Orbit Stabilization
at
Taiwan Light Source

Kuo-Tung Hsu

December 6, 2004
NSRRC Accelerator

- Storage Ring (1.51 GeV)
- Booster Ring (1.51 GeV)
- LINAC
- Transport Line

- Bending Magnet
- Quadrupole Magnet
- Pulsed Injection Magnet
- Sextupole Magnet
- SRF Cavity
- Insertion Device

- BM2
- BM1
- SWLS (6 T)
- W20 (1.8 T)
- SW6 (3.2 T)
- IASW6 (3.5 T) x 3 sets
- EPU5.6
- U5

December 2004
4 Conventional IDs
2 Superconducting IDs
22 Beamlines
56 End-stations

- U9 (1.25 T)
**Major Parameters of the Storage Ring**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lattice type</td>
<td>Combined function Triple Bend Achromat (TBA)</td>
</tr>
<tr>
<td>Operational energy</td>
<td>1.5 GeV</td>
</tr>
<tr>
<td>Circumference</td>
<td>120 m</td>
</tr>
<tr>
<td>RF frequency</td>
<td>499.654 MHz</td>
</tr>
<tr>
<td>Harmonic number</td>
<td>200</td>
</tr>
<tr>
<td>Natural beam emittance</td>
<td>25.6 nm-rad</td>
</tr>
<tr>
<td>Natural energy spread</td>
<td>0.075%</td>
</tr>
<tr>
<td>Momentum compaction factor</td>
<td>0.00678</td>
</tr>
<tr>
<td>Damping time</td>
<td></td>
</tr>
<tr>
<td><strong>Horizontal</strong></td>
<td>6.959 ms</td>
</tr>
<tr>
<td><strong>Vertical</strong></td>
<td>9.372 ms</td>
</tr>
<tr>
<td><strong>Longitudinal</strong></td>
<td>5.668 ms</td>
</tr>
<tr>
<td>Betatron tunes horizontal/vertical</td>
<td>7.18/4.13</td>
</tr>
<tr>
<td>Natural chromaticities</td>
<td></td>
</tr>
<tr>
<td><strong>Horizontal</strong></td>
<td>-15.292</td>
</tr>
<tr>
<td><strong>Vertical</strong></td>
<td>-7.868</td>
</tr>
<tr>
<td>Synchrotron tune</td>
<td>1.06<em>10^{-2} (SRF, 1.52</em>10^{-2})</td>
</tr>
<tr>
<td>Bunch length</td>
<td>9.2 mm (Doris Cavities, 800 kV)</td>
</tr>
<tr>
<td><strong>Radiation loss per turn (dipole)</strong></td>
<td>128 keV</td>
</tr>
<tr>
<td><strong>Nominal stored current (multibunch)</strong></td>
<td>200 mA (<del>2004), 300</del>400 mA (2005~)</td>
</tr>
<tr>
<td><strong>Number of stored electrons (multibunch)</strong></td>
<td>5*10^{11} (SRF cavity, 10^{12})</td>
</tr>
</tbody>
</table>
Efforts to Improve Beam Stability

Coupled-bunch instability:

- RF gap voltage modulation (~ October 2004)
- Superconducting RF (December 2004 ~)
  (to accompany double the stored beam current).

Coupled bunch feedback system

Orbital stability:

Source Elimination

- Ambient temperature, Water temperature, Enhance data acquisition system, Vibration elimination, Power quality improvement, Power supply improvement …etc.

