Technical review LHC Beam Screen Heater Card

Date: February 4th, 2013

Attendance list.

Johan Bremer (TE-CRG); Etienne Carlier (TE-ABT); Juan Casas-Cubillos (TE-CRG); Adrien Chiron (EN-ICE) ; Serge Claudet (TE-CRG); Fabio Formenti (TE-HDO) ; Marco Pezzetti (TE-CRG); Antonio Suraci (TE-CRG); Laurent Tavian (TE-CRG); Nikolaos Trikoupis (TE-CRG); Nicolas Vauthier (TE-CRG).

Reviewers.

Raphael Berberat (TE-MPE); Marzia Bernardini (EN-MEF); Evangelia Gousiou (BE-CO); Walter Snoeys (PH-ESE); Giovanni Spiezia (EN-STI); Nicolas Voumard (TE-ABT).

Executive summary.

This review has been particularly useful to gather the feedback from the cryogenic operation team and collect their wishes for improvements, as in particular the need for a manual safety switch to power OFF the heater in all cases of urgent actions. It was however recognized that it was not made available a systematic description of the requirements that motivate consequent engineering implementations.

The main consolidation needs have been identified because of problems related to the board communication, missing safe protection in case of heating overrun, interlock automatic re-enabling following an overheat alarm and lack of radiation tolerance of some components. Other complementary improvements that were recognized concerned the implementation of h/w diagnostics and improved electrical parameter measurements.

The most important issues that affected the production concerned the urgent ordering of critical components, their validation for radiation tolerance and full batch procurement, the update of the test bench system software (in time for the prototype qualification) and the support required from other groups for the board commissioning in the machine.

Several topics have been debated and sorted in the following sections: specifications and design, operation, radiation tolerance, fault tolerance and fault diagnosis, system application, test bench and testing, PCB and board production, planning.

 Edited by F. Formenti

Introduction.

The Beam Screen Heater card is part of the Cryogenic Crate system installed in all LHC arcs and located either below the magnet chain or in the radiation protected areas. About 800 crates are deployed for the whole LHC needs.

Each Cryogenic Crate contains the electronics for measuring the temperature, the pressure and the level of the liquid helium, for reading the status of the digital valves and controlling their position and for supplying power to the heater elements.

The supervision layer for the cryogenic operators is provided by SCADA, allowing automated or manual control of the actuators and display of the cryogenic system status, alarms and interlocks. A lower layer of control, linking directly the FE electronics boards, is provided by CIET and it is used by the expert system managers.

The subject of the review concerned the Heater Electronic cards only, more specifically the upgrade of the specifications, the consolidation of their hardware, the organization of the production and its quality assurance plan. These units are part of a closed loop control system (PID implemented in a PLC) to provide power to several heater elements (about 2500 electrical resistors). Two modes of operation are possible: DC power for 25W maximum during the on-beam conditions and AC power for 500W (200W in the new design) power during the off-beam bake out periods.

Motivation and scope of the review.

The run out of control of the heater system provoked overheating of the electrical heater elements in a few occurrences. Analysis of the system brought to the conclusions that there are components not fully compliant with the radiation environment and that the specifications could be improved to provide better safe either in case of miss-cabled temperature sensors or in case of loss of communication.

The review aimed at discussing the specification changes for the Heater Card's consolidation and approving solutions or recommending actions for the safest implementation of the Beam Screen Heater system.

Agenda and available documentation.

The agenda can be found at https://indico.cern.ch/conferenceDisplay.py?confId=228651 and the presenting material can be downloaded from there.

Technical Review on Beam Screen Heater Electronics

Monday, February 4, 2013 from **14:00** to **17:00** (Europe/Zurich)
at **CERN (6/R-012)**

Description Technical Review on Beam Screen Heater Electronics

Reviewers: Raphael Berberat (TE-MPE), Marzia Bernardini (EN-MEF), Evangelia Gousiou (BE-CO), Walter Snoeys (PH-ESE), Giovani Spieza (EN-STI), Nicolas Voumard (TE-ABT)

Monday, February 4, 2013

14:00 - 14:15 System overview, consolidation needs and project planning *15'*
Speaker: Juan Casas-Cubillos (CERN)
Material: **Slides**

14:15 - 14:25 Operation of the beam screen heaters *10'*
Speaker: Serge Claudet (CERN)
Material: **Slides**

14:25 - 15:10 Design and prototyping of the heater supply board *45'*
Speaker: Nikolaos Trikoupis (CERN)
Material: **Slides**

15:10 - 15:25 Coffee break

15:25 - 15:55 Quality assurance plan: production, installation and commissioning *30'*
Speaker: Nicolas Vauthier (CERN)
Material: **Slides**

15:55 - 16:25 Round table discussion *30'*

Suggestions and Recommendations:

The review consisted of a half-day of presentations attended by reviewers and other CERN experts.

