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High Voltage consolidation of the temperature measurement channels of the LHC superconducting current leads

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Recurrent dielectric breakdowns on the cryogenics instrumentation during the CERN LHC Electrical Quality Assurance (ELQA) campaigns led to an investigation of their root causes. During the CERN Long Shutdown 2 (LS2), several weaknesses were identified like floating wires or cable screens, cabling non-conformities, connector assembly issues, and weakness of the electronic conditioning cards. The paper presents the cabling layout from the sensor till the acquisition cards and the actions undertaken to increase the robustness against dielectric ruptures. These actions include rebuild of the cabling and connectors using a laser stripping machine, new wiring patterns and upgrades on the electronic cards.

Summary (500 words)

I. Introduction

As part of the LHC quality assurance program, ELQA campaigns are performed during shutdowns and before the restart of the machine operation. During those campaigns, voltage levels up to 1.8 kV with respect to the ground are applied to the LHC magnetic circuits and the full chain from the magnet to the acquisition electronics shall withstand this test voltage. During the CERN Long Shutdown 2 (LS2), an increased number of dielectric breakdowns occurred; such events may damage the temperature sensors that cannot be exchanged and systematically destroy electronic components on the electronic cards. This triggered an effort to understand the root causes of those breakdowns.

II. Cabling and electronics non-conformities

In-situ diagnostics in the LHC tunnel revealed multiple non-conformities:

- A) The double shielded cable used by the cryogenics for the acquisition of the HV temperature channels fulfils the initial LHC HV requirements but is designed for low voltage applications. This cable wire insulation is far too thin (between 0.145-0.365 μm). For Run 2, the ELQA test voltage values were significantly increased resulting in numerous dielectric ruptures, manufacturing defects like insulator scratches were the main culprit.
- B) The use of thermo-shrinkable tubes resulted in overheating and moderate melting of the wire insulations; the effective insulation became even thinner.
- C) Due to the increased ELQA HV voltage requirements, some electronic cards were upgraded to a different version that didn't provide connection to the ground for the inner shields of the cable. HV voltages were coupled via these floating shields to healthy channels resulting in multiple breakdowns. This non-conform configuration was further analyzed in laboratory tests.
- D) During an ELQA HV breakdown, voltage differentials appear across the positive and negative terminals of the wire pairs exceeding the specifications of the front-end analog circuit components. A design review is on-going to investigate if the analog circuitry can be better protected, even if this problem is also observed on cards using voltage suppression circuitry.

III. Laboratory tests, equipment selection and repair procedures

To consolidate the cabling problems, a complete replacement of the cabling (several kilometers partially in ducts) was not an option due to the additional delay that would cause to the restart of the LHC machine. The impact of floating inner shields was analyzed during laboratory tests, and it was shown that they can

induce, due to coupling, high voltages to other wire pairs of the same cable. Different methods and machines were investigated including a mechanical rotary and a laser stripping machine. Due to the construction of the cable, wire twisting and insulation variations, only the laser stripping machine was capable to safely remove the various insulations without collateral damage. New cable and connector repair procedures were defined and optimized in the laboratory.

IV. Summary

Towards the end of the LHC LS2 shutdown, cabling non-conformities were identified in the LHC cryogenics instrumentation cabling. Within the allotted short time, extensive diagnostics and repairs were performed to allow a smooth restart of the LHC machine.

Primary author: TRIKOUPIS, Nikolaos (CERN)

Co-authors: CASAS-CUBILLOS, Juan (CERN); BUSTAMANTE DELGADO, Eduardo Antonio (CERN)

Presenter: TRIKOUPIS, Nikolaos (CERN)

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