Overview of all superconducting splices in the LHC machine

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Chamonix 2010 LHC Performance Workshop
25 January 2010
The making of the electrical interconnections in the LHC

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Total current through one interconnection: about 110,000 A

PERFORMANCE OF THE SUPERCONDUCTING CORRECTOR MAGNET CIRCUITS DURING THE COMMISSIONING OF THE LHC


1. CERN includes the power from 55 A to 11.8 kA. A large effect related to possible features and detection currents. A set with the surrounding cool completed with a sensitivity may be finally discussed.

MAGNET TYPES, TARGETS

Compared to the main magnets, the LHC correctors are designed for the critical current (Table 1). On the other hand, the challenge is to maintain them for a long period. The LHC correctors are manufactured to ensure a very high current density (see Table 1).
Outline

- Splices Inventory. Numbers and circuit criticality
  - Stored Energy
  - MIITs and hot spot temperature
- 600 A corrector circuits
  - Brief description
  - Line M and N. US welding
  - PCS measurements during HW Commissioning
  - Existing NC
- Inner triplet 13 kA splices
- Future
  - MCI
  - Missing studies
### Superconducting splices. How many?

<table>
<thead>
<tr>
<th></th>
<th>Line</th>
<th>Magnet Splices</th>
<th>Interconnection Splices</th>
<th>Current rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>RB</td>
<td>M3</td>
<td>9856</td>
<td>3372</td>
<td>13 kA</td>
</tr>
<tr>
<td>RQF/RQD</td>
<td>M1, M2</td>
<td>3940</td>
<td>6744</td>
<td>13 kA</td>
</tr>
<tr>
<td>Spool Pieces</td>
<td>M1, M2</td>
<td>30860</td>
<td>33920</td>
<td>600 A</td>
</tr>
<tr>
<td>Correctors</td>
<td>N</td>
<td>27006</td>
<td>16000</td>
<td>600 A</td>
</tr>
<tr>
<td>Individually powered magnets</td>
<td>N’</td>
<td>1644</td>
<td>532</td>
<td>6 kA</td>
</tr>
<tr>
<td>Inner triplet quads</td>
<td>N’</td>
<td>80</td>
<td>112</td>
<td>13 kA</td>
</tr>
<tr>
<td>Inner triplet correctors</td>
<td>N’</td>
<td>704</td>
<td>480</td>
<td>600 A</td>
</tr>
</tbody>
</table>

- More than 100000 ($10^5$) splices!!
Energy Stored in the magnets

- Magnetic energy stored in the circuit [GJ]

- Magnetic energy stored in the magnets [GJ]
Criticality of a SC circuit

Main circuits incorporate more protection
- Cold diodes
- Energy Extraction
- Larger bus-bar cross-section

MIITs and hot spot temperature estimated in the bus-bar according to real decay data and bus-bar section
- Not a factor $10^4$ but a factor 2
- Always safe as in nominal conditions

What about failures
- In the quench detection?
- In the EE switches opening?

Quench of the bus-bar in adiabatic conditions. Thanks to G. Kirby
Splice types in the LHC.

- Splices vary in length, copper to SC ratio, insulation, mechanical fixation
- You will hear in the following talks about 13 kA and 6 kA
Corrector circuits 600 A. Lines M and N

The making of the electrical interconnections in the LHC

- Spool pieces busbars: Junction technology: Ultrasonic welding
  - Clean method (no flux)
  - Oxyde destruction by friction
  - Contact resistance between 3 and 5 nOhm
  - High reproducibility and reliability
  - On-line process control
  - Mechanical resistance: equivalent to base material
  - Fatigue life: more than 500 cycles at room and cryogenic temperatures

Achieved electrical contact resistance: 3 to 5 nOhm in average
Line M interconnection

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Spool pieces busbars: Electrical insulation

- Welded area
- Existing insulation
- Polymide tube on welded area
- Second layer of scotch
- Existing insulation
- First scotch layer
- Polyimide tube

J. Ph. Tock
AT-CRI
Review of the LHC Electrical Interconnects & Electrical Quality Assurance Procedures
CERN – 18th & 19th March 2004
EDMS 455919
**Line N Interconnection**

