MICE-NOTE-GEN-431

The MICE Controls & Monitoring System for MICE Step IV

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19 December 2016

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1 Introduction

MICE is a precision experiment which will make high resolution measurement. It is therefore imperative that experimental parameters be understood and stable so as not to contribute to the experimental systematic errors. Anything unavoidable systematic effects that may contribute to systematic errors need to be monitored and recorded so that they may later be reliably used for calibrations and/or corrections to the data.

MICE Controls and Monitoring (C&M) serves to:

- interface to MICE hardware for remote control and monitoring
- provide user interfaces via graphical user interfaces (GUIs)
- provide equipment protection via hardware interlocks and audible alarms in the MICE local control room (MLCR)
- provide data quality protection via audible alarms in the MLCR
- provide remote montoring for MICE collaborators not in the MLCR
- provide data archiving of parameters
- send automated SMS messages to system experts in case of emergencies

2 Design Philosophy

The design philosophy of the MICE C&M is that of divide-and-conquer the components of the hardware. This is followed by a logical organization of these components into subsystems. The MICE Step IV subsystems are:

1. Beamline
   - target
   - conventional dipole and quadrupole magnets
   - decay solenoid
   - proton absorber
   - beam stop
   - diffuser
2. Detectors
   - luminosity monitor
   - ToF0, ToF1, ToF2
   - Ckov-A, Ckov-B
   - Trackers: TKU & TKD
   - KL
   - EMR
3. Channel
   - SSU
   - FCU or FCD
   - SSD
   - LH_2 absorber
4. Environment
5. Services

Other systems also exist, which do not fall into these categories. More details of the subsystems are found in 4.

A wrapper Input/Output Controller (IOC), see 3, for each subsystem is developed to provide uniform control and monitoring.

Above the wrapper IOC is a finite state machine for each subsystem. This is a separate IOC which is defined to be purely passive.

3 C&M Framework

3.1

The MICE C&M is built using the EPICS[1] framework. EPICS (**E**xperimental **P**hysics and **I**ndustrial **C**ontrol **S**systems) is open source software and community. A simple description is depicted in Fig. 1. Here hardware devices are connected to via hardware drivers to computers (PCs or VME crates) which serve as Input/Output Controllers (IOCs). In addition to being a computer, the IOC is a process which creates Process Variables (PVs) which represent physical parameters of the hardware device under control; e.g. temperature, flow, etc. The PVs, in turn, have native fields which further define their functionality; e.g. scanning frequency, alarm limits, operational limits, engineering units, etc. The IOCs also act as servers which provide PVs on a local area network (LAN) such that they can be used by client processes: GUIs, alarm handlers, archivers, or even other IOCs.

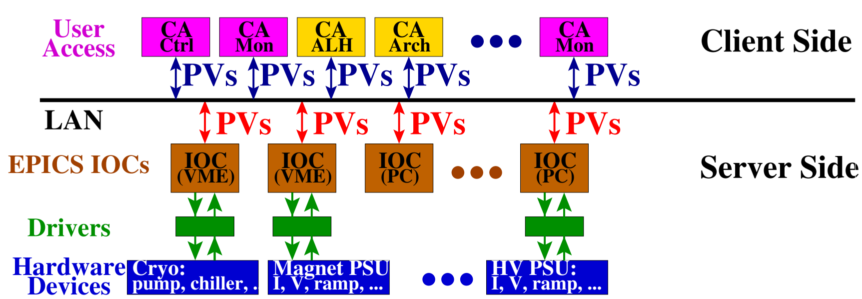

Figure 1: Simplified diagram of EPICS showing hardware devices connected to IOCs which create PVs and serve them on a LAN for client or other IOC use.

For this document, only Step IV major subsystems are considered. Figure 2 shows an organizational chart in which the different devices and subsystems are catagorized as belonging to Environment, Facilities, Beamline, Detectors, MICE Channel, or Electrical/Computors; those boxed in the figure represent IOCs which are combined into a single IOC. The lower portion of the figure identifies the components for each item; all require an IOC, most have one or more GUIs, most have alarm handlers and/or archivers. The larger and more complex systems additionally have a finite state machine, see Sec. 5.

