

SOFTWARE SYSTEM FOR MONITORING AND CONTROL AT THE SOLENOID TEST FACILITY *

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Abstract

A new facility to test superconducting solenoid magnets has recently been commissioned at Fermilab. At the heart of this facility's control and monitoring system lies a highly configurable scan subsystem targeted at precise measurements of low temperatures with uniformly incorporated control elements. A multi-format archival system allows for the use of flat files, XML, and a relational database for storing data, and a Web-based application provides access to historical trends. The DAQ and computing platform includes COTS elements. The layered architecture separates the system into data archival subsystem, Windows operator stations, the real-time operating system-based DAQ and controls, and the FPGA-based time-critical and safety elements. The use of the EPICS CA protocol opens the system to many available EPICS utilities.



Figure 1: Solenoid Test Facility.

INTRODUCTION

The purpose of the Solenoid Test Facility (SolTF) [1], a unique magnet test facility recently commissioned at Fermilab, is to provide an environment for testing large aperture superconducting solenoid magnets [2] at temperatures ranging from 300 K to 4.5 K. Such magnets usually have different dimensions than typical accelerator magnets and produce strong fringe magnetic fields. A new monitoring and control system has been developed for the facility. The system is integrated with a quench detection and characterization subsystem and a power control system to allow for testing while protecting the magnet (see Fig. 1).

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ARCHITECTURE

The SolTF monitoring and control system has a layered architecture, incorporating a Web-based data layer, a Windows PC-based user interface layer, and a real-time target-based data acquisition layer (see Fig. 2). It follows an architectural client-server pattern, with the servers located in the real-time system and the clients in the Windows-based user interface stations. The DAQ hardware has been assembled relying on National Instruments COTS products, such as cRIO crates with the VxWorks RTOS and GPIB instruments.

The monitoring and control subsystem employs an EPICS server to provide a unified and standardized interface to its process variables and, therefore, allows for the use of any EPICS tools in addition to the specialized programs developed for the facility.

Strong fringe field generated during testing of large solenoids necessitates distant operation of the facility. Therefore, provisions have been made for remotely operating the test stand, either from an auxiliary location in the same building or from the main control room of the magnet test facility. The SolTF is equipped with video and sound surveillance equipment to further enhance the remote operations experience.

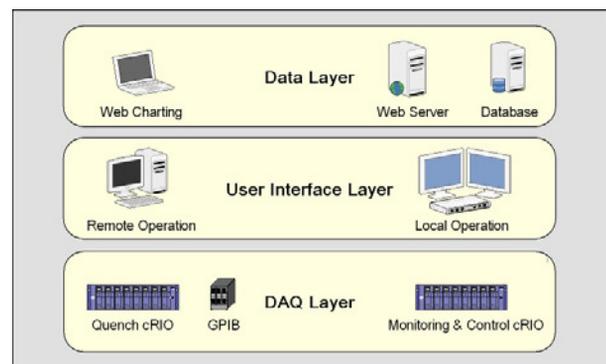


Figure 2: Architecture.

MONITORING

Monitoring and control functionality is implemented in the data acquisition layer. The monitoring and control system is built on the concept of a scan. A scan is a periodically executed sequence of reads and/or writes from/to device channels. A hardware channel corresponds to a single input or output of some physical quantity and is either direct access (DIO, AIO) or multiplexed (Keithley DMM with a multiplexer). The physical quantities such as temperatures, pressures, levels, and flows are obtained from raw voltages using calculations attached to channels and are presented to the user as

Process Variables (PV's). These PV's are published via EPICS Channel Access protocol.

Definitions of scans, PV's, sensors, calibrations, devices and calculations are provided in a configuration that defines the functionality of the system and can be relatively easily modified or replaced to accommodate the test of a different magnet. The PV is the main component of the configuration, through which all of the other elements are related. Each PV has a channel assigned to it on a device used for reading or writing its values. Devices correspond to physical instruments or virtual devices. A PV is also associated with calculations and sensors.

