature Sensor Diagram

# APPENDIX C - SCU0 INSTRUMENTATION LIST

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SCU0 Instrumentation List** | | | | | | | | |  | | | |
|  |  |  |  | |  | |  | |  | | | |
| **Sensor** | **Label** | **Location** | **Sensor type** | | **Device type** | | **No. of pins** | | **no. of Signals** | | | |
|  |  |  |  | |  | | **192** | | **62** | | | |
|  |  |  |  | |  | |  | |  | | | |
| **Temperature sensors all use Lakeshore model 218S monitor** | | | | | | | **128** | | **32** | | | |
| **Sensor** | **Label** | **Location** | **Sensor type** | | **Wire type** | | **No. of pins** | |  | | | |
| 1 | TT01 | Cryocooler DS TOP 1st stage | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 2 | TT02 | Cryocooler DS TOP 2nd stage | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 3 | TT03 | Cryocooler US TOP 1st stage | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 4 | TT04 | Cryocooler US TOP 2nd stage | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 5 | TT05 | Cryocooler DS BOTTOM 1st stage | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 6 | TT06 | Cryocooler DS BOTTOM 2nd stage | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 7 | TT07 | Cryocooler US BOTTOM 1st stage | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 8 | TT08 | Cryocooler US BOTTOM 2nd stage | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 9 | TT09 | 500A HTS lead1 top | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 10 | TT10 | 500A HTS lead2 top | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 11 | TT11 | 100A-DS HTS lead1 TOP | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 12 | TT12 | 100A-DS HTS lead2 TOP | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 13 | TT13 | 100A-US HTS lead1 top | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 14 | TT14 | 100A-US HTS lead2 top | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 15 | TT16 | LHe tank top | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 16 | TT17 | LHe tank bottom | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 17 | TT15 | LHe recondenser | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 18 | TT18 | LHe bottom supply pipe | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 19 | TT19 | SC Magnet top core | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 20 | TT20 | SC Magnet bottom core | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 21 | TT21 | Beam chamber DS | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 22 | TT22 | Beam chamber US | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 23 | TT23 | Beam chamber centre | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 24 | TT24 | 60K radiation shield | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 25 | TT25 | 20K radiation shield | Cernox | | 4-wire QT-36 | | 4 | |  | | | |
| 26 | TT26 | Reserve |  | | 4-wire QT-36 | | 4 | |  | | | |
| 27 | TT27 | Reserve |  | | 4-wire QT-36 | | 4 | |  | | | |
| 28 | TT28 | Reserve |  | | 4-wire QT-36 | | 4 | |  | | | |
| 29 | TT29 | Reserve |  | | 4-wire QT-36 | | 4 | |  | | | |
| 30 | TT30 | Reserve |  | | 4-wire QT-36 | | 4 | |  | | | |
| 31 | TT31 | Reserve |  | | 4-wire QT-36 | | 4 | |  | | | |
| 32 | TT32 | Reserve |  | | 4-wire QT-36 | | 4 | |  | | | |
|  |  |  |  | |  | |  | |  | | | |
| **Voltage tap signals 16 Bit A-D or better Voltage Range** | | | | | | | **40** | | **20** | | | |
| 1 | VT1 | 500A HTS lead1 top and Bottom | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 2 | VT2 | 500A HTS lead2 top and bottom | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 3 | VT3 | 100A-DS HTS lead1 top and bottom | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 4 | VT4 | 100A-DS HTS lead2 top and bottom | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 5 | VT5 | 100A-US HTS lead1 top and bottom | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 6 | VT6 | 100A-US HTS lead2 top and bottom | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 7 | VT7 | SC Top main coil | | +-10V\*\* | | 2-wire TP DT-36 | | | | 2 |  | |
| 8 | VT8 | SC Bottom main coil | | +-10V\*\* | | 2-wire TP DT-36 | | | | 2 |  | |
| 9 | VT9 | SC US correction coils | | +-10V\*\* | | 2-wire TP DT-36 | | | | 2 |  | |
| 10 | VT10 | SC DS correction coils | | +-10V\*\* | | 2-wire TP DT-36 | | | | 2 |  | |