Orbit feedback system

Top-up injection
# Mechanical Related Source Elimination

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance, T &lt; sub&gt; orbit&lt;/sub&gt; lo/lo</td>
<td>&gt; 1</td>
<td>~ 0.25</td>
<td>&lt; 0.2</td>
<td>~ 0.15</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>(drift&gt;50 m) &gt;1%</td>
<td>3 m rms</td>
<td>(drift~20 m)</td>
<td>&lt;3 m rms</td>
<td>0.1 m rms</td>
<td>0.1 m rms</td>
<td>0.3%</td>
</tr>
<tr>
<td></td>
<td>~0.15%</td>
<td>&lt;0.5%</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>~0.06%</td>
</tr>
<tr>
<td>(drift&gt;50 m) &gt;1%</td>
<td>20 m</td>
<td>(drift&lt;5 m)</td>
<td>50 m</td>
<td>&gt;50 m</td>
<td>&gt;50 m</td>
<td>&gt;1%</td>
</tr>
<tr>
<td></td>
<td>~0.25</td>
<td>&lt;1 m rms</td>
<td>~0.5%</td>
<td>&lt;1 m rms</td>
<td>&lt;0.3%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>~0.25</td>
<td>&lt;0.3%</td>
<td>&lt;0.2</td>
<td>&lt;0.3%</td>
<td>&lt;0.2</td>
<td>&lt;0.3%</td>
</tr>
</tbody>
</table>

1. **Utility Capacity Improvement**  
   - CTW, CHW Stability  
   - Utility building #2 construction  
   - CHW capacity improved

2. **Heat Source Stabilization**  
   - Global effect studies (air/water temp., cable heat)  
   - Injector energy upgrade full energy injection  
   - EPU air temp.  
   - Power supply heating  
   - U5 air temp.

3. **Thermal-Mechanical Effects**  
   - Girder, thermal insulator, vacuum chamber, SR heat mask  
   - BL-, RF-DIW temp.  
   - I monitor

4. **Vibration**  
   - AHU, crane vibration pre-reduced  
   - Damping study  
   - Piping improv.  
   - Floor meas.

5. **Sensors Implementation**  
   - Air temp. sensors  
   - Position sensors  
   - SCADA implementation electrical sensors

6. **Control System**  
   - Water control system upgrade  
   - VF controller implementation  
   - Utility data archive system  
   - AHU controller upgrade  
   - AHUs reorganized

(J. R. Chen, et. al.)
Magnet (Water Temperature)

Caused by the temperature fluctuations of magnet cooling water
Magnet deformed ~ 10 m/
Induced beam orbit drift: 5 ~ 50 m /
Current status
Cooling water temp.: ~ 0.1
Girder Displacement

- Main cause: air temperature
  - Sensitivity to air temp.: ~10 m / 
  - Induced beam orbit drift: 20-100 m / 
- Current status: < 0.1 m per 8 hr shift
  - Air temp. : < 0.1 
  - (utility control system improved)
  - Thermal insulator jacket
Expansion of Vacuum Chamber

- Caused by synchrotron light irradiation.
  - Sensitivity to water temp.: $\sim 10$ m/
  - Move the girder ($\sim 0.3$ m/) and BPM ($\sim 1$ m/)
  - Induced beam orbit drift: $\sim 10$-30 m/

- Current status
  - Vacuum cooling water temp.: $\sim 0.5$
Power Supply Related High Frequency Orbital Noise (Source Elimination)

Beam Spectrum Observation

@ 136 mA (August 22, 2001)
High Frequency Corrector Power Supply Noise

Typical Corrector Spectrum

Before Improve

After Improve

(K.B. Liu et al.)
Observation at Infrared Beamline

Before
Improve
Mar.08, 2002
186mA

After
Improve
June 13, 2002
185mA

RMS=0.03%
RMS=0.16%

(Y. C. LO, et al.)
Orbit Feedback System Summary

* 22 correctors + 30 BPMs for both plane
* Using measured response matrix
* Singular Value Decomposition (SVD) approach to invert the response matrix
* Proportional, Integral and Derivative (PID) control algorithm
* Orbit acquisition rate 1 kHz
* Loop bandwidth is about 5 Hz now (30 Hz before December 2003)
* Unified system for global feedback and local feedback system
* Remote enable/disable of the feedback loop
* Orbit excursion reduced to less than ~ um level for ID operation
  - U5, U9 and EPU5.6
* Suppress orbit leakage due to non-ideal dynamic local bump
  - EPBM
* Prototype local feedback loop by using e-BPMs
Orbit Feedback System Summary (cont.)

