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 reqiurements for:

Angular Stability:

(assuming planar crystal monochromator)

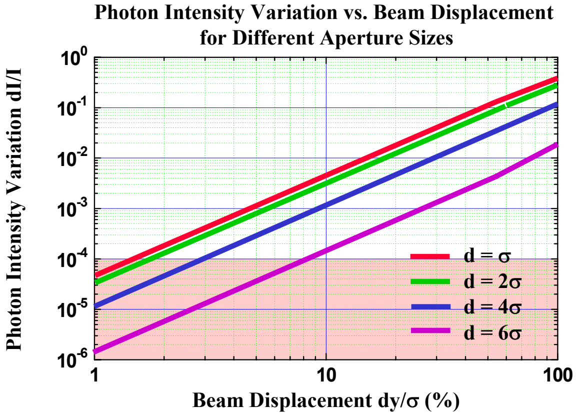
Bragg's law: $\frac{\Delta E_{ph}}{E_{ph}} = \frac{\Delta\Theta}{\Theta_B}$

with Bragg angle $\Theta_B \sim 5° - 45°$ **(90 - 800 mrad)**

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

Position Stability:

(assuming gaussian beamshapes)



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

for low ε and low beta machines: < 1 μm

Stability Requirements II

Typical integration times of experiments

• >> 100 s …….	e.g.:	inelastic x-ray scattering
• 0.1 s - 100 s ...	e.g.:	protein cristallography (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 ε_{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)

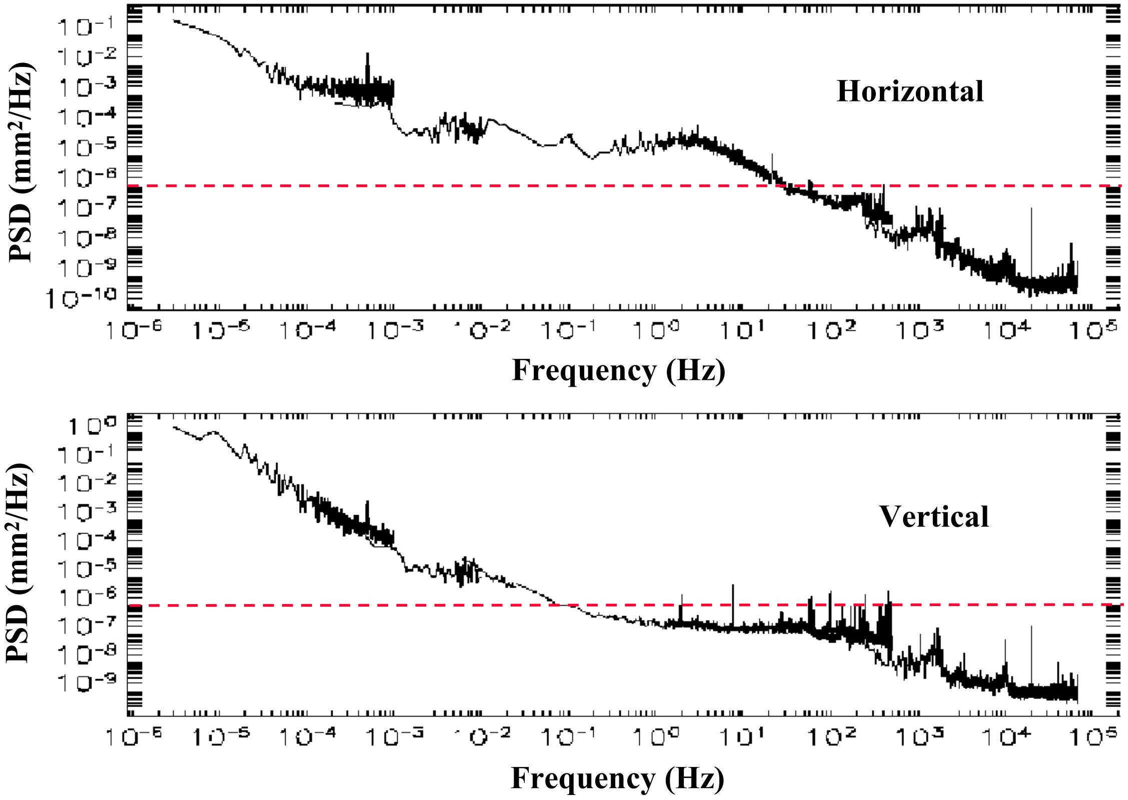
• ID gap changes	(< 100 µm)
• ID polarization switching	(< 100 µm)
• ground vibrations, traffic…	(< 10 µm)
• cooling water	(< 10 µm)
• injector operation	(< 10 µm)

High frequency motions (sub-milliseconds)

• single and multi-bunch instabilities	(< 100 µm)
• synchrotron oscillations	(< 100 µm)
• pulse power sources	(< 10 µm)

Noise Sources at SR Facilities II

APS Noise Spectrum without FB (courtesy of Glenn Decker)



Long term beam motions can be reduced by...

