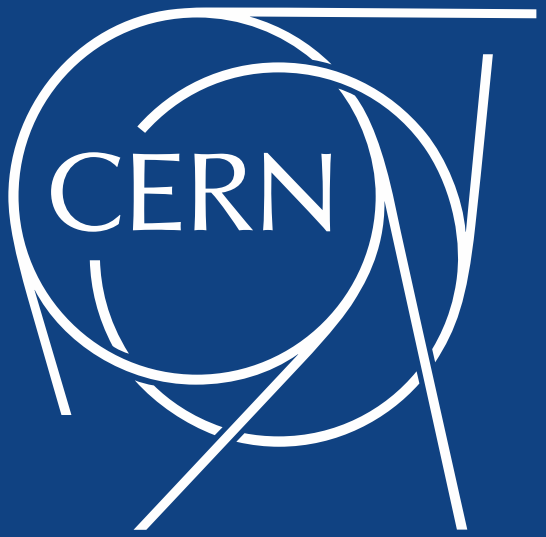
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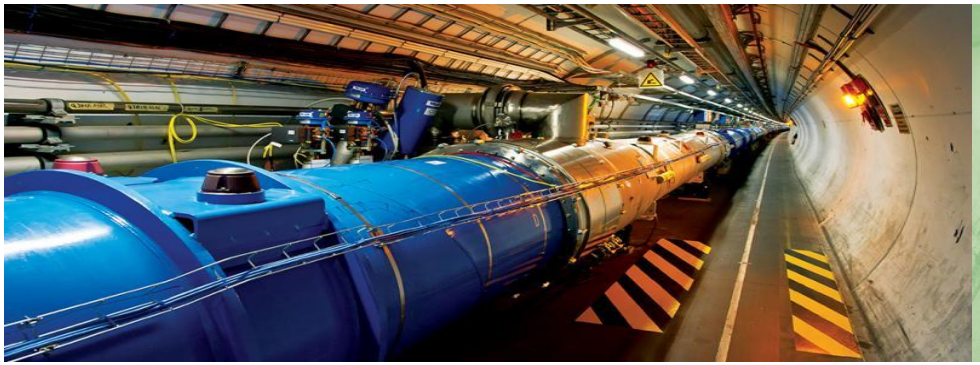
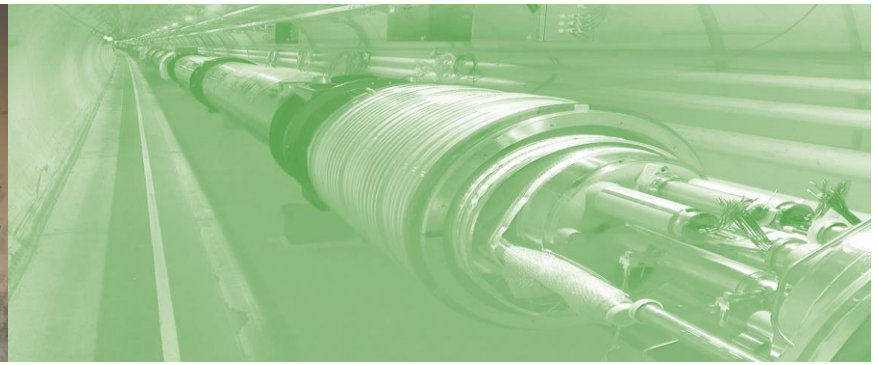