* DSP feedback engine was replaced by general purpose PPC module
  User friendly development environment
  Lift maintenance difficults
  Slightly increase jitter < 50 μsec (DSP < 10 μsec)

* Robustness enhancement of the feedback loop
  BPM Check
    RMS, data change rate, …etc
  Limited correct setting range
Problems and Plan of the Orbit Feedback System

Major Problems:
* Loop bandwidth is too small right now
  => cannot eliminate mechanical related oscillation
  => Limited gap/phase changing speed of IDs

Short-term Plans:
* Increase sampling rate o 2 kHz to 4 kHz
* Modify corrector power supply regulation loop
* Increase loop bandwidth > 100 Hz
Closed Orbit and Orbit Stability

Closed Orbit: $\sim 10 \, \mu m$ rms with DC correction schemes. (Peace Chang et al.)

Orbit distortions: $< 10 \, \mu m$ rms during insertion gap scan can be compensated for using look-up correction tables. (Peace Chang et al.)

Beam orbit stability: *a few $\mu m$ level (peak-to-peak)* with a global feedback system. (C. H. Kuo et al.)
Eliminated Orbit Leakage for EPBM Operation

Block Diagram of Control Electronics for Elliptical Polarization from Bending Magnet (EPBM) Project

Clock Generator

Line Driver x 2

EPBM

12 Bits DAC

Bump Coefficient (± 10 V)

Ratio Amplifier x 4

Instrumentation Amplifier x 8

Correction Strength

ILC03

ILC12

EPBM flip bump without feedback

* EPBM dynamic bump with feedback

(C.H. Kuo et. al.)
Insertion Devices in the TLS Storage Ring

<table>
<thead>
<tr>
<th>Insertion Device</th>
<th>SWLS</th>
<th>EPU5.6</th>
<th>U5</th>
<th>SW6</th>
<th>W20</th>
<th>U9</th>
<th>IASW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location Section</td>
<td>S1</td>
<td>S2</td>
<td>S3</td>
<td>S4/RF</td>
<td>S5</td>
<td>S6</td>
<td>Arc 2,4,6</td>
</tr>
<tr>
<td>Type</td>
<td>SC</td>
<td>Pure</td>
<td>Hyb.</td>
<td>SC</td>
<td>Hyb.</td>
<td>Hyb.</td>
<td>SC</td>
</tr>
<tr>
<td>Magnet Length (M)</td>
<td>0.835</td>
<td>3.9</td>
<td>3.9</td>
<td>1.404</td>
<td>3.0</td>
<td>4.5</td>
<td>0.85</td>
</tr>
<tr>
<td>Period Length (cm)</td>
<td>25</td>
<td>5.6</td>
<td>5</td>
<td>6</td>
<td>20</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>(Min.) Gap (mm)</td>
<td>55</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>22</td>
<td>18</td>
<td>18.5</td>
</tr>
<tr>
<td>Number of Periods</td>
<td>1.5</td>
<td>66</td>
<td>76</td>
<td>16</td>
<td>13</td>
<td>48</td>
<td>7.5</td>
</tr>
<tr>
<td>Maximum By (Bx) Field (Tesla)</td>
<td>6</td>
<td>0.67 (0.45)</td>
<td>0.64</td>
<td>3.2</td>
<td>1.8</td>
<td>1.25</td>
<td>3.5</td>
</tr>
<tr>
<td>Photon Energy (eV)</td>
<td>Min.</td>
<td>4000</td>
<td>80</td>
<td>60</td>
<td>5000</td>
<td>800</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>38000</td>
<td>1400</td>
<td>1500</td>
<td>14000</td>
<td>15000</td>
<td>100</td>
</tr>
<tr>
<td>Defection Parameter Ky (Kx)</td>
<td>190.5</td>
<td>3.52 (2.37)</td>
<td>2.99</td>
<td>17.9</td>
<td>33</td>
<td>10.46</td>
<td>19.6</td>
</tr>
<tr>
<td>Vertical Tune Shift (Horizontal Tune Shift)</td>
<td>0.0504 (-0.014)</td>
<td>0.011 (-0.012)</td>
<td>0.008</td>
<td>0.036</td>
<td>0.036</td>
<td>0.033</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The photon flux vs. photon energy of bending magnets and IDs at TLS. Two Taiwan beamlines, SP8-BM and SP8-U3.2, at Spring 8 are also depicted.
With the follow-gap look-up table and global orbit feedback system, the orbit drift of the field scan of U5, U9 and EPU5.6 can be reduced from a few hundred microns to \textit{a few microns}. When the gaps of U5, U9 and EPU5.6 are scanned from 19, 21, and 21 mm to 39, 41, and 41 mm, the closed orbit distortions indicated by the R4BPM5X (blue) and R3BPM3Y (green), those are used in the faster orbit feedback system, are within 2 microns in both horizontal and vertical planes.