The monitoring system communicates with the quench subsystem via a hardware heartbeat signal.

CONTROL

PID Controller

The system allows for both manual and automatic valve control. In the manual mode, it is the operator who sets the desired position of the valve. The automated control employs a PID-based regulation and is used to maintain flow, temperature and liquid levels in the system. The control system also allows for valves controllable via more than one PV e.g., a valve may be controlled based either on the required flow or temperature. It is selectable to the operator by a toggle switch or settable by the system when running one of the automated processes.

Special attention was given to ensure bumpless control transfer when switching between manual control and PID control.

Automated Operation

The system also allows for fully automated operation. In this mode, the operator chooses a process to be executed, and this will then run without operator input.

When testing the MICE coupling coil [2], controlled cool-down and warm-up of the coil are required to prevent excessive thermal stresses in the cold mass. To accomplish this, two automated processes are available. These automated processes not only can manipulate (control) set points for PID controllers and select controlled PV's, but may also switch between alternative methods of reading monitored quantities. For example, when any of the above mentioned automated processes is active, both the minimum and maximum temperatures in the MICE coupling coil are determined by its resistance, but when no active control process is selected, those temperatures are determined by RTD sensors.

DATA ARCHIVING AND TRENDS

The data archiving subsystem consists of several applications accessing data, the database where the data is stored, and the Web service that provides access to the database. The core of the system is the SOAP Web service that provides a single point of contact for both saving and accessing the monitoring data. This service archives the provided data in the database, or retrieves requested data from the database.

Database

As default, the monitoring data are archived in a database. It is worth noting that the system has provisions for several data archivers running concurrently and has the ability to distinguish between different recording sessions, called runs. Separate tables are used to store different data types.

Data Archiver

Monitoring data can be archived using the data archiver application. This application allows for acquiring data from a data source (EPICS Channel Access server), storing the data in a database and/or storing the data in a file system using the CSV or TDMS formats. Both of those data formats are readable by Excel as well as any text editor.

The archiver application periodically acquires new values and periodically saves them. The initial intervals are obtained from a configuration file, but can be modified by the user at run-time. The data is stored in the database with a given archiver name and a run number. Some additional information, such as timestamps and status describing the data quality are recorded with the values as well.

In addition to saving data, the archiver application allows for viewing numerical values of all available PV's. Information for each PV is shown in a separate row and includes, besides its value, the time when this PV value was acquired and its status. The green background indicates that the PV value has been updated by the DAQ subsystem since the last retrieval by the archiver, the red colour indicates errors, and grey is stale/unchanged values.

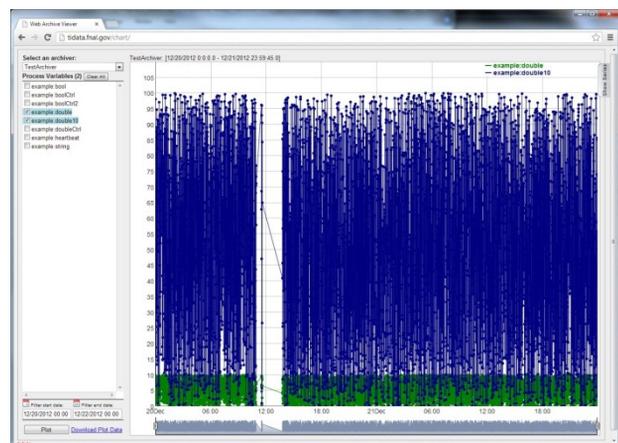


Figure 3: Web-based Data Viewer.

Web-based Data Viewer

A Web-based plotting application has been developed in HTML 5 that uses the Web service to access measurement metadata and offers it to the analyst to use in selecting the specific data to display (see Fig. 3). That data then is obtained via the same web service, formatted, and presented in an interactive plot for analysis.

