RF and ADT hardware performance

A. Butterworth BE/RF

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Outline

RF
- Summary of Run 1 HW issues and LS1
- Replacement of cavity module
- HW availability and issues in 2015
- Mitigation & improvements for 2016

ADT
- Upgrades in LS1
- Performance and operational issues in 2015
- Mitigation & improvements for 2016
Run 1 HV faults

RF fault statistics dominated by:

- Spurious crowbar trips
  - Thyratrons prone to spontaneous firing
- Klystron filament current glitches
- High voltage interlock
LS1 HV & Power consolidation

- All klystron HV connectors were found defective => repair campaign
- Crowbars: Thyratrons replaced by Solid State devices (better performance & reliability)
- 8/16 klystrons replaced – age profile

No more klystron filament glitches
No more spurious crowbar trips
Replacement of cavity module

- From 2009, Cavity 3 Beam 2 was quenching after a few minutes at 2 MV CW nominal
  - Evidence of high X ray emission and cryo consumption
- Eventually clamped at 1.2 MV for the rest of Run 1
  - Missing voltage distributed to the other seven Beam 2 cavities
- Despite careful conditioning after each technical stop, no change of behaviour.
Replacement of cavity module

- Decided to replace the 4-cavity cryomodule containing the faulty cavity
- LHC ACS module M1.B2 America was replaced by the spare module Europa during LS1.
- America was stored under vacuum in SM18 awaiting repair
- Recovery options:
  1. Conditioning
  2. He processing
  3. Dismantling and cavity replacement

Don’t touch it until the 4 modules in LHC work properly with the full beam at 6.5 TeV!
America measured in SM18

X Rays at 2 meters from Cavity B

Onset of field emission at 1.2 MV

Radiation [mSv/h]

Accelerating voltage [MV] CW

26/01/2016 RF & ADT, Chamonix 2016
America performance recovery

X Rays at 2 meters from Cavity B

Before treatment

After pulsed conditioning to high voltage with quenches at 2.8 MV

After further high pulse treatment

Radiation [mSv/h]

Accelerating voltage [MV] CW

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America performance recovery

- Conditioning in pulsed mode to burn emitters was successful
- Nominal performance (>2MV) regained
- He processing was not necessary
- Not necessary to open the module
- Full power revalidation was successful on all 4 cavities
- America now a valid spare module
LHC Cryomodule project

- Produce stock of fully conforming spare units
- Re-establish Cu-Nb cavity technology at CERN

Deliverables:
  - Cavity #19 to validate/re-process
  - Practice cavities (spinning) x 2 (in progress)
  - Model cavities (electro-hydraulic forming) x 2
  - Dressed cavities x 4
  - New spare cavity units x 10
  - As-built design folder
  - Inventory of CM parts & tooling
  - Cryomodule CM6-7 integration (TBC)
Dressed cavity #19: status

- Measured stiffness 16.3 kN/mm
- Warm RF test done
- LPWR (max 7 bar) in SM-18 in Jan
- Vertical test in SM18 Mid-Feb
- If not successful:
  - Strip, clean, and redo Nb-sputtering
  - Optical inspection
  - Warm and cold testing
RF availability 2015

• 57 RF and HV trips recorded, 76 hours downtime in AFT
• 13 beam dumps (higher bars) – all during 25 ns run
• 15 categories

- He tank pressure exceeded
- HOM temp
- Klystron temperature
- Electrical glitch
- Klystron focus current
- Klystron vacuum
- Klystron cathode current too low
- Main coupler blocked
- Crowbar fired
- Cavity main coupler window temp

25 ns proton run
RF faults 2015

Number of faults

- LLRF & CTRL: 19%
- LLRF/CTRL/FESA: 19%
- Beam intensity related: 15%
- High voltage: 17%
- Child faults: 19%
- Mitigated faults: 26%

Downtime

- LLRF/CTRL: 15%
- Mitigated faults: 22%
- Beam intensity related: 25%
- Child faults: 32%
- High voltage: 6%
**RF faults 2015**

- **LLRF/CTRL Hardware**: 4%
- **LLRF & CTRL FESA**: 19%
- **Beam intensity related**: 15%
- **High voltage**: 17%
- **Mitigated faults**: 26%

**“Mitigated faults”**
- Interlock levels
- Main coupler blocked: communication protocol error in control card. **Solved during TS1**
- Temperature glitches: **Solved during TS2**
- No trips since mid-September

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RF & ADT, Chamonix 2016
RF faults 2015

