LHC Enhanced Quench Protection System Review

24 -26 February 2009

Review Panel

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Introduction

The LHC Quench Protection System (QPS) is being enhanced as a result of experiences learned following sector commissioning and the incident of 19 September 2008. Enhancements will provide for better detection, protection and redundancy within the system. Three major enhancements are planned; high resistance splice protection, symmetric quench protection and a redundant UPS system. This external review panel was formed by the CERN management to review the new Enhanced QPS System.

The external Enhanced QPS review panel is one of two panels set up by the CERN management. The other, the “risk” review is to examine the risks to future operation of the LHC, taking into account the implementation of the technical and operational measures foreseen and being implemented following the incident of 19 September 2008.

Charge

Following an understanding of the behavior of the QPS system on 19 September, the mandate of the review panel is to:

1. Review in terms of completeness, the functional specifications of the proposed new system, in particular, the strategy for the proposed new scheme to detect (and protect against) abnormally high resistance "splices" and the detection of a symmetric quench.

2. Review and analyze the technical details of the proposed implementation of the new enhanced Quench Detection and Protection system paying particular attention to the critical nature of the system with respect to LHC operation.

3. Examine all operational issues associated with the new system, in particular the two extremes of failing to trigger when necessary and spuriously triggering unnecessarily, and thereby causing down time of the LHC.

4. Review the planning schedule foreseen for the completion of the new Enhanced QPS system and define priorities (high resistance splice detection versus symmetric quench).

5. Review the robustness of the new system which should operate reliably during many years in a hostile environment (including radiation) of the LHC tunnel.

Report

1 Functional Specifications

A High Resistance Splice Detection

Findings

The specification has been presented to the panel as:

Joint interlock system

A detection threshold of 0.3 mV is needed to interlock and protect the RB bus and joints in all imaginable conditions. A detailed analysis of the RQ buses was not presented, but the panel was told that a similar threshold should be sufficient to protect them.

The original system used a 1 V threshold.

Early warning system

The system is capable of measuring joint resistances to a resolution of < 1 nΩ, using a specialized stepped ramp.

Continuous resistance monitoring at a reduced resolution will also be performed. The early warning system is new.

Recommendations

Write a formal overall project specification for the design of the splice protection system, including an analysis of the required thresholds for both the RB and the RQ buses.

B Symmetric Quenches

Findings

The original system compared two aperture coil voltages within one magnet and was vulnerable to symmetric quenches.

The new system compares four different total magnet voltages, with a 3+1 topology in the case of the dipole circuit.

The new system will be capable of monitoring magnet voltage differences, and of detecting quenches at the 200 mV detection level.

Recommendations

Write a formal overall project specification for the design of the symmetric quench protection system.

C General

Findings

Many of the Quench Protection calculations were executed years ago by people no longer in the project. When we challenged one of the MIITS calculations, no document could readily be found to answer our question.

The original calculation which concluded that a 1 volt threshold was adequate for protecting the splice was found to be misleading, since it neglected the difference in insulation layers between the splice and the bus. This suggests that a review of the old calculations might be useful.

Recommendations

Collect and review existing MIITS limit calculation documentations for all components in all circuits and generate a summary document for design and reference. Use it to verify existing circuit protection designs.

2 Technical Details

A High Resistance Splice Detection

Findings

Electronics will be located under Dipole B in each LHC half cell.

Solution will reuse an existing board designed for the protection of the HTS leads in LHC.

In Mr. Verweij's presentation, he concluded that the Sept.19th event could only have come from a splice that had both a bad superconducting joint and bad copper joints as well. Bus bar QPS threshold was reached before any voltage increase was detected in the adjacent magnets, suggesting that the quench originated in or near the bus bar joint.

In the presentation on attempts to manufacture bad joints, it was shown that the superconducting joints tended to measure good even with poor joint manufacturing techniques that resulted in a mechanically weak joint.

Ultrasonic testing of main bus bar joints was performed toward the end of installation. This technique was only capable of determining insufficiently filled solder joints on the sides of the U shaped copper stabilizer.

