FLS 2006: ERL Stabilization

What are good stabilization strategies and their limits in ERLs

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- Introduction
- Orbit Stability
- Top-off benefits (could be there in ERLs as well)
- Beamsize Stability
- Summary

Introduction

- Will try to stick to proposed format, i.e. short talk, open discussion
- Try to not be too storage ring biased (admit to be difficult)
- Some statements/conclusions depend on
  - who users will be
  - how experimental techniques evolve
  - I assume the 3rd generation ring users will be dominant user group at ERLs
- Will concentrate on transverse direction (position/size)
  - Slow (similar to closed orbit/beamsize stability/feedback in rings)
  - Fast (similar to multibunch feedbacks)
- Additional complication: For size, you probably need to address issues at the source (laser shaping, …) in the ERL case

Intro (II)

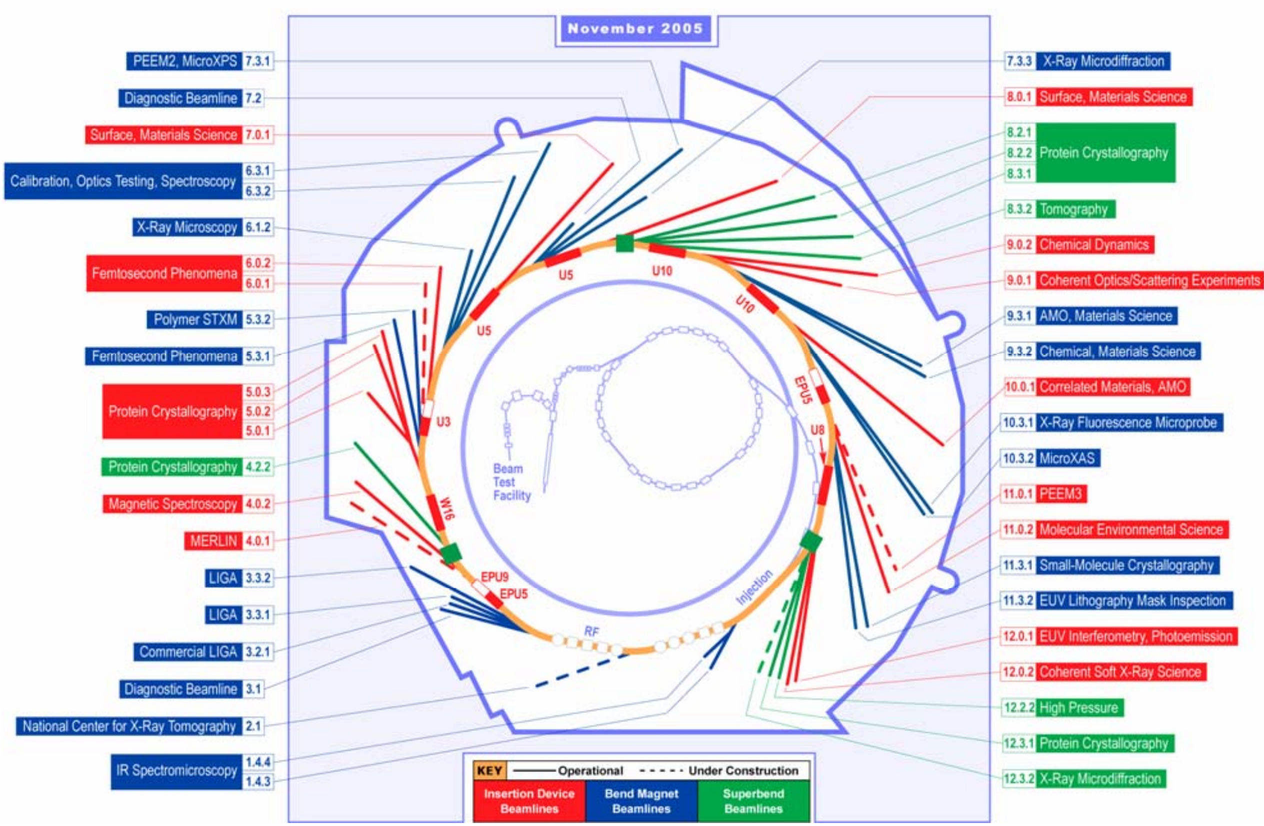
- Will not get into timing, bunch length, energy, energy spread …
- Is a very interesting topic by itself and also provides unique challenges for ERLs
- Storage rings are very stable in all of these aspects and some users make use of it
- Tides are well compensated in storage rings, have not seen schemes for ERLs, yet