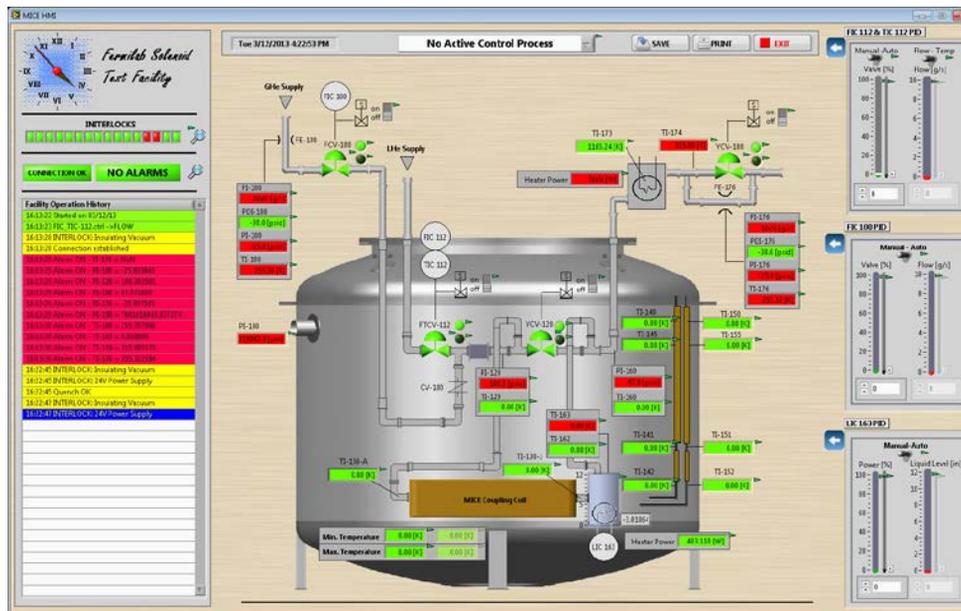


Figure 4: Human Machine Interface.

The time range of displayed data can be further manipulated with two sliders located at the bottom of the plotting area. Any of the displayed plots can be temporarily hidden by deselecting it from a short list of active plots.

The data shown on the chart can be downloaded to a local computer for further processing and analysis.

USER INTERFACES

There are several user interface programs, including a central HMI program for observing and controlling the system, a real-time charting application, a numerical display and a scan monitor.

HMI

The HMI application (see Fig. 4) is the fundamental operations tool. It presents an animated overview of the system together with a subset of crucial process variables, and allows for controlling the valves and the power heater. It has special provisions for controlling and tuning PID loops, and for activating automated processes. All major events and alarms as well as operator actions are displayed and logged in files to facilitate future inspection and debugging. PV's in the alarm state can be easily distinguished by their red background colour.

Real-Time Plotter

The real-time plotter program (see Fig. 5) allows for viewing trends of selected process variables. The list of variables as well as the chosen display horizon and plotting interval can be saved in settings files. Hence, the process variables of interest can be manually selected or loaded from a previously saved settings file. Plotting can be temporarily suspended, and the user can scroll through the locally stored historical values.

Several plotting programs may run concurrently, each showing a separate group of plots. Each plot area has two independent Y scales to allow for grouping PV's according to their ranges, while preserving a common timeline.

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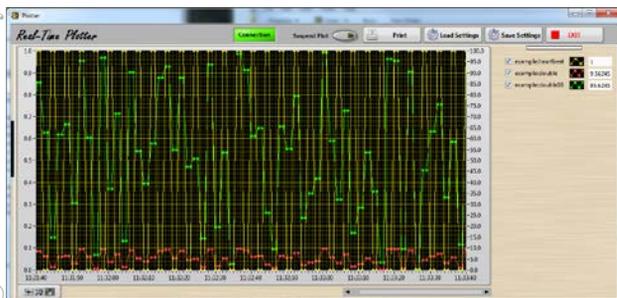


Figure 5: Real-time Plotter.

