Global Position Feedback in SR Sources

Volker Schlott, PSI

- Stability Requirements
- Noise Sources
- Feedback Scheme
- Feedback Key Components
- Feedback Implementations
- Conclusions
Stability Requirements I

**General statement of users:**

Source fluctuations should be one order of magnitude below the resolution and detectivity of experimental stations.

**Experiments have achieved:**

- photon energy resolution of $10^{-4}$ to $10^{-5}$
- detectivity resp. S/N-ratios on the sample of $10^{-3}$ to $10^{-4}$

This translates into requirements for:

**Angular Stability:**
(assuming planar crystal monochromator)

Bragg’s law:

$$\frac{\Delta E_{ph}}{E_{ph}} = \frac{\Delta \Theta}{\Theta_B}$$

with Bragg angle $\Theta_B \sim 5^\circ$ - $45^\circ$

(90 - 800 mrad)

$$\Delta \Theta_{beam} < 1 \mu \text{rad}$$

**Position Stability:**
(assuming gaussian beamshapes)

$$\Delta x_{beam}, \Delta y_{beam} < \frac{\sigma}{10}$$

for low $\varepsilon$ and low beta machines: $< 1 \mu \text{m}$

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**Stability Requirements II**

**Typical integration times of experiments**

- > 100 s ……. e.g.: inelastic x-ray scattering
- 0.1 s - 100 s … e.g.: protein crystallography (PX)
  μ-tomography (CMT)
- < 0.1 s ……… e.g.: time resolved EXAFS (QEXAFS)
  time resolved x-ray diffraction (XRD)
  dichroism spectroscopy

**Experiment integration time >> orbit fluctuations:**

Beam motions *do not* cause noise,
but experiments observe “blow-up”
of effective emittance $\varepsilon_{\text{eff}}$ and a
 corresponding reduction of flux.

**Experiment integration time ~ orbit fluctuations:**

Beam motions *add* directly noise
to experiment.

**Experiment integration time << orbit fluctuations:**

Poor reproducibility of photon beam position.
(Dynamic) re-alignment of storage ring
components or experimental apparatus
may represent a cure.
Noise Sources at SR Facilities I

Long term motions (weeks - years)

- ground settlements (> 1 mm)
- seasonal ground motions (< 1 mm)

Medium term motions (minutes - days)

- filling pattern and machine refills (< 500 μm)
- diurnal temperature (< 100 μm)
- crane motion (< 100 μm)
- gravitational earth tides (< 50 μm)
- RF drifts (< 10 μm)

Short term motions (millisecond - seconds)

- ID gap changes (< 100 μm)
- ID polarization switching (< 100 μm)
- ground vibrations, traffic… (< 10 μm)
- cooling water (< 10 μm)
- injector operation (< 10 μm)

High frequency motions (sub-milliseconds)

- single and multi-bunch instabilities (< 100 μm)
- synchrotron oscillations (< 100 μm)
- pulse power sources (< 10 μm)
Long term beam motions can be reduced by...
- Frequent (dynamic) re-alignment campaigns
- Temperature and beam current stabilization

Medium and short term beam motions can be reduced by...
- Careful mechanical and electrical engineering
- “Top-up” operation of storage ring
- Global and/or local position feedback systems

High frequency beam motions can be reduced by...
- Multi-bunch feedback systems
- 3rd harmonic cavities
**Global Position Feedback in SR Sources**

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**Global Position Feedback Architecture**

- **Digital Part**
  - PID Controller
  - Correction Algorithm
  - Data Acquisition

- **Analog Part**
  - Power Supply
  - Correctors, Vac. Chamber

**Golden Orbit** & **BPM Noise**

\[ \Theta_d + \delta \Theta = R^{-1} \cdot (u_d + \delta u) \]

- **M rf and/or photon-BPMs measure orbit motions** \( u_d + \delta u \)
  - Filtering of rf-signals prevents aliasing of higher frequencies into the digital part of the loop
  - Analog and digital noise is introduced through BPM electronics

- **Dedicated network transfers data to processing station(s)**

- **PID-controller regulates feedback loop performance**
  - P-gain: provides efficient step response
  - I-gain: provides effective suppression of low frequency noise
  - D-gain: provides loop stability near high frequency cut-off

- **Correction algorithm determines N correction kicks** \( \Theta + \delta \Theta \)
  - Through direct response matrix inversion or application of SVD

- **Corrector Magnets, Power Supplies and Vacuum Chamber**
  - Apply corrections to the beam
  - Introduce analog or digital noise
  - Act as first order low-pass filters (through eddy currents)
Global Position Feedback in SR Sources

