DEVELOPMENT OF A QUENCH DETECTION SYSTEM FOR THE FAIR SUPERCONDUCTING DEVICES

V. Raginel, M. Dziewiecki, W. Freisleben, P. Szwangruber, L. Theiner
GSI, Darmstadt, Germany

Abstract

The Facility for Antiproton and Ion Research (FAIR), which is presently under construction in Darmstadt (Germany), will incorporate a large variety of superconducting devices like magnets, currents leads and bus bars. These components depend on an active protection in case of a transition from superconducting to the resistive state, so-called quench. In this framework, a FAIR Quench Detection System (F-QDS) is being developed based on analogue and digital electronics and will be implemented in several machines of the FAIR complex. This paper describes the development of the F-QDS. An overview of the F-QDS electronics is given followed by a description of the system integration to the infrastructure of various machines. Initial test results of the F-QDS prototype system are presented and discussed.

INTRODUCTION

The heavy ion synchrotron SIS100 [1] and the Super Fragment Separator [2] of the FAIR accelerator complex [3] will mostly consist of superconducting magnets.

The SIS100 superconducting magnets based on Nuclotron cable [4] are fast ramped, up to 28 kA s^{-1} [5,6]. SIS100 has a large variety of superconducting devices: 108 main dipoles, 166 main quadrupoles, 252 low current coils of 6 different types, more than 500 current leads and about 8 km of bus bars.

On the other hand, the Super-FRS magnets are cooled in a helium bath and are slowly ramped (about 2 A s^{-1}) [7, 8]. There are 221 superconducting magnets and their current leads to protect.

The FAIR Quench Detection System (F-QDS) has been developed to protect all the superconducting devices of both of these machines. In this contribution, the different F-QDS components and their features are presented. Their integration in both machines is described. And finally some initial tests on prototype electronics are shown.

QUENCH DETECTION ELECTRONICS

The core components of the F-QDS are the Quench Detection Units (QuD-U). As shown in Fig. 1, the QuD-U is composed of two separate printed circuit boards: the analogue board (QuD-A) and the digital board (QuD-D).

The main tasks of the analogue board are:

- To acquire and filter signals from the voltage taps at the machine,
- To separate the inductive voltage from the error voltage via bridge configuration,
- To compare the error voltage to a threshold, so-called quench threshold,
- To publish quench trigger to the fast beam abort system (FBAS) and/or to the adequate magnet power converter.

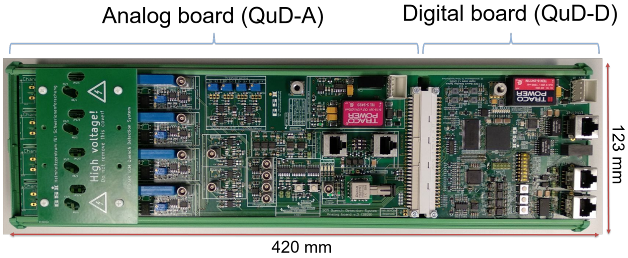

Figure 1: Quench Detection Units (QuD-U).

The QuD-A has four differential input channels. A voltage separation from the magnet circuit, up to 2 kV referred to ground, is provided by an insulation amplifier for each input channel.

The input voltage range, quench detection logic and trigger interface of the QuD-A is adapted to the superconducting device to protect. About 10 different QuD-A board types will be installed in the tunnels. The board layout is always identical, only the assembly configuration differs. The input voltage range of the boards are set according to the inductance of the protected device and its maximum expected current ramp rate. The range is from 100 mV for HTS-part of current leads to 200 V for SIS100 injection and extraction quadrupoles. The four input channels can be combined in different ways to achieve different quench detection logic. Input channels can be grouped by two (bridge configuration), such that the bridge voltage is compared to a threshold. This is typically done to protect a magnet coil, i.e. comparing two magnet halves or two magnets. Input channel voltages can also be directly compared to a threshold voltage, this is typically the configuration to protect current leads. Up to four quench threshold voltages can be set on the board. Thresholds are either controlled via potentiometer or via the QuD-D. A quench trigger is published once the threshold is exceeded for a validation time, usually set between 5 and 10 ms.

The digital board is connected to the analogue one via a 64-pin connector. The main task of the digital board is to enable data acquisition, remote control of the QuD-A and communication to the FAIR control system. The core of the QuD-D is a FPGA chip with its peripheries (SDRAM, FLASH, etc.). A 16-bit ADC is used to acquire the four input channel voltages and two bridge voltages of the QuD-A. The quench thresholds are controlled and monitored via four 16-bit DACs and one 4-channel 12-bit ADC.

The QuD-D features an Ethernet interface and supports several communication protocols. Below a list of some of the supported protocols:

- The SUSI protocol (Simplified USI [9]) over UDP for device control and data transfer (i.e. post-mortem data).
- A real-time data transfer protocol based on UDP, transmitting all acquired data with a rate of 2 Mbit s^{-1}.
- PTP over UDP for time synchronization of the unit.