- Frequent (dynamic) re-alignment campaigns
- Temperature and beam current stabilization

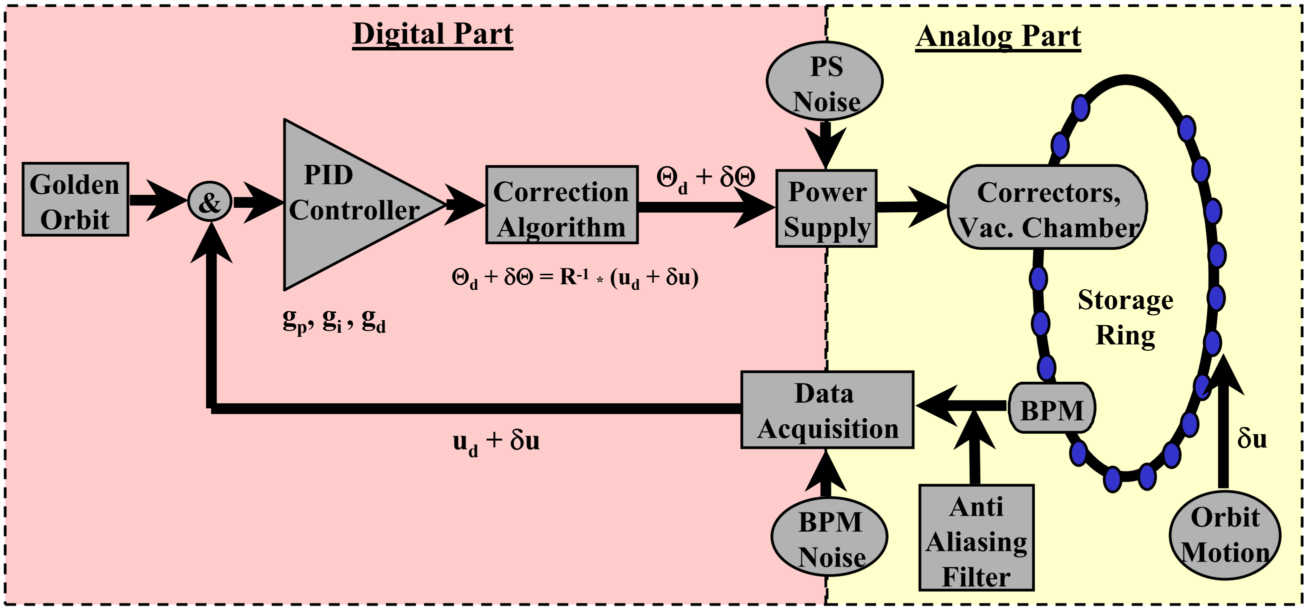
Medium and short term beam motions can be reduced by...

- Careful mechanial 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 Architecture



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)

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/$\sqrt{\text{Hz}}$)
• 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

	multiplexed systems	parallel systems
bandwidth *	limited / aliasing problems	high
resolution **	good (still sufficient)	good (still sufficient)
linearity	excellent	excellent
current dep.***	low	limited
dynamic range	large	large

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.

Key Components II: Photon-BPMs

Photon BPMs

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

courtesy of Karsten Holldack (BESSY)

