Software Interlock System

J. Wenninger

SIS team: L. Pereira , L. Ponce, J. Wenninger, J. Wozniak (LP^2 + JW^2)

SIS Overview

- SIS @ LHC used for:
  - Injection interlocking.
  - Circulating beam interlocking (→ dump).
  - Powering & access interlocking – not for today.
  - Beta* reconstruction and publication (via MTG) – not for today.
- To perform its job @ LHC:
  - **SIS has subscriptions to 2409 control system devices / parameters.**
  - **SIS exports signals to:**
    - BICs (8 signals) update period 2 s BIC timeout 20 s
    - MTG (2 signals) update period of 4 s
    - PICs (36 signals) update period of 2 s

SIS Overview

- Interlock types:
  - *Initially*: used simple test logic comparison of acquired value to reference value (number or boolean) – hardcoded into configuration.
  - *Now*: more and more complicated interlocks (JAVA) that pull together multiple signals and DB references. Very flexible, but complex interlocks are tricky to test !
- For the moment all interlocks are maskable except:
  - XPOC
  - BIC pre-operational checks
  - LHCf injection inhibit.
- Masking:
  - Independent of SBF.
  - Allowed for all holders of RBAC roles : LHC-EIC, MCS-SIS

SIS Availability

- LHC SIS runs on dedicated HP server in the CCR.
  - The server is equipped with a timing card (CTRI).

- The SIS processes of SPS and LHC have never failed during operation in the last 2 years.
  - Server crashes were however observed in the 2009-10 shutdown. This was traced to a timing library (concurrency) and fixed.
  - In case of failure the timeouts on the SIS inputs to the BICs lead to beam dump/injection or extraction inhibit.

SIS Injection Interlocks

Test	Coverage	Status	Comments
PC states	All PCs	Operational	
PC currents	RB, RQ, RD, MCBX	Operational	Extend to IPQ?
QPS_OK	All circuits with QPS	Operational	
RF	Synchronization Cryo maintain	Operational	A few interlocks on fRF to come
BTV position	Ring and dump line BTVs	Operational	Dump BTV not tested with intensity (more int. needed)
Injection bucket	Abort gap and over-injection protection	Operational	Some issues with BQM reliability
Injection mode		Operational	Avoid injecting with wrong mode
Energy		Operational	
(Pre)-op checks	XPOC, PM, IQC, BIC	Operational	
LHCf		Operational	via DIP
Triplet alignment	WPS in all IRs	Operational	

Injection summary

- Large number of interlocks (> 3000!):
  - Very high reliability given the number of signals.
  - Loosing one injection is not too dramatic – can afford to be tough, but must avoid too many false decision (credibility !).
  - A few more interlocks to come…
  - Availability issues:
    - BQM – issue with the crate for beam1.
    - LHCf in 2009 – ‘solved’.

SIS Circulating Beam Interlocks

Test	Coverage	Status	Comments
SMP energy	All RBs, SMP energy	Operational	0.2% to 1%, relax with faster ramp?
SMP energy distribution	All BLM crates	Operational	Verify energy across all BLM crates
BETS	Q4 and MSD in IR6	Masked	**Ready to go**
TCDQ – beam	Beam center in TCSG TCSG gap TCDQ-TCSG retraction	Operational Masked Masked	Achievable tolerances depend on orbit stability
COD integral	All arc Hor. CODs	Operational	dp/p < 0.2%
Orbit	All ring BPMs	Operational	Achievable tolerances depend on orbit stability
COD settings	All CODs	Operational in stable beams	Achievable tolerances depend on reproducibility and variation in ramp & squeeze
COD trips	60 A CODs (not in PIC)	Masked	Dump if COD(s) trips and missing kick > threshold. **NEW.**

Orbit and COD interlocking

- Principle:
  - Limit global orbit excursions.
  - Catch un-detected orbit bumps (via COD settings).
  - Interlocks settings per COD/monitor:
    - Reference, tolerance, enable flag.

- Tolerances are a balance between safety, availability and interlock complexity.
  - So far the tolerance settings were limited by beam excursion in ramp and squeeze. Much better now with OFB.
  - Ramp and squeeze cleanup will also allow for tigh(er) COD interlocks.