Nondestructive testing techniques using X-ray was unsuccessful in achieving sufficient resolution.

The main bus bar structure was designed to keep the joint in the neutral position when cold. To affect this, the joint is assembled warm under compression.

All main bus bar joints were inspected by the installation contractor as well as independent inspection staff contracted by CERN. Sample joints were made (in the tunnel) with the soldering station and tested for quality. Each machine produced 3 to 4 samples during the soldering of a sector.

All main bus bar joints were soldered under pressure (2.2 tonne) using an automatic induction heater. Data records of the soldering process were stored locally on the machine. The records of many of the joints were corrupted by the EMI from the induction heater.

Temperature regulation of the soldering (275˚C) was accomplished using a thermocouple imbedded in the superconductor overlapped joint. It was stated that the thermocouple wires were twisted together, but not welded at the tip. The effects of twisted versus welded thermocouple wires was not investigated.

Comments

The Machine Protection staff has demonstrated a deep understanding of the issues involved in the design of this system: noise levels, filtering, choice of electronics, radiation sensitivity, etc.

We have full confidence that their new system will have the ability to detect and interlock errors on the level of 0.3 mV and to give early warnings for suspicious splices measured at the level of 1 nΩ.

With this system in place, they will be able to detect resistive splices.

Procedures, quality assurance and testing of the main bus bar joints do not present a plausible explanation for a 200 nΩ joint resistance in Sector 34.

The bus bar stabilizer joint was designed with minimal copper to copper surface area, no permanent mechanical clamping and no visible means of verifying solder flow in critical areas.

It is our concern that there could be joints in the machine that have good superconducting joints and bad copper joints. Without the good copper joints, the splice will fail if it quenches at high current as a result of the beam or from heating due to a quench in a nearby magnet.

The panel is concerned that not welding the thermocouple wires together could have resulted in improper temperatures during soldering. Performing tests while monitoring multiple thermocouples may be justified.

Recommendations

We recommend that the Machine Protection staff develop a technique to put current through the splices while in a non-superconducting state in an attempt to measure voltages across the buses and uncover any splices that have poor electrical contact through the copper stabilizer in the main bus joint. Any such splice, if present, would be undetectable by the High Resistance Splice Detection system and have the potential for a bus failure whenever it quenched at operational current levels.

B Symmetric Quenches

Findings

A secondary quench on 6 June 2008 in Sector 56 showed an unusual signature that was later shown to be a symmetrical quench. It was calculated that this magnet saw 50 MIITS. The panel was told that 33 MIITS (adiabatic) is considered the dipole magnet limit. Further investigation showed that there had been other symmetric quenches during commissioning. All symmetric quenches were secondary quenches in magnets next to a training quench. Limits were imposed on machine energy until a protection scheme could be implemented.

The final topology choice was selected to take advantage of the cabling already required for the new splice protection system.

Electronics will be located under Dipole B in each LHC half cell.

With the 3+1 topology, after the first quench, the system reverts to comparing the remaining three magnet voltages. After the second quench, the remaining two magnet voltages are compared. After a third quench, heaters in both remaining magnets are fired.

Comments

The machine Protection staff has grasped the opportunity provided by the installation of the splice detection system to design an excellent Symmetric Quench detection system, making good use of the new cables to minimize the effort required and selecting the system with the best features of all of the considered alternatives (the 3+1 system in the case of dipoles).

We have confidence that this system, once its design is complete, will be able to detect quenches at the 200 mV level [twice the normal detection level] and will provide an important redundant back-up to the existing magnet coil quench protection system.

Recommendations

None

C Existing QPS

Findings

The magnet systems are hipotted to 1900 volts at liquid helium temperatures.

The Enhanced QPS system will add a considerable load to the existing hardwire loops. The panel was told that the existing hardwire loops were capable of handling the additional load.

In every dipole there is one internal magnet splice, and in every quadrupole there are four internal magnet splices, which are not being monitored in the existing QPS system.

