Status and evolution of radiation dose on 60A power converters

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HL-LHC TCC, November 23rd, 2017

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HL-LHC WP10
Outline

• Introduction
• Monitoring and calculation of LHC radiation levels
• HEH fluences and their evolution
• TID BLM values
• Conclusions & Outlook
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Setting the scene

- 752 60A correctors installed in the LHC ARC; in even cells from 12-34
- Possible upgrade of LHC60A-08V correctors for ensuring radiation tolerance, also compatible with HL-LHC high-availability; ready for operation as of LS3
- Present system: most reliable converter in LHC, with MTBF of ~1M hours, and therefore compliant with HL-LHC availability requirements
- New design would need to be redundant (i.e. 2x 60A-10V power bricks) in order to ensure availability requirements
- New design to be based on components qualified for 600A and 4-6-8 kA, and to also serve as building block for 120A (i.e. 3x 60A-10V)
- Radiation lifetime of present converter estimated to be 30-50 Gy based on two tested units, therefore initially thought to be only compliant with LHC lifetime (i.e. not beyond LS3)
- Purpose of the study presented here: to re-evaluate the need of a new 60A design due to radiation lifetime requirements and based on estimated lifetime and HL-LHC radiation levels
Equipment location

- 60A correctors + FGClite
- RYLA racks, under MBB magnets in even half-cells, from 12 to 34 (both included)
- 752 units in LHC ARC
Bathtub curve – stochastic versus end-of-life

- **Cumulative Radiation Damage**
  - Total Ionizing Dose (TID)
  - Displacement Damage (DD)
- Can impact availability of accelerator
- Risk of lifetime issues arriving nearly at the same time
- Estimation for 60A correctors: 30-50 Gy

Institute of Machine Components, University of Stuttgart | Reliability Training Course
Before moving into the ARC

- R2E failures (i.e. leading to dump) in present LHC machine (~5-10/year) are dominated by power converters in RRs of IP1 and IP5
- Reasonably transparent for operation, however if scaled with radiation levels for HL-LHC (factor ~10 due to luminosity and TCL impact) can become an availability limitation
- R2E/EPC development & qualification of 600A, 4-6-8 kA and FGCLite for HL-LHC lifetime and failure limits, requiring 2-3 weeks of test of 2-3 systems in parallel

“Update on expected HL-LHC radiation levels with a focus on Point 7, Point 1 and Point 5”, R. G. Alia, HL-LHC week 2017
“Recent result on qualification of PC for HL radiation levels” R. V. Herrero, HL-LHC week 2017
FGClite development, qualification & operation

- System based on modular design (7 boards) and broad range of micro-electronic components
- Qualification against radiation at component and system level
- TID lifetime of >200 Gy, SEE cross section upper limit of $10^{-12}$ cm$^2$/unit, compliant with HL-LHC lifetime and SEE failure requirements
- LHC ARC deployment for 60A correctors in EYETS 16-17, excellent performance in 2017
- Deployment in RRs planned for LS2 (along with the 600A and 4-6-8 kA power converters)
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BLM and intensity calculations

- Contributors: Oliver Stein and Kacper Bilko (MCWG), with support from BLM team
- Dedicated Python workflow for data retrieval and analysis
- Main objective of calculating TID levels along the LHC and normalizing with integrated luminosity/intensity
- BLM offset subtraction, losses per beam mode/operational conditions (on-going), implications on equipment damage (R2E), etc.
RadMON high-energy hadron fluence measurement

- Capable of measuring quantities relevant to all types of radiation damage: total ionizing dose, 1 MeV neutron equivalent fluence (displacement damage) and high-energy hadron fluence (Single Event Effects)
- Placed 70 cm below the beam (i.e. at rack equipment height) but typically in the interconnects; located in cells 12-20 of LHC ARC, one RadMON per cell; on-line measurements
- RadMON values reported in this presentation correspond to annual HEH fluences
- In the LHC ARC, most 2016/17 measured annual values are $\sim 5 \times 10^7$ HEH/cm$^2$, considered as baseline value
• Absolute values are factor ~200 larger than measured values due to assumed residual gas density of $10^{15}$ m$^{-3}$ (actual situation 2-3 orders of magnitude lower)
• Fluence-to-dose ratio in peaks: $\sim 1 \cdot 10^9$ HEH/cm$^2$/Gy
• RadMON values of $\sim 5 \cdot 10^7$ HEH/cm$^2$ correspond to $\sim 50$ mGy
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RadMON HEH fluences during 2016

