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A quality assurance and calibration procedure for fiber optic sensors in high energy physics applications

The Inner Detector of the ATLAS experiment will be completely replaced by the Inner Tracker (ITk) in preparation for the High-Luminosity upgrade of the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland. The ITk will target an operational dew point of $-60\text{ }^{\circ}\text{C}$, requiring precise environmental monitoring to ensure reliable detector performance. With normal operation at $-20\text{ }^{\circ}\text{C}$, and fault conditions potentially leading to local temperatures as low as $-55\text{ }^{\circ}\text{C}$, the monitoring system must protect the detector and prevent condensation on sensitive electronics through accurate temperature and humidity measurements—a critical challenge in high-radiation and high-electromagnetic-field environments.

This paper details the mechanical design, calibration framework, and quality-assurance protocols for radiation-tolerant fibre-optic sensor (FOS) packages developed for this purpose. Each integrated FOS package combines a radiation-hard fibre Bragg grating (FBG) for temperature measurement, a radiation-sensitive FBG for temperature and radiation measurement, and a long-period grating (LPG) sensitive to humidity, temperature, and radiation. A novel ultra-low-thermal-expansion Neoceram package body houses the sensors, while a custom PCB provides electrical conductivity between the mounting bolts for EMI/ESD protection. Structural integrity was validated through thermal cycling between $-30\text{ }^{\circ}\text{C}$ and $70\text{ }^{\circ}\text{C}$ to ensure robustness under extreme operational conditions.

A data-driven calibration procedure addresses the high-accuracy requirements of the ITk using a climatic chamber equipped with precision humidity control and a chiller. A PID-controlled system automates data collection across temperatures from $-20\text{ }^{\circ}\text{C}$ to $25\text{ }^{\circ}\text{C}$ and relative humidity from 0% to 100% RH. FOS outputs are calibrated against electronic reference sensors, while a dedicated algorithm decouples radiation and temperature effects from the LPG humidity response. Rigorous QA/QC protocols ensure measurement reproducibility through an established procedure designed to maintain measurement accuracy within the ITk specifications.

This work establishes a high-reliability framework that combines radiation-tolerant mechanical design with algorithmic calibration and quality-assurance methodologies, providing a comprehensive approach for the deployment of fibre-optic environmental monitoring systems in extreme high-energy physics environments.

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