Comments

The proposed solution for including the un-monitored internal magnet splice is to include it in the high resistance splice protection system. This was proposed in order to leave the existing QPS system unchanged. This configuration would treat this splice differently from all other internal magnet splices.

Recommendations

We recommend that the existing RB and RQ quench protection systems be modified to include the internal magnet joints that are presently not monitored. Accomplish this by changing voltage taps used in the existing QPS so that they all can be measured at the 10 nΩ level. With three known bad internal splices already identified, we feel that these joints cannot be left unmonitored. Although a failure of this joint will not be as harmful as that of a bus joint, the failure will destroy the individual magnet and will have the capability of burning holes within the magnet cryostat. We recommend that the unmonitored joint be included with the magnet joints and not with the bus joint monitoring. If done the latter way, any detection of a questionable bus joint will raise the question of whether it is really the bus or in the magnet. The difference in damage potential between these two possibilities is extreme, and it would be good to know what kind of problem had been uncovered.

3 Operational Issues

Findings

We note that the redundant UPS protection for the Quench Protection system is not complete unless the new UPS system is installed AND the new symmetric quench protection system is operational.

Recommendations

Energize magnets only after the splice protection, symmetric quench protection and redundant UPS systems have been installed and commissioned.

Prior to superconducting operation, either experimentally verify that all main bus copper stabilizers exhibit adequate longitudinal conductance or set appropriate operational limits.

Prior to physics operation, measure all splice resistances (bus and magnet) using developed techniques.

Define a dedicated operational procedure for taking, analyzing and responding to joint resistance measurement data.

4 Planning Schedule

Findings

During the Chamonix workshop, the schedule changed for the installation of the symmetric quench protection system. Prior to the workshop, the installation was linked to higher energy operation (7 TeV).

Comments

The scope of the Enhanced QPS system required for operation in fall was considerably increased at the Chamonix Workshop without a change in schedule. The work load for the quench protection group appears to have doubled without any increase in the overall schedule.

We are encouraged that overall Enhanced QPS project management is being developed.

Recommendations

Laboratory management should ensure that proper resources required from outside the MPE group be made available.

Review the resource assignments to confirm resource requirements and availability for the critical tasks.

Develop workflow plans for production and installation of the Enhanced QPS. This should include process flow diagrams and layouts of testing, staging and work centers.

Quality assurance and maintaining functional requirements must take priority over schedule.

5 Robustness

Findings

Diodes were radiation hardness tested to 2000 Gy. They have a maximum reverse voltage limit of 350 volts.

The new circuit designs for the high resistance splice protection and the symmetric quench protection systems contain components which have not yet been qualified to the radiation dose specification.

The new power supply and the existing HTS lead boards are being tested for radiation hardness. Symmetric quench protection boards will be tested after the first prototype boards are received. Testing is scheduled at PSI in April and at CERN CNGS later this year.

Comments

Radiation tolerance testing dates appear to be in place. Timely qualification of components will be required in order to maintain an already tight production schedule.

Recommendations

Complete the radiation hardness testing of all new equipment which will be located in the LHC tunnel.

Monitor the radiation exposure at each Enhanced QPS system crate and develop a maintenance plan.

Ensure tunnel dehumidification and temperature control in order to maintain electronics and connector reliability.

Ensure timely procurement and testing of spare components (such as cold diodes).

Agenda

LHC QPS Review Committee

from **Tuesday 24 February 2009 (08:00)**
to **Thursday 26 February 2009 (18:00)**
Europe/Zurich
at **CERN**

Description:

External Panel for Review of the Enhanced Quench Protection System

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- Review the robustness of the new system which should operate reliably during many years in a hostile environment (including radiation) of the LHC tunnel.