The main discussion topics and specific comments are grouped into the following sections. Each point is raised as recommendation (*R#*) or suggestion (*S#*).

As a general remark, the circuit diagram of the new board was not yet available and reviewers could not judge on the real case for the new Heater Cards. In most circumstances similar circuit implementation as in the present Heater Card was adopted.

1. Specifications and design.

1.1) Lack of details on functional specification from operation and consequent engineering card specifications to implement those functions.

R1.1: In order not to miss any important functions or produce unnecessary needs, before starting the detailed circuit design, it is recommended to provide a full list of requirements and discuss the engineering solutions.

1.2) The validation of the FPGA code must be carefully checked if using antifuse FPGAs.

R1.2: Due to the one-time only programmability of these FPGAs, it is recommended to adopt the strategy of validating the FPGA code by functional simulations performed by a different person than the designer.

1.3) Percentage of occupation of FPGA vs. routing efficiency.

S1.3: It is suggested to select the FPGA size according to the rule of the thumb that the internal resource occupation should not raise above 80%. This does not seem the proposed case.

1.4) Thermocouple interlocking system "auto enable" mode.

R1.4: In the present Heater Card this mode allows re-powering of the heater element if the overheating alarm condition falls back below threshold. This is not a safe condition for an interlock alarm. It is recommended to implement manual re-powering of the heating element after checking of the alarm causes by an expert operator.

1.5) Safety of ac voltage to power the heating element.

R1.5: The voltage in ac mode is above 100V and long cables are used. It is essential that electrical safety rules are respected, as for instance cable cross section, connectors, differential protection. It is recommended to get in contact with a CERN responsible for electrical safety to discuss the correct system implementation.

1.6) Read back of card parameter's configuration.

S1.6: Although not preventing the correct operation, it is a good design practice to implement read back of status and data registers for providing easier remote fault diagnostics.

1.7) Use of the step down transformer.

S1.7: The full power to the heating element is limited to 200W by an external 230V/142V transformer, but this does not provide enough damage protection against stuck-on-heating faults. The transformers increase the project cost of ~30kchf and add a risk of system commissioning delays. It is suggested to reconsider the real need of these transformers.

2. Operation.

2.1) Switching between DC (25W) and AC (200W) powering modes.

S2.1: The AC mode shall only be used when there is not beam. It was not explained through what mechanism this mode change gets synchronized. It is suggested to investigate how protecting the mode selection against operator's mistakes.

2.2) Power cycle in case of hang up.

R2.2: If the new Heater Card gets stuck, a power cycle can be remotely scheduled provided that the WorldFIP interface is alive. It is recommended to investigate what solutions can be adopted in the event that this interface is also unreachable.

3. Radiation tolerance.

3.1) Significant characterization work was done regarding the radiation tolerance, but key components (e.g. OpAmps, ADCs, DACs) belonging to the original Bill of Material (more than 6 years ago) are newly purchased and also new components are added for the new design.

R3.1: There are worries concerning the validation of radiation tolerance for COTS. It is recommended that all components are procured as full batch and re-checked as soon as possible. To fit the strict plan, the test could also be performed at the level of the new prototype and deploying available system h/w and s/w to the radiation test facility. Reviewers consider that radiation tests performed at the time of the prototype board are still meaningful as they can provide knowledge of potential weaknesses.

3.2) The antifuse technology shows a high level of radiation tolerance, however SEUs can still affect the configuration registers.

R3.2: It is recommended to evaluate the solution of protecting critical registers by triple redundant logic.