Electrical Performance of LHC Magnet Circuits

F. Rodriguez Mateos, TE/MPE-EE
Chamonix 2016
Session 3: LHC Hardware Performance

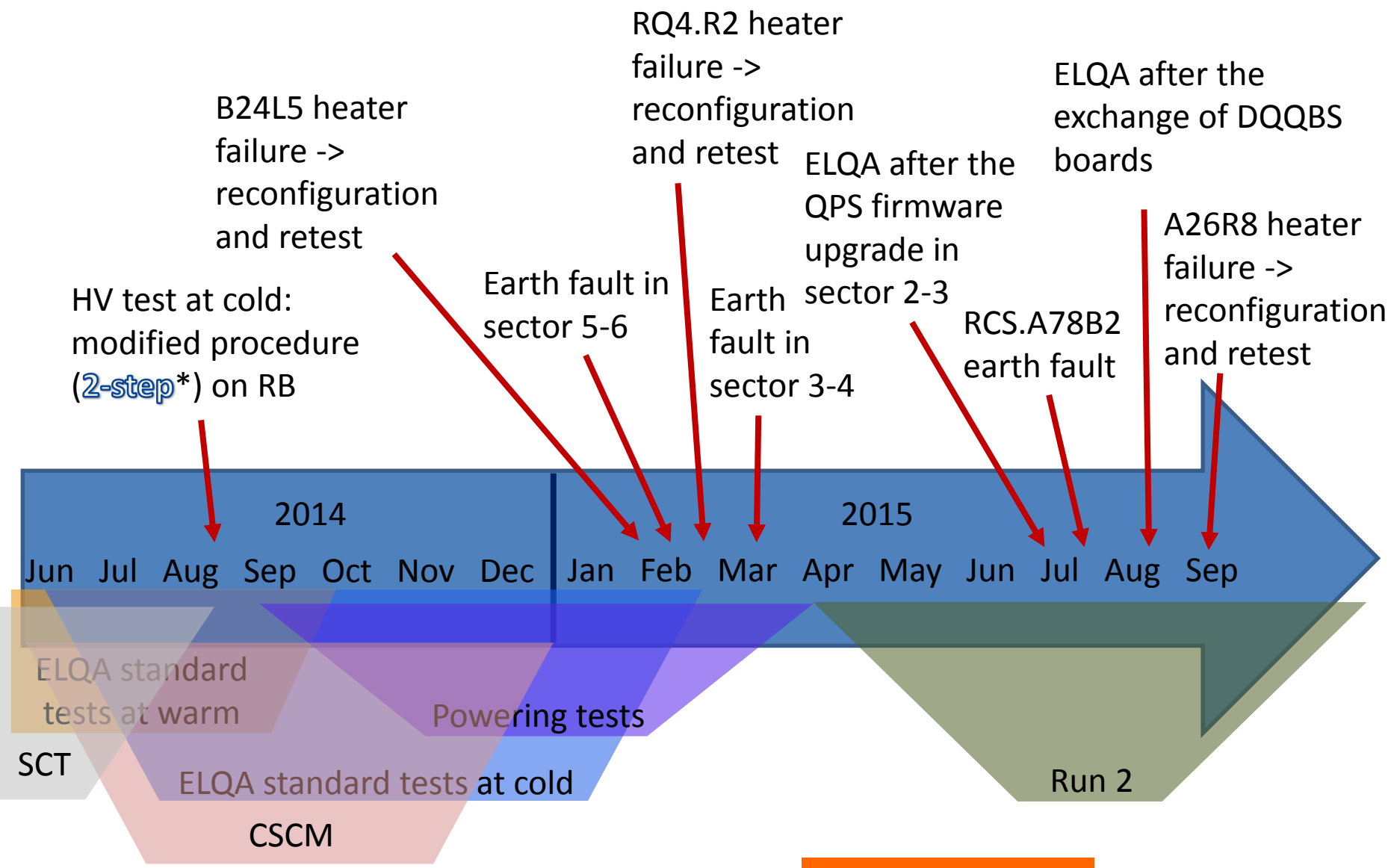
Outline

- Introduction : what systems/aspects are covered in this presentation?
- Chronology since last Chamonix Workshop
- Main events/faults
- On-going actions during YETS
- Future actions (planned and unplanned)
- Conclusions

Introduction

- What systems/aspects are covered in this presentation?
  - Electrical integrity at cold and at warm (ElQA)
  - Energy extraction systems (EE 13kA and EE 600A)
  - Quench Heater Discharge Supplies (DQHDS)
  - DFB instrumentation (DFB-I) and current lead heating (CL-H)

Chronology (highlights)



* 2.1kV and 1.5kV

Availability Matrix – Electrical Eng. Systems

Subsystem	Faults	Average intervention time [h]	Power Aborts	Remote	Access	In masked time	Foreseen mitigation	Remark
Energy extraction 600 A	11	1.5	9	3	8	3	New *spares* in the long run	5 breakers replaced 2 LV Traco 1 wire in trafo 3 miscel.
Energy extraction 13 kA	3	3.0	0	1	2	0	*Spare* fans for DRQs	1 AC/DC bridge rectifier 2 fans
Quench heater power supplies	5	1.0	0	0	5	4	Front switches verified	1 phase-neutral short 1 charging fuse blown 3 front switch problem (lag LS1 intervention)
DFB cabling	3	3.2	0	0	3	2	None	2 contact in connectors 1 damaged cable
Current lead heating system	4	1.0	0	0	4	2	None	4 static relays in crates
	26		9	4	22	11		