- 2016 RadMON levels in the ARC:
  - Baseline annual values of $\sim5 \times 10^7$ HEH/cm$^2$ (corresponding to $\sim150$ mGy on BLM)
  - Table shows **peak values**, defined as 10 times above baseline (in red, more than 100 times larger)
  - Peaks of $\sim10^{10}$ HEH/cm$^2$ correspond to $\sim10$ Gy
  - RadMONs located in interconnects – at equipment locations below the magnets, we expect $\sim3$ times lower value

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RadMON HEH fluences during 2017

- 2017 RadMON levels in the ARC (*):
  - Baseline annual values of \( \sim 5 \times 10^7 \) HEH/cm\(^2\) (corresponding to \( \sim 150 \) mGy on BLM)
  - Table shows **peak values**, defined as 10 times above baseline (in red, more than 100 times larger)
  - Peaks of \( \sim 10^{10} \) HEH/cm\(^2\) correspond to \( \sim 10 \) Gy
  - RadMONs located in interconnects – at equipment locations below the magnets, we expect \( \sim 3 \) times lower value

(*) IP3 and IP7 data not included

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November 23, 2017

HL-LHC TCC

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LHC ARC: 16L2 and 19L2

- Two examples of ARC radiation level peaks: 16L2 (intensity driven) and 19L2 (luminosity driven)
- 16L2 losses already significant during scrubbing; steady-state losses disappeared (i.e. compatible with baseline level) after BS flushing (compatible with BLM observation)
- Radiation levels in 16L2 (19L2) in 2017 were a factor 20 (100) larger than baseline value
- Just two examples of arc peaks → currently under further investigation with focus on equipment impact
- Main message: luminosity-driven annual dose peaks of ~10 Gy can appear even deep in the arc
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Total integrated dose for [20160403 : 20161030]

**2016, sector 12**

**General behaviour:** baseline annual values of ~100 mGy, plus peaks of up to >10 Gy in cells 12-17, mainly in IP1, 5 and 8

**Beam-gas baseline ~100 mGy**
General behaviour: baseline annual values of ~100 mGy, plus peaks of up to >10 Gy in cells 12-17, mainly in IP1, 5 and 8.
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2016, sector 56

DS-like peaks up to cell 17

Beam-gas baseline ~80 mGy
DS-like peaks up to cell 17

General behaviour: baseline annual values of ~100 mGy, plus peaks of up to >10 Gy in cells 12-17, mainly in IP1, 5 and 8

Beam-gas baseline ~20 mGy
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Expected radiation level evolution for HL-LHC

- Beam-gas baseline levels expected to scale with integrated intensity (factor ~4 larger HL-LHC annual value with respect to 2016/17) and residual gas pressure
- Considering baseline of worst-case sectors for 2016/17 and scaling with intensity and a safety margin of 10 related to residual beam gas leads to HL-LHC annual values of ~1 Gy/year on equipment → OK for present 60A lifetime
- However, peaks of >10 Gy/year, mainly in (but not limited to) IP1, 5 and 8 and cells 12-17, and potentially scaling with luminosity, are certainly a TID lifetime threat (not only for 60A equipment)
Conclusions & Outlook

• Possible R2E/EPC approach for HL-LHC 60A converters:
  • development of 60A power brick based (when possible) on qualified components; qualification at system level, and to serve also as building block for 120A
  • production of 60A redundant converters for cells 12-17; LS3 deployment and use of removed units as spares
  • active monitoring of radiation levels on 60A converters and preventive rotation/substitution (challenging coverage due to distributed nature of system)

• Present lifetime estimation based on two measurements could be significantly improved by testing several (i.e. at least 3) systems in the CHARM mixed-field facility

• New 60A design could require new Bri/Tri volt PSU for FGC, thus also potentially needing a rad-tol development

• Important to consider aspects not directly related to radiation, e.g. part obsolescence, other type of degradation/lifetime constraints, availability of spares