

A Quench Management System for Testing Superconducting Magnets

D. F. Orris, R. Carcagno, S. Feher, M. J. Lamm, J. Nogiec, P. Schlabach, M. Tartaglia,
and J. C. Tompkins

Abstract—A quench management system has been developed for the Fermilab Magnet Test Facility as part of the overall data acquisition and control system for testing superconducting accelerator magnets. The quench management system accepts a standard set of quench input signals such as magnet voltages and current, safety interlocks, and power supply status, which are multiplexed from several independent test stands. It also issues a standard set of output control signals that are used to activate the dump, the quench protection heater power supplies, and to control the magnet ramp down in the event of a quench. Triggers generated by the quench management system are used to save the logged quench data from both the fast and slow data acquisition instrumentation. The hardware architecture of the quench management system will be discussed along with analog quench detection, digital quench detection, quench logic, and the user interface for configuring and controlling this system.

Index Terms—Superconducting magnets, quench protection, instrumentation and controls.

I. INTRODUCTION

THE Magnet Test Facility at Fermilab has two separate power systems for testing superconducting magnets: a 10KA system and a 20KA system (soon to be upgraded to 30KA). Current is distributed from these two systems to three horizontal test stands and two vertical dewars; however, only one test stand can be powered by each power system at a time. Each power system provides a means for supplying current as well as extracting energy from the magnet under test. The quench Data Acquisition (DAQ) and Control systems are local to the test stand area and can be configured for testing specific magnets. Since a variety of superconducting magnets are tested in this facility, from model magnets for R&D to full-scale production magnets, the design characteristics and test requirements of these magnets vary widely. A Modular and Extensible DAQ and Control System was developed [1] in order to accommodate this wide range of requirements and to provide a means for easily reconfiguring the test stand/power system to match the magnet under test. The Quench Management System is at the heart of this modular system and can be multiplexed between different test stands and power systems.

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II. THE QUENCH MANAGEMENT ARCHITECTURE

A. Overview of the Quench Management System

The Quench Management Architecture consists of three principle components: Quench Detection, Quench Logic, and the Quench Management Software. The Quench Management Hardware accepts a standard set of quench signals from the superconducting magnet under test. These signals originate from several test stands, although a programmable logic controller (PLC) interlock system monitors the correct hardware configuration to ensure that the magnet being powered is the magnet being protected. These quench signals are input to the Quench Detection System where they are conditioned then compared to user-set quench thresholds. When these thresholds are exceeded a "Tripped" state occurs and a quench status is set. The Quench Logic Module (QLM) monitors the quench status and sets off a chain of events that controls the power supply ramp-down, the energy extraction circuit firing, and the magnet quench protection heater discharge. This is purely a hardware response. The quench manager output signals make up a standard set of control signals that are also multiplexed to more than one power system. The Quench Management Software manages the operation of the quench manager hardware and its interaction with external components such as the quench characterization hardware, which is used for capturing and characterizing magnet instrumentation data, and the quench protection heaters. It also provides user settable parameters via a graphical user interface (GUI), fig 1.

B. Quench Manager Hardware Components:

The Quench Manager system hardware includes a VME crate, a VME embedded PowerPC processor (MVME2604), an 8-Ch Analogic ADC (DVX-2503) for digital quench Detection, an 8-CH anti-aliasing Bessel filter, a QLM, a D/A-A/D-DIO (MD-DAADIO) module for magnet protection heater monitoring and control, a Change of State module (VMIVME 1160A) for monitoring quench hardware status signals, analog quench detection circuits (AQDs), a quench signal multiplexer, the quench signal isolation amplifiers, and the quench protection heater distribution box. The block diagram of the quench management hardware system is represented in fig 2.

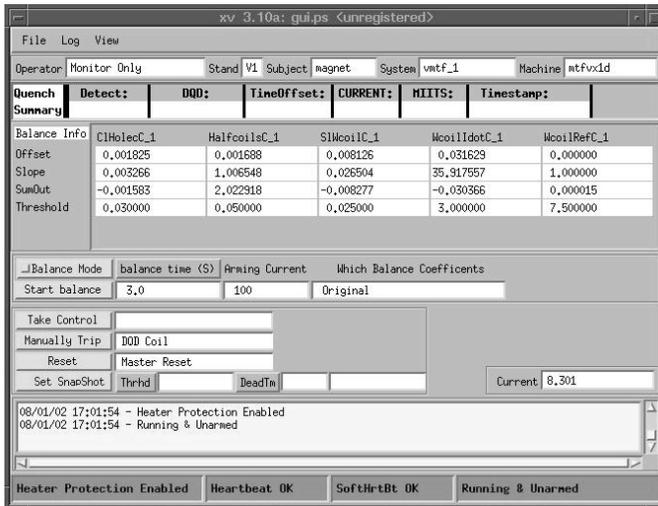


Fig. 1. The Quench Management Graphical User Interface (GUI).