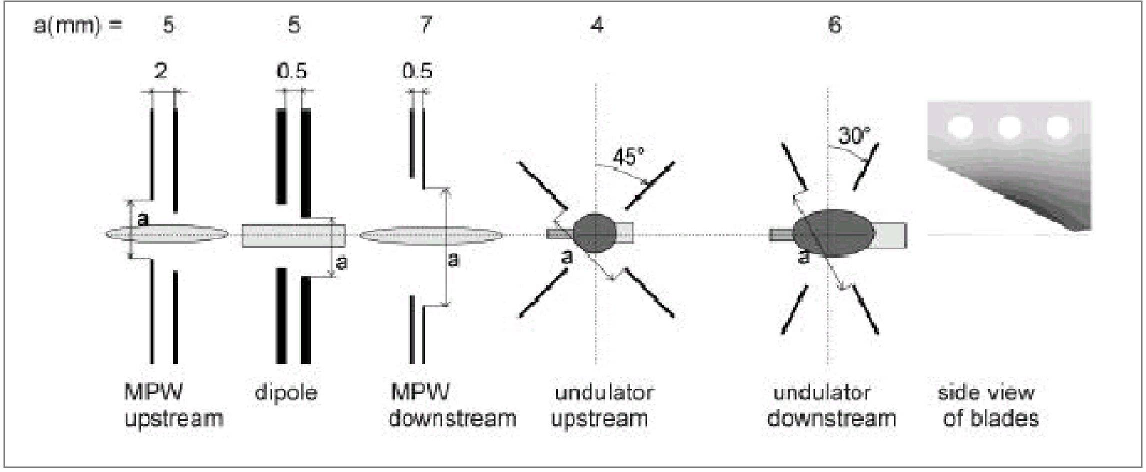


Fig. 2 Blade geometries for staggered pair monitors (SPMs) for dipoles and multipole wigglers as well as XBPMs in undulator frontends. (light shading:dipole and wiggler fans; dark shading:undulator radiation).

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

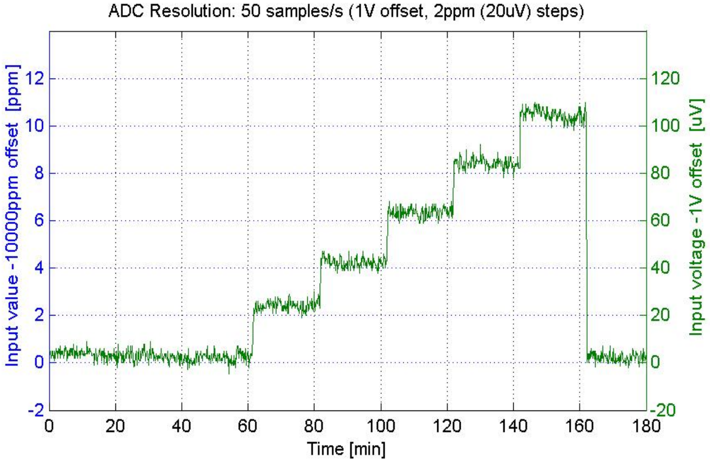
ID photon BPMs need:

- ⇨ 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)

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**


ADC Resolution: 50 samples/s (1V offset, 2ppm (20uV) steps)

  - ⇨ **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 ~ 10 Hz**
	Cu	**f_c ~ 40 Hz**
	CuNi (SPEAR 3)	**f_c ~ 120 Hz**
	2 mm stainless (SLS)	**f_c ~ 120 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 ~ 100 Hz)**
- **Still moderate BW-limitations since both elements can be treated as first order low-pass.**

