LHC Orbit Feedback Control

Summary of control strategies

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Details are available on :
http://proj-lhcfeedback.web.cern.ch/proj-lhcfeedback/workshop/workshop.htm

Requirements

- Orbit must be stabilised within
  - globally:
    - global r.m.s. — < 0.5 mm
      (smooth operation during e.g. ramp)
    - preserving 'scrubbing' performance — < 0.2 mm
      (electron cloud reduction)
  - locally:
    - centering the beam at the dampers — < 200 μm
    - collimators (IR 3 & 7) — < 70 μm
      (cleaning efficiency is depends on the beam position)
    - pre-alignment for the luminosity feedback — < 70 μm
    - (preserving dynamic range of its ADC)
    - TOTEM experiment — < 10 μm
      (tough! possible compromises? to be verified.)

Expected Sources for Orbit Movements

- External sources:
  - Ground motion
    (only random ground motion contributes to orbit movements)
  - to be identified other sources

  -> expected drift velocities smaller than < 10 μm/s

- Machine inherent sources:
  - Decay and Snapback of the dipole field of the main-bends during injection
  - Change of machine optics – Squeeze
  - persistent currents in the vacuum chambers
  - COD Power-Converter and Magnet failures
  - Other dynamic effects (e.g. during ramp, beam-beam)

  -> largest contribution, perturbations up to 20 mm
  (however, they are to a certain extend predictable)

Feedback Architecture

Local

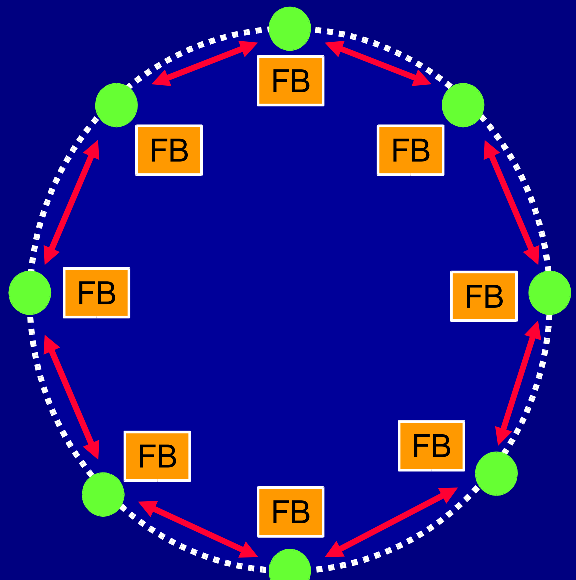
reduced # of network packets/s.
faster computation.
…

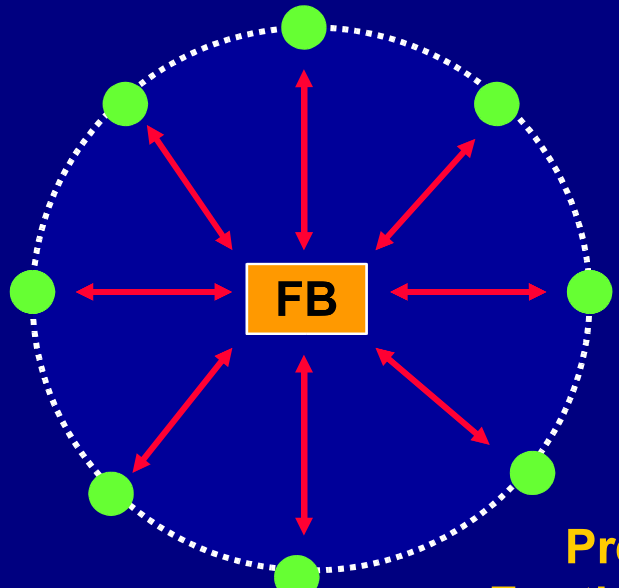
- × less flexibility
- × not ideal for global corrections.
- × coupling between loops
- × problem with boundary areas to ensure closure.
- × ...

