Highlights of the 2\textsuperscript{nd} Workshop on Beam Orbit Stabilization

12/04-06/2002, Spring8, Japan

Invaluable experience from electron & hadron rings such as ESRF, SLS, ……
(in orbit stabilization will benefit nanosize beam collider designs)

V. Shiltsev, A. Seryi

ICFA Nanometre Size Colliding Beam 2002

Y. Chao
Beam Physics Seminar
02/07/2003
3 Days of Workshop (9 am – 7 pm)

~ 40 presentations & ~5 discussion sessions

Organized by H. Tanaka, Spring 8

- Facility Reports
- Source Suppression
- Slow Orbit Measurement & Correction
- Fast Orbit Measurement & Correction
- Spring8 Tour & Invited Talk
- Strategy toward Sub-Micron Stability
Golden Rules

Requests from SR Users are Unlimited.

Users doubt Light Source before doubting their Own Equipments.

Collaboration between machine people and users is essential to achieve ultimate performance.
Extreme Sensitivity to Electron Beam Position

- Photon spectrum dependence on incoming beam position
  Notable shift with ~mm change in position
- Crystal monochromator

\[ \lambda = 2d \sin(\theta) \rightarrow \Delta \lambda = 2d \cos(\theta) \Delta \theta \]

- Thomson Scattering (slide of T. Ishikawa)

\[
E_{\text{distribution}} = E_{\text{point charge}} \int \int \int \rho(x) \exp[-i(K_s - K_o) \cdot x] d^3 x
\]

3D Fourier Transform of Charge Density

Scattered Intensity

\[
I = I_{\text{single}} \left| \int \int \int \rho(x) \exp[-i(K_s - K_o) \cdot x] d^3 x \right|^2
\]

\[
= \frac{r_s^2 \sin^2 \alpha}{r^2} I_0 \left| \int \int \int \rho(x) \exp[-i(K_s - K_o) \cdot x] d^3 x \right|^2
\]
Photon Users Can Provide Feedback on Electron Beam Quality

- Source beam size measurement
  - X-ray slit interferometry
- Optimal orbit / Orbit stability
  - Correlation with X-ray intensity & spectrum
What New Sciences will Come Up with the Further Stability of the Beam?

- Phase-Sensitive Imaging (such as holography) demands ultimate overall stability.
- Phase Retrieval of Coherent Scattering
### Causes for Orbit Distortions

#### Thermal

#### Vibration

#### Insertion Device Errors

#### Power Supply Ripple

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

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

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*Advanced Light Source*

December 4, 2002

Christoph Steier, IWBS 2002
Source Suppression

Temperature

Cooling water (temperature fluctuation, flow rate, valve shape, …..)

Ground motion – short & long term

Power supply

BPM drift/noise – thermal, intensity dependence, rogue HOM’s

Vacuum chamber vibration

ID induced disruption
4. Stabilization of F. O. V.
Fast (0.1 Hz ~ several kHz)
97’~02’ : Precise correction of gap & \( \phi \) dependent ID error fields (by ID Gr.)
00’winter : Suppression of Quad. Mag. PS current ripple I (by Takebe)
00’autumn: Suppression of coherent synchrotron oscillation
00’~02’ : Precise correction of ID error fields driven by fast phase switching (by ID Gr. and PJ team)

Fast (0.1 Hz ~ several kHz)
00’~01’ : Suppression of Quad. Mag. PS current ripple II (by Takebe)
01’~02’ : Suppression of Chamber Vibration in Quad. Mag. (by Matsu/Oishi)
Alignment / Monitor Methods at SLS (M. Boege)

**SR - Innovative Subsystems - Magnet Girders**

- Girders movable in 5 degrees of freedom
- Position monitoring systems on girders
- Girders Rail Precision: 15 μm
- Magnet Axis Calibrations: 30 μm
- Remotely Controlled Girders Movers
  - "Beam-Based Girders Alignment"
- Null Orbit x rms ~ 2 mm, y rms ~ 1 mm
- -> Magnet Misalignments < 50 μm

**SR - Innovative Subsystems - POMS**

- Measure BPM/Quadrupole offsets with 0.5 μm resolution in x and y
- 6 BPMs per sector
- BPMs rigidly attached to girders (BPM support mounted on girding rail)
- BPM supports serve as supports for the vacuum system (~ BPM chamber)

**Orbit Stability at the SLS**

- Tunnel Temperature stabilized to <0.5 deg peak-peak
  - 4 girders per sector connected through "virtual joints" established by IPS with 0.5 μm precision (~ "Train link")
  - Girders of sector self-contained with 2 reference points at the beginning of straight sections (~ x)
  - Absolute girders positions reconstructed from reference points and "virtual joints"