Global FB Simulations

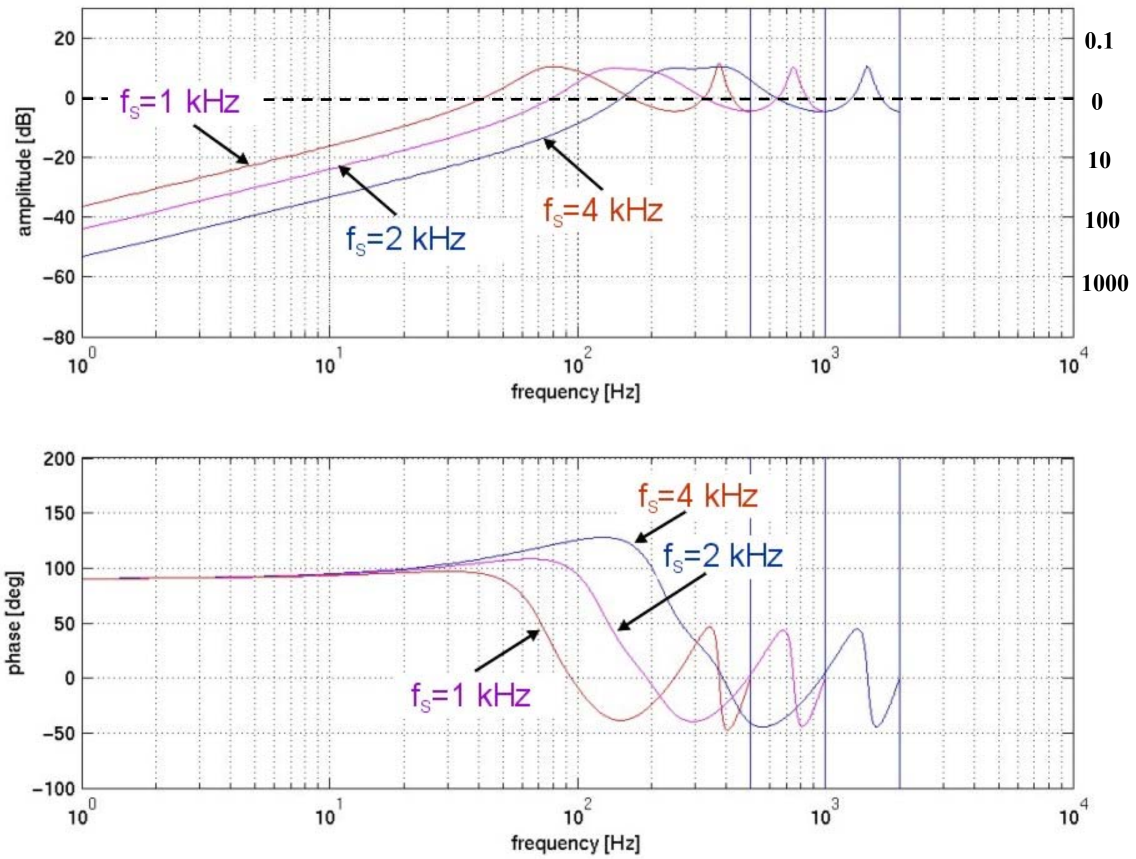
PID Controller

- 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 µm rms (@ 4 kHz), ~16 nm/$\sqrt{\text{Hz}}$
PS bandwidth	2 kHz
f_c of corr. / vac. chamber	120 Hz

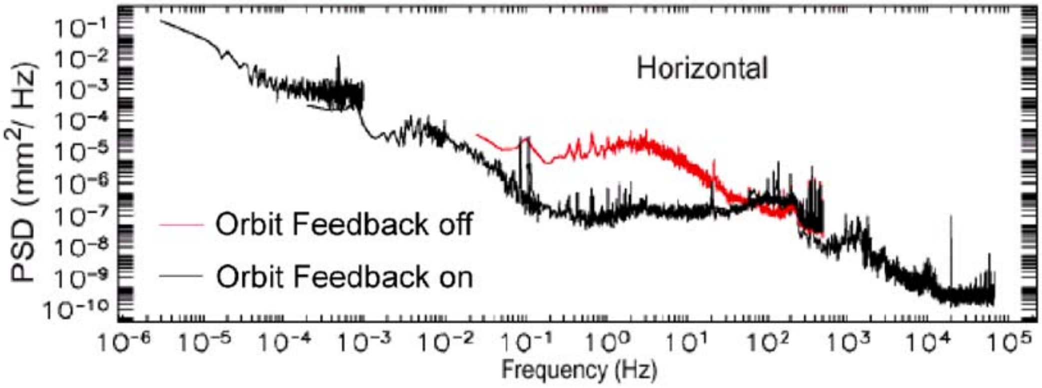
- Loop latency time including data transfer, PID controler and calculation of corrector kicks was assumed to last one sampling cycle of BPM system

