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Electro-Migration Driven Failures on Miniature Silver Fuses at the Large Hadron Collider

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In the Large Hadron Collider (LHC), the cryogenics instrumentation infrastructure uses fuse-protected high-voltage isolated temperature transducer cards. Spurious faults were observed at their miniature silver fuses during the periods 2008-2010 and 2014-2016 and a study was launched to understand the underlying failure mechanism.

The study uses data from Scanning Electron Microscopy (SEM), spectrometry, Weibull reliability calculations, operating temperature profiles and existing data logging tools. For the period 2014-2016, the fuse failures followed a Weibull distribution of $\beta = 3.91$ and $\eta = 2323$ days. The leading failure mechanism was attributed to electro-migration phenomena.

Summary

In the Large Hadron Collider (LHC), the cryogenics instrumentation infrastructure uses fuse-protected high-voltage isolated temperature transducer cards. Approximately 1200 such cards are installed and each of them is protected by a miniature fuse based on a thin silver wire. The typical current consumption per electronic card is 0.5A.

Fuse failures were observed during periods 2008-2010 and 2014-2016. Those failures resulted in loss of instrumentation signals, occasional loss of cryogenic conditions and required multiple in-situ interventions. Every failure was a “sudden”event. After the failures of the first period, the fuse current rating was increased as a corrective measure, all fuses were replaced and no further failures were observed until 2014. After the failures of the second period, a study was launched to understand the underlying failure mechanism.

The study uses data from Scanning Electron Microscopy (SEM), spectrometry, Weibull reliability calculations, ambient data and data logging tools. The paper presents the difficulties of preparing the data for a Weibull reliability analysis; exact knowledge of electronic cards installation time, operating temperatures, replacements due to other failures and periods during which they could have been unpowered.

During the first period, the rating of the operating fuse was 1 A. 1202 cards were installed at 19 different locations and the failures started occurring at 3 locations having the highest fuse temperatures. At those 3 locations, 150 cards were installed and the failures of those 150 cards followed a Weibull distribution of $\beta = 2.8$ and $\eta = 2215$ days. After 2010, the fuses were replaced with others having a higher rating of 1.25 A. Furthermore, 764 out of the 1202 cards were upgraded to another version consuming less current. Therefore only 438 cards of the “original”failing type remained in operation. For this second period of 2014-2016, failures were observed at 2 locations and for a total population of 46 cards. Due to the upgrade of the cards, there were no cards of the “original”failing type at the third location. The failures of the second period followed a Weibull distribution of $\beta = 3.91$ and $\eta = 2323$ days. When using failure data of only the same 2 locations for the period 2008-2010, the failures followed a Weibull distribution of $\beta = 3.43$ and $\eta = 1687$ days for a total of 102 cards. The leading failure mechanism was attributed to Electro-migration phenomena.

It is therefore concluded that the upgrade of the fuses from 1 A to 1.25 A led to an increase of the MTTF but the underlying failure mechanism remained the same. The temperature and electrical current through the fusing wire were the leading factors of the aging mechanism. A component considered as “lifetime”had much lower than expected Mean Time to Failure (MTTF) based on its operating conditions.

During the last technical shutdown, this problem has been addressed by using a fuse with a higher stated reliability and by increasing the electronic cabinet separation to improve the natural convection resulting in a lower fuse temperature.

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