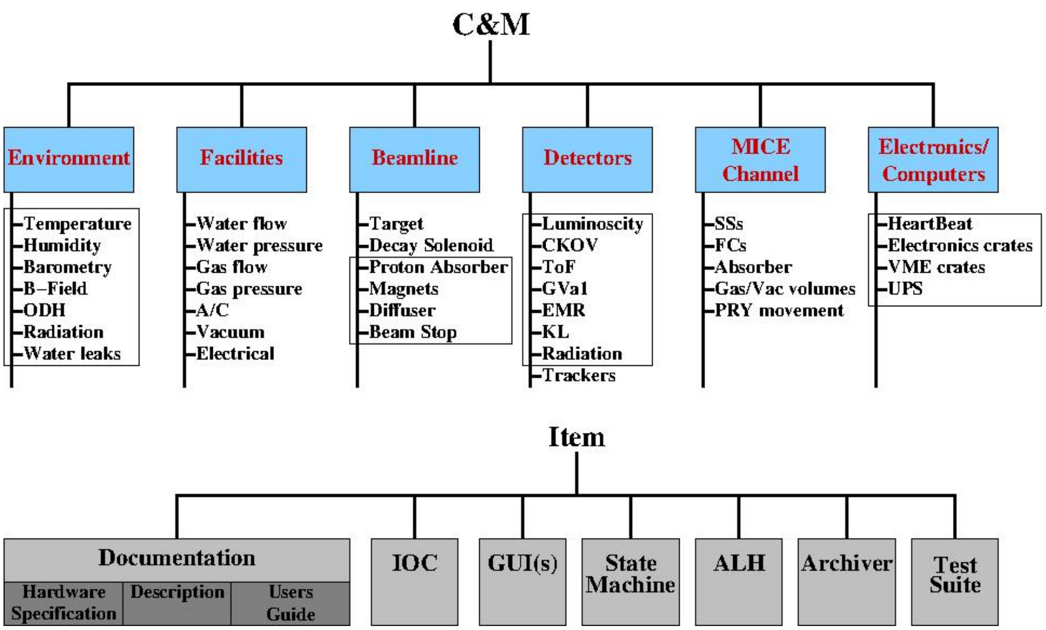

Figure 2: C&M organization chart catagorizing the different IOCs; the diagram below shows the different parts of each item above.

3.2 Procedure

- Each major subsystem of MICE is to be based on a state machine
- For each state, parameters of interest are to be identified:
  - alarm limits are determined
  - archiving parameters are determined
  - AutoSMS is enabled/disabled
- Interlocks are determined
  - software interlocks

- hardware

- Consultant/Experts are identified for each state
- "What if ...? questions are identified
  - power interuptions
    - all power loss
    - single system power loss
    - combination of systems power losses
  - signal failures
  - meeting with experts categoized by state
  - ...
- Documentation
  - subsystem descriptions
  - subsystem operation manuals
  - integrated system manual

3.3 Subsystems

From a controls perspective, MICE is composed of the following subsystems, with subsystem owners:

- Beamline
  - Target – P. Hodgeson
  - Conventional magnets – H. Nebransky
  - Decay solenoid – M. Courthold
  - Proton absorber – P. Hanlet
  - Beamstop – H. Nebransky
  - Diffuser – V. Blackmore
- Particle Identification
  - GVa – Y. Karadzhov
  - CKOV – L. Cremaldi
  - ToF – Y. Karadzhov
  - KL – L. Tortora

  - EMR – R. Asfandiyarov
  - LM – P. Soler

- Cooling Channel
  - Tracking Spectrometers
    - Spectrometer solenoids – S. Virostek
    - Trackers – A. Bross
  - Absorber/Focusing Coils
    - Focusing coils – T. Bradshaw
    - Absorbers: LH_2 system and solid absorbers – S. Watson
  - Radio Frequency/Coupling Coils – not used in Step IV
    - Coupling coils – A. Moss
    - Radio frequency cavities – D. Li
  - Radiation shutters – M. Uchida
  - Integrated QPS – P. Hanlet

- Computing/Electronics Infrastructure
  - Data acquisition – Y. Karadzhov
  - Target data acquisition – E. Overton
  - Tracker data acquisition – D. Adey
  - Controls and Monitoring – P. Hanlet
  - VME crates – DL team
  - Trigger electronics – Y. Karadzhov
  - Equipment protection – P. Hanlet

- Environment/Facilities
  - Temperature – P. Hanlet
  - Humidity – P. Hanlet
  - Radiation – M. Uchida
  - Water pressures/flows – DL team
  - Air pressures/flows – DL team
  - Vacuum – V. Francis (?)