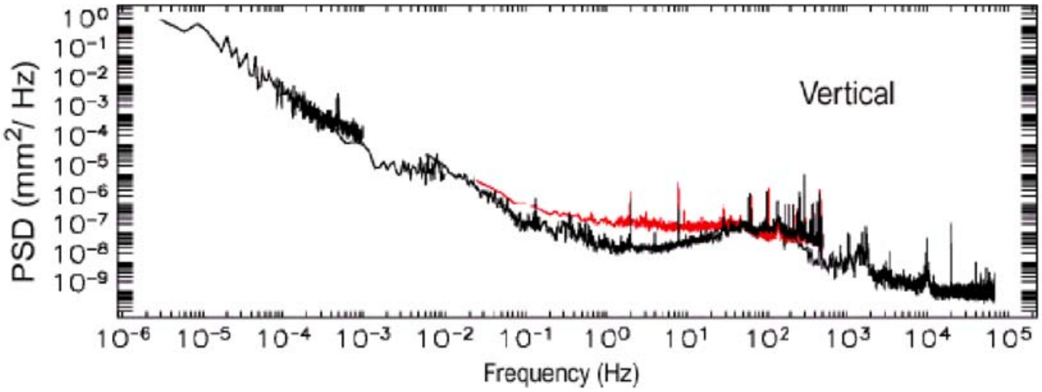
Bode Plot of SLS Feedback Loop



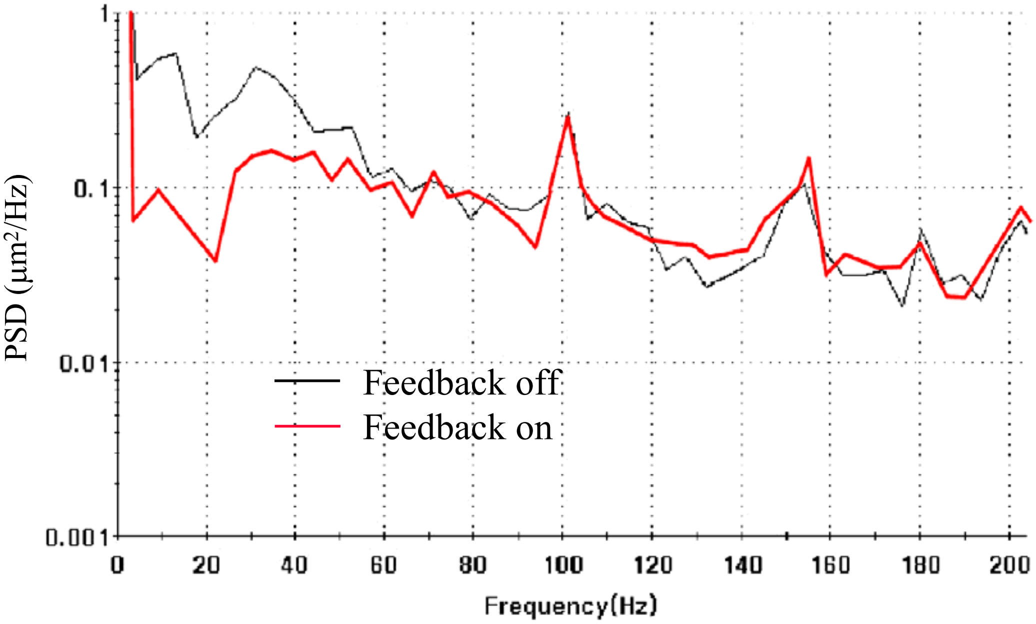
Examples of Global Position Feedbacks

APS (courtesy of Glenn Decker)





ESRF (courtesy of Eric Plouviez)