Aerial view of Advanced Light Source

jc/ALSaerial/11-96

ALS Parameters and Beamlines

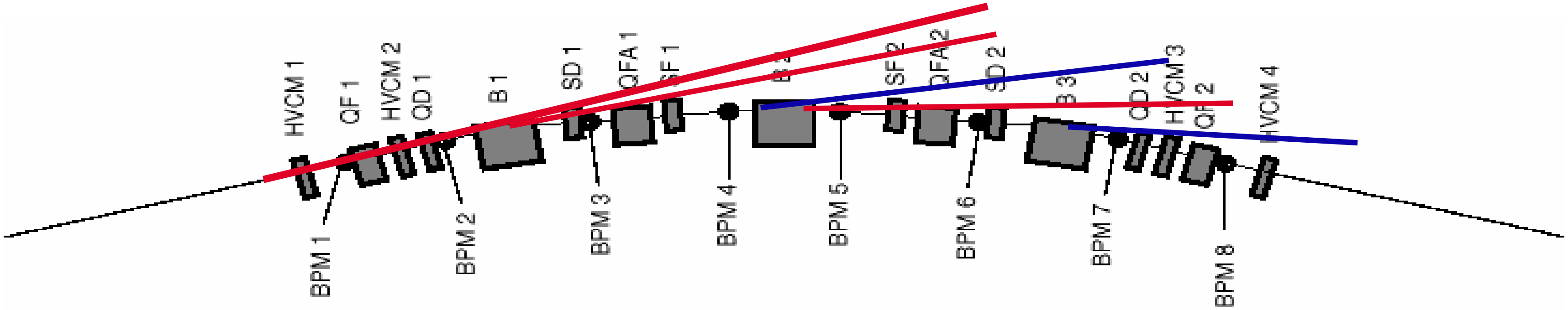
Nominal Energy	1.5-1.9 GeV
Circumference	196.8 m
RF frequency	499.642 MHz
Harmonic number	328
Beam current	400 mA multibunch (future 500 mA) 65 mA two-bunch
Nat. emittance	6.3 nm at 1.9 GeV
Emittance Coupling	Typical about 2% (future 0.4%)
Nat. energy spread	0.097%
Refill period	3 daily fills multibunch 12 two-bunch (future top-off about every 30 s)



1/10 Electron Beam Size ⇒

Sorce Location	Horizontal	Vertical
Straight Section	30 μm	2.3 (0.8) μm
Bend Magnet #2	10.3 μm	1.3 (0.5) μm

BPM, Corrector locations



- 12 nearly identical arcs – TBA; aluminum vacuum chamber
- 96 (turn-by-turn)+52 (feedback) beam position monitors in each plane
- 8 horizontal, 6 vertical corrector magnets per arc (94/70 total+chicanes)
- Beam based alignment capability in all quadrupoles
- 22 corrector magnets in each plane on thinner vacuum chamber pieces - FOFB

What has been/will be done to maximize stability (ALS)

"PASSIVE"

(i.e. remove the sources)

- Temperature stability (air below 0.1, water below 0.5 degree peak-to-peak)
- Minimize water induced vibrations
- Power supply stability (no switched mode supplies, thick aluminum vacuum chamber in most magnets)
- Vibration - reduce the effects by mechanical design or remove the source
- Reduce RF-phase noise (mode-0 noise for IR users)
- Top-off

FEED FORWARD

- Insertion device compensation (10 Hz for most IDs, 200 Hz for EPUs)
- Consists of beta-beating, tune, coupling and orbit feed-forward
- Potentially introduces additional orbit changes!

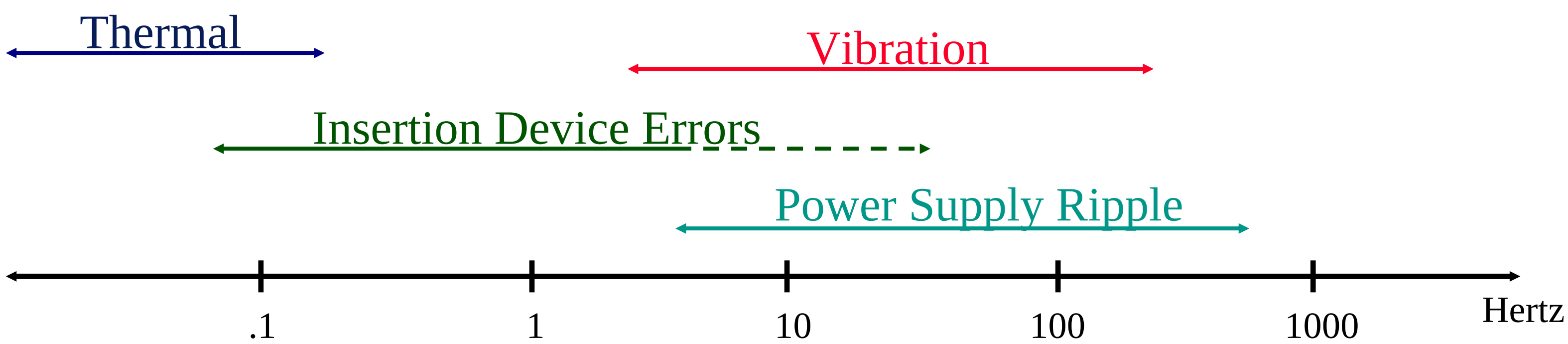
FEEDBACK

- Local orbit feedback (not routinely used at ALS) – generally seems to be problematic once you have several fast ones (noise amplification at higher frequencies, …)
- Global orbit feedback (1 Hz update rate slow, coordinated with >1 kHz update rate fast system)
- BPM position detection incorporated into feedback (relative to common accelerator-experiment ground plate, not yet)
- Magnet or girder position feedback (not yet)

