Plans & commissioning for the PLL-based LHC tune tracking system

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Topics

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Tune & Chromaticity requirements

Tolerances on the beam parameters

[BI Specification Team LHC-BSRL-ES-0001]

- dQ =< (Qx-Qy)/10 ⇒ .003 at injection
  .001 in collision
- dQ′ =< ±1 at injection (transverse stability)
  ± 3 at 7 TeV (contribution to tune spread)

Expected time scales for variations (worst cases)

[BI Specification Team LHC-BSRL-ES-0001]

- Snap-back: dQ <= 0.0008 per second over up to 60 seconds
  dQ′<= 2.7 per second over up to 60 seconds

Feedback *probably* required on both tune and chromaticity (see *Day N*).

Tune Measurement

Methods for feed-forward:

Beam excitation	Comments
Single kick	Uses pulsed kicker magnet. Damped oscillation from initial large amplitude Precision depends on damping time
Random noise kicks	Injected into transverse feedback loop. Useful for broad-band spectral analysis. Precision 10^{-3} - 10^{-4}
Sine wave frequency sweep ("chirp")	Synchronous detection of beam motion ⇒ full beam transfer function (amplitude and phase). Precision typically 10^{-4}, limited by beam stability and measurement time.
Sine wave at fractional tune frequency	PLL keeps exciter on tune (at low amplitude) Best for tracking tune changes. Precision ~ 10^{-5}, for PLL BW 1-10 Hz
Sine wave at frequency outside tune spread	So-called "AC-dipole" method. Excitation ramped up and down adiabatically. "No" emittance blowup.

Physics beam measurements more delicate:

- limited BDI ε blowup budget (~2%)
- active transverse damping (t_d ~ 50 turns)

Chromaticity measurements

1. Tune difference for different beam momenta.	Used at HERA, LEP & RHIC in combination with PLL tune tracking.
2. Width of tune peak or damping time.	Model-dependent, non linear effects. Used at DESY.
3. Amplitude ratio of synchrotron sidebands.	Difficult to exploit in hadron machines with low synchrotron tune.
4. Excitation of energy oscillations & PLL tune tracking.	First promising steps at SPS.
5. Bunch spectrum variations during betatron oscillations.	Difficult to measure.
6. Head-tail phase advance (same as 5 but in time domain).	Very good results. Requires kick stimulus $\rightarrow \varepsilon$ growth.

Commissioning – Day 1

Beam: 1 pilot ($5 \cdot 10^9$ p/bunch).

Excitation: single kick.

Detector:

- **BPM**: 500 button monitors/ring, both transverse planes
  - FFTs gives good tune accuracy.
  - Phase information ➔ integer part of Q.
  - BUT, 1 bit ~ 20 μm ➔ will need ~mm kicks (➔ ε blowup).
- **Tune couplers**: 15mm stripline couplers
  - more sensitive than 500 BPMs for sub-mm oscillations (but still ε blowup).

Q' : - from FFT measurement with different Δp *or*

- from head-tail monitor after kick.

Commissioning – Day 1 + 1

Beam: several bunches ($5 \cdot 10^9$ … $5 \cdot 10^{10}$ p/bunch)

Excitation: turn-by-turn kicks

- small stripline coupler;
- transverse feedback kicker.

Detector: as before + **Resonant BPM.**

- Sensitive to small beam excitations ➔ little ε blowup
- Can be used as part of a PLL system & for feedback.

PLL tune-tracking without tune feedback.

i.e. feedforward of "tune history" to next ramp, squeeze…

Q' : from Δp modulation
- a) below $q_S/5$
- b) above $5q_S$

Commissioning – Day N

Beam: ~ 3000 bunches up to 10 $\cdot 10^{11}$ p/bunch.

Excitation: as *Day 1+1* but bunch excitation compatible with transverse resistive damping.

Detector: as before.

Decision on feedback when machine reproducibility & *real* machine parameters are known.