| 11 | VT11 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 12 | VT12 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 13 | VT13 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 14 | VT14 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 15 | VT15 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 16 | VT16 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 17 | VT17 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 18 | VT18 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 19 | VT19 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
| 20 | VT20 | Reserve | | +-10V | | 2-wire TP DT-36 | | | | 2 |  | |
|  |  |  | |  | |  | | | |  |  | |
|  |  |  | |  | |  | | | |  |  | |
|  |  | **Heaters** | | **V and I for PS** | |  | | | | **16** | **8** | |
| 1 | JC01 | Cryocooler DS TOP 2nd stage | | 20V 2A | | 2-wire 24 AWG? | | | | 2 |  | |
| 2 | JC02 | Cryocooler US TOP 2nd stage | | 20V 2A | | 2-wire 24 AWG? | | | | 2 |  | |
| 3 | JC03 | LHe tank | | 20V 2A | | 2-wire 24 AWG? | | | | 2 |  | |
| 4 | JC04 | LHe thermosyphon return pipe | | 20V 2A | | 2-wire 24 AWG? | | | | 2 |  | |
| 5 | JC05 | SCU TOP core to force quench | | 20V 2A | | 2-wire 24 AWG? | | | | 2 |  | |
| 6 | JC06 | SCU Bottom core to force quench | | 20V 2A | | 2-wire 24 AWG? | | | | 2 |  | |
| 7 | JC07 | Vacuum chamber | | 20V 2A | | 2-wire 24 AWG? | | | | 2 |  | |
| 8 | JC08 | Reserve | | 20V 2A | | 2-wire 24 AWG? | | | | 2 |  | |
|  |  |  | |  | |  | | | |  |  | |
|  |  | **LHe Level Sensors using American Magnetics model 135 display unit** | |  | |  | | | | **8** | **2** | |
| 1 | LI1 | LHe tank\* | | Probe | | 4-wire QT-36 | | | | 4 |  | |
| 2 | LI2 | LHe tank\* | | Probe | | 4-wire QT-36 | | | | 4 |  | |
| \*these signals exit on the center turret port using 9 pin sub D CF feedthrough | | | | | | | | |  | | | |
| \*\*these voltage taps will be divided by 4 | | | |  | |  | |  | | | |  | |
| 128 pins are available on the four 32 pin connectors on the large turrets, | | | | | | | |  | | | |  | |
|  |  | all other leads can exit through center turret vacuum port | | | | | |  | | | |  | |
|  |  |  | |  | |  | |  | | | |  | |
| **Compressor Alarm DIO (not included in total signals or pins for cryomodule)>>** | | | | | | | | **64** | | | | **32** | |
| 1 | CI1 | DS TOP Pressure Alarm | | DIO Relay | | 2 | |  | | | |  | |
| 2 | CI2 | DS TOP He discharge High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 3 | CI3 | DS TOP He after cooler High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 4 | CI4 | DS TOP H2O High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 5 | CI5 | US TOP Pressure Alarm | | DIO Relay | | 2 | |  | | | |  | |
| 6 | CI6 | US TOP He discharge High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 7 | CI7 | US TOP He after cooler High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 8 | CI8 | US TOP H2O High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 9 | CI9 | DS BOT Pressure Alarm | | DIO Relay | | 2 | |  | | | |  | |
| 10 | CI10 | DS BOT He discharge High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 11 | CI11 | DS BOT He after cooler High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 12 | CI12 | DS BOT H2O High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 13 | CI13 | US BOT Pressure Alarm | | DIO Relay | | 2 | |  | | | |  | |
| 14 | CI14 | US BOT He discharge High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 15 | CI15 | US BOT He after cooler High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 16 | CI16 | US BOT H2O High Temp | | DIO Relay | | 2 | |  | | | |  | |
| 17 | CI17 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 18 | CI18 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 19 | CI19 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 20 | CI20 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 21 | CI21 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 22 | CI22 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 23 | CI23 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 24 | CI24 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 25 | CI25 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 26 | CI26 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 27 | CI27 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 28 | CI28 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 29 | CI29 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 30 | CI30 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 31 | CI31 | Reserve DIO | |  | | 2 | |  | | | |  | |
| 32 | CI32 | Reserve DIO | |  | | 2 | |  | | | |  | |