Availability Matrix – Electrical Eng. Systems

Downtime [h]

Frequency

	< 1h	1-4	4-8	8-12	> 12
1/week					
1/month	EE 600 A QH PS	DFB cabling			
1/year	CL HS	EE 13 kA			
< 1/year					

Green: mitigated/not expected to re-appear

Red: not yet mitigated/mitigation not justified

Violet: partially mitigated

Courtesy Andrea Apollonio, TE

13 kA Energy Extraction Systems

- One issue (22/07/15) due to an AC/DC bridge rectifier which failed in short circuit leading to an impossibility to close extraction switches of the related RB EE system in S34 in Point 3.
  - This has been the third such a case registered since 2007
  - Study is still on-going and a possible re-design of this auxiliary circuit could be planned for future LS
- Two issues due to quadrupole dump resistor cooling fan failure:
  - 03/11/15 - A fault of the fan (wrong connection of the terminals) tripped the local circuit breaker preventing of having the extraction switches of RQD.A43 closed
  - 13/12/15 - A ruptured fan-stator coil slowed down the dump resistor cooling process of RQF.A12 energy extraction system
  - Three broken fans have been registered since 2008

600A Energy Extraction Systems

- 11 interventions in total

- 8 in the tunnel:
  - 5 breakers replaced (2 x main ax, 1 micro-switch, 1 holding coil, 1 producing closing failures requiring re-adjustment)
  - 2 LV TRACO power supplies (in total 3 cases during the 2015 calendar year)
  - 1 case of loose wire (post LS1) on a new small transformer

- 3 faults that could be reset remotely

Quench Heater Discharge Supplies

- 6000 units distributed along arcs and, matching sections and insertions
- The earthing fuse was replaced by a fast-reacting fuse with short arcing time in all main dipole units during LS1.
  - During this operation, the re-mounting/re-tightening of the frontal ON/OFF switch can be made in a wrong way as the fixing is a bit tricky
- The machine is not stopped when one HDS drops to too low-voltage in a dipole rack (3oo4 logic). This is why in most cases, we could replace faulty units in the shade of other svstems' access

date	equipment	symptom	failure & cause	Intervention in shade of others
20.03.2015	RQ4.R1	One HDS discharging slowly	Probably charging fuse blown due to a problem on the main transformer	yes
10.05.2015	B28L7	F3 circuit breaker down	HDS3 had a short between phase and neutral	no
4.06.2015	A20R2	HDS3 at 0V	Front switch badly fixed (after the fuse change campaign in 281)	yes
28.07.2015	C29R2	HDS1 at 0V	Front switch badly fixed (after the fuse change campaign in 281)	yes
28.07.2015	B14L3	HDS2 at 0V	Front switch badly fixed (after the fuse change campaign in 281)	yes
16.10.2015	C26L3	HDS4 was off	Faulty front switch (problem not solvable on site)	yes

During this 2015-16 YETS it has been discovered that in some cases the frontal ON/OFF switches do not trigger the internal discharge of the capacitors. All units with this problem (13 in total) have been fixed or replaced – this is not a design issue.

DFB instrumentation and CL heating

System	Circuit	Failure Description	Failure Cause	Repair Description	In masked tim
C.L. Heating system	RSD1.A81B2	Current lead heating system temperature variation too high	Static relay broken	Replaced the static relay	NO
C.L. Heating system	RQ8.R2	Current lead DFLCS.7R2.8, RQ8.R2, TT893 (Warm Temp sensor) went below threshold and caused a power abort.	Static relay malfunctionning	Replaced the static relay	YES
DFB_TT	RQX.R2	Lost cold probe 891A	Bad contact in cable	Change cable CS9	NO
C.L. Heating system	RB.A23 lead 5	low temperature on the current led on RB.A23 lead 5	Static relay broken	Exchange the static relay and varistor.	NO
DFB_TT	RQ10.R6 Lead#2 TT891	Bad reading on TT891 (cold) of C.L.#2	Sub-D connector at the back of PE	Open Sub-D, pushed back Canon pin #1	YES
DFB_TT	RCS.A78.B1	reading of warm TT sensor of CL #45 is too noisy	Damaged instrumentation cable	replacement of CS I	YES
C.L. Heating system	RQ8.L6	Warm temperature too cold on RQ8.L9	Static relay inside the crate	Replacement of the current lead heating system crate by a spare one from lab	YES

Fig 1. The Canon C50 connector (300V).

