LHC RF System Performance in 2017

H. Timko,
CERN, BE-RF

Availability

- High- and low-power RF
- Controls
- ADT
- Full detuning

Diagnostics

- New tools

Studies

- Relevant to operation
Fault Analysis

AVAILABILITY
Global RF System Availability

Overall Availability: 99.0 %

31 faults, 47.3 h downtime
RF Faults Breakdown

- **19 hardware faults**
  - 36.3 h total, 1.9 h average duration

- **10 controls faults**
  - 9.1 h total, 0.9 h average duration

- **3 other faults**
  - 1.9 h total, 0.6 h average duration
Concentrated in weeks 23-33

- Klystron (4)
  Cooling, vacuum level, thyratron oil level, high cathode current
- Power supplies (3)
- Crates down (2)
- FESA process missing (1)
- Spurious trips (2)

Clustered (3 events): loose connection on interlock crate (hard to diagnose)

- 14.0 h, most of it lost during RF MD

Clustered (3 events, 4.8 h): loose cable on C4B2 main coupler bias

Actually after the reference period...
Controls Faults

Mainly between weeks 25-34

- FESA process needs restarting (2)
  (+1 on previous slide)
- FEC needs reboot (1)
- Spurious trips, arcs, or interlocks (3)
  (+2 on previous slide)
- Communication issues (3)
  Between different FESA classes (RDA comm. error)
- Replacement of LLRF module (1)
  (hardware issue...)

About half of the time the OP crew can solve the issues by a restart/reboot
Other Faults

Few scattered faults

- Spurious interlocks
  - Vacuum level
  - Main coupler temperature
  - Arc in circulator
- Typically reset within a few minutes

![Weekly Fault Summary (Radio Frequency > Other)](image)
Availabilty Comparison 2016/17

2016 Proton Run
25-03-2016 09:00 – 31-10-2016 06:00
• More faults distributed over the year; longest intervention 7 h

2017 Proton Run
28-04-2017 18:00 – 10-11-2017 15:00
• Less faults distributed over the year; a difficult intervention of 14 h
• Less available, but just as reliable

36 faults
40.1 h downtime

31 faults
47.3 h downtime
ADT Availability

- Trip of module V1B1 load
- Trip of module V1B1 with timeout on reset
- Reboot of crates for both modules of B1H
- Abort gap cleaning not working for module B1V

**Comments (27-Jul-2017 12:58:27)**

ADT was innocent!

NOW: fill for VDM scans for LHCb then ALICE

NOTE: New filling scheme!

**AFS:** Multi_57b_56b_25_20_24_4bpi_15inj

Only 4 faults
3.8 h downtime

Weekly Fault Summary (Transverse Damper)
Using full detuning in physics ⇒ klystrons work mostly at ~100 kW
  • Still, similar availability

Most frequent faults are related to
  • Klystron
  • Power supplies
  • Unavailability of crates or FESA processes

Antenna of cavity 1B1 gave a weak signal this year; had to change to spare antenna
  • Measurement campaign in YETS to verify all antennas
With 2017 beam parameters, the (mean) power consumption at arrival to flat top was reduced to about 100 kW in all cavities

- Power required is independent on beam current; smooth operation

Estimated accuracy on power measurement ±20 %

Full Detuning: Experience in 2017

$$P = \frac{V_0 I_{b, pk}}{8}$$

03/06/2017

Half detuning

Expect 190 kW @ 1.5 MV, 0.5 A DC
Full Detuning: Experience in 2017

With 2017 beam parameters, the (mean) power consumption at arrival to flat top was reduced to about 100 kW in all cavities

- Power required is independent on beam current; smooth operation

\[ P = \frac{V_0^2}{8R/QQL} \]

Estimated accuracy on power measurement ±20 %

03/11/2017

Full detuning

Expect 104 kW at 1.5 MV, QL=60k
New in 2017

SOFTWARE & DIAGNOSTICS
Commissioned this year; available data

- Cavity sum amplitude & phase → e.g. phase shifts for full detuning
- Beam pick-up amplitude & phase → beam stability
- Derived: stable phase (beam w.r.t. RF) → e-cloud