QUENCH DETECTION TEST SYSTEM

An automated test system was developed to test and prepare each of the 1500 QuD-U boards for operation. The standard testing procedure of the board covers the following items:

- Check power consumption of the unit.
- Adjust potentiometers: input symmetry, bridges balance and offsets.
- Set analogue voltage thresholds (adjusting potentiometers).
- Check signal integrity and trigger system.
- Program FPGA chip.
- Test communication interfaces.
- Check remote control functionality and data acquisition system.

Thanks to the test system, all QuD-U are tested in a consistent manner with well-defined test conditions and a detailed test documentation is generated for each unit. Moreover, human errors can be largely avoided and the testing time is minimized.

As shown in Fig. 2, the test system consists of several measurement devices (oscilloscope, digital voltmeter), a power supply, a waveform generator and HV amplifier to generate test signals and a custom switch box including one LV and one HV signal switch matrix.

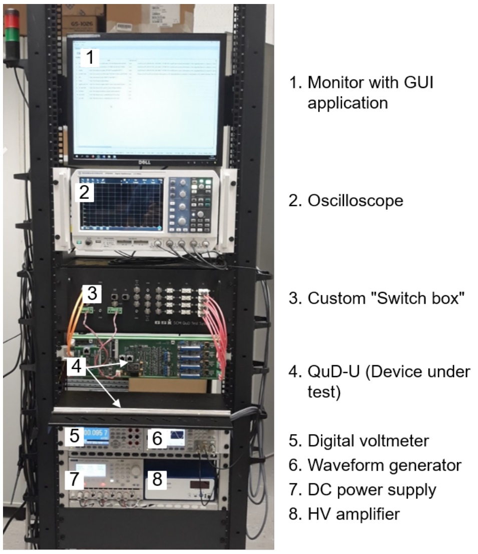

Figure 2: Test System for Quench Detection Units.

A control software was developed for the test system. It includes interfaces to all the involved hardware, a framework to define and launch test procedures and logging the test results, as well as a GUI.

QUENCH DETECTION IN SUPER-FRS

The Super-FRS superconducting magnets are individually powered. Each coil and its two copper current leads are monitored by a single QuD-U. Two input channels form a bridge comparing two magnet halves, the bridge voltage is then compared to a threshold. The two other channels are used to protect the current leads, the voltage across each current lead is compared to a threshold. If a quench is detected, a trigger is sent to the power converter, which informs the control system and the fast beam abort system. The QuD-Us are installed within the magnet power converter cabinets.

QUENCH DETECTION IN SIS100

The SIS100 accelerator has four main magnet circuits (one dipole and three quadrupole) and six types of low current magnet. More than 1100 QuD units are necessary to protect those devices. The QuD-Us are installed in dedicated cabinets located in the service tunnel, where radiation levels are expected to be low. In case of quench, a QuD-U sends a trigger to the fast beam abort system and to the power converter via a trigger concentrator.

Main Circuits and Quench Conditioning Boxes

The main magnets are monitored by comparing the voltages of two adjacent magnets, in an overlapping structure as shown in Fig. 3, such that a magnet is protected by two QuD-U.

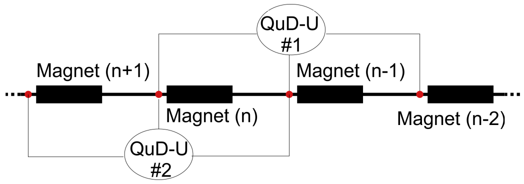

Figure 3: Quench Detection Layout for SIS100 main magnet circuits.

As the quench electronics is located in the service tunnel, the cabling distance between the superconducting device and the QuD-U can be up to 150 m. To prevent false triggers, the quench detection cabling has been designed to minimize electromagnetic interference (EMI) and loops. Special Quench Conditioning Boxes (QCB) will be installed below each cryo-module as shown in Fig. 4). The task of QCB is to merge the voltage signals coming from three different cryo-modules into a single EMI-optimised cable, which is connected on the other end to a QuD-U (see Fig. 5). A total of about 440 QCBs will be installed in the accelerator.

Correctors and Injection/Extraction Quadrupoles

The correctors and injection/extraction quadrupoles are powered via Cu-HTS current leads. Each corrector coil

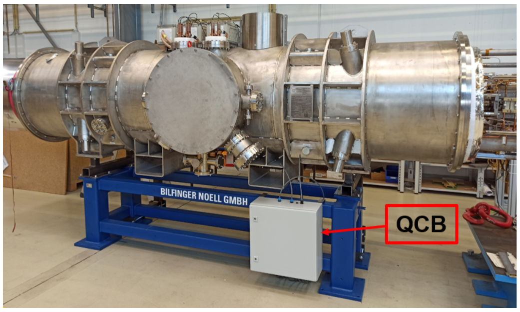

Figure 4: A Quench Conditioning Box installed on the SIS100 First of Series Quadrupole Doublet Module.