Fig 2. Lemo/Redel S series 51 pin assembly (3,2kV).

- In all DFBAs, the Canon connectors on proximity equipment linked to the main circuits have been replaced by Lemo-Redel with a better dielectric withstand.

- Top part of the current leads must be maintained at room temperature to avoid heavy condensation or ice formation. Cartridge heaters are incorporated in the top of each current lead.
- When one of the CL heating systems stops working, it does not trigger dumping of the beams. The system will need to be repaired in the tunnel after the first upcoming beam dump.

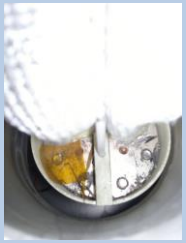
Electrical integrity at cold and at warm

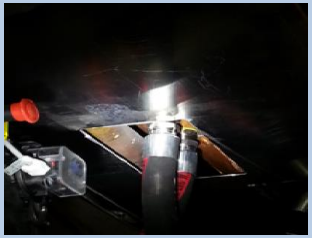
- Short circuit diagnostics and identification
  - Known reasons (most of them)
  - Unknown reasons
    - RB.A56: intermittent, already during CSCM
    - RCS.A78B2: under investigation
  - See summary of short-circuits by Mateusz at LMC on 18/11/2015https://indico.cern.ch/event/462280/contribution/7/attachments/1189007/1725293/Earth_fault_history.pptx
  - See actions by EN-EL presented by Daniel at LMC on 15/04/2015http://indico.cern.ch/event/387239/contribution/11/attachments/773496/1060810/150414_CABLING_WCC_InterventionP8L_IsolationFault_RBA78.pdf

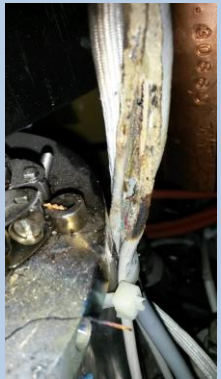
History of shorts-to-ground

Commissioning

- RB.A56
  - 2 intermittent earth faults during CSCM – disappeared
  - 1 intermittent earth fault after training – disappeared
- RB.A34
  - Active water coupling nut vs. grounded surface on surrounding infrastructure
- RQF.A12
  - Active water coupling nut vs. grounded surface on surrounding infrastructure
- RB.A34
  - Diode pot saga (“to burn or not to burn”)
- RQX.L1
  - Instrumentation cable burnt







Beam operation

- RB.A78
  - 8 h LHC downtime on 8/7/2015
  - 5 h LHC downtime on 10/8/2015
  - 19 h LHC downtime on 11/8/2015
  - Water coupling nut/ 2x earth detection card
- RQF.A78
  - 5 h LHC downtime on 13/10/2015
  - Water leak
- RCS.A78B2
  - 9 h LHC downtime on 18/7/2015
  - 10 min LHC downtime on 13/8/2015 (not incl. pre-cycle)
  - Under investigation

Availability Matrix – Earth Faults

Downtime [h]

Frequency	< 1h	1-4	4-8	8-12	> 12
1/week					
1/month			Other Circuits	Main Circuits	
1/year					
< 1/year					

Green: mitigated/not expected to re-appear
Red: not yet mitigated/mitigation not justified
Violet: partially mitigated

Courtesy Andrea Apollonio, TE

Actions at present (YETS)

- EN-EL
  - Consolidating mechanical supports of copper bus bars in all the UA ceilings with insulating wedges
- TE-EPC
  - Fusing value at PC goes down from 1 A to 200 mA in order to make voltage feelers more efficient in localizing the problem (first done only in S56)
- TE-CRG
  - Consolidation of the cables of the TT893 temperature sensors on the 7.5 kA current leads of all DFBXs
- TE-MPE
  - Investigations on RCS.A78B2
  - Voltage feelers on main circuits: frequency goes up from 1.25 Hz to 10 Hz (provided compatibility with tunnel infrastructure is confirmed)
  - Clarification on ElQA after YETS considering temperature in DFBs (back to 1-step HV test at 2.1 kV?)
- EN-EL / TE-MPE
  - Started discussions for common ElQA procedures before powering tests
  - EN-CV should also be involved (e.g. circulation of water in circuits, settings)