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→ **Auxiliary busbars: Assembly procedure**

**HALF CELL**

**INSERTION DIRECTION OF CABLE**

Tool for cable pulling

Reel

Downstream line N Board

+ Fully assembled cable (Plug included) on a transport reel
+ Line N board components
+ Protection covers for transport
+ Wires identification
+ Certificate of conformity
+ Cable segment identifier
Line N Interconnection

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- **Auxiliary busbars: Assembly procedure**

  Operation #LI-2-05  “Assemble the connection box”
  Operation #LI-2-06  “Perform electrical test”
  Operation #LI-2-07  “Weld line N auxiliary bus bars”
  Operation #LI-2-08  “Perform electrical test”
  Operation #LI-2-09  “Insulate electrically the aux. Bus bars”
  Operation #LI-2-10  “Perform electrical test”

Ultrasonic welding
Problems with ultrasonic welding in sector 7-8. Line N.

- Reported by D. Tommasini to MARIC on November 2006 after the inspection of the first installed sector
  - Presence of insulation between wires
  - Bad alignment with reduction of contact surface
- Cryolab measurements showed 4 to 19 nOhms
- US welding machines put in conformity
- Suspected interconnections re-done during following warm-up
- Test proposed during powering to spot catastrophic cases
PCS splice verification

- Test systematically done during powering tests for all 600 A circuits
- Current plateau at minimum current (200 A). Resistance deduced from QPS voltage measurements.
- Repeated at nominal current. Data stored in MTF
- Assumed resolution < 1 μOhm
Resistance is indeed proportional to the number of splices but noise is very high.

Noise depends on the circuit type. Cable length, number of magnets and inductance.

RCO circuit is a 120 A circuit and test is done at 100 A.
Expected value is between 4 and 6 nOhms

RQ6 (6xMQTL) has a higher average splice value.
  - Systematic. May be due to internal splices in the magnet

RCO splices are nominally higher than others
First circuits to verify and re-measure

Resistance at nominal current measured during Powering

Average resistance per splice
Existing NC in 600 A circuits

Sketch of the RCO.A81.B2 circuit - External aperture

Circuit found open, at 1.9K, on 23/03/2009 between B12.L1 and B11.L1

<table>
<thead>
<tr>
<th>Position</th>
<th>Magnet name</th>
<th>Upstream position</th>
</tr>
</thead>
<tbody>
<tr>
<td>C12.L1</td>
<td>MBB_3094</td>
<td>26171.6225</td>
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<tr>
<td>B12.L1</td>
<td>MBA_3174</td>
<td>26187.2825</td>
</tr>
<tr>
<td>A12.L1</td>
<td>MBB_1144</td>
<td>26202.9425</td>
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<tr>
<td>Q11.L1</td>
<td>SSS_524</td>
<td>26218.6025</td>
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<tr>
<td>C1</td>
<td></td>
<td>26226.3475</td>
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<td>B11.L1</td>
<td>MBA_1158</td>
<td>26240.0642</td>
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<tr>
<td>A11.L1</td>
<td>MBA_1103</td>
<td>26255.7242</td>
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<tr>
<td>Q10.L1</td>
<td>SSS_641</td>
<td>26271.3842</td>
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<tr>
<td>B10.L1</td>
<td>MBA_1160</td>
<td>26279.1292</td>
</tr>
</tbody>
</table>
Inner triplet 13 kA splices

- Two double bus-bars Cu/SC
  - 5 kA and 8 kA
  - Brazed similarly to the 6kA flat cable
- All splices protected together with the magnets at a 100mV threshold
Inner Triplet splices during interconnection
As for the spool, high resistance was seen during the EIQA tests (>µOhm)

Need to open the cryostat to locate and repair the fault
Conclusions

What is the maximum credible incident (MCI) affecting each of these circuit types

- Quench detection failing? Non propagating quench
- Arcing in a spool piece next to M1, M2 line
- ...

Work ahead of us:

- Investigation of excessive resistance in 600 A circuits
- Verify the splice parameters (mainly for US magnets)
- Evaluate heating of the bus-bar under accidental conditions
- ...