Orbit interlocking

- Enforce overall orbit envelope. Present settings:
  - Per plane and beam accept max of 10 BPMs out of tolerance.
  - Faulty BPMs are ignored.
  - Tolerances (wrt ref) stable beams : ± 2.5 mm IR1,2,5,8, ± 2 mm elsewhere
  - Tolerances (wrt ref) other modes : ± 6 IR1,2,5,8, ± 3-3.5 mm elsewhere

    - larger tolerance in IRs to cover separation ON/OFF phases.

    >> Provides de facto an energy offset interlock of 0.1-0.2 %.
- Tolerances can now be significantly tightened with OFB.
  - Could reduce tolerances to around ±1 mm (at least in arcs + IR 3,4,6, & 7), maybe even less for stable beams.

    - Could be a problem at injection (before orbit corrected). Deactivate automatically if intensity < 5E10 & injection energy?

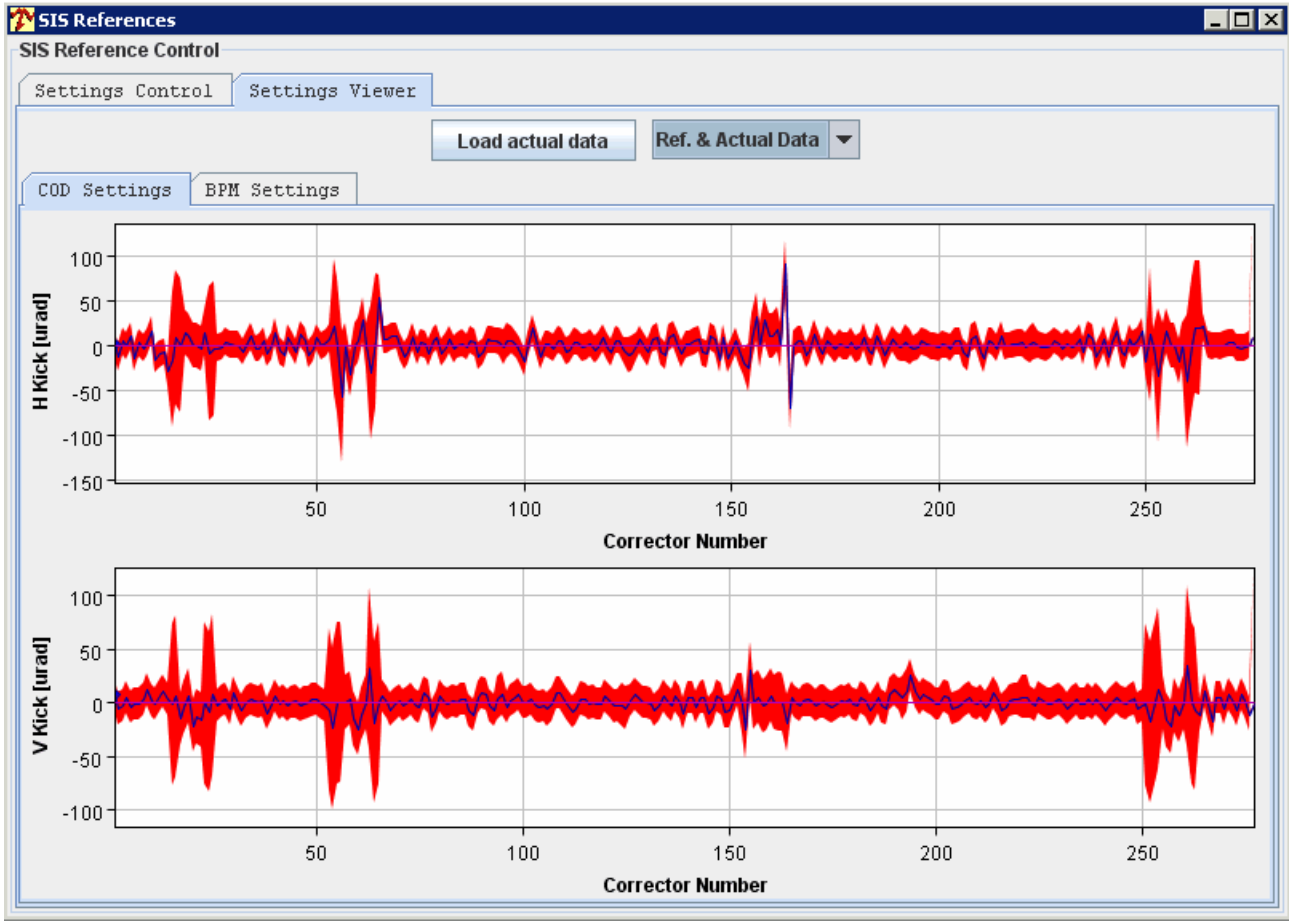
COD settings

- Aim is to catch bump-like structure that are only visible on few BPMs.
  - Simple logic: trigger when 2 kicks are out of tolerance (pi-bump like, but also for 'larger' bumps).
  - Could be made more intelligent – but would involve more complex dependence (optics…).
  - Settings stable beams : $\pm$ 50 μrad IR1,2,5,8 (sep. scans), $\pm$ 25 μrad elsewhere

    probably possible to reduce with OFB (not IR1,2,5 and 8).
  - Settings other modes : to be defined. One value + tolerances per COD to cover ramp and squeeze.
- Complex changes of COD settings in ramp and squeeze:
  - Need SW to analyze changes and define tolerances around required operational margin (in preparation…). But this also needs a number of ramps in regular operation to define reliable limits.

Orbit interlocking in steering

- Display of orbit and COD interlock settings together with actual data, and handling of settings in the steering application.



TCDQ orbit interlocking

- Ensures beam centered in TCSG (←→ offset wrt TCDQ):
  - Present setting : tolerance of ± 2 mm (independent of E).
  - Limited so far by:
    - Orbit changes in ramp & squeeze >> solved now by OFB.
    - Intensity dependence (BPMSB – the worst guys !).
    - Collimator gap consistency (injection → stable beams).
- Very efficient – triggered already a few times – no false decision.