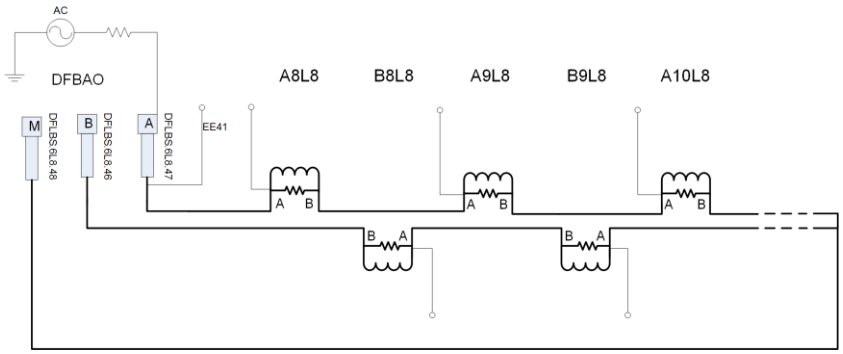
RCS.A78B2 earth fault investigation

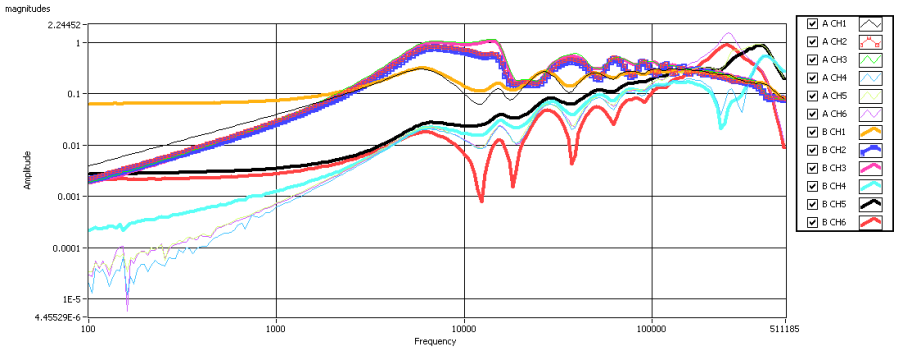
See presentation by Arjan at LMC on 18/11/2015

- This earth fault is conditioned by the powering of other circuits, independently from the powering of the RCS circuit itself
- Machine can operate without this circuit
- However the origin of the fault needs to be understood as soon as possible
  - Plan corrective interventions at this location, but also preventively at other symmetrical locations
- Type-test results from a special measurement set-up:
  - Noise levels are fairly low
  - Measurement precision is high
  - Results are nevertheless very difficult to interpret due to a complex topology of the circuit
  - One more calibration run needed at fully superconducting state

RCS.A78B2

Courtesy Mateusz Bednarek, TE



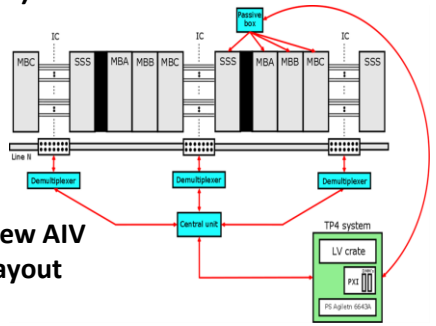


Future actions – ElQA (1)

- New hardware and software with improved features - ongoing
  - New DAQ Interface and other upgrades of the High-Voltage Insulation Testers, with delivery of 10 complete systems
  - New hardware for the Arc Interconnection Verifications (nAIV) units
  - New software tools for ELQA