3.4 Experts List

As of the writing of this document,

3.5 Controls Hardware

The larger systems: target, conventional beamline magnets, decay solenoid, trackers, spectrometer solenoids, focus coil, and vacuum/compressors have control systems built by a controls team at Daresbury Laboratory (DL) in the UK. Each IOC is a VME based system with a Hytek[2] processor running VxWorks[3]. Sensor controllers are interfaced via RS232. CANbus is employed for interlocks and digital controls, while analog devices are monitored and controlled with VME based ADCs and DACs.

The LH_2 system, due to its sensitive nature, is controlled by Omron PLCs and is completely self-contained. EPICS is used solely for remote monitoring of this system.

Other IOCs for MICE have been implemented on Linux PCs. These include Ckov, radiation monitoring, high voltage for the PID detectors, proton absorber, beamstop, diffuser, UPS monitoring, environment monitoring, air conditioning, LH_2 monitoring, PRY movement, and computer/electronics "heart beat" monitoring. These IOCs employ a variety of interfaces: serial RS232 and RS485, SNMP, modbus, and TCP/IP.

Though the C&M hardware items are built separately, requirements are defined by the subsystem owners. MICE, as an international collaboration, has institutions from around the world providing subsystems and components. It is therefore the challenge of the C&M team to provide uniform control and interfaces to all of the apparatus.

3.6 Higher Level Controls

What is described above identifies all of the IOCs associated with hardware. Additionally, many of the subsystems will interact with each other, need to share resources, and/or require sequencing for proper operation. This functionality is referred to as to higher level controls and include the use of finite State Machines and Run Control.

A top down model for MICE C&M is to use Run Control, see Sec. 6, as the principle user interface; in addition to users, Run Control interfaces with the MICE Configuration Database (CDB), the data acquisition system (DAQ), IOCs, and major subsystem state machines.

The next layer down from Run Control is that with State Machines, see Sec. 5,for major subsystems or combined systems. These IOCs are passive in that they have no control functionality; they only report the state of the device and handle alarms, archiving functionality, and flag critical variables required to notify experts in case of subsystem problems.

The lowest layer is that of the hardware IOCs which interfaces with the equipment.

In what follows, Sec. **??** will briefly describe the hardware control systems.

The following section, Sec. 6, will describe the MICE Run Control system: it's logic and responsibilities. This will be followed by, Sec. 5, which will describe the logic and functionality of the MICE State Machines and list the states for the major subsystems.

4 MICE Subsytem Controls

4.1 Target

4.2 Conventional Magnets

The beamline magnets are conventional, water-cooled electromagnets. They consist of quadrupoles: Q1, Q2, Q3 and dipole D1, which reside in the ISIS vault; dipole D2 and quadrupoles Q4, Q5, Q6 in the DSA; and quadrupoles Q7, Q8, Q9 in the MICE hall. Each of these magnets are water-cooled and powered by Danfysik power supplies. The control system is operated by miceioc3 which is a VME crate running IOC CS4.

4.3 Decay Solenoid

The decay solenoid is a 5 m long, 5 T superconducting solenoid magnet from PSI. The control system is operated by miceioc1 which is a VME crate running IOC CS1. Additionally, there is a Windows PC which operates the Linde refrigerator; this also runs an IOC which picks up the parameters.

4.4 Other Beamline Elements

The target and decay solenoid are sufficiently complicated so as to warrent their own state machines. In order to simplify a state machine for the other beamline devices, the remaining beamline IOCs have been combined into a single BeamLine IOC. The beamline elements of this IOC are: the conventional magnets, proton absorber, beamstop, and diffuser.

The proton absorber is a pneumatically operated device which employs a TCW181B [4] controllable switch to control a Norgren Valve Island[5] to operate the actuators for each absorber plate. Additionally, a SecurityProbe 5ES[1] system from AKCP[6] monitors limit switches which are activated when a plate reaches its upper or lower position, thus indicating that it is fully open or closed. The Security probe is also used with 4-20mA sensors to read out pressure transducers on the input and output air streams of the Valve Island.

The beamstop uses the SecurityProbe to read out limit switchs to indicate that it is fully open or closed.

The diffuser is also a pneumatically controlled device and its controls is home made by Oxford University. Its communication is via an RS232 serial line and uses asynchronous protocols. Additionally, a pressure transducer is used to mon-

[1] The AKCP Security Probe 5ES is a networked device which is controlled and monitored via SNMP. This device many types of sensors which are connected to it either directly or through expansion ports via CAT5E cables

itor the input air pressure; this is read out via a 4-20mA sensor with the SecurityProbe.