3.3) The ProASIC3 FPGA family can be a valuable alternative to the antifuse family. It has a lower level of radiation immunity but it has much lower cost and it has been already tested by other projects in similar critical environment (e.g. QPS)

R3.3: It is recommended to better develop the trade-off between guaranteed radiation tolerance, component cost and FPGA feature's availability, for instance for Triple Redundant Module design. BE-CO has a large amount of A3P400 (same of those used by the QPS project), that will be tested in PSI in March. Purchasing from BE-CO can be organized. The design file does not need conversion as both technologies use the same developing environment (just to target the device type).

3.4) The power MOS devices have been tested at CNRAD in the 1Hz switching mode.

S3.4: It is preferred to test them in the worst case condition, i.e. having them always ON. However, as these devices are powered only during off-beam conditions, the probability of SEB should be rather small. Moreover, in case that the 230V/142V transformer is used, there is enough voltage de-rating that improves the safe margin.

3.5) The power relays could contain plastic parts that are sensitive to radiations.

R3.5: It is recommended to verify that relays are compatible with the radiation environment.

3.6) The radiation vulnerability of the ISO150 digital insulator has been proven by other projects: following a SEU only a power reset could re-establish the operating conditions.

R3.6: For the new design it is recommended to replace the ISO150 insulator by other devices more radiation tolerant. The ADuM3xxx, already used by the QPS, could be a good alternative.

4. Fault tolerance and fault diagnosis.

4.1) A fault tree analysis of the new design was not presented (e.g. consider the possible failure of a relay to switch properly).

R4.1: It is recommended to perform a systematic study of the possible faults, to define the ways of detecting the faulty cases and to identify possible protective actions.

4.2) Protection interlock based on analogue signals.

R4.2: Protection signal processing based on ADCs is not judged the best choice for the highest level of safety. It is recommended to provide an alternative protection path based on a discriminated ON/OFF signal.

4.3) Diagnostic at the AC power line (voltage and current measurements) to detect failure location in case of problems.

S4.3: The fuse provides protection for the card, but it may not help to localize a system short circuit. If the selectivity is not correctly implemented the general differential breaker could also trip and the identification of the defect is not obvious. A technical discussion with power distribution experts should be triggered.

5. System application.

5.1) Hardware interlock to provide protection in case of inverted thermocouple.

R5.1: Although the solution is suitable to prevent critical overheating, it is recommended to apply appropriate cabling quality inspection and direct non-conformity correction.

5.2) Possible EMC issues linked to the PWM at high frequency on mains.

S5.2: Although the resistive load (heater) and the possibility to work in zero crossing mode should help to avoid injecting high frequency harmonics, it is suggested to plan for the insertion of a filter.

6. Test bench and testing.

6.1) The AC mode is not tested with the nominal performance.

R6.1: It is not a good approach to validate the AC mode with a resistive load x10 higher than nominal.

6.2) Heater Card and test bench are designed by the same engineer.

R6.2: For optimal design's crosscheck, the test bench development should be based on the engineering specifications of the Heater card and should be built by a different engineer. If manpower constraints do not allow this, then it is highly recommended that another person reviews the test bench functionality.

6.3) Qualification test for mass production.

R6.3: The proposal of an Automated Optical Inspection test shall be discussed with the MPE-EM workshop experts to define detailed requirements and specifications.

7. PCB and production.

7.1) Additional rigidity bars on the length of the PCB.

S6.1: The presence of heavy heat sinks could damage the pretty long PCB if the cards are manipulated without care. The addition of rigidity bars is suggested to avoid transport and handling problems.

7.2) Mass production organization.

R6.2: Partial board deliveries are recommended to anticipate tests and installation in the LHC sectors. Estimated component deliveries are not enough and real offers shall be asked as soon as possible.

8. Planning.

8.1) Resources and interaction with other activities during LS1.

R6.1: It is recommended to present and discuss the installation and commissioning plans with the EN-MEF coordination team. Resources coming from other groups (e.g. power distribution by EN-EL, LHC database by BE-CO, communication s/w layer by EN-ICE) shall be discussed and agreed as soon as the h/w design phase starts.

8.2) The planning does not include the test bench upgrade.

R6.2: The test bench upgrade is performed by the same person re-designing the Heater Cards. It looks likely that both these activities do not match the needs of producing the prototype and having at the same time ready the facility for testing. It is recommended to identify additional technical support for the limited development time of the test bench upgrade.

 Edited by F. Formenti