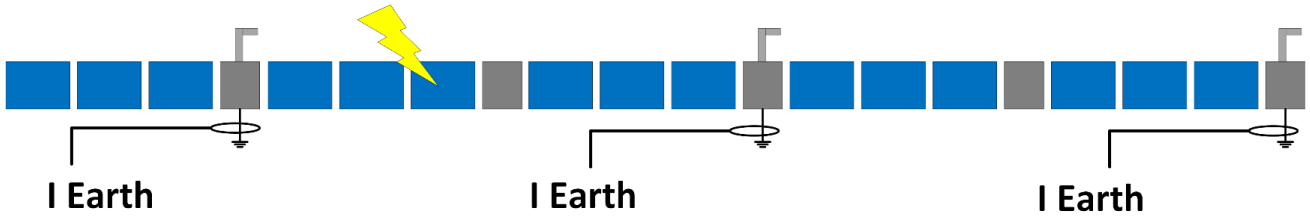
Courtesy Knud Dahlerup-Petersen, TE

3 kV crate with the new DAQ prototype



New AIV Layout

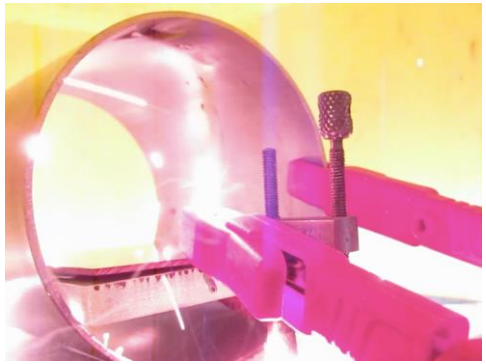
- New methods for earth faults localization – under feasibility study
  - Use of additional signals
    - U_{diode} to be triggered by earth faults
    - Current measurement transformers at the level of the current leads
    - Current measurement in grounding loops

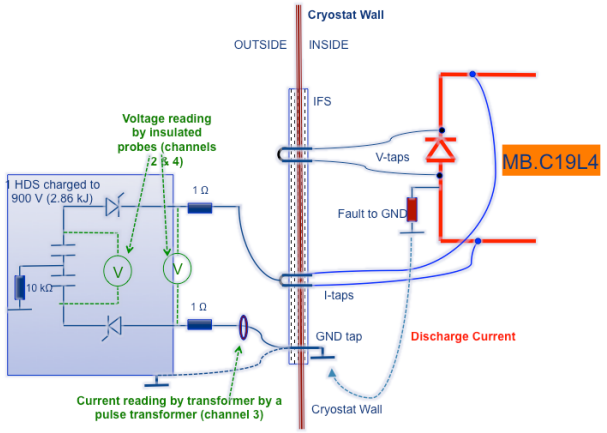


See presentation by Mateusz at LMC on 18/11/2015

Future actions – ElQA (2)

- Preventive action – (very) preliminary phase of study
  - Galvanic separation in an automated manner of warm and cold parts of the main circuits by means of a *disconnector* would help in reducing intervention times, minimizing manipulation risks and improving safety. Technical and financial feasibility of this in the LHC main circuits should be analyzed in view of a possible activity during LS2
- Curing weak spots – one (urgent) prototype unit produced
  - Hardware: “weak-spot blower ” – new version required, more controllable, possibility to cover larger voltages as shorts may occur above the HDS level (900 V)
  - Procedures

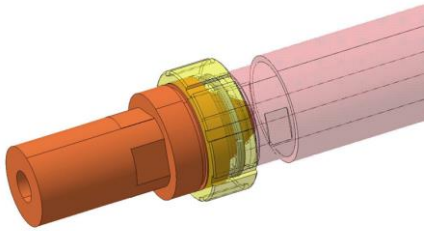




Future actions – hi-current conical joints

- Other improvements
  - Monitoring of conical joints (ongoing project in TE/MPE)
  - Development of a device to tighten conical joints during installation/repairs (not yet done due to lack of resources)

Preliminary ideas



Courtesy Kurt Artoos, EN

Future actions – Energy Extraction Systems

- Regular maintenance of systems is imperative, particularly for 13kA switches (contract signed with IHEP, Protvino (RU), up to end of 2018)
- Replacement of the 13kA breaker controls boards which today is based on flash-EPROMs