As previously described in Sec. 4.2, the conventional magnets have their own IOC. Nonetheless, these are combined in the BeamLine IOC with the increased functionality of having single PVs to identify if all the magnets are ready for operation, if all the magnets are at their specified currents, and the ability to turn them all on, off, or to set all magnet currents with single commands.

4.5 Spectrometer Solenoids

4.6 Focus Coils

4.7 Trackers

The C&M requirements for the trackers are spread over a number of systems which can be divided into two sections:

- systems which maintian the vacuum, pressure, helium flow, and cryogenic temperature of the VLPC cryostat
- the system which performs the fine temperature control of the VLPC modules and all front end readout.

The first set of systems is primarily developed by Daresbury laboratory using their standard technique. This provides the majority of the monitorable parameters, inlcuding cryostat vacuum, helium gas pressure, and temperatures at various points in the cryostats. Interlocks are put in place to ensure pressure release, smoke detection, and others.

The second set of systems is based on the DØAnalgoue Front End. In terms of monitoring this only provides feedback on the fine temperature control of the VLPC modules, recording their temperature when in the 9K region. The controls of this system takes the form of an initialisation procedure to be performed at the bebinning of a data taking period. This must involve setting the desired temperature, VLPC bias, discriminator thresholds and a number of other analogue and digital settings. This requires communication with FPGAs and ASIICs on the Analogue Frot End board via a Mil-1553 controller, which is itself controlled through a VME interface.

4.8 Detectors Coils

4.9 LH_2 Absorber

5 MICE Subsystem State Machines

For each subsystem, the states are defined below. Note that the principal purpose of the state machines is not to safely protect the equipment, this is assumed to be done by the control systems. Rather, the purpose of the state machines is to operate the subsystems with maximal efficiency. This means that for each state, the pertinent parameters, or "process variables" (PVs in EPICS speak), are selected and their alarm limits and archiving features are set. Furthermore, the critical variables are selected for use in AutoSMS. The values for these parameters are stored in the MICE Configuration Database, or "CDB". Thus, for each state, the state machine performs the following functions:

1. Enter state and set control panel buttons for new state
2. Read CDB for this subsystem in this state
3. Loop over parameters from CDB and fill:
   - alarm limits
   - archiver features
   - turn on/off AutoSMS variables
4. Run Archiver restart script
   - create soft link to archiver configuration file; 1 xml file exists per subsystem and state
   - stop then restart archiver (now picking up new configuration file)
5. Enable/Disable software interlocks
6. For states with power to the magnets, perform check on quench detected PV and transitions to "Quenched" state if necessary
7. Perform checks on software interlocks for this state and transition to "Error" state if any test is failed
8. Perform checks on parameter limits for this state and transition to "Error" state if any test is failed
9. Perform check for transition to new state and transition to new state if conditions are met

Steps 2-5 are used to initialize the state with parameters obtained from the CDB to ensure consistent values. Step 3 sets the PV fields for the state. Step 4 re-initializes the archiver with the state settings. Step 5 performs the only "control" functions for the state by enabling/disabling flags for equipment operation; e.g. ensuring power supplies are off when a superconducting magnet is not yet cold.

Steps 6-8 comprise the loop of the state in which checks are continuously made to determine if the state should persist or transition to another state. Step 6 checks for interlocks; e.g. a quench of a superconducting magnet. Step 7 checks for errors which would not permit the state to be maintained; this may be a hardware error which would eventually cause the parameters of the state to change, or a fluctuation which is sufficiently persistent to require the state to retreat to a previous state. Finally, step 8 compares the transition values to those read from the CDB to ascertain if the state can transition to the next state; e.g. a sufficient LHe level to ensure that superconduction coils are cold and ready to be powered. This algorithm is shown graphically in Fig. 3.