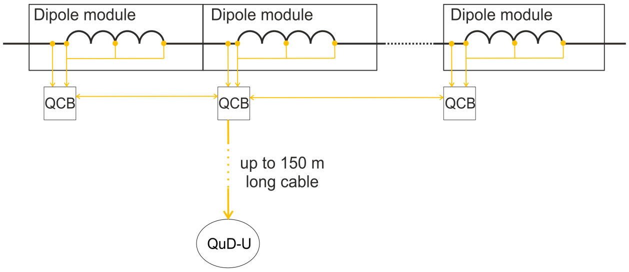

Figure 5: Principle of the SIS100 Quench Conditioning Box.

and its current leads are monitored by two fully redundant QuD-Us. Two channels are used to monitor the superconducting coil by comparing its voltage to the voltage of a co-wound single strand - the MID strand [10]. The two other channels are used to monitor the current leads (Cu+HTS voltage monitored by a single channel).

Quench Detection Cabinets

The QuD-U are installed in the Quench Detector Cabinets which are distributed all around the accelerator ring in the service tunnel. Each of these cabinets can host up to 24 QuD-U. The QuD-U are powered by two redundant 24 V power supplies and capacitor-based UPS to improve the system reliability. As shown in Fig. 6, the cabinet also features a patch panel for easy connection of the quench detection cables coming from the accelerator tunnel. The cabinet temperature is controlled by a thermostat and a roof-mounted fan. A second type of cabinet, the Quench Control Cabinet (standard 19 inch), is hosting the trigger concentrators and the Ethernet switches. One of these cabinets can serve up to four Quench Detector Cabinets (96 QuD-Us).

PROTOTYPE TESTS

A first batch of 25 QuD-U have been produced and have already passed the in-coming test with the quench detection test system. The units are now in a long term stand-alone operation, to check the stability of the analogue circuits and to search for so-called rare problems. In Fig. 7, one can see the stability of the bridge voltage for five QuD-U over a period of 11 days. The maximum observed drift is well below 1% of the quench threshold. The jump observed after 2 days of operation is due to a new setting of the cabinet thermostat in order to force continuous operation of the fan.

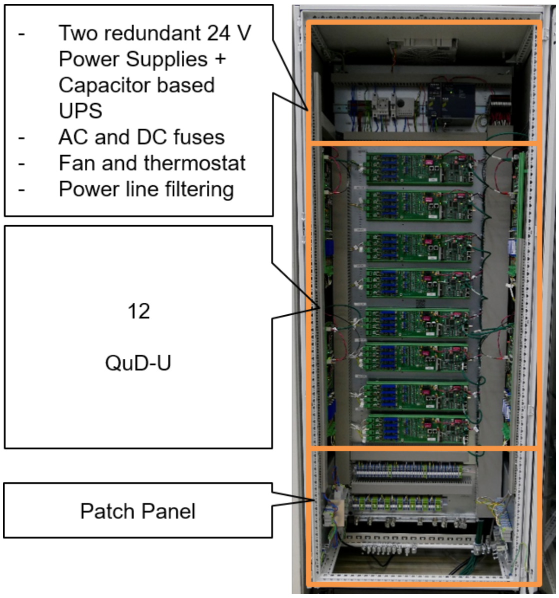

Figure 6: Prototype of the Quench Detector Cabinet. Only the front side of the cabinet is equipped with 12 QuD-U. The series cabinet will have the front and rear side equipped (24 QuD-U).

These results are very preliminary. Tests will go on for several months, including tests with SIS100 dipole, quadrupole and corrector magnets and as well as with current leads.

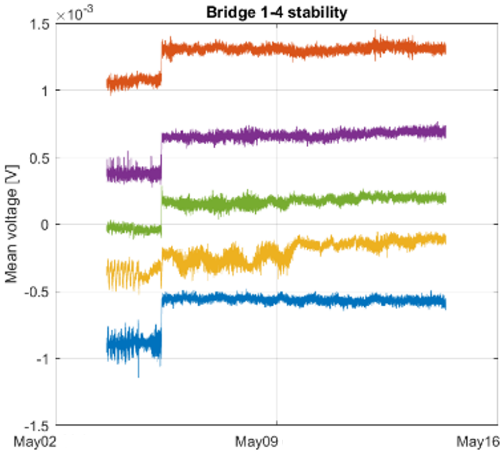

Figure 7: Stability of the bridge voltage (channel 1 - channel 4) for five QuD-U over a period of about 11 days.

CONCLUSION

Most of the FAIR Quench Detection System components are in their final stage of design. An intensive test campaign is ongoing to determine the long term performance of the electronic components. Series production and testing are the next phase of the project, which will be followed by the installation in the tunnel and commissioning.

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