Central

entire information available.
all options possible.
can be easily configured and adapted.
…

- × network implementation more critical : delays, packet collecting, synchronization
- × …





Preferred !!
For the moment…

equipment: Beam Position Monitors (BPMs)

- BPMs: ~1100, over the two rings distributed
  (controlled by approximately 80 front-end crates)
  - Each measure horizontal and vertical position
    - Redundancy (to a certain extend), sampling at high and low β
    - Measurement precision: 200 μm/shot
      -> closed orbit (255 turns) ~5 μm
    - possible (tested) sampling rates up to 100 Hz
  - data rates:
    - short bursts of data
    - full orbit acquisition (80 packets) ~ 32 kbytes / sample
    - e.g. 25 Hz sampling: ~ 780 kbytes / s
      ~ 6 % of 100 Mbit/s
      < 0.3 % of 2 Gbit/s
    - delay due to bandwidth at controller front-end: ~ 1 ms / sample
  - Additional function: 100k turn measurement creates ~16 Mbyte / crate
    - increasingly requested during snapback, ramp and squeeze when 'blackouts' are especially awkward for the feedback
    - possible interference with RT orbit acquisition

equipment: orbit correction dipoles (CODs)

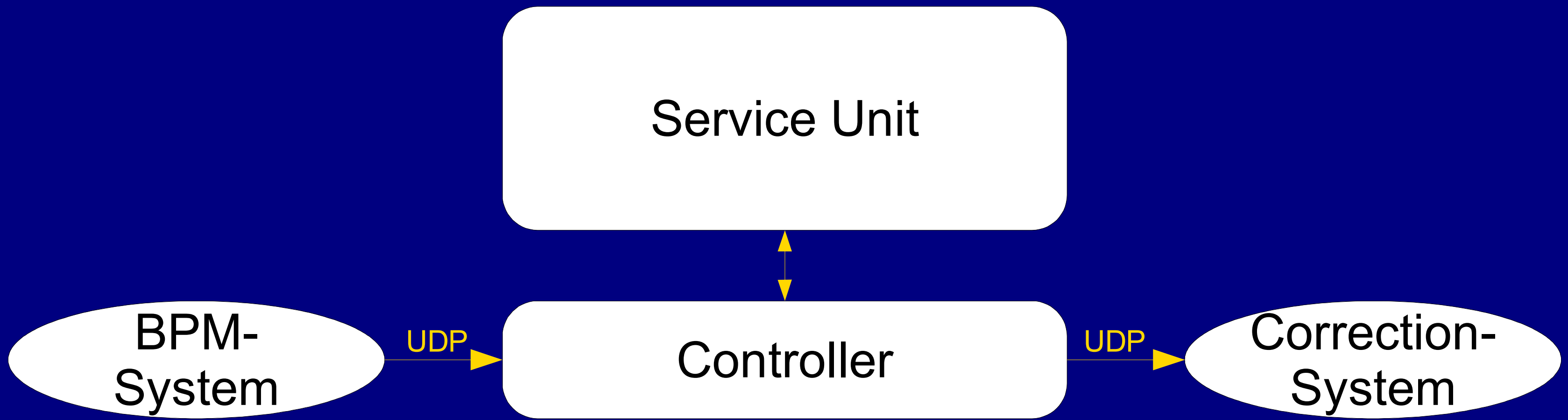
- Both rings (H&V) are equipped with about ~600 individually powered CODs
(controlled by approximately 40 front-end crates)
  - natural time constants of magnets:
    - cold magnets (most) 200 s
    - warm magnets (only a few) 10 s
  - Power converter steers with effective bandwidth f_b of ~ 1 Hz

-> the PC can generate (compensate) orbit oscillations (at high β)
~13 μm @ 1 Hz

  - PC are connected through WorldFIP bus with crate
    - access rate is limited to f_s=50 Hz
    - determines max. feedback frequency!
-> sufficient for (even optimal use of CODs) in a digital feedback loop ($f_s > 20\text{-}30 \times f_b$)

Feedback Controller

Splitting the controller into a Controller and a Service unit:



Controller:

- collecting of the BPM data
- comparison of the measured orbit with a reference
- Correction in space: calculation of new steady state deflection
- Correction in time: selected control algorithm (PID, Smith-Predictor)
- Conversion of the deflections angles into currents
- Send the new settings to PC gateways

