Operational and beam dynamics aspects of the RF system in 2015

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Outline

RF operation in 2015
• LS1 changes & recommissioning
• Operational parameters
• Operation with other beams
• New diagnostics
• LLRF & controls reliability (RF reliability in O. Brunner’s talk)

Beam dynamics aspects
• MDs in 2015
• Longitudinal beam stability
• Controlled emittance blow-up

Outlook for 2016
OPERATIONAL ASPECTS:

RF SYSTEM IN 2015
LS1 Changes

- Migration of LLRF CPUs to linux: went quite smoothly
- Migration to FESA3: was supposed to happen during LS1, but in the beginning of LS1 the framework was not yet ready to use
  Continued in coming YETS for part of the classes. Needs to be done latest by mid-LS2, but FESA2 support stops end of 2015
- SR4 works: air conditioning
- High-power RF: see Olivier’s talk

Recommissioning

- LHC reference for bucket 1 adjusted after SPS LLRF re-cabling
- RF noise level ~ 10 dB larger in B1 than in B2
  VCXO of B1 changed during last ion run, leading to a somewhat larger abort gap population in B1, but not posing an issue for operation
Studies during recommissioning

- Synchronisation loop step response measured
  Fits design & beam simulations

- Beam transfer function measured via step in RF phase

Phase error at 6.5 TeV

Phase error with 10° step at 450 GeV

Synchronisation error at 6.5 TeV

Beam profile before and after step at 450 GeV
Operational parameters in 2015

Operational voltage was 10 MV at 6.5 TeV (2012: 10 -> 12 MV)

- Choice combining bunch length requirements & power limitations
- Preparations for 300 kW klystron power (see talk by O. Brunner)

Beam-loading compensation using half-detuning scheme

- Tuning algorithms works as expected
  Adjustment becomes critical as power grows quickly with detuning

Increased target bunch length to 1.35 ns for the blow-up

- Letting the bunches shrink on flat top
- In long fills, can reach the limit of stability, but worked fine with $1.15 \times 10^{11}$ ppb with up to 2244 bunches
Power transients with a full machine (2244 bunches, fill 4565, 2nd November)

Half-detuning (1)
Half-detuning (2)

Demanded RF power \( P = \frac{1}{8} V \times I_{\text{peak,RF}} \)

- With 1.25 MV/cavity, we are operating at the limit of the present system with up to \( P = 210 \text{ kW} \) (peaks up to 250 kW)
- By commissioning to 300 kW, can gain another 20% \( (P = 250 \text{ kW}) \)

Present operating point assuming different bunch distributions
Operation with other beams

Operation with doublets
- Need 1 single nominal to adjust injection and stable phases
- Otherwise unproblematic

Operation with ions
- Capture and acceleration unproblematic
- Different proton/ion settings for beam phase acquisition due to different intensity
Settings to be added to LSA

First injection of ions in bucket 1, B2
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 timber

- Now a fixed display is available

Frequent problems with interface to spectrum analyser, to be made more robust. Source of problems under investigation
Diagnostics (2)

Improved peak-detected Schottky spectra
  • Faster rise time for better resolution of bunch centre
    Available only for one beam; further modules needed

Observation Box extensively used for longitudinal observation (see also talk by T. Levens)
  • Used during scrubbing run & MDs
  • Stable phase acquisition for e-cloud monitoring: fixed display available, but no logging yet
    Logging is expert only at the moment; logging FESA class to be written

Beam profile screens in CCC (using 1 GHz scopes in SR4)
  • New hardware for streaming to make it more robust
  • Software upgrade planned for next year
ObsBox beam phase display

ObsBox Phase Display - LHC.USER.ALL - (INCA)

Beam 1 phase [06/10/15 17:12:08]

Beam 2 Phase [06/10/15 17:12:08]

History Beam 1 phase [06/10/13 17:12:03]

History Beam 2 Phase [06/10/15 17:12:08]

No Exception to display...