Members:
Reinhard Bacher, DESY
George Ganetis, BNL
Howard Pfeffer, FNAL
Dan Stout, ITER
Jim Strait, FNAL
Jay Theilacker (Chair), FNAL

For your information :
LHC Performance Workshop Chamonix 2009
More documentation (please use username "lhc" and password "qps")

Tuesday 24 February 2009

08:30->*08:45* **Executive session** (6-2-004)

08:45->*09:00* **Introduction** (6-2-004)

09:00->*13:00* **Summary talks** (6-2-004)

09:00	How all the systems are working together (30'+15') (Powering interlocks for the LHC) (30') (Slides)	Markus Zerlauth
09:45	Summary of the 34 event (30'+15') (30') (Slides)	Pierre Strubin
10:30	coffee break (15')	
10:45	Busbar joint stability (30'+15') (30') (Slides)	Arjan Verweij
11:30	Busbar quench protection enhancement (20'+10') (20') (Slides ; document)	Knud Dahlerup-Petersen
12:30	Lunch (1h30')	

14:00->*15:30* **Attend summary sessions of the LHC Performance Workshop** (Main Auditorium) agenda

15:45	transport from main building (steps) to bldg. 30 (15')

16:00->*17:30* **Executive session** (30-5-039)

17:30->*18:30* **Discussion of agenda for Wednesday** (30-5-039)

Wednesday 25 February 2009

08:30->*17:30* **Individual short presentations/discussions addressing panel questions** (30-5-039)

08:30	Symmetric quench experience and planned solution (20'+10') (30') (Slides)	Reiner Denz
09:00	Are there any other superconducting busses not being monitored by a quench detection system: the diode area (15') (Slides)	Michael Koratzinos
09:15	Are there any other superconducting busses not being monitored by a quench detection system: 13kA & 6kA & 600A (20') (Slides)	Robert Flora
09:40	Mechanical details of the bypass diodes (15')	Knud Dahlerup-Petersen

09:55	How were the diodes tested prior to installation (15') (Slides)	Andrzej Siemko
10:10	Stresses on diode joints (20')	Knud Dahlerup-Petersen
10:30	coffee break (20')	
10:50	Effects of standard component failures as well as radiation damage on the operation of the QPS (fail safe or not). What design features make the system fail safe? Details on the detection circuits. (30') (Slides)	Reiner Denz
11:20	What limits the maximum negative di/dt for the magnet systems (20')	Hugues Thiesen
11:40	Which experiences have been gained from the accident with respect to the expected behaviour of the existing QPS. Did everything react as designed? Did quenches propagate along the magnet chain due to transients and sudden current changes? (30') (Slides)	Sandrine Le Naour
12:10	MI^2T limits for magnets, what are they and how where they developed. Time budgets for detection and energy extraction for the various magnet system. (15') (Slides)	Andrzej Siemko
12:40	lunch (1h20')	
14:00	Description of energy extraction components and design criteria (15') (Slides)	Knud Dahlerup-Petersen
14:15	How does electromagnetic noise (from environment and beam) affect the novel protection circuits for bus bar splices? (15') (Slides)	Robert Flora
14:30	Reserve (15')	
14:45	Procedures used and the resulting traveler associated with the failed busbar joint. Ultrasound tests of joints. (15')	Paolo Fessia
15:00	Stresses on busbar joints. (15')	Paolo Fessia
15:15	QPS commissioning plan. Quality assurance during the installation of the new quench detection systems. (15') (Slides ; more information)	Fabio Formenti
15:30	Schedule foreseen for the completion of the new Enhanced QPS system (20') (Slides ; more information)	Fabio Formenti
15:50	How does standard component failure effect the operation of the QPS? In particular, what will happen in case of a mains power loss? Does the system rely on the proper functioning of a UPS system? Is the redundancy system properly designed on all levels? (20') (Slides)	Knud Dahlerup-Petersen
16:10	coffee break (20')	
16:30	Reserve (30')	

17:00->*18:00* **Executive Session** (30-5-039)

20:00	Dinner Auberge Communale de Meyrin (15')

Thursday 26 February 2009

08:30->*17:00* **Day reserved for follow-up questions and panel report preparation.** (30-5-039)

15:00	Summary and preliminary recommendations (1h00') (Slides)	Jay Theilacker