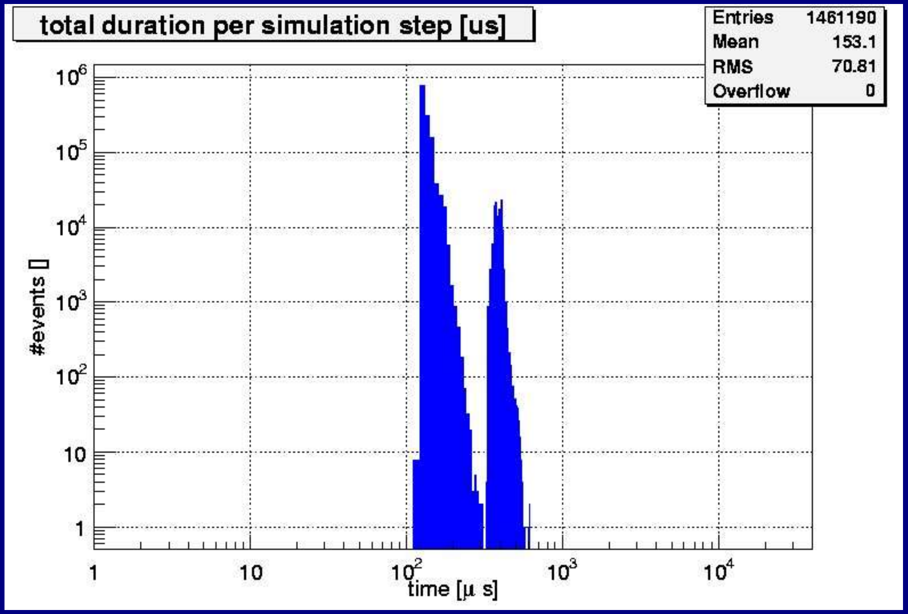
Feedback Controller

- Service unit:
  - Continuous verification of the data quality (sanity checks) and of the state of COD PCs (cross-check between numerical stored and actual current)
  - detection of BPM and COD faults
  - Monitoring of machine states (energy, optics, mode [injection, ramp, squeeze,..]) to trigger
  - Update of the orbit response matrices and quantities derived from it (SVD decomposition…) whenever the relevant machine or equipment conditions are modified.
  - Interface to machine operation and experts.
  - Interface to LHC controls and other users
  - Data monitoring (logging).

- Advantages:
- The controller and service units essentially differ by their criticality. While during most machine phases, a temporary unavailability of the service unit will not stop the feedback, the loop stops immediately when the controller is no longer operational.
- The segmentation of the orbit feedback controller gives the possibility to change the implementation of the controller while avoiding the necessity of changing the Service module as well, in case the performance, reliability etc. must be improved.

SPS/LHC Testbed

- A testbed that simulates the open loop and orbit response consisting of COD->BEAM->BPM was developed. It implements the same data delivery mechanism/infrastructure as the BPM and COD front-ends.
- The testbed runs up to 1 kHz for a full SPS resp. 50 Hz for a full LHC orbit simulation which is sufficient for a precise simulation of the plants that have bandwidths of ~14Hz (SPS) and ~1 Hz (LHC) and closed orbit movements in the machines.
- three dedicated machines for (Controller, Service Unit and Testbed
  - present and future feedback controller can be tested and validated without beam and running machine
  - controller be tested under LHC similar conditions.
  - Decay/Snapback, GM simulations
  - Simulation of failure scenarios and environmental influences
  - ...



Issues to be solved I

- Network: 4 QoS queues:
  - Presently two queues are used: 1:Net-Ops 2: General Purpose (all share the same bandwidth)
  - Open another QoS for real-time control
    - what other services (Orbit FB, LHC alarm system, Luminosity feedback, Voice over IP?.....) will be in that queue, can be tolerated?
    - experimental verification of worst case latencies

- Front-ends:
  - Minimizing the interference of real-time data channel with the low-priority big data chunks
    -> packet scheduling on all involved FE (preferred: OS-based)
  - scaling issues (non linear delays)
  - improvement of delays: length but more important their determinism
  - Delay fingerprints in order to be able to compensate it with the Smith-Predictor
  - understanding systematic BPM effects

    (drift due to changing intensity, bunch length....)

Issues to be solved II

- Front-ends:
  - further cross-checks of the Testbed simulation with real-machine measurements (test scenarios)
  - Possible “fill-to-fill feed-forward” (very slow orbit feedback) implementation
    - “back-up” in case the feedback drops out or is switched off
    - Feedback controller must be aware of absolute current in the PC in order to (due to rate limiter) do consistent corrections!

    -> cross checks with the PC gateway at low frequency (1 Hz or less) in case it's changed by other processes.
  - Choice of final implementation:
    - hard: DSP/ FPGA based solution (if delay will matter)
    - Soft: which real-time operating system (LynxOS, Linux (2.6), RT-Linux) test to be continued...
  - other requests...