Importance of 'passive' design

- Sources have to be well engineered from the start
  - Some retrofits are possible (water, vib. dampers)
- There is balance between effort for passive stability (expensive) and active feedback (limited gain)
  - In light sources there are very extreme cases to both sides of this debate …
- Ground plate design, HVAC systems, girder and magnet design, lattice amplification factors/girder grouping, cooling water, use of vibration damping, alignment scheme, site selection all can make huge difference in noise level (more than 1 order of magnitude for 3rd generation sources)
- Need integrated approach early in design to have reasonable cost and performance estimate

Causes for Orbit Distortions + Magnitude of uncorrected effects in ALS



Frequency	Magnitude	Dominant Cause
Two weeks (A typical experimental run)	±200 μm Horizontal ±100 μm Vertical	1. Magnet hysteresis 2. Temperature fluctuations 3. Component heating between 1.5 GeV and 1.9 GeV
1 Day	±125 μm Horizontal ±50 μm Vertical	Temperature fluctuations
8 Hour Fill	±50 μm Horizontal ±20 μm Vertical	1. Temperature fluctuations 2. Feed forward errors
Minutes	1 to 5 μm	1. Feed forward errors 2. D/A converter digitization noise
.1 to 300 Hz	3 μm Horizontal 1 μm Vertical	1. Ground vibrations 2. Cooling water vibrations 3. Power supply ripple 4. Feed forward errors

Beam Stability in straight sections w/o Orbit Correction, w/o Orbit Feedback, but w/ Insertion Device Feed-Forward

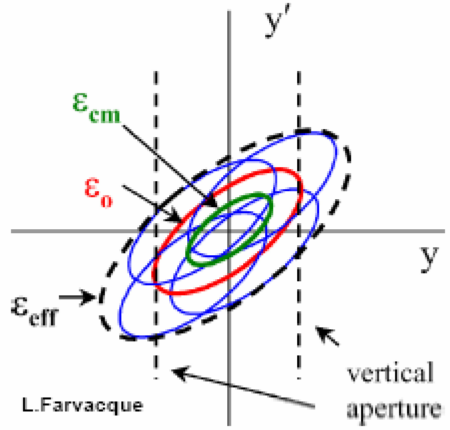
Orbit Stability Requirements

INTRODUCTION

Table 1: Typical stability requirements for selected measurement parameters common to a majority of experiments (Courtesy R. Hettel)

Measurement parameter	Stability requirement
Intensity variation $\Delta I/I$	$<$0.1 % of normalized I
Position and angle accuracy	$<$1 % of beam σ and σ'
Energy resolution $\Delta E/E$	$<$0.01 %
Timing jitter	$<$10 % of critical t scale
Data acquisition rate	$\approx 10^{-3}$-10^{5} Hz
Stability period	$10^{-2(3)}$-10^{5} sec

$\Rightarrow$ **Stabilization of the electron beam in its 6D phase space to meet stability requirements for the photon beam parameters. Effect of photon beam instability on flux depends on the time scale of the fluctuation τ_f relative to the detector sampling and data integration times τ_d:**



- $\tau_d \gg \tau_f$:
  $\epsilon_{\rm eff} = \epsilon_0 + \epsilon_{\rm cm}$:
  Motion of $\approx$**30 %** of σ and σ'
  $\Rightarrow$ *smeared out*
  $\Rightarrow$ **10 %** increase in $\epsilon_{\rm eff}$
- $\tau_d \ll \tau_f$:
  $\epsilon_{\rm eff} \approx \epsilon_0 + 2\sqrt{\epsilon_0 \epsilon_{\rm cm}} + \epsilon_{\rm cm}$:
  Motion of $\approx$**5 %** of σ and σ'
  $\Rightarrow$ *new measurement noise*
  $\Rightarrow$ **10 %** increase in $\epsilon_{\rm eff}$

User requirements (ALS)

Most users at the ALS are happy with current level of orbit stability

Two examples of experiments that currently are the most sensitive:

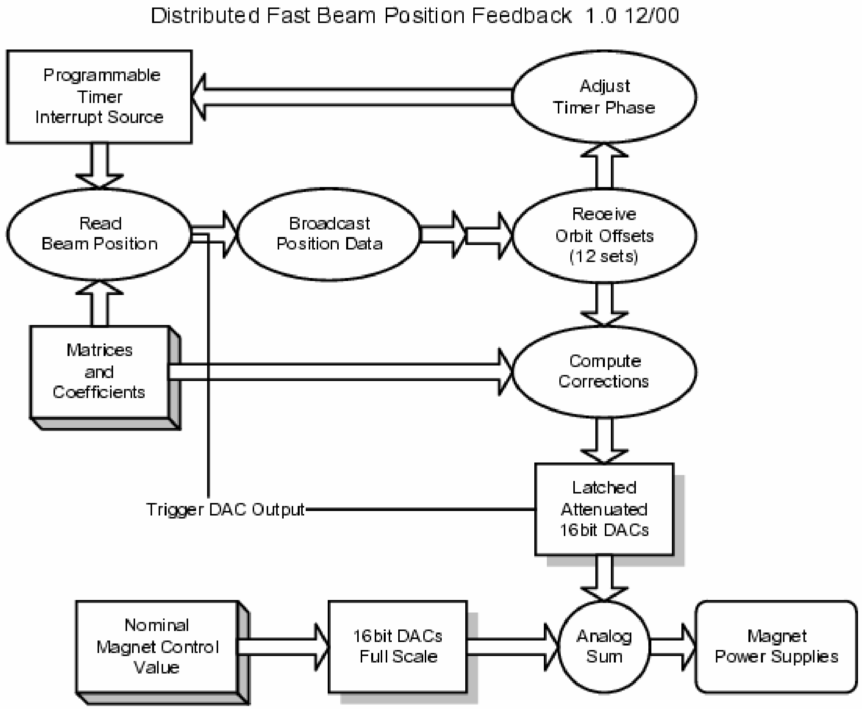
- **Micro focusing beamlines on bending magnets (e.g. Micro XAS, especially in combination with molecular environmental science samples, i.e. dirt); problem is that sample is very inhomogenous and small source motion causes the spectrum to change significantly. I_0 normalization does not help!**
- **Dichroism experiments (i.e. on EPUs) measuring very small polarization asymmetries; orbit motion can cause small shifts of the photon energy out of the monochromator, resulting in fake asymmetries.**

Orbit Correction

- **Fast (200 Hz) or slow (10 Hz) local feed forward for all insertion devices (2-d tables for EPUs)**
- **Fast global orbit feedback (1111 Hz, up to 60 Hz closed loop bandwidth)**
- **Slow global orbit feedback (1 Hz)**
- **No frequency deadband between feedbacks**
- **Complete (more correctors) global orbit correction plus local orbit correction at all IDs every 8h after refill.**
- **Photon beam position monitors at ALS are not used to correct beam orbit – instead they feed back on beamline optics. Bandwidth from h to about 10 kHz (IR beamline)**

Fast Feedback Layout

- Motivation: Orbit stability at ALS with passive measures is already very good (1-4 microns rms). Improvement into <μm range requires active/fast feedback



- Design choices:
  - Distances at ALS are relatively large -> distributed system
  - Wanted to avoid expensive specialized hardware (like reflective memory, DSPs)
- Multiplexed (Bergoz) BPMs provide enough bandwidth and low enough noise
- D/A converter resolution for corrector magnets was upgraded from 16 to 20 Bit.
- Update rate of system is currently 1.11kHz.