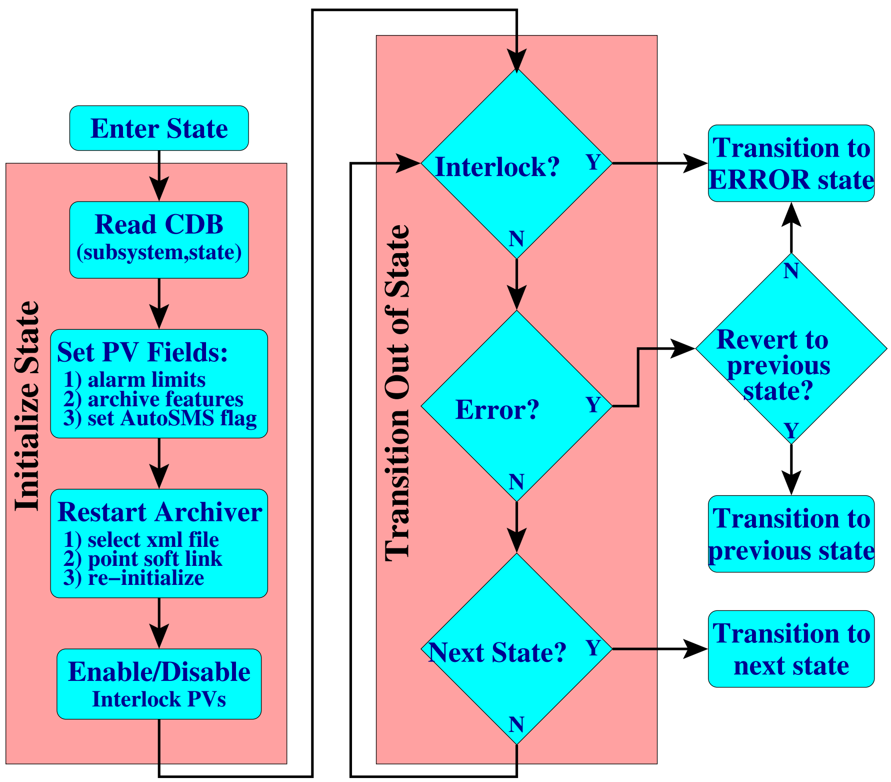

Figure 3: State Machine algorithm: for each state of each subsytem, the state machine performs this sequence.

Note that some of the transitions are manual and others are automatic. Control of this is automated in the state machine gui. For each state of each subsystem, the following information is generated. Much of this information is stored in the CDB. Subsystem owners are expected to generate this information:

1. Description
2. Parameters (PVs) of Interest
3. Alarm Limits
4. Archiving
5. AutoSMS
6. Hardware Interlocks[2]
7. Software Interlocks
8. Transition to next state

In what follows, the subsystems requiring state machines, are identified. For each subsystem, the states are listed along with their descriptions, transitions, and types of parameters (PVs).

[2]Note that the hardware interlocks are implemented in the hardware and *not* the state machine. However, they are more easily identified in the context of state machines, and are therefore considered here.

5.1 Target

1. **Offline**
   (a) Description: *Target is completely powered down*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *None*
2. **Parked Powered On**
   (a) Description: *The vac-rack electronics are powered, target inactive*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *PSUs, cooling water temperature, frame position*
3. **Holding Raised**
   (a) Description: *The frame is raised (outside ISIS) and the target is ready to be actuated*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *PSUs, cooling water temperature, frame position, target position*
4. **Actuating Raised**
   (a) Description: *The target is actuating in the raised state*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *PSUs, cooling water temperature, frame position, target position, quadrature brightness, minimum position, starting point, acceleration*
5. **Holding Moving**
   (a) Description: *Target frame is moving between outside and inside ISIS*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *frame position, ???*
6. **Holding Lowered (Ready)**
   (a) Description: *Target frame lowered and target ready to be actuated*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *PSUs, cooling water temperature, frame position, target position, quadrature brightness, minimum position, starting point, acceleration*

7. **<u>Actuating Lowered (Data Taking)</u>**

   (a) Description: *The target is lowered and actuating to make muons for MICE*

   (b) Transition into state: *Manual*

   (c) PVs of Interest: *PSUs, cooling water temperature, frame position, target position, quadrature brightness, minimum position, starting point, acceleration, ISIS intensity, ISIS beam losses*

8. **<u>Error</u>**

   (a) Description: *Error state*

   (b) Transition into state: *Known error*

   (c) PVs of Interest: *All*

9. **<u>Unknown</u>**

   (a) Description: *Invalid state*

   (b) Transition into state: *Unknown Error*

   (c) PVs of Interest: *All*

5.2 Conventional Magnets

This system has a simple state machine with only 6 states: Off, On_Unpowered, Ramping, Powered, Error, and Test. The purpose of this state machine is to allow magnets to be set and ramp, which means that while ramping the currents will be changing and therefore would alarm.