- With OFB active, the interlock windows can be reduced – exact values to be confirmed.
  - Tolerance: ± 1 mm is in reach (1.5 sigma @ 3.5 TeV).

COD trips

- 60 A arc CODs are not interlocked by PIC.
  - Presently a PC trip does not lead to a beam dump (only injection inhibit via SIS !).
- New interlock in SIS to catch 60 A trips:
  - Monitor all 60 A states and detect any PC failure.
  - Dump beam if the total kick of failing PC(s) exceeds a threshold (so far 10 μrad).
  - Tested at 450 GeV and ready to go…

Settings management

- Settings for orbit, COD and TCDQ interlocks are ‘virtual’ critical devices in LSA – digitally signed (role LHC-MCS-SIS).
  - Requires regular updates to follow evolution of the machine.
  - This will hopefully become more stable soon….
  - So far I manage all the settings – need some people to back me up !

Running faster?

- SIS evaluates its checks every 2 seconds.
  - Server CPU load ~ 20-30%
- Main clients provide data at 1 Hz or less.
  - Orbit at 1 Hz.
  - PC states and currents at 0.5 Hz.

>> Could move to 1 s period – but gain is probably marginal.

Safety…

- Protection of the subscription UI.
  - Avoid accidental stopping of data subscription – mostly availability, but also safety when there are timeouts.
- Masking.
  - So far masking rights apply to all signals. Could consider making masking role-dependent.
  - Could consider making masks of selected interlocks SBF dependent.

    - not clear how much work this implies.

Summary

- SIS is a reliable solution for quite a class of interlocks:
  - Injection interlocks (reliability less critical).
  - (Complex) interlocks involving multiple systems.
  - Interlocks for distributed systems like orbit.
  - Quick solutions for un-expected situations.
- It is all software:
  - Reaction time limited to around 1 second.
  - Safety will never be SIL3… even if it is better than what I would have expected some years ago.
- Interlocks on orbit and CODs:
  - Quite powerful – but require constant checking to follow evolution of the machine.
  - One can do better – but watch out for the settings nightmare !