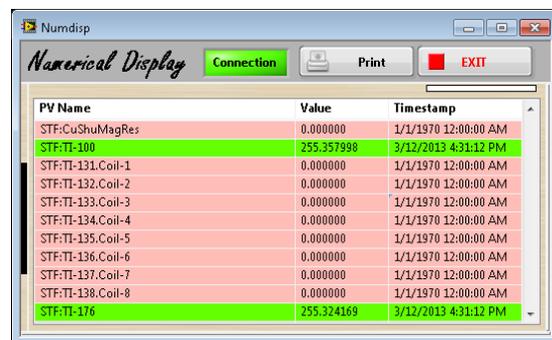


Figure 6: Numerical Display.

Numerical Display

Whereas the real-time plotter presents data in a graphical form, the numerical display program does it in a tabular, numerical form (see Fig. 6). Similar to its plotting counterpart, the numerical display application allows the selection of PV's to be displayed, and also provides for the saving and loading of these selections. It

can even use the settings previously stored by the plotter application and vice versa.

Scan Manager

The scan manager program helps the operator to assess the status of all monitoring and control scans running on the DAQ target. The scan manager activates or deactivates scans by pressing the button corresponding to a chosen scan. Normally control of scans is disabled to prevent unintentional interference with the scanning system.

INTERLOCKS AND ALARMS

The interlock logic is implemented in a separate process that monitors vacuum, quench status and temperatures, and which responds immediately to all prescribed conditions.

Apart from the interlocks, the system also periodically checks values of PV's, and values outside of allowed regions for the current mode of operation are reported as alarms.

Operators are notified of alarm and interlock conditions via an automated paging system, which can also notify people off-site. All interlock conditions and alarms are captured by the system and latched. Each interlock condition detected by the system is accompanied by the information about the time when the interlock condition was met. The operator must acknowledge these events to eliminate them from the list of pending significant events. If the interlock condition is still present at the time of clearing it, the indicator will remain red and the recorded time will change to the time when the clearing action was attempted.

Interlock conditions take into account the mode of operation. For example, the quench interlock can only be activated by a quench signal received while in the normal mode of operation, whilst it is ignored when the cool-down or warm-up automated processes are active.

An alarm indicates a PV value is outside of its expected range. Each alarm condition is configured for a specific mode of operation (e.g., cool-down, normal, and warm-up). Consequently, a set of alarm conditions may exist for a single PV. Detected alarms are added up and the number of outstanding (not confirmed) alarms is shown on the alarm indicator. The operator can see the detailed alarm information by clicking on the alarm indicator or the magnifying glass icon next to it. In response, a pop-up window is displayed showing the history of the alarms. All alarms and interlock detections are recorded in the system log (providing the user has not disabled the system logging function in the system configuration file), and select alarms and interlocks activate the paging system, which contacts the operator on shift.

The monitoring and control system is integrated with the IFIX-based control system for the magnet test facility to unify operator paging and response to significant events in both facilities. The SolTF control system is also integrated with the electronic logbook system which provides a unified operations log for several facilities.

SUMMARY

The Solenoid Test Facility, a new facility to test large aperture solenoid magnets, has been commissioned at Fermilab. A configurable system based on COTS hardware elements has been developed and successfully deployed to control this facility. This monitoring and control system has the following characteristics:

- A layered architecture with clear separation of concerns.
- A highly configurable scanning system to monitor RTD's, strain gauges, pressures, liquid levels, flows, and Hall probes.
- User-level scan control and status monitoring.
- Integration with EPICS tools via the EPICS CA protocol.
- Cryogenic control with PID controllers.
- Interlocks and alarms with operator paging system.
- Remote operation capability with video and sound surveillance equipment.
- Fully automatic operation capability with user-selectable processes.
- Data archived in a database, and/or TDMS or CSV files.
- Real-time trend plotting and numerical displays.
- SOAP Web service for data access and a Web-based charting and data extraction utility.

The Solenoid Test Facility is currently being used to test a coupling coil for the Muon Ionization Cooling Experiment (MICE), and its future uses include solenoid magnets for the Fermilab Mu2e experiment.

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