The states for the conventional beamline magnets are:

1. **Off**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
2. **On_Unpowered**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
3. **Ramping**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
4. **Powered**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
5. **Error**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
6. **Test**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:

5.3 Decay Solenoid

1. **Off**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
2. **Pumped**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
3. **Cooling1**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
4. **Cooling2**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
5. **ColdReady**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
6. **Powered**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
7. **Error**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:

8. **Quenched**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:
9. **Test**
   (a) Description:
   (b) Transition into state:
   (c) PVs of Interest:

5.4 Spectrometer Solenoids

All Spectrometer Solenoids have PV prefix: "MICE-SS1-" or "MICE-SS2-". SS2 will be used in the cooling channel's upstream position and SS1 will be in the downstream position. A full description of this state machine is found in Appendix **??**. The states for the Spectrometer Solenoids are:

1. **Offline**
   (a) Description: *System is offline*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *none*

2. **Pumping**
   (a) Description: *Cryostat vacuum is being established*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *Vacuum*

3. **Pumped_Warm**
   (a) Description: *Cryostat vacuum established, vessel ready for cooling*
   (b) Transition into state: *Automatic: satisfactory vacuum*
   (c) PVs of Interest: *Vacuum*

4. **Pre_Cooling**
   (a) Description: *Cold gaseous N_2 is pumped throught the cold mass. The cold mass temperature must not drop below 90 K; therefore, the 2-stage cryo-coolers must remain off. The vacuum will continue to drop and the temperatures will drop. The single stage cryo-cooler will be turned on to cool the radiation shield, but there are no C&M for this device. Warning states are announced, but there are no interlocks for protection.*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *Vacuum, Temperatures*

5. **Cooling**
   (a) Description: *Pump and purge cycles of the cold mass must be performed prior to entering this state to ensure that no residual N_2 will freeze in the cold mass. Cryo-coolers are used to further reduce the temperature of the cold mass prior to LHe cooling. The cryo-coolers water circuits must be turned on. Temperature and vacuum are expected to drop further. Because the cold mass pressure can now go sub-atmospheric, the heating loop must be ensured to be on.*

(b) Transition into state: *Manual*

(c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers*

6. **LHe_Filling**

   (a) Description: *The cold mass is now pumped, purged, and cool. The radiation shield is now cool. LHe will now be introduced into the cold mass; vent valves must be open. Temperature and vacuum are expected to drop further. Level gauge is monitored; level gauge overflow is monitored to avoid overfilling. Cold mass fill line temperature is monitored to ensure that liquid is flowing.*

   (b) Transition into state: *Manual*

   (c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers, Cold mass pressure, LHe level, Heater status*

7. **Cold_Ready**

   (a) Description: *Once the magnet is filled with LHe, a quiescent period will be required to ensure that the magnet is stable before powering. This state will occur:*

      - *when cooling the magnet for the first time*
      - *when recovering from a quench*
      - *when leaving the magnet cold, without current, and safe*

      Temperature alarm limits are set from quiescent values as determined from archived data according to the sensor position. All alarm limits are tightened and archiving is all monitored. AutoSMS is invoked since magnet may be left unattended.

   (b) Transition into state: *Automatic: Sufficient LHe level and quiescent timer*

   (c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers, Cold mass pressure, LHe level, Heater status*

8. **Ramping**

   (a) Description:
      Up until this point of operation, there was nothing that could cause damage to the magnet. When putting high current into the magnet, there is now the possibility of burning HTS or LTS leads or coils. In order to power the magnets, several conditions must be satisfied:

      - *water to energy absorbers*
      - *QPS must be in operation*

- *vacuum gate valve closed*
- *vacuum pumps off*
- *power supplies turned on*
- *gate valve to relief valves open*
- *contactors reset and enabled*
- *power supplies reset and enabled*
- *area cleared of magnetic materials*

In order to reset the power supplies and open the contactors, several interlocks must be made:

- *water to energy absorbers*
- *top plate of HTS leads must be cold*
- *LHe level must be >?%*

There are presently two modes for removing energy from the magnet, though three are possible:

- *quench – all contactors are opened, and energy is dissipated in the internal passive quench protection system*
- *controlled ramp – all contactors remain closed and energy is slowly dissippated in the energy absorbers and/or through the power supplies*
- *fast discharge (not implemented) – main contactors are opened which disconnects the power supplies, and power is dissippated through the energy absorbers in a rapid, uncontrolled manner*

(b) Transition into state: *Manual*

(c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers, Cold mass pressure, LHe level, Heater status, Water flows, PSUs, Contactors*

9. **Powered**

(a) Description: *Once the ramp up of currents is complete, the magnet will be in the "Powered" state. At this point, the alarm limits will be tightened on the power supplies.*

(b) Transition into state: *Automatic: all currents reach set points*

(c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers, Cold mass pressure, LHe level, Heater status, Water flows, PSUs, Contactors*

10. **Error**

(a) Description:
This is a catch all state to which the state machine will transition when alarm limits are violated, or software interlocks are broken. With experience, this will be made more sophisticated and states may transition backward instead of go to an error.

