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Reliability Run and Data Analysis of the Accelerated Aging of Present and Future Electrolytic Capacitors Installed in the Protection Systems of Superconducting Magnets of the Large Hadron Collider at CERN

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This study evaluates the lifetime and aging process of the aluminium electrolytic capacitors to be used in the new protection systems of the High Luminosity LHC superconducting magnets. The accelerated testing and analysis of several groups of capacitors aged for more than one year provided insights into their expected lifespan and aging process. The results obtained have practical implications for maintenance and replacement schedules, as well as for selection and acceptance of capacitors for new Heater Discharge power Supplies (HDS) equipment. The knowledge gained from this study ensures the safety and reliability of the LHC and its electronic components.

Summary (500 words)

The Large Hadron Collider (LHC) at CERN is a long-term scientific project that requires periodic, preventive, and corrective maintenance of its electronic components. Among these components, aluminium electrolytic capacitors are an essential part of the protection systems of the high-field superconducting magnets being developed for the HL (High Luminosity) LHC project. More than 36,000 of these capacitors, rated for 500 V and 4.7 mF, are installed in the LHC tunnel and are operational since the collider's start-up phases in 2007. Failure of these capacitors could cause significant damage to the superconducting magnets, delaying operation and running into very costly repairs, which is why it is crucial to evaluate their lifetime and aging process.

To achieve this, representative samples from the global population were aged in test beds and ovens, enabling the accelerated evaluation of their lifespan. Regular measurements of capacitance, equivalent series resistance, leakage current, and weight -to calculate electrolyte loss- were conducted throughout the aging process to evaluate the capacitors' performance. The conclusive results obtained from the analysis of several groups of capacitors aged at 85℃ and 70℃ for more than one year indicated that aging processes are consistent, and the results provide valuable insights into the capacitors' expected lifetime.

The knowledge gained from the lifetime studies of a subset of capacitor after LHC runs 1 and 2 has been applied to qualify different candidates for the new production of Heater Discharge power Supplies (HDS) equipment to be installed for the HL-LHC, including a new family rated for 105 ℃. After careful consideration, a candidate was chosen, and a few capacitors from the distinct production batches received were put to age for one year. The results obtained from the analysis of these batches allow for the extrapolation of their reliability and electrical behaviour throughout their expected lifetime.

The findings of this study have practical implications for the maintenance and replacement of the LHC's and HL-LHC electronic components. By understanding the capacitors' aging process, it is possible to identify which variables are better indicators for final use evolution across different families and manufacturers, and provide an expected margin of error given the input data used.

In conclusion, this study provides a comprehensive analysis of the aging process of the aluminium electrolytic capacitors to be used in the new HL-LHC protection systems for high-field superconducting magnets. The accelerated testing and evaluation of the capacitors' performance provided valuable insights into their aging process and expected lifetime, and allows for more confident selection and preliminary evaluation of new candidates for similar use cases ensuring the safety and reliability of the LHC.

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