“Child faults”
- Electrical glitches: e.g. thunderstorms
- Loss of cryogenic conditions: related to the increase of beam intensity (heat load)
- 2/13 beam dumps

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RF faults 2015

**HV system crowbars**
- Spurious crowbars were a major cause of trips during Run1
- In 2015 all “real” crowbars (klystron vacuum activity)
- All (except 1) **soon after restarting the RF system** (in particular after long periods at 10kV)
- 1 beam dump
RF faults 2015

Beam intensity increase
- **2015**: nominal intensity : $1.15 \times 10^{11}$ p/bunch, 25ns, 10MV
- => RF feedback power transients reaching limit (250 – 280 kW)

Faults related to beam intensity increase
- 7 beam dumps (50%)
- Klystron vacuum: Klystron oversaturated => fine adjustment of half detuning
- Cavity main coupler window overheated => better cooling system under study
- Arc detectors: no evidence of real arcs! Maybe radiation induced? => YETS: modification + diagnostic system
- **2016**: klystrons, MC couplers & cavities will be conditioned to nominal 300 kW
Arc detectors

Trips on klystron window and circulator/load
Arc detector diagnostics

• 16 oscilloscopes installed in UX45
• Record output waveforms of arc detectors
• Distinguish between signature of arc or radiation-induced spike
Low-Level RF and controls

- Reboot, FESA class hiccups, RF frequency interlocks
- Several LLRF cards, PLC/CTRL IO modules, 5V power supplies replaced
- 3/13 beam dumps
LLRF & controls availability

- Few false alarms from RF frequency interlock
  - Single spike filtering of beam energy signal and diagnostics implemented; if recurrent, data to be analysed
- Two LLRF VME modules and a 5V power supply failed
  - First electronics failure since LHC start-up in 2008
  - More spares needed to keep system operational
- Long recovery time after power cut on VME crates in the Faraday cage
  - Took > 6 hours in one case
  - Problem with reloading FESA persistent data understood, fixed in 2016
- Spurious dump due to PLC receiving an RF off command
  - Source of command unidentified, occurred only once
Diagnostics (1)

- High-resolution beam profiles at 40 Gs/s
  - Fast scopes (1/beam) installed in ex-klystron galleries
    - Expert only at the moment; user interface planned
- Beam spectrum logged in MeasDB
  - Now a fixed display is available
    - Frequent problems with interface to spectrum analyser, to be made more robust. Source of problems under investigation
- Improved peak-detected Schottky spectra
  - Faster rise time for better resolution of bunch centre
    - Available only for one beam; further modules needed
- Beam profile screens in CCC (using 1 GHz scopes in SR4)
  - New hardware for streaming to make it more robust (Ph. Nouchi, U. Wehrle)
  - Software upgrade planned for 2016

2011: using scope in SR4
2015: using scope in UA43, corrected for transfer function of shorter cables
Observation Box

- LLRF and Transverse Damper (ADT) acquire bunch-by-bunch phase and position
- Short memory buffers on-board for HW diagnostics (~70 turns)
  - Not intended for beam observation!
- Boards have fiber/copper Gbit serial links for interconnect
  - Use these to stream data to an external computer with lots of memory
  - Make it available to whoever wants it via FESA
- Rack-mount server with 128 Gbyte of RAM (expandable)
  - 6 minutes of data at full 40 Mspfs on 4 channels
  - Improved FESA interface for 2016: huge buffer will disappear, replaced by multiple triggerable buffers, logging
- Install 4 boxes in ADT, 2 in LLRF
ObsBox beam phase display

J-E Muller, G-H Hemelsoet
ObsBox in ADT
ADT
Availability in 2015

18 ADT Faults in 2015

- UW45 cooling recovery ADT: 4
- ADT Power: 2
- ADT controls /interlocks: 4
- ADTLL/configuration: 9

Three largest faults → 82% of fault time:
- UX45 interlock chassis (22.05 h), → 3 interventions
- CV water cooling UW45 recovery (9.27 h), → 2 interventions
- Gbit Link ADTLL (3.16 h), → 3 interventions

Hours recorded:
- 5.48
- 9.27
- 26.02
- 1.02

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Major upgrades during LS1

• New, much more performant signal processing hardware
• Properly integrated all the new functionality added during Run 1:
  • Fully independent feedbacks for main loop and witness bunches
  • Abort gap and injection gap cleaning
  • Blowup
  • Excitation functionality to perform controlled kicks through the whole cycle
Operational issues in 2015

• Answer to the question: is the damper working?
• Confusion between operational and special settings (cleaning, blowup…)

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Is the damper working?