Require careful post-processing; re-calibration needed in 2018
Data for Full Detuning

Full detuning successfully commissioned in the beginning of 2017

• Was running reliably since

ObsBox cavity voltage amplitude & phase used by experiments to predict shift in collision time/position (DIP data base)

Phase delay Beam 1
Delay of collision
Phase delay Beam 2
Shift of IP in Z
ADT Instability Detection

Real-time transverse instability detection & online monitor
- Bunch-by-bunch transverse activity published every 4000 turns by ADTObsBox
- Coherent activity $\Rightarrow$ triggers the LHC instability trigger network LIST

Freezing of observation buffers from different instruments in case of instabilities
- Tune and damping time at injection
- Important diagnostics tool for transverse instabilities

Losses along the ring; bunches marked with a cross are detected by the ADT as unstable
Further ADT tools put in place in 2017

- **Transverse oscillation frequency spectrum**
  In view of HL-LHC civil engineering

- **Logging of bunch-by-bunch injection data**
  For drift observations

- **ADT-AC dipole excitation**
  For the automatic coupling measurement and correction
  To be extended in 2018 to on-demand bunch-by-bunch tune measurements
High-Resolution Profiles

Logging FESA class is being worked on; foreseen to log

- Both raw & corrected profiles (in case the transfer function changes)
- Logging frequency: 1/min (MDB), 1/10 min (LDB)

Scope for B1 replaced in 2017

- Presently still an issue with the signal (broadened bunch length)

2011: using scope in SR4, raw data

2015: using scope in UA43, corrected for transfer function of shorter cables
First attempts this year using S. Hancock’s reconstruction software

- To be made operational next year

B2 reconstructed phase-space distribution after 15 h in Stable Beams

23-11-2017
New Commissioning Software

Commissioning scripts were migrated from MATLAB to Python

• No MATLAB license needed
• PyJapc instead of JavaCoInterface
• Automatic backup/restore
• Improved data processing
• New algorithms added

Exhaustive testing being performed

• In the test stand
• 4-5th Dec. 2017 with RF ON
• Will be used next March!
Keep on migrating Labview panels to Inspector and adding diagnostics on power supplies, interlocks

Expert acquisition to come!
Accomplished & Planned

Improved in 2017

• Logging FESA class for high-resolution profiles *underway*
• FESA3 migration of BQM *scheduled for YETS*
• Beam spectrum logging: communication issues with instrument *resolved*
• LLRF recovery after power cut or power cycle: test in laboratory *foreseen*
• Logging for ObsBox data *operational*
• ADT instability triggering *operational*
• New commissioning scripts *being completed*

On the list for 2018

• FESA migration: 22/50 classes still to be migrated + all front-ends to 64-bit
• Expert acquisition interfaces
• Fixed display for high-resolution profiles
• Re-calibration of stable phase measurement
• Tomoscope
Studies with Implications on Operation

STUDIES
Instabilities at Injection (1)

Persistent injection oscillations & instabilities observed (MD2042)

- Amplitude much larger than seen on stable phase
- Survives the ramp & could impact the blow-up

20 min of oscillations ⇒ ~10 % bunch lengthening (IBS only 3 %) and ~5 % particle loss for < 2×10^{11} ppb!
Instabilities at Injection (2)

450 GeV, phase loop closed

BLonD simulations with LHC impedance model

Measured decay time: 300 s for $1.9 \times 10^{11}$ ppb, 1.7 ns (4 sigma) at injection
Simulated decay time: ~45 ms
The LHC RF system was working reliably and with high availability throughout 2017

- Full detuning operational and reliable
- Huge amount of work performed also in 2017 to
  Maintain the system
  Commission new tools
  Develop software for diagnostics and expert tools
- Beam studies show undamped injection oscillations
  Amplitude of oscillations larger than previously assumed
  Can lead to losses

Thanks to the entire team involved!

Thank you for your attention!