**SR - Stability - Worst Case Estimate**

- $\beta_x = 1.4$ m, $\beta_y = 0.9$ m at ID position of section n8
- $\sigma_x = 84 \mu$m, $\sigma_y = 7 \mu$m assuming emittance coupling $\epsilon_x/\epsilon_y = 1$
  - With stability requirement $\Delta \sigma = 0.1 \times \sigma$

**Requirement:** Orbit jitter < 1 μm at insertion devices

<table>
<thead>
<tr>
<th>Worst case Noise estimate</th>
<th>30 Hz</th>
<th>62 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic measurements</td>
<td>300 nm</td>
<td>30 nm</td>
</tr>
<tr>
<td>Damping by hall's concrete slab</td>
<td>neglected</td>
<td></td>
</tr>
<tr>
<td>Girder resonance max amplification</td>
<td>&lt; 10 dB</td>
<td>&lt; 10 dB</td>
</tr>
<tr>
<td>Closed orbit amplification hor./vert.</td>
<td>8/5</td>
<td>25/5</td>
</tr>
<tr>
<td>Maximum Orbit jitter hor./vert.</td>
<td>24/15</td>
<td>7.5/1.5 μm</td>
</tr>
<tr>
<td>Attenuation by orbit feedback</td>
<td>~55 dB</td>
<td>~35 dB</td>
</tr>
</tbody>
</table>

**Maximum Orbit Jitter hor./vert.**
- 40/30 μm
- 130/30 μm

IWBS'02
Excitation due to Vacuum Chamber Vibration (through Induced Eddy Current) S. Matsui & M Oishi, Spring-8
Magnet Ripple Induced Field due to Chamber Asymmetry,

H. Takebe, Spring-8

Q magnet Power Supply Tuning and Modification History

- 2000 Aug. 23–30: Thyristor Phase Tuning
- 2000 Sep. 8–10: Input Transformer adopted
- 2001 May 8–10: DCST exchange
- 2002 Jan.: Phase Control Circuit Modify
Damping Links at ESRF
(L. Farvacque & L. Zhang)
Invar Strut Support for BPMs

SPEAR 3

(J. Safranek/SSRL)

Rigidity against temperature change

With photon beam line users, absolute alignment of BPM’s becomes more favorable to many light sources.
Characterizing Ground Motion Caused by Lorry Traffic at SOLEIL (M-P. Level)

- Can be up to 0.7 µm peak-to-peak, too much
- Test conducted by running trucks on neighboring roads
- Condition for worst source of 2.5 Hz vibration identified as resonance between truck suspension & characteristic frequency of the ground
  → 60 km/h truck over 3m long ground deformations

We notice that the lorry produces essentially a frequency of 2.5 Hz (0.57 micron peak-to-peak)
Slow Orbit Control

Architecture (some control system particularities)

Configuration issues (full or partial SVD, interference of control loops, …….) General understanding in this circle appears elementary

Stability on slow time scale (precision of magnets, BPM resolution, DAC/ADC, ……..)

ID related issues (XBPM used in loop, special ID bump configuration, impact of ID motion/switching)

Operational issues (BPM offset dependence on current degradation, top-up impact, ………)

Most systems can get close to µm level, but requirements are tightening up…….
Fast Feedback

- Mostly about digital BPM’s
- Mostly similar architecture with ~kHz update rate correcting to a few µm

SLS Digital BPM System
(T. Schilcher)

4 kHz planned for 2003

Decentralized system
Strategy toward Sub-Micron Stability

- Electrical power systems
- BPMs (resolution & stability)
- Feedback on X-rays
- ID improvements
- Building stability
Digital BPM’s
Configurable for both high bandwidth (turn by turn) and low bandwidth (closed orbit correction)

R. Ursic (Inst. Tech.)
M. Boege (SLS)
BPM options for high resolution, high stability operation

J-C. Denard (SOLEIL)

0.2 µm / sec; 3 µm / month
X-BPM

Example: APS XBPMS used in insertion devices

Metalized CVD diamond blades

Provides additional accuracy needed in the ID

Integrated into the global orbit control system

0.2 $\mu$rad over 24 hrs.

Variable ID gap calibration
MOSTAB

User keeps complaining!

MOSTAB (Monochromator Stabilization) module applies a feedback voltage to the piezo actuator of DCM.
Tour of SPring8 & 1 km Beamline

3D reconstruction of non-crystalline structure

50 nm 3D
8 nm 2D
Conclusion

• Very interesting progress has been made worldwide towards achieving micron orbit stability over broad time scale

• Major challenge seems to be ground motion, while other causes can be isolated and addressed

• Active control mainly benefited from BPM improvements. But configuration / algorithm issues will catch up sooner or later.

• Digital boundary further upstream

• A few things that we can learn from