Orbit Feedback Trickery at the NSLS VUV ring

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EPAC 2008
Genoa, Italy
June 25, 2008
Motivation & Introduction (NSLS, VUV ring, why feedback, some history)

Present Orbit Feedback System & Design Tradeoffs

Dynamic Orbit Bump

Outlook
NSLS Accelerators Today
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- **Booster & Linac**
  - \( E = 0.12 - 0.8 \text{ GeV} \)
  - \( C = 28 \text{ m}, 0.7 \text{ Hz} \)
  - \( I = 0.01 \text{ Amp} \)
NSLS Accelerators Today

**VUV RING**
- $E = 0.8\ \text{GeV}$
- $\epsilon_x = 155\ \text{nm}$
- $C = 51\ \text{m}$
- $I = 1\ \text{Amp}$
- 4 CG Cells, 2 IDs

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Orbit Feedbacks – Motivation and History

- Environmental noise on the beam
  - Eliminate the source or
  - Build an orbit feedback system

- NSLS efforts
  - Late 80s: Analog local feedbacks in ID beamlines
  - Late 80s: Analog global feedback in VUV & X-ray
  - Mid-90s: Test digital global system in X-ray

- Test digital system
  - Low sampling rate (15 Hz) -> small BW
  - Slow drift & booster noise reduced
  - Demonstrated the potential of going digital
    (such as scalability, flexibility, enable/disable, etc.)

- Present 5 kHz digital system – operations early 2000s

O. Singh et al., 1998

Diagram: Orbit motion spectrum, arb. over frequency, Hz.
NSLS Orbit Feedback System Design

Sampling/update rate = 5 kHz
Stand-alone system
Digitize with off-the-shelf ADCs

Eddy Current BW ~30Hz/60Hz (H/V)
Speed Limitation due to Eddy Currents in the Al Vacuum Chamber

- Rounded corner rectangular beam chamber 42x80 mm², 4 mm thick
- Chamber dominates (small signal) response, corrector PS, BPMs, sample rate, calculation delays are much faster
- 3dB BW is ~30 Hz (hor), ~60Hz (vert); 10-90% rise-times of 6 & 12 ms
- Limitation on feedback gain*BW product ...

Hole probe with and w/o chamber; B horizontal
NSLS Orbit Feedback System
Implementation

VUV Ring Digital Orbit Feedback Crate

Hor. & vert. in one system
Each plane includes
- 24 BPMs and 8 (16) trims
- 8 SVD eigenvectors
NSLS Orbit Feedback System Implementation

VUV Ring Digital Orbit Feedback Crate

- Hor. & vert. in one system
- Each plane includes:
  - 24 BPMs and 8 (16) trims
  - 8 SVD eigenvectors
Feedback Performance:
High Frequency Orbit Noise Reduction

Driven Responses

- Correction bandwidth of up to 200 Hz possible
- Selective narrow band correction still possible using notch filters
- Control theory tricks to keep system stable
- It works! Provides >25 dB damping @ 60 Hz
- Integrated RMS is reduced to <3% of $\sigma_y$
Feedback Performance: Slow Orbit Drift Reduction

Vertical Drift, Standard VUV ops, 5 hr standard fill

- VUV: Average drift reduced 35 μm -> 6 μm (<3 % beam size); same % in hor.
Feedback works great! Why fix it?
New User Requirements for Orbit Control at U4B Source Point

- U4B is the only NSLS beamline providing variably polarized photons from a bend magnet.

- Linearly or Circularly polarized photons with energy range 20-1500 eV
- Studies of magnetic properties of transition metal & rare earth systems (thin films, alloys)
- Moving VFM wrt to e-beam orbit samples different ellipticity + helicity
- Present work aims to provide faster helicity switching by moving e-beam instead of VFM
Bipolar periodic angular shifts of +/- 0.25 mrad at the source point equivalent +/-0.4/γ ↔ +/-1 mm on VFM ↔ helicity sign change @ 70% polarization +/- 0.4 mm motion on BPMs on either side of the bend magnet

Frequency -> As High As Possible (present mirror move takes minutes), 10 Hz is the present goal

Time Dependence:
- Ideal: square wave (SW)
- Acceptable: SW w. reduced duty factor (no data taken for zero lock-in trigger)
- Rise-time (not shown) and ringing reduce the duty factor ⇒
- +/- 10% on ringing is O.K.
- 80% duty factor is O.K.

Dedicated time setup is straightforward
Goal to be part of regular operations i.e. invisible to the rest of the users
Constrains & General Approach

- We are not the first ones to try this out
- Other solutions exist (SLS, TLS, MAX2)
- VUV ring is densely packed with hardware => (Additional/modified hardware is hardly possible)
- We attempt to achieve the goals without new hardware but rather by modifying the existing 5 kHz orbit feedback system
- Establish a local bump desired by U4B users
- Change the fdbk algorithm to vary the reference orbit
- Change the algorithm to include feed-forward
- Feedback corrects for imperfect bump closure

- What is the maximum achievable rate? Is this acceptable to the rest of the users?
Local bump was established
Helicity, polarization checked by U4B group
There are other users “inside the bump” in addition to U4B
They will experience higher noise levels => rms comparable to the beam size => O.K. for some but not all
Coupling is not a problem
Trim power supplies are driven up to +/- 100% of their allowed range => large signal behavior becomes important…
Control Aspects of Dynamic Bump

- Original control design through loop shaping taking into account
  - User requirements
  - Noise spectrum & corr. capabilities
- Reference orbit was assumed fixed => never paid attention to “reference tracking”; as a result the tracking is quite poor =>
- Well-known control design trade-off: disturbance rejection vs. reference tracking
- Optimization is in progress, settling times of <10 ms are feasible (esp. if give up notch filter) => 10 Hz bump rate O.K.

Better tracking is possible at the expense of bandwidth (and give up notch filter)

- 160 Hz, 100 Hz, 80 Hz
- and hence 60 Hz rejection
- 30 dB, 7 dB, 2 dB
Corrector Power Supply Limitations

• Trim coils are inductive, $L$ up to $\sim 40$ mH
• Large signal PS response is sub-optimal - “spiky” output if hit slew rate or voltage limits
• Impose limitation for amplitude/speed of dynamic orbit bump; $L \Delta I / \Delta t < V_{\text{max}}$ ($\Delta I = 5\, \text{A}$, $V_{\text{max}} = 10\, \text{V}$) gives $\Delta t > 20$ ms, hence bump rate $< 5$ Hz
• Next steps are trying gradual ramps as well as adding matching networks at the PS output

KEPCO BOP-20-10 power supplies

- 0.1 V p-p, no DC offset
- 0.2 V p-p, 5V DC offset
We built 5 kHz digital orbit feedback systems for NSLS VUV (and X-ray) rings. The systems have unique architecture; they are compact and simple yet highly effective in suppressing orbit disturbances (up 100+ Hz) and are useful as diagnostics.

New user requirements at U4B bend magnet beamline call for large amplitude dynamic orbit bump at their source point.

Original control design for fixed reference orbit was done emphasizing disturbance rejection (vs. dynamic tracking); this is easily correctable and is not a severe limit on bump rate.

Orbit bump rate is limited due to sluggish and non-linear large signal step response of trim power supplies; we estimate that rates < 5 Hz should be possible w/o hardware modifications.

Further tests and user observations are planned for late 2008.
Acknowledgements

I am grateful to my colleagues from NSLS and elsewhere for their contributions to this work:

Dario Arena
Joe Dvorak
Brian Kushner
Susila Ramamoorthy
Om Singh
Dmitry Teytelman
Yong Tang
Emil Zitvogel