III. QUENCH DETECTION SYSTEM

The Quench Detection system has two primary components: the analog quench circuits and the digital quench detection system. A standard set of magnet quench signals are input to isolation amplifiers where they are amplified and summed. This standard set includes three magnet coil segments and two power-lead segments. The system is designed to accommodate up to two cold masses powered in series by summing these segments at the outputs of the isolation amplifiers. Therefore no special jumpering is necessary as the quench segments are inherently configured via the magnet feed can wiring. The amplifier output signals are then distributed to both the analog quench circuits and the digital quench detection hardware.

A. Analog Quench Detection

The Analog Quench Detection (AQD) serves as a backup to the digital quench detection system, since they are reliable hardware components. These circuits are the only NIM modules used in the quench management system. Their technology for detecting quenches is based on the comparison between the difference of two input voltages with a threshold voltage, a technology that has been in use for many years. The standard magnet quench signals are input to the AQDs where they are amplified, if necessary, then subtracted. When the threshold voltage is exceeded a status output is latched in the tripped state. The quench logic system monitors this status signal then implements the necessary control logic for protecting the magnet when a trip occurs. The status outputs of the AQDs are monitored by the change of state module via the logic analyzer program and GUI. The AQDs are also set up for remote reset and manual trip via the DAADIO module and the Quench Manager program and GUI.

B. Digital Quench Detection

The Digital quench detection runs on a PowerPC under the VxWorks real-time operating system and communicates with

the Quench Management Software. Three main advantages of the DQD are its ability to be easily configured, its digital filtering allows lower threshold voltages, and it has a second trigger arming option to allow capturing of low level quenches that recover before magnet protection is necessary. The (DQD) system uses a VME 16-Bit analog to digital converter (ADC) to digitize the standard set of quench signals from the isolation amplifiers. An analog anti-aliasing filter is used as the front-end signal conditioner to the ADC. The ADC samples at a rate of 11,520Hz, which is more than twice the Nyquist frequency set by the stop band edge of the filter. A decimation filter (DSP) is applied to the sampled data so that the final sample rate is reduced typically to 2400Hz. The two sample rates were chosen to optimize noise rejection while minimizing delay. The total group delay of the combined analog and digital filters is ~ 1.9 msec. Since the final sample rate is 2400Hz, the maximum error in the quench decision time is ~ 2.4 msec. Note that the DQD system design and performance are covered in more detail in a previous paper [4]. The quench signals are then digitally bucked and compared to user defined threshold values. When a threshold value is exceeded, the status is latched and sent to the quench logic system via the VME bus. A heartbeat is sent periodically (< 8.2 msec) to the quench logic system signifying the DQD is operating correctly.

C. Software Quench Detection

The Software Quench detection was developed for testing high temperature superconducting power leads. It is an extension of the quench management system, coupling cooperating data acquisition systems for monitoring other parameters, such as temperature, for a quench. The cooperating systems are chained via a software heartbeat and the action taken upon detecting a quench is to ramp the power system down slowly via power supply control software. The hardware quench system is always armed at higher thresholds

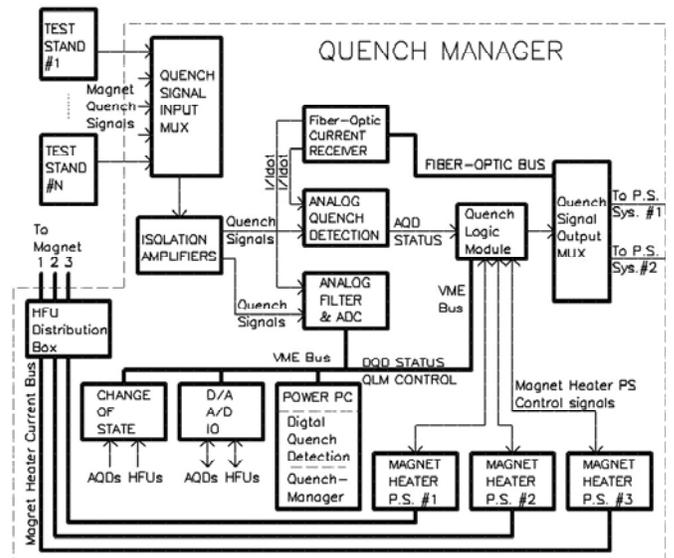


Fig. 2. The Quench Management Hardware Configuration block diagram.

as a backup. This system is also discussed in more detail in a previous publication [6].