15:02:52 - connection to ctc:src4-siloastb1:4645 is connected to ctc:src4-siloastb1:4645/1
LLRF & controls reliability

- Few false alarms from RF frequency interlock
  Single spike filtering of beam energy signal and diagnostics implemented; if recurrent, data to be analysed

- Some electronics failures: (i) a Clock Generation module during recovery from TS2, (ii) a Tuner module (DSP core voltage failure), (iii) a 5V power supply on the Tuner crate
  First electronics failure since LHC start-up in 2008. More spares needed to keep system operational. High-priority effort needed!

- Long recovery time after power cut on VME crates in the Faraday cage; recovery took > 6 hours in one case
  Unresolved problem with reloading persistent data requiring software improvement, presently under investigation

- Spurious dump due to PLC receiving an RF off command
  Source of command unidentified, occurred only once
BEAM DYNAMICS ASPECTS:

BEAM STUDIES IN 2015
MDs – Longitudinal beam stability

- Successful identification of single-bunch stability threshold
- First attempts of measuring the coupled-bunch threshold

Studies to be continued

Single-bunch threshold based on several measurements
MDs – Shaping the bunch profile

- Uses single-frequency sinusoidal RF phase modulation targeting the core of the bunch
- Bunch flattening is an optional tool for heat load reduction, beam stabilisation in physics, and pile-up density reduction

Well-tested & ready to use, but application expert only at the moment

Measured on 28th October 2015 at the end of a physics fill
Controlled emittance blow-up

Theoretical & simulation studies during LS1
  • To better understand the relation of noise spectrum and resulting profile in the presence of acceleration and feedback loops
    Single-bunch effects well understood, but multi-bunch to be studied

Optimisation of noise spectrum during commissioning
  • Shaping noise spectrum to counteract the beam phase loop action
    Noise shape depends on bunch profile

Bifurcation of bunch lengths in multi-bunch case
  • Observed in MD when the initial spread in bunch length is large
    In operation we’re close to the limit
    Effect not yet understood (e.g. how much contribution from intensity effects?), simulation studies needed

Tests to optimise off-momentum loss maps with blow-up
  • To minimise the number of ramps. Gain at flat top is marginal
Longitudinal beam stability (1)

Longitudinal emittance damping time due to synchrotron radiation at 6.5 TeV: 16.2 h

- Observations confirm that emittance growth time due to RF noise & IBS is much slower

Single bunches (nominals) at 6.5 TeV, 26\textsuperscript{th} May

Rough estimate of bunch length shrinkage
- Observed: 58 ps (B1), 53 ps (B2) in 2 h
- Predicted by SR*: 73 ps (B1), 72 ps (B2)

(*) scaled from emittance

N.B. round bunches at arrival to flat top, becoming Gaussian gradually; a proper estimate requires particle simulations!
Longitudinal beam stability (2)

At the end of long physics fills, Landau damping was lost

- With 2015 end-of-fill beam parameters, coupled-bunch instability not observed, only single bunch instability

Bunch flattening can be used as a mitigation if needed

Loss of Landau damping in the longest fill of the year.

Single-bunch threshold obtained in MDs.
Commission klystrons to a power of 300 kW (see O. Brunner’s talk)

Continued studies on

• Voltage phase modulation (full-detuning) scheme
  Top priority to demonstrate its feasibility in case intensity is increased already in Run3; to be detailed by P. Baudrenghien in Chamonix 2016

• Coupled-bunch instability threshold due to
  • full machine impedance
  • cavity impedance at fundamental component (HL-LHC study)

• Controlled longitudinal emittance blow-up to understand multi-bunch effects (bifurcation of bunch lengths)

Controls development

• Continue migration from Fesa2 to Fesa3
• Consolidate longitudinal diagnostics tools & make them user-friendly
References

• **Half-detuning scheme**

• **Longitudinal beam stability**
  J. F. Esteban Müller et al., *Beam measurements of the LHC impedance and validation of the impedance model*, IPAC 2014.

• **Bunch flattening using sinusoidal modulation**
  E. Shaposhnikova et al., *Flat bunches in the LHC*, IPAC 2014.

• **Controlled longitudinal emittance blow-up**
  H. Timko et al., *Studies on controlled RF noise for the LHC*, HB 2014.

• **Synchrotron radiation damping & IBS**
  F. Antoniou et al., *Building a luminosity model for the LHC and HL-LHC*, IPAC 2015.

Thank you!