Commissioning of SOLEIL Fast Orbit Feedback System

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Summary

• SOLEIL characteristics
• Fast Orbit Feedback principle
  – Beam Position Monitors
  – Correctors
• Architecture
  – Algorithm computation
  – Data Distribution
  – Power-supplies control
• Data Processing
• First results
  – Commissioning
  – FOFB efficiency
  – Future improvements
• Conclusion
SOLEIL Main Characteristics

- Storage Ring circumference: 354 m
- Energy: 2.75 Gev
- Nominal current: 500 mA (fall 2008, presently 300 mA)
- 3rd generation => 29 % of circumference for Insertion devices
- Extended photon spectral range:
  - From UV (5 eV) up to hard X-rays (30 keV)

- First beam in 2006
- 14 beam lines take beam
- +12 beam lines under construction
- 800 A.h integrated current (today)
Beam Stability

- Great care has been taken in the design of the machine to improve its stability:
  - Long term (year):
    - Foundations:
      - Slab of the ring and experimental hall on ~600 15 meters long piles
  - Medium term (24 hours):
    - Temperature is regulated:
      - Experimental hall: $21^\circ\text{C} \pm 1^\circ\text{C}$
      - Storage ring (air and water cooling): $21^\circ\text{C} \pm 0.1^\circ\text{C}$
    - BPMs blocks are bolted to girders and mechanically isolated (bellows)
    - A Slow Orbit Feedback System (since May 07)
      - Correction rate 0.1 Hz
    - Top-up (end 2008)
  - Short term:
    - Girder design (lowest ringing frequency: 46 Hz)
    - Fast Orbit Feedback System
Fast Orbit Feedback Principle

• Purpose of the system
  – Stabilizing the beam position in the high frequencies (>0.1 Hz)

• Perturbation sources in this frequency range:
  – Ground vibrations (girder modes)
  – Mains frequency (50 Hz)
  – Overhead cranes of the Experimental Hall
  – Insertion devices (transitions of the feedforward correction during gap changes)

=> Fast orbit feedback system should have its cut-off frequency above 150 Hz
Fast Orbit Feedback Principle: Beam Position Monitors

- BPM blocks:
  - 120 units
    - 48 on the straight sections
    - 72 in the arcs

- BPM electronics:
  - 120 “LIBERA” modules
    - Developed by Instrumentation Technologies and SOLEIL
    - Subsequently used and improved by most storage ring in the world
    - Based on an FPGA
    - Data stream for the Fast Orbit Feedback:
      - Frequency rate: 10 kHz
      - Resolution in 100 Hz BW: 200 nm
Fast Orbit Feedback Principle: Correctors

• Choice of the correctors:
  – 56 Slow correctors for slow orbit feedback are located inside the sextupoles.
  – Vacuum chambers are in Aluminum for low vacuum chamber impedance with NEG coating
  – Eddy currents in Al prevents high frequency corrections

=> Necessity to have different correctors for the Fast Orbit Feedback

  – Air-coil correctors
  – Over stainless steel bellows
  – Located on each side of the 24 straight sections
    => 48 units
  – 20 µrad maximum strength
  – Cut-off frequency: 2.5 kHz
FOFB Architecture

- The most demanding part for computing resources is a matrix multiplication
  - Inversed response matrix (SVD computation is done offline)
  - Difference between current orbit and golden orbit

- Matrix multiplication is split and distributed:
  - Processing of one line of the matrix is done in one Libera FPGA
  
  \[ \text{Inversed response matrix (SVD)} \times \begin{pmatrix} \Delta X_i \\ \Delta Y_i \end{pmatrix} \]

  => 48 Liberas (out of 120) are calculating correction data for FOFB
FOFB Architecture

- An ‘all embedded’ solution
  - All the processing of the FOFB is done in the LIBERA FPGA, on top of the position calculation provided by Instrumentation Technologies
  - Different interfaces for data exchanges are built in the LIBERA.

![FOFB Architecture Diagram](image)

- RS485
- Ethernet
- Rocket I/O

To corrector power supplies
Configuration and monitoring
Position Data from 119 other BPMs
FOFB Architecture: Fast Dedicated Network (10 kHz)

- **Global Feedback:**
  - All position data have to be delivered to all BPM modules
FOFB Architecture: Power Supply Control

Overall latency ~360 µs
FOFB Architecture:

4 power supplies
=> 2 correctors

RS 485 links

Copper links

Optic fibers
Data Processing

Beam Position Monitor application
(provided by Instrumentation Technologies)

Communication Controller: designed by Diamond Light Source
Initial Design of the Fast Orbit Feedback for Diamond Light Source, ICALEPS 2005
FOFB Commissioning

• Schedule:
  – October 2007: Data distribution is operational
  – December 2007: Feedback loop is closed
  – January -> July 2008: Optimization of the system
  – September 2008: FOFB to be available for operation

• 2 configurations tested:
  – 48 BPMs and 48 correctors
  – 120 BPMs and 48 correctors

• FOFB is efficient from DC to ~100 Hz (cut-off frequency:~400 Hz)

• System efficiency:
  – The frequency range where the FOFB has an influence can be divided in 3 area:
    • 1 Hz to 350 Hz : Ground vibrations, mains,…
    • 0.01 Hz to 1 Hz : Insertion devices, crane
    • DC to 0.01 Hz : Drifts (thermal effects)
FOFB Efficiency (1-350 Hz)

HORIZONTAL

Measurement on a BPM outside the feedback loop

VERTICAL

Noise Spectrum in horizontal plane

Noise spectrum in vertical plane

Integrated noise horizontal plane

Integrated noise vertical plane
FOFB Efficiency (0.01 Hz – 1 Hz)
Effect on the perturbations caused by the insertion devices
(vertical position at source points )
FOFB efficiency (DC to 0.01 Hz): slow drifts (thermal effects)

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<th>UV</th>
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FOFB efficiency and future improvements

- High frequencies: 1-350 Hz
  - FOFB efficiency is already OK, but could be improved around 50 Hz (number of eigen values optimization)
  - Not much noise added (mainly around 200 Hz)

- Low frequencies: 0.01-1 Hz
  - Very good efficiency
  - Perturbations caused by insertion devices transitions or cranes movements are strongly suppressed

- Drifts: DC to 0.01 Hz
  - FOFB can correct the drifts for ~8 hours, before its correctors reach the saturation
  - Seems OK, even if it is not as efficient as the Slow Orbit Feedback System
Conclusion

• Low cost system
  – Using computing resources of FPGA BPM system

• Global orbit correction
  – Distribution of all BPM data around the ring with a dedicated network

• Air-coil correctors over stainless steel bellows with high cut off frequency

• Flexible
  – Easy change of correction algorithm

• First results are very promising
  – System should be available for user operation in the coming months
Acknowledgements

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