- Spares for 600A switches should be envisaged for after LS2 (up to LS2 we should have enough units in reserve). Latest news: 2015 statistics shows the need for corrective maintenance on at least 10 breakers
- Improve automated diagnostics and analysis of failures

see slides from Mirko at 6th Evian Workshop, December 2015

Future actions - DQHDS

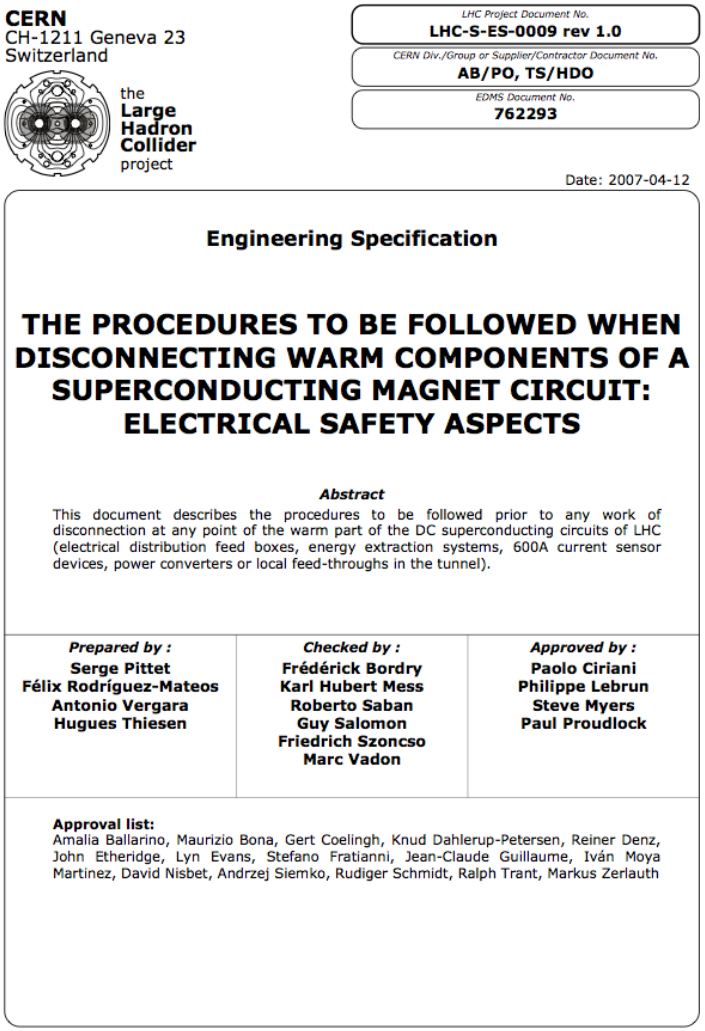
- Proposal – a study to be conducted over a sample of units from the tunnel in order to analyze where are we at present with respect to the lifetime of the 6000 units
  - Special aging tests + radiation tests should allow to get an estimation of the remaining (statistical) lifetime
- The main quadrupole units will be upgraded with respect to I/V monitoring and fast earthing fuse during LS2 (project on-going)

Conclusions

- A picture on the electrical faults during post-LS1 commissioning and 2015 beam operation has been presented for relevant systems pertaining to the LHC Magnet Circuits
  - Nothing dramatic, on the contrary the overall behavior is in good shape
- However, activities for the future should concentrate on improving understanding of:
  - earth faults, in particular with procedures and hardware for diagnostics and for “curing” known cases
  - margin with respect to lifetime for some large scale systems (e.g. capacitors in HDS)
  - long term evolution of high-current joints’ resistance
  - possible designs of tooling for applying torques in a controlled manner to conical joints mechanical assemblies
- Work ahead is intense and manpower efforts should be properly estimated for the tasks not yet launched

A final remark … on safety

- EN-EL (S. Baird) proposed at the end of last year to review and issue a new version of EDMS 762293 as to improve safety for interventions on the warm parts of the circuits during beam operation periods
- Not to forget . . .



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CH-1211 Geneva 23
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the Large Hadron Collider project

LHC Project Document No.
LHC-S-ES-0009 rev 1.0

CERN Div./Group or Supplier/Contractor Document No.
AB/PO, TS/HDO

EDMS Document No.
762293

Date: 2007-04-12

Engineering Specification

THE PROCEDURES TO BE FOLLOWED WHEN DISCONNECTING WARM COMPONENTS OF A SUPERCONDUCTING MAGNET CIRCUIT: ELECTRICAL SAFETY ASPECTS

Abstract

This document describes the procedures to be followed prior to any work of disconnection at any point of the warm part of the DC superconducting circuits of LHC (electrical distribution feed boxes, energy extraction systems, 600A current sensor devices, power converters or local feed-throughs in the tunnel).

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