(b) Transition into state:
Automatic: alarm limits violated or software interlocks broken

(c) PVs of Interest: *All*

11. **Quenched**

    (a) Description: *Cold mass and coils warmed, loss of LHe*

    (b) Transition into state: *Automatic: QUENCH interlock*

    (c) PVs of Interest: *All*

12. **Test**

    (a) Description: *This state is intended to be expert only! Interlocks will be disabled and will allow the system to be vulnerable. Alarm handler MUST be kept in operation.*

    (b) Transition into state: *Manual*

    (c) PVs of Interest: *All*

5.5 Focus Coils

The states for the Focus Coils are:

1. **Offline**
   (a) Description: *System is offline*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *none*

2. **Pumping**
   (a) Description: *Cryostat vacuum is being established*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *Vacuum*

3. **Pumped_Warm**
   (a) Description: *Cryostat vacuum established, vessel ready for cooling*
   (b) Transition into state: *Automatic: satisfactory vacuum*
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4. **Pre_Cooling**
   (a) Description: *Cold gaseous* N_2 *is pumped throught the cold mass. The cold mass temperature must not drop below* 90 K*; therefore, the 2-stage cryo-coolers must remain off. The vacuum will continue to drop and the temperatures will drop. The single stage cryo-cooler will be turned on to cool the radiation shield, but there are no C&M for this device. Warning states are announced, but there are no interlocks for protection.*
   (b) Transition into state: *Manual*
   (c) PVs of Interest: *Vacuum, Temperatures*

5. **Cooling**
   (a) Description: *Pump and purge cycles of the cold mass must be performed prior to entering this state to ensure that no residual* N_2 *will freeze in the cold mass. Cryo-coolers are used to further reduce the temperature of the cold mass prior to* LHe *cooling. The cryo-coolers water circuits must be turned on. Temperature and vacuum are expected to drop further. Because the cold mass pressure can now go sub-atmospheric, the heating loop must be ensured to be on.*
   (b) Transition into state: *Manual*

(c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers*

6. **LHe_Filling**

   (a) Description: *The cold mass is now pumped, purged, and cool. The radiation shield is now cool. LHe will now be introduced into the cold mass; vent valves must be open. Temperature and vacuum are expected to drop further. Level gauge is monitored; level gauge overflow is monitored to avoid overfilling. Cold mass fill line temperature is monitored to ensure that liquid is flowing.*

   (b) Transition into state: *Manual*

   (c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers, Cold mass pressure, LHe level, Heater status, Strain gauges*

7. **Cold_Ready**

   (a) Description: *Once the magnet is filled with LHe, a quiescent period will be required to ensure that the magnet is stable before powering. This state will occur:*

      - *when cooling the magnet for the first time*
      - *when recovering from a quench*
      - *when leaving the magnet cold, without current, and safe*

      Temperature alarm limits are set from quiescent values as determined from archived data according to the sensor position. All alarm limits are tightened and archiving is all monitored. AutoSMS is invoked since magnet may be left unattended.

   (b) Transition into state: *Automatic: Sufficient LHe level and quiescent timer*

   (c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers, Cold mass pressure, LHe level, Heater status, Strain gauges*

8. **Ramping**

   (a) Description:
      Up until this point of operation, there was nothing that could cause damage to the magnet. When putting high current into the magnet, there is now the possibility of burning HTS or LTS leads or coils. In order to power the magnets, several conditions must be satisfied:

      - *water to energy absorbers*
      - *QPS must be in operation*
      - *vacuum gate valve closed*
      - *vacuum pumps off*

- *power supplies turned on*
- *gate valve to relief valves open*
- *contactors reset and enabled*
- *power supplies reset and enabled*
- *area cleared of magnetic materials*

In order to reset the power supplies and open the contactors, several interlocks must be made:

- *water to energy absorbers*
- *top plate of HTS leads must be cold*
- *LHe level must be >?%*

There are presently two modes for removing energy from the magnet, though three are possible:

- *quench – all contactors are opened, and energy is dissipated in the internal passive quench protection system*
- *controlled ramp – all contactors remain closed and energy is slowly dissipated in the energy absorbers and/or through the power supplies*
- *fast discharge (not implemented) – main contactors are opened which disconnects the power supplies, and power is dissipated through the energy absorbers in a rapid, uncontrolled manner*

(b) Transition into state: *Manual*

(c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers, Cold mass pressure, LHe level, Heater status, Strain gauges, Water flows, PSUs, Contactors*

9. **Powered**

(a) Description: *Once the ramp up of currents is complete, the magnet will be in the "Powered" state. At this point, the alarm limits will be tightened on the power supplies.*

(b) Transition into state: *Automatic: all currents reach set points*

(c) PVs of Interest: *Vacuum, Temperatures, Cryo-coolers, Cold mass pressure, LHe level, Heater status, Strain gauges, Water flows, PSUs, Contactors*

10. **Error**

(a) Description:
This is a catch all state to which the state machine will transition when alarm limits are violated, or software interlocks are broken. With experience, this will be made more sophisticated and states may transition backward instead of go to an error.

(b) Transition into state:
Automatic: alarm limits violated or software interlocks broken

(c) PVs of Interest: *All*

11. **Quenched**

    (a) Description: *Cold mass and coils warmed, loss of LHe*

    (b) Transition into state: *Automatic: QUENCH interlock*

    (c) PVs of Interest: *All*

12. **Test**

    (a) Description: *This state is intended to be expert only! Interlocks will be disabled and will allow the system to be vulnerable. Alarm handler MUST be kept in operation.*

    (b) Transition into state: *Manual*

    (c) PVs of Interest: *All*

5.6 Trackers

5.7 LH_2 Absorbers

6 Run Control

A top down model for MICE C&M is to use RunControl as the principle interface for users. RunControl is responsible for operating equipment at non-expert levels; namely using commands: Initialize, Start, Pause, and Stop[3]. RunControl will:

1. query user for run information
2. query MICE Configuration Database (CDB) for operating parameters
3. query individual state machines to ascertain equipment readiness to operate
4. set operating parameters
5. query individual state machines to ensure that equipment parameters are correctly initialized
6. initialize the DAQ
7. start/pause/stop the DAQ
8. write configuration information to CDB at the beginning and end of a run

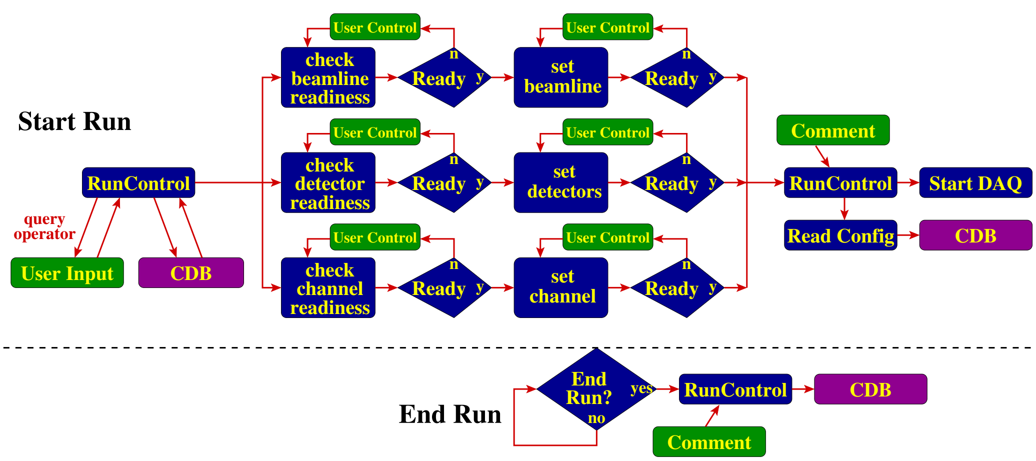

Figure 4: The MICE Run Control logic diagram.

[3]Note that expert level control continues to exist, but requires password access

7 Conclusions

/biblio.tex

References

[1] http://aps.anl.gov/epics.

[2] http://www.hytek.com.

[3] http://www.vxworks.com.

[4] http://www.tcw.com.

[5] http://www.norgren.com.

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