**Key Components I: rf-BPMs**

**General Requirements** (for < 100 Hz, sub-µm position feedback)

- bandwidth / sampling rate: some kHz
- resolution / noise figure (within FB bandwidth): < 0.3 µm (< 15 nm/Hz)
- long term stability (typ. hours): 1 µm
- reliability: high

**RF BPMs**

- Since capacitive pick ups are part of SR vacuum chamber, the mechanical BPM positions need to be stable to a sub-µm level

**Solutions:**

- stiff and mechanically de-coupled supports (SPEAR 3, ELETTRA)
- monitoring of mechanical BPM movements (SLS, ELETTRA)

- Multiple choices of electronics

<table>
<thead>
<tr>
<th></th>
<th>multiplexed systems</th>
<th>parallel systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>bandwidth *</td>
<td>limited / aliasing problems</td>
<td>high</td>
</tr>
<tr>
<td>resolution **</td>
<td>good (still sufficient)</td>
<td>good (still sufficient)</td>
</tr>
<tr>
<td>linearity</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>current dep.***</td>
<td>low</td>
<td>limited</td>
</tr>
<tr>
<td>dynamic range</td>
<td>large</td>
<td>large</td>
</tr>
</tbody>
</table>

**Remarks:**

- kHz multiplexing frequencies may turn longitudinal beam oscillations through aliasing into noise in the correction BW.
- reliability needs to be improved by feature like electronics self tests and data validity checks
- resolutions may be improved by direct digitization of rf-signals (300 - 500 MHz) with fast ADCs.
- current dependency represents no concern with “top-up” operation of storage ring.
**Photon BPMs**

- Pick ups are part of the front end sensing the photon beam by using the photoemission effect

![Diagram of Photon BPMs](image)

Fig. 2 Blade geometries for staggered pair monitors (SPMs) for dipoles and multipole wigglers as well as XBPMs in undulator frontends. (light shading dipole and wiggler fans; dark shading undulator radiation).

- monitorheads are stiff and cooled
- no intensity and/or bunch pattern dependency
- higher resolution than rf-BPMs
- bandwidth limitation of electronics to < 2kHz

**ID photon BPMs need:**
- precise mapping of undulator modes
- removal of contamination from bending magnet stray radiation through low-/ bandpass filtering of signals (VUV) or introduction of ID chicanes (hard x-rays)
Global Position Feedback in SR Sources

Key Components III: Power Supplies, Correctors, Vacuum Chamber

Power Supplies (e.g.: SLS digital PS)

- PS for feedback purposes are usually operated in the small signal regime providing up to 2 kHz BW
- Sufficient resolution (> 16 bit, 15 ppm)
- Stability:
  - short term (hours) : < 1 ppm
  - long term (weeks) : < 15 ppm

Corrector Magnets and Vacuum Chambers

- Bandwidth limitations through eddy currents:
  - use of low conductivity material and/or reduced thicknesses of vacuum chambers
e.g.: Al (APS) \( f_c \sim 10 \text{ Hz} \)
  - Cu \( f_c \sim 40 \text{ Hz} \)
  - CuNi (SPEAR 3) \( f_c \sim 120 \text{ Hz} \)
  - 2 mm stainless (SLS) \( f_c \sim 120 \text{ Hz} \)

- Air core corrector magnets provide high BW
  - relatively high power requirements
  - bulky

- Laminated corrector magnets
  - can be used for static and dynamic corrections
  - laminations < 1 mm thickness provide still sufficient bandwidth \( f_c \sim 100 \text{ Hz} \)

- Still moderate BW-limitations since both elements can be treated as first order low-pass.
Global Position Feedback in SR Sources

Global FB Simulations

PID Controller

- $G_p$, $G_i$, $G_d$ have been optimized for suppression of typical noise spectra in SR sources
- Transfer functions of SLS FB key components have been supposed
  - BPM sampling rates: $1$ kHz, $2$ kHz, $4$ kHz
  - BPM noise: $< 1 \, \mu$m rms (@ $4$ kHz), $\sim 16$ nm/Hz
  - PS bandwidth $2$ kHz
  - $f_c$ of corr. / vac. chamber $120$ Hz
- Loop latency time including data transfer, PID controller and calculation of corrector kicks was assumed to last one sampling cycle of BPM system

Bode Plot of SLS Feedback Loop

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Examples of Global Position Feedbacks