IV. QUENCH LOGIC SYSTEM

A. Overview

The Quench Logic System processes the sequence of logic that takes place when powering a superconducting magnet. It responds to operator inputs to configure and reset the system, and it sends the necessary hardware control signals to protect the magnet when a quench is detected. At the heart of the quench logic system is the Quench Logic Module (QLM), fig 3. It is a singlewide VME module that is configured by programs running on the quench computer via the quench manager and HFU/Dump GUIs. The QLM monitors the quench detection "quench status" inputs and latches the first to trigger. If a magnet quench is detected then the output relays change state, initiating the power supply ramp down, the magnet energy extraction circuit (dump) discharge, and the magnet protection heaters to fire. These output states are also augmented by internal delays set by the user; *i.e.*, the magnet protection heater can be set to discharge at a user specified time (say 25msec) after the quench is detected. However, if a power lead causes the trip then all delays are bypassed in order to minimize damage to the leads. Magnet ground current is also monitored and the QLM will disable the quench logic sequence and ramp the magnet current down at 300Amps/sec to minimize magnet to ground voltage. In addition, the magnet protection heater system continuity is monitored. If the continuity breaks, the QLM will ramp the magnet down at 300Amp/sec but keeping the quench logic sequence armed in

case a magnet or leads trip occurs. This is done in order to maximize the magnet and power lead protection.

B. The QLM Internal Logic

The Quench Logic Module (QLM) is designed as a VME A16D16 slave module. All digital logic and VME interfacing is done using Complex Programmable Logic Device (CPLD) technology. The IC chips chosen for the QLM are Atmel's ATF1500 CPLDs. The ATF1500's are packaged as 44-Pin PLCC chips so each IC can be programmed and, if needed, reprogrammed using a standard EPROM programmer prior to installation.

C. QLM Inputs and Outputs

All QLM logic inputs and outputs to the CPLDs and the VME bus are buffered using standard TTL 16-Bit Transceivers. Logic inputs to the CPLDs coming from other external sources are also buffered. External outputs going to high power devices such as power supplies and heater firing units are optically isolated using Photovoltaic solid-state relays. Voltage isolation is 3500VDC. The QLM is designed to trip off the power supplies and implement magnet protection in the event that it or any of its signal sources loose power. It also performs in a similar manner when the digital quench detection system fails to send a heartbeat in the allotted time.

V. QUENCH MANAGEMENT SOFTWARE:

A. Quench System Software Organization:

The quench system is based on the architectural framework provided by the Distributed Monitoring and Control System project [2][3], which provides means for communication, synchronization, and configuration in heterogeneous distributed systems. The details of the quench system are specified in configuration files that are written using a proprietary hardware definition language. Those configuration files are used to initialize the system, which is built as a set of collaborating tasks distributed between the quench detection, quench characterization, and signal conditioning/processing computers. The system is controlled via a set of graphical user interfaces that enable the user to view and control the state of the system as well as to perform some diagnostics and calibrations. Data captured by the quench detection and characterization system is stored in binary files using a specialized format called the Chunk File Standard (CFS). CFS is an extensible data format, which allows for storing different data in one file. This type of a flexible and extensible data format is especially attractive for storing quench data, where various data acquired by different components and requiring different formats have to be stored together. Consequently, information about quench propagation, quench detection, cryogenic conditions, and signal processing is stored in a single hierarchical file.