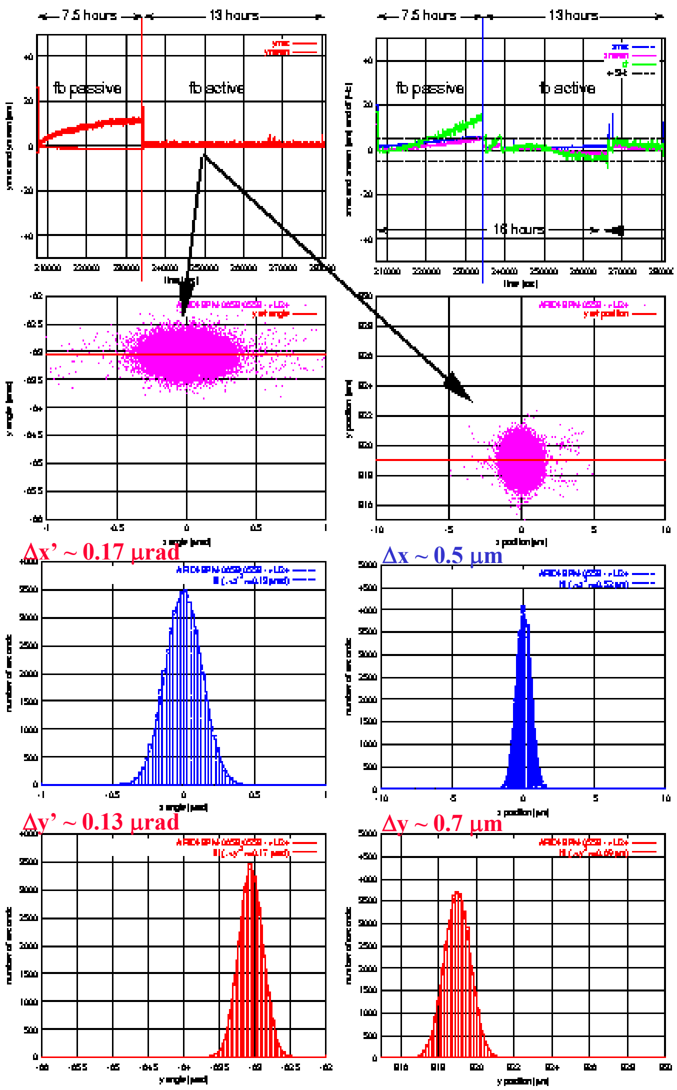
Examples of Global Position Feedbacks

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

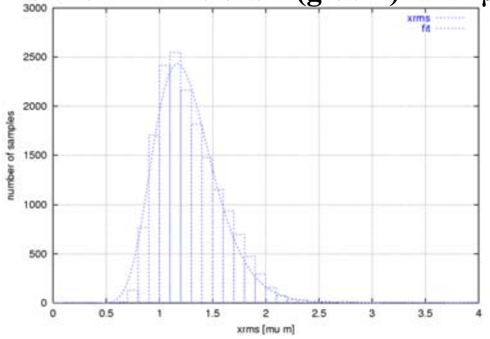
Short term stability (13 hours) at 6S

angular stability **position stability**

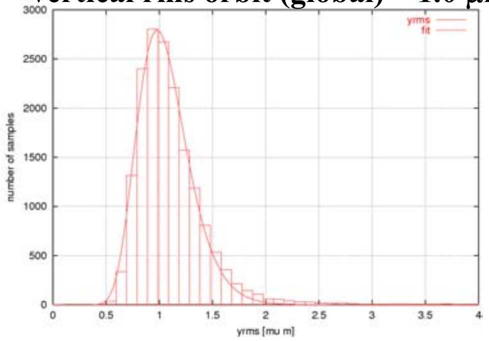


Long term stability (14 days)

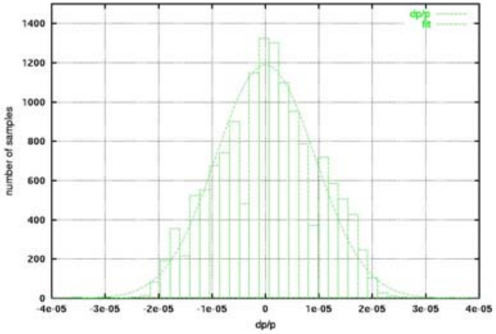
horizontal rms orbit (global) ~ 1.2 μm



vertical rms orbit (global) ~ 1.0 μm



energy stability ~ $1 \cdot 10^{-5}$



SLS global fast orbit feedback (up to 100 Hz) is under commissioning

Position Feedback Implementations

SR facility	FB type	Monitors	max. BW	Stability
ALS*	G	rf-BPMs	< 100 Hz	< 1 µm
APS	G and L	rf & p-BPMs	< 30 Hz < 50 Hz *	< 2 µm < 1 µm *
NSLS	G	rf-BPMs	< 200 Hz	0.5 µm
SPEAR 3*	G	rf-BPMs	< 200 Hz	< 1 µm
BESSY *	L	rf and p-BPMs	< 100 Hz	< 1 µm
DELTA	G	rf-BPMs	< 1 Hz	< 5 µm
ELETTRA *	L	rf-BPMs	< 20 Hz	< 0.2 µm
ESRF	G	rf-BPMs	100 Hz	0.6 µm
MAX-lab	G	rf-BPMs	1 Hz	< 3 µm
SLS *	G	rf & p-BPMs	100 Hz	< 0.5 µm
SRS	L	p-BPMs	0.03 Hz	1 µm
SUPER-ACO	G	Rf-BPMs	< 150 Hz	< 5 µm
DIAMOND *	G	rf-BPMs	100 Hz	< 1 µm
SOLEIL *	G	rf and p-BPMs	100 Hz	0.2 µm
KEK-PF	G	rf-BPMs	3 Hz	< 5 µm
SPRING-8	G	rf-BPMs	< 0.01 Hz 200 Hz *	< 3 µm < 1 µm *

* 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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