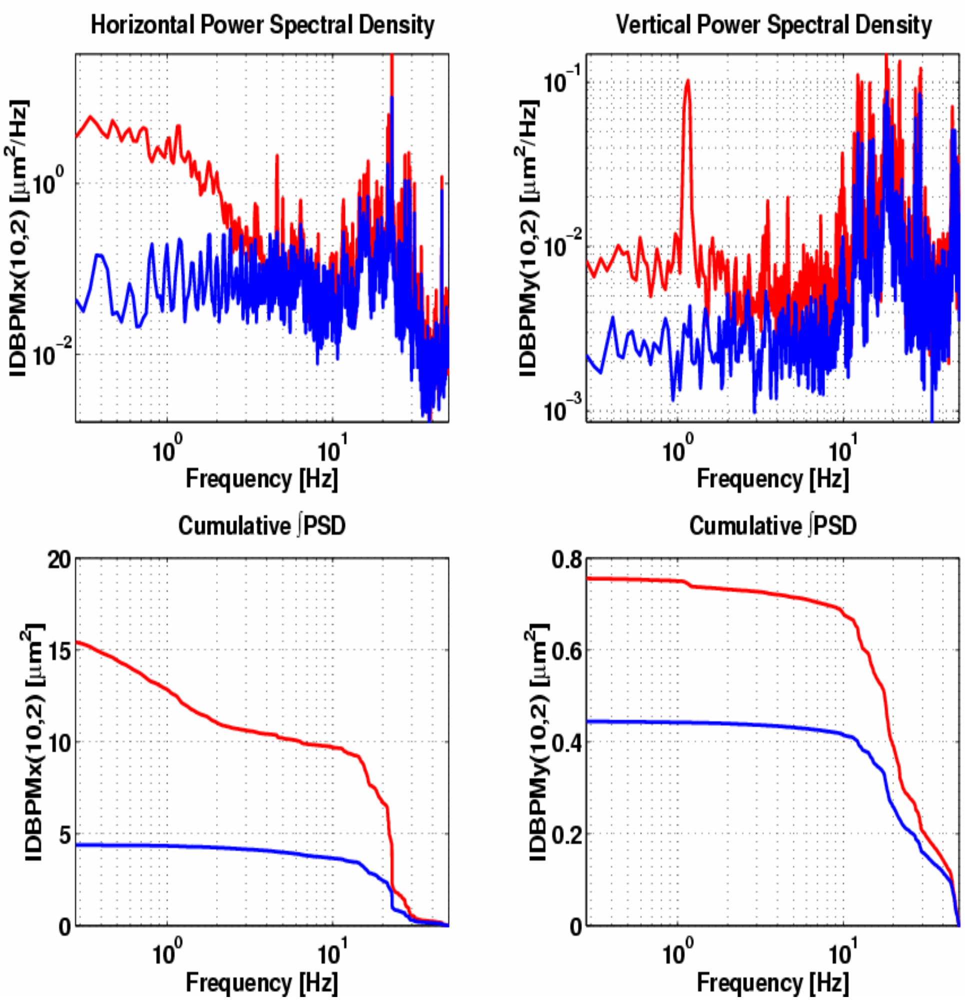
Feedback Implementation Details

- Combination of fast and slow global orbit feedbacks in both planes – no frequency deadband
- Fast Feedback currently 24 BPMs in each plane and 22 correctors in each plane. 1.11 kHz update rate, bandwidth DC-60 Hz. Only ½ of singular values used.
- Slow Feedback 52 BPMs in each plane, 26 horizontal correctors, 50 vertical correctors, RF frequency correction. 1 Hz update rate, about 60% single step gain, bandwidth DC-0.1 Hz. Typically all SVs used.
- Slow feedback communicates with fast feedback to avoid interference in frequency overlap range. Setpoints/golden orbit used by fast feedback is updated at rate of slow feedback.

Orbit feedback performance

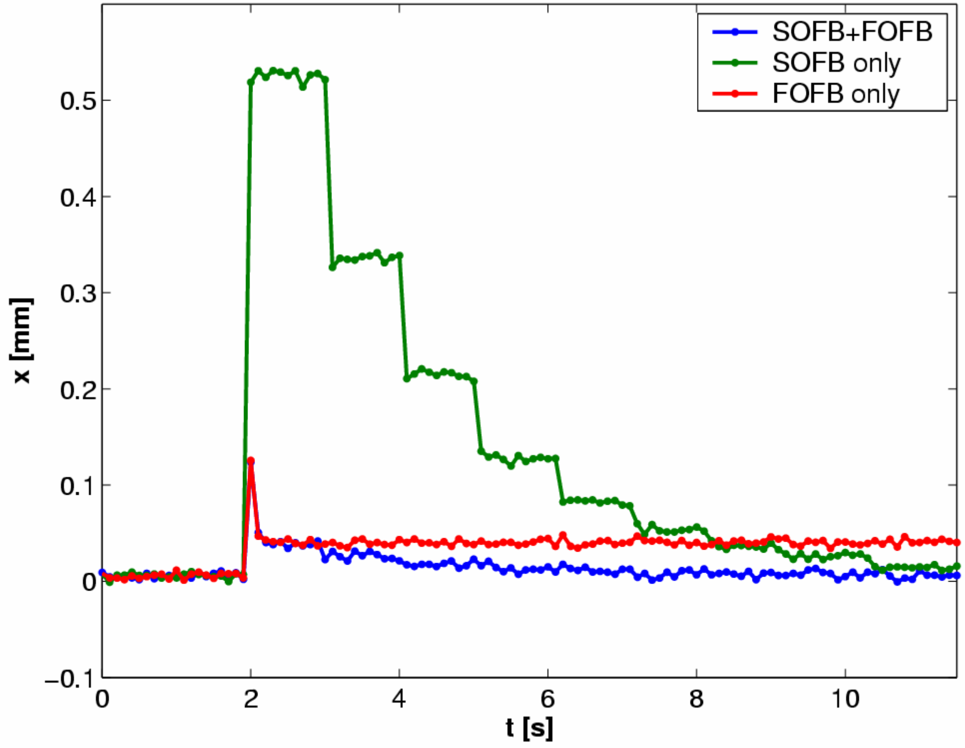
- Fast feedback routinely used in user operation since spring'04 with very positive user response.
- Extremely reliable. One beam dump and total of 4 (minute long) feedback outages.
- With slow and fast orbit feedback the ALS achieves submicron stability in the vertical plane:
    - Integrated rms motion 0.01 to 500 Hz in the vertical plane is significantly below 1 micron (at 3.65 m beta function, 23 micron vertical beamsize)
    - Horizontally the integrated rms motion is now reduced from about 4 to about 2 microns (at 13.5 m beta function and 300 micron horizontal beamsize).
- Long term stability (week) is of the order of 3 microns.