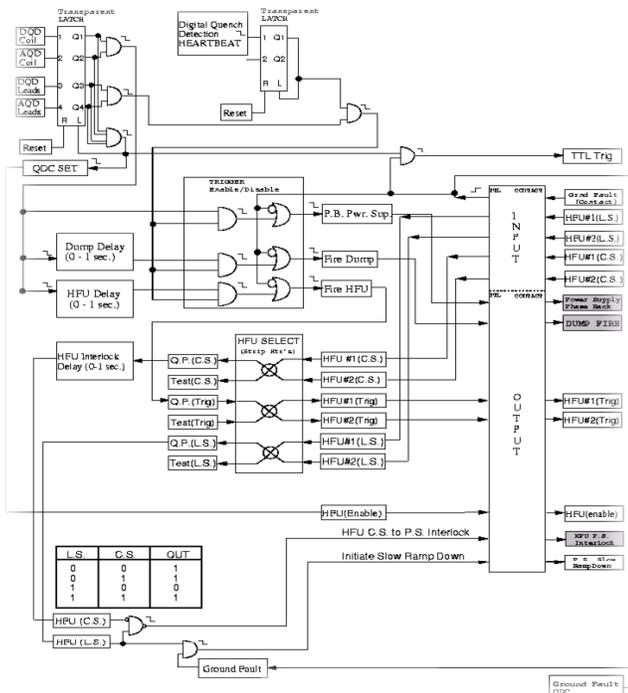


Fig. 3. The Quench Logic Module Logic Diagram.

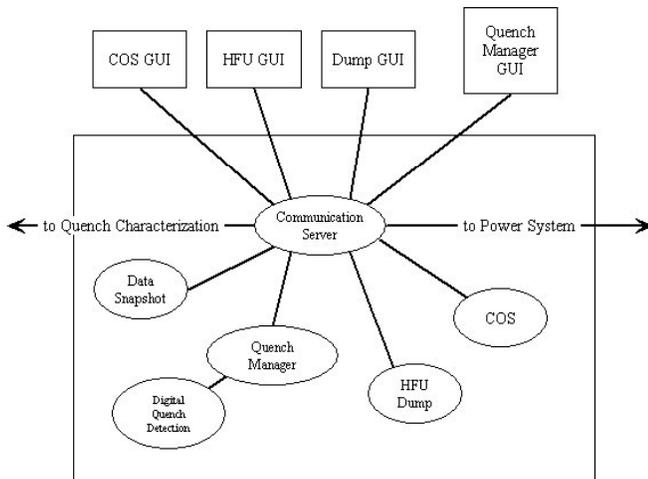


Fig. 4. The Quench Manager Software Organization.

The quench system is integrated with other subsystems such as power supply control and cryogenic monitoring systems (see fig 4). Since all the systems are built on top of the same framework, data is exchanged easily between those systems. The architecture of the software quench system is described in detail elsewhere [5].

B. Quench Management Software Components:

All quench management components are located in the quench computer (see fig 2). The heart of the system is the quench manager module, which communicates with local subsystems such as the quench detection component and with remote subsystems such as the power control system and the quench characterization subsystem. Remote communication is provided by the communication server, which also enables communication with graphical user interfaces running on other computers. The sequence of events during quench is captured by the COS component, whereas quench detection signals are acquired by the data snapshot task. Separate components are devoted to controlling the heater firing units and the dump.

VI. FUTURE UPGRADES

The only components that are not easily configured are the analog quench detection circuits. These NIM based modules must be configured locally, which means setting their gains, thresholds, and balance settings by hand. An upgrade of these modules is currently in progress. The following are some basic features of the new AQDs: 1) They will be 6U VME A16, A32, D16 modules capable of accepting a wide range of voltage signals from superconducting magnets; 2) All parameters will be fully software programmable (gains, attenuations, bucking, thresholds) and defaults will be stored in flash memory; and 3) The design will be based on FPGA/CPLD and Intel 80C196NU 16 bit micro controller technology. These improvements will allow the quench management system to be completely configured via software, which will reduce the effort required to configure the system

for a new magnet.

The QDQ program uses considerable CPU resources even with a 2604 PowerPC processor. Implementing a dedicated DSP processor to handle the filtering and other computing-intensive tasks looks attractive for the future.

VII. CONCLUSION

The Quench Management System is composed of a standardized set of hardware components that can be multiplexed to several test stands and power supply systems as well. This modular architecture works well because the quench signals have also been standardized so that the number of input channels is fixed. This is not restrictive, however, since this system is capable of testing all production magnets, short R&D magnets, and high temperature superconducting leads that the Fermilab Magnet Test facility is required to test. Taking advantage of the quench management's modular hardware design, the quench management software can also be easily reconfigured to match the requirements of the magnet under test.

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