- Typical cycle observed every year since 2010:
  - Beam unstable
  - Increase ADT gain
  - Beam still unstable
  - Increase octupole current
  - Beam still unstable
  - Increase ADT gain
  - Beam still unstable
  - Increase octupole current
  - Repeat n times…
  - Octupole current at max
  - ADT gain at max
  - Beam still unstable
  - Yes, it does
  - Recursion, see Recursion.
Is the damper working?

- Basic hardware check in IQC:
  - All signal processing modules are receiving correct data and able to function correctly
- Online monitoring of the damper performance with beam at injection and through the cycle
  - Injection oscillation analysis: damping times, per-bunch tune, phase advances between pickups (and many more)
  - Same thing through the cycle by on-demand active excitation
  - All data will be made available via logging and display/application in CCC
Is the damper working?

An example: damping time extraction

- Need to extract many more beam parameters important for proper functioning of ADT
- Injection analysis and damper performance: BE-RF + BE-OP
- Instability analysis: BE-ABP
Settings confusion

- The cleaning and the blow-up functionality will be completely decoupled
  - Sacrifice last free channel foreseen for future special manipulations
- Intensity settings of beam position measurement front-ends now available from a CCC application (pilot, nominal, high intensity)
  - Already since autumn 2015
Summary: RF

- Major Run 1 hardware issues with HV & klystrons fully mitigated during LS1
- Cavity module successfully replaced & recovered
- Many faults mitigated during TS1 and TS2
- Beam intensity related issues with peak klystron power: condition to nominal 300kW for 2016
- Arc detector trips not understood: diagnostics installed
- LLRF spares start to become important
- Some controls issues to mitigate for 2016
- New powerful diagnostics based on ObsBox
Summary: ADT

- Hardware availability is good
  - Few minor isolated issues
- Operational issues identified
  - Monitoring of performance with beam
  - Settings management
  - Will both be addressed for the startup
Damping Times per bunch

Oscillation amplitude (per PU per bunch) - ADTmDSPUHorM1B2
Acquisition date 11-Oct-2015 10:55:17

All bunches excited coherently during one turn.
Transverse deflection by ADT << 1 mm.
⇒ expected blow-up less than 1%.

Damper was originally designed to counteract maximum injection errors of 3.3sigma corresponding to 4 mm at beta=185m, with an estimated emittance blow-up better than 2% [1]

Factor 2 between bunches in the centre and the edge of trains > 12 bunches
Pathological Case: Over-Damping

See also: “MARGINS TO INCREASE ADT GAIN AT INJECTION”, W. Hofle, LBOC 49, 6 Oct. 2015

https://indico.cern.ch/event/451051/

VME modules with integrated Transmitters

Computer in TN

LHC / SPS /..

Transmitter
Transmitter
Transmitter
Transmitter

Fiber

SPEC
SPEC
SPEC
SPEC

Linux
kernel

Driver
Stack

4 x 1 / 2.5 Gb/s

PCie (DMA)

RAM

GPGPU

syscalls & sysfs

CUDA/OpenCL

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Ethernet

ObsBox class

FESA 3
RDA 3
CMW

OP application
Java
RDA 3

Observation Box

ObsBox
## Faults summary in 2012

### Total downtime 18 hours in 2012

<table>
<thead>
<tr>
<th>Tetrode exchange</th>
<th>Amplifier faults</th>
<th>HV Power supply faults</th>
<th>PLC &amp; Server faults</th>
<th>Kicker Faults</th>
<th>Low-level RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>#9 #12 #16</td>
<td>#3 PT100 (exchange amplifier)</td>
<td>#15-16 HV cables burnt</td>
<td>#11-12 FESA server crashed</td>
<td>RB46 TPG 300 exchange</td>
<td>40MHz clock havoc after TS</td>
</tr>
<tr>
<td>#3 #15 #6</td>
<td>#8 PT100 (exchange amplifier)</td>
<td>#9-10 Gate control failure</td>
<td>#9-10 FESA server crashed</td>
<td></td>
<td>Gigabit link connector bad soldering</td>
</tr>
<tr>
<td>#14 #1 #4 #2</td>
<td>#2 attenuator (exchange amplifier)</td>
<td></td>
<td>#11-12 Beckhoff module exchange</td>
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</tr>
<tr>
<td><strong>Total 20 tetrodes out of 32 replaced</strong></td>
<td>#9 HV load (exchange amplifier)</td>
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<tr>
<td></td>
<td>#10 water flow meter</td>
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