**APS** (courtesy of Glenn Decker)

**ESRF** (courtesy of Eric Plouviez)
Examples of Global Position Feedbacks

SLS: Global Slow Orbit Feedback (SOFB) (see THPR1030)

- SOFB corrects each plane to "golden orbit" every 3 seconds
- all 72 BPMs and all 144 (72 h./72 v.) correctors are used
- rf-frequency is used to compensate for SR circumference changes

Short term stability (13 hours) at 6S  Long term stability (14 days)

Horizontal rms orbit (global) ~ 1.2 $\mu$m
Vertical rms orbit (global) ~ 1.0 $\mu$m
Energy stability ~ 1 $\times 10^{-5}$

SLS global fast orbit feedback (up to 100 Hz) is under commissioning
Global Position Feedback in SR Sources

Position Feedback Implementations

<table>
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<tr>
<th>SR facility</th>
<th>FB type</th>
<th>Monitors</th>
<th>max. BW</th>
<th>Stability</th>
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</thead>
<tbody>
<tr>
<td>ALS*</td>
<td>G</td>
<td>rf-BPMs</td>
<td>&lt; 100 Hz</td>
<td>&lt; 1 µm</td>
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<tr>
<td>APS</td>
<td>G and L</td>
<td>rf &amp; p-BPMs</td>
<td>&lt; 30 Hz</td>
<td>&lt; 2 µm</td>
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<td></td>
<td></td>
<td></td>
<td>&lt; 50 Hz *</td>
<td>&lt; 1 µm *</td>
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<tr>
<td>NSLS</td>
<td>G</td>
<td>rf-BPMs</td>
<td>&lt; 200 Hz</td>
<td>0.5 µm</td>
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<tr>
<td>SPEAR 3*</td>
<td>G</td>
<td>rf-BPMs</td>
<td>&lt; 200 Hz</td>
<td>&lt; 1 µm</td>
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<tr>
<td>BESSY *</td>
<td>L</td>
<td>rf and p-BPMs</td>
<td>&lt; 100 Hz</td>
<td>&lt; 1 µm</td>
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<td>DELTA</td>
<td>G</td>
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<td>rf-BPMs</td>
<td>&lt; 20 Hz</td>
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<td>ESRF</td>
<td>G</td>
<td>rf-BPMs</td>
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<td>0.6 µm</td>
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<tr>
<td>MAX-lab</td>
<td>G</td>
<td>rf-BPMs</td>
<td>1 Hz</td>
<td>&lt; 3 µm</td>
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<tr>
<td>SLS *</td>
<td>G</td>
<td>rf &amp; p-BPMs</td>
<td>100 Hz</td>
<td>&lt; 0.5 µm</td>
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<td>SRS</td>
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<td>p-BPMs</td>
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<td>SUPER-ACO</td>
<td>G</td>
<td>Rf-BPMs</td>
<td>&lt; 150 Hz</td>
<td>&lt; 5 µm</td>
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<td>DIAMOND *</td>
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<td>rf-BPMs</td>
<td>100 Hz</td>
<td>&lt; 1 µm</td>
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<tr>
<td>SOLEIL *</td>
<td>G</td>
<td>rf and p-BPMs</td>
<td>100 Hz</td>
<td>0.2 µm</td>
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<tr>
<td>KEK-PF</td>
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<td>SPRING-8</td>
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<td>&lt; 0.01 Hz</td>
<td>&lt; 3 µm *</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>200 Hz *</td>
<td>&lt; 1 µm *</td>
</tr>
</tbody>
</table>

* proposed or not yet fully implemented FB systems

Position FB Schemes:

- local positions feedbacks for each experiment individually
- combination of (fast) global and (slow) local feedbacks
- combination of fast and slow global feedbacks
- single feedback covers slow and fast corrections as well as stabilization local and global “golden orbit” disturbances
Conclusions

- Increasing user requirements for position stability are only achievable through feedbacks

- A single global position feedback system represents most effective approach to correct distributed sources of orbit disturbances as usually found in SR facilities

- Decreasing HW costs should motivate to consider the implementation of global position FB from the beginning

- “Hard correction” to the “golden orbit” delivers best results for machine and experiments at the same time

This should be possible if:
  - Correctors are not saturating (DC-corrections through feature like “dynamic alignment”)
  - BPM systems become more reliable (self-tests...)

- Feedback bandwidth depends strongly on latency time through the system

- Higher resolution of photon-BPMs should be used

- RF-frequency should be included in global position FB

- Signals from experimentalists should be made available to detect sources of beam motion on the samples and to permit active FBs of beamline components (mirrors...)
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