Beam spectra with feedback



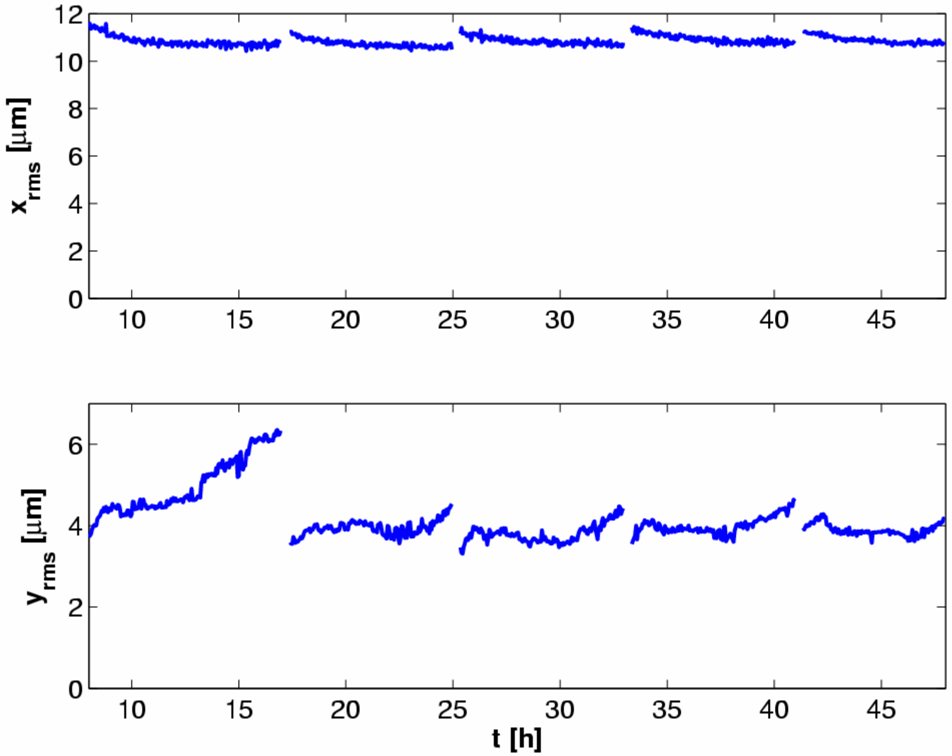
- Beam motion with feedback in open (red) and closed loop (blue) at out of loop BPM.
- Feedback is quite effective up to about 40 Hz. Right now closed loop bandwidth is about 60 Hz (best systems elsewhere order 100 Hz)
- Correction at low frequencies down to the BPM noise floor.
- System is set up conservatively at the moment – no excitation at higher frequencies.

Frequency Overlap – Master/Slave



- **ALS needs slow and fast feedback (do not have enough fast correctors)**
- **Avoided frequency dead band – fast system not DC blocked**
- **Synchronization by SOFB updating FOFB golden orbit**

‘Long term’ orbit stability



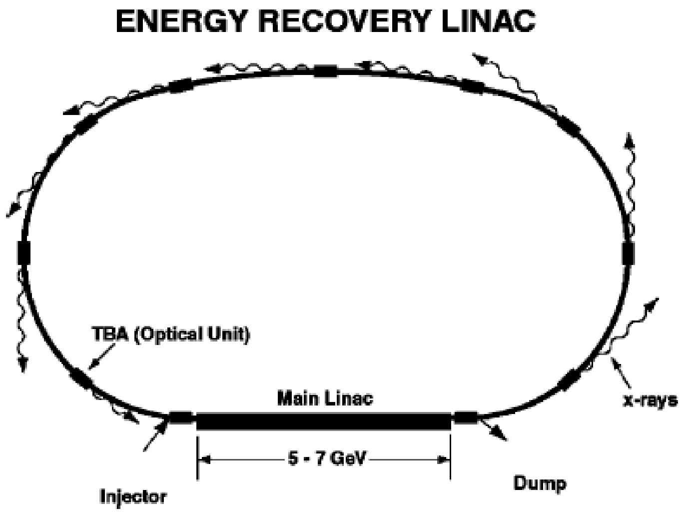
- Rms orbit error over the course of 1.5 days.
- first fill is after a beam dump, i.e. the thermal stability is not as good
- Normally rms change is below 1 micron

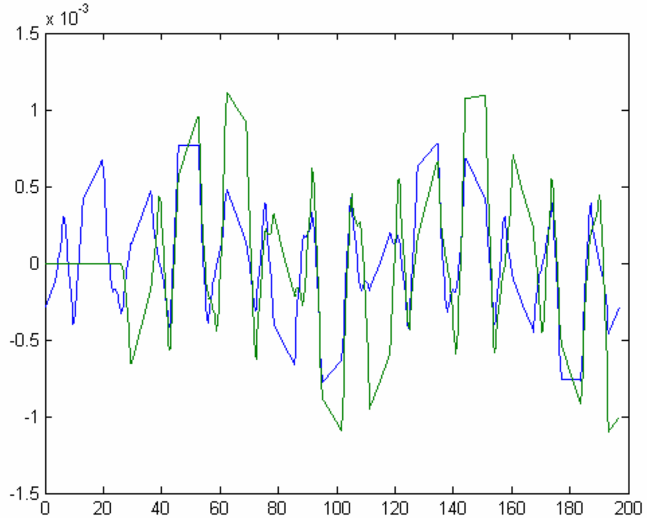
Main reasons for long term orbit drift at ALS:

1. Physical movement of BPM chambers (measured this offline so far)
2. Current and fill pattern dependence of BPMs (relatively small above 200 mA – less relevant in top-off)
3. Use of less corrector magnets than BPMs, and a relatively limited number of BPMs (52) and correctors

For ERLs

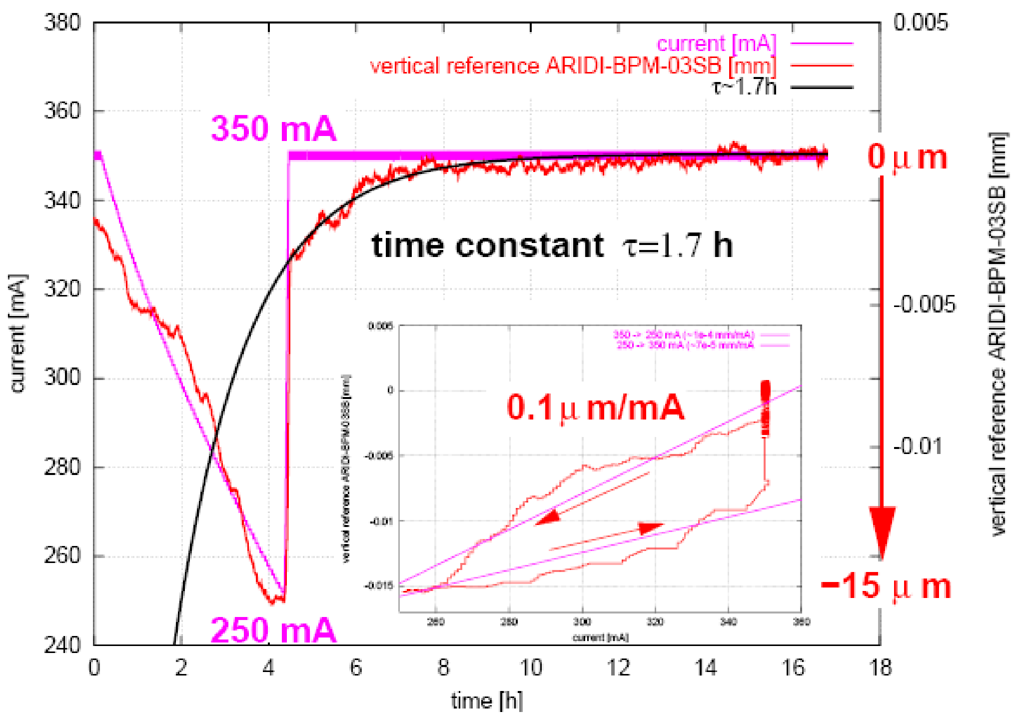
- ‘Slow’ system (i.e. order 100 Hz bandwidth)
- BPM resolution is about where you need it
  - — Amplification factors are similar for closed orbit/single trajectory
  - — Problem area is where you have two beams (definitely if all buckets are filled)
  - — Will have to wait for faster ADCs?
- Fast system (intratrain, bunch-by-bunch, same bunch ?)
  - — Curved geometry or return helps (latency)
  - — BPM resolution (FLASH several microns single bunch, single shot) not quite there
  - — Kicker driver will be challenge (5 GeV)
  - — Noise levels of multibunch feedbacks at light sources are low enough, but ‘damping’ time is about 50 μs, probably too slow





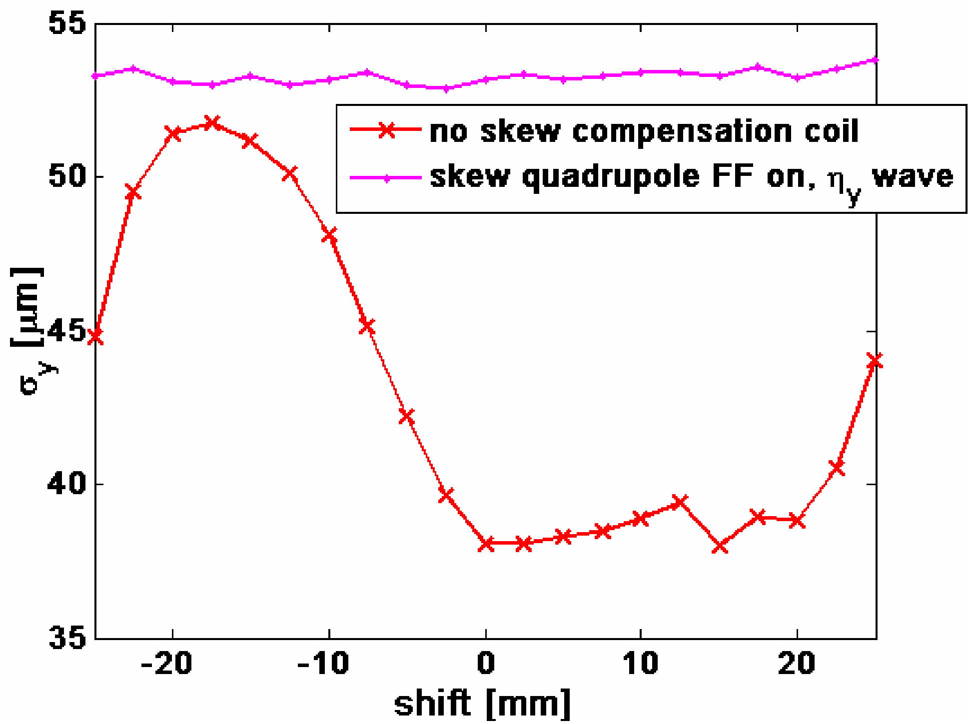
Top-up + thermal stability

- **Top-up provides much better thermal stability: Accelerator and Beamline Optics – ESRF/APS BLs needed about 1h after refill!**
- **Challenges for ERL:**
  - **Average current stability**
  - **Reliability (Light Sources achieve MTBF of 30 – 70 h)**



Beamsize Stability

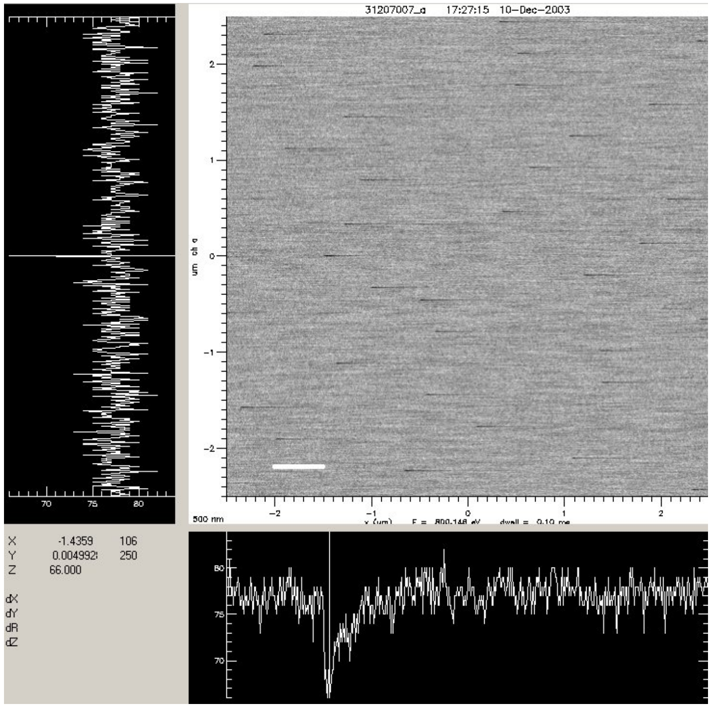
- **Receive more inquiries about beamsize than orbit stability!**
  - **Most sensitive in our case: STXM, microfocus**
- **Vertical beamsize variations due to EPU motion were big problem.**
- **Is caused by skew quadrupole (both gap and row phase dependent)**
- **Installed correction coils for feedforward**
- **Now <0.5% vertical beamsize variations**



- **Just for reference: In ALS about 200 magnets change (FF+FB) if user changes undulator gap!**

Time scale of size fluctuations

Recorded image



15 %

Horizontal scale is 60 ms

Second “Injection” test
7 Dec 2003 STXM 11.0.2
septum magnet turned off

- **Normally storage rings have very stable beamsize on faster timescale**
- **Potential exception: Injection transients (top-off): Here observed with STXM**
- **Very sensitive due to combination of high resolution zone-plate and pin hole.**
- **Gating can be implemented relatively easily.**
- **In ERL case probably many sources of beamsize fluctuations on this timescale – presumably feedback necessary (if similar users …). Seems very demanding to do on sub-ms level.**

Beamsize/Emittance 'Feedbacks'

- In storage rings we need
  - Lattice correction (dispersion, horiz.+vert.)
  - Coupling, skew correction (vert.)
    - Both mostly done by feedforward
  - Multibunch feedbacks (instabilities, horiz.+vert.+long.) – 100s of turns damping rate
  - Can have very slow beamsize feedback (synchrotron light monitor)
- ERLs
  - Same as above, instabilities probably not curable with feedback
  - Addition: Gun charge+emittance fluctuations
    - Might need (depending on amplitude, time structure, user sensitivity) feedback mechanism from measurement (synchrotron light) into gun (laser shaping?)

Summary

- Storage ring based 3rd generation light sources are extremely stable (submicron, permille beamsize)
  - Combination of passive source suppression
  - Active feed-forward, feedback
- ERLs with their smaller beamsizes will be more challenging and need to incorporate stability in design from beginning
  - Ground plate/site, temperature, cooling water, girder, magnet mounting, …
  - Orbit feedback for ‘slow’ (100 Hz) effects seems well in reach with technology extrapolation (except linac)
  - Fast feedback more similar to multibunch feedbacks in rings, easier in return line configs, but resolution needs improvement
  - Beamsize stability will involve gun feedback
  - Overall many more challenges for ERLs!