(Peace Chang, et. al.)
Photon Beam Stability Monitor ($\Delta I_o / I_o$)

Sensitive to:
- Beam size instability
- Orbit instability
- Energy instability

Signpost of overall beam stability from users’ viewpoints

Demagnification factor: 3

50 um pinhole

Photo Diode

Electron Beam Stability (Transverse, Longitudinal, Beamsize, …)

Thermal Deformation

Backlash

Driver Mechanism (Optimization)
History of the Photon Beam Stability ($\Delta I_0/I_0$)

(K.K. Lin et al.)
Top-up Injection Project

Top-up injection scheme planned.
Feasibility demonstrated.

Date: Dec. 31, 2002 Top-up mode Test

*Orbit change referred to the data at 1130 minute is taken with 10 Hz sampling rate.

ΔR3BPM3Y (red line)

ΔR4BPM5X (blue line)

Stored beam current
*Injection threshold current is 198 mA

(G.H. Luo et. al.)
Experiment of Top-up injection

Filling pattern at the beginning of top-up injection

User's shift decay mode

Test of top-up mode

Filling pattern at the end of top-up injection

Zoom in, injection interval 2 min.

(G.H. Luo et. al.)
Cooling Water and Chamber Temperature

Outlet cooling water temperature
Chamber’s temperature
Top-up test run

(G.H. Luo et. al.)
Compound Displacement of the Beam Position Monitor Reading

- Intensity dependency of BPM electronic and BPM support fixtures (~ μm)
- Filling pattern dependency of BPM electronics (~ μm)
- RF gap voltage condition variation
- BPM support structure (~ 10 μm)
- Thermal related (~ 10 μm)

δx ~15 μm

δy ~5 μm

Top-up test run

(G.H. Luo et. al.)
Vertical Beam Position Variation

R1BPM1Y

Top-up test run

R2BPM7Y

20 µm

R6BPM4Y

20 µm
Horizontal Beam Position Variation

R1BPM1X

\[ \downarrow 20 \, \mu m \]

R3BPM8X

\[ \downarrow 9 \, \mu m \]

R4BPM3X

\[ \downarrow 5 \, \mu m \]

Top-up test run
Renew 1.5 μsec half-since injection kicker to reduced jitter and to improve waveform matching. Gate of the orbit feedback loop is a provincial solution to remedy mismatching problem of the injection kickers. User experiment with injection gate and without is performed, acceptable results get up to now. Improve gun pulser and linac performance to improve filling pattern control. Studies of the injector reliability, injection efficiency, and minimization of orbit perturbation during injection, etc., are ongoing. Top-up operation is scheduled in late 2005.
### Parameters of the Proposed Taiwan Photon Source

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Energy</td>
<td>3 ~ 3.3 GeV</td>
</tr>
<tr>
<td>Current</td>
<td>400 mA at 3 GeV or 300 mA at 3.2 GeV (Top-up injection)</td>
</tr>
<tr>
<td>SR Circumference</td>
<td>518.4 m (h = 864 = 2⁵·3³, dia.= 165.0 m)</td>
</tr>
<tr>
<td>BR Circumference</td>
<td>499.2 m (h = 832 = 2⁶·13, dia.= 158.9 m)</td>
</tr>
<tr>
<td>Lattice</td>
<td>24-cell DBA</td>
</tr>
<tr>
<td>Straight-section</td>
<td>10.5 m x 6 (v = 10.5 m, h = 160 m)</td>
</tr>
<tr>
<td></td>
<td>6 m x 18 (v = 8 m, h = 110 m)</td>
</tr>
<tr>
<td></td>
<td>3 m x 12 (v = 4.5 m, h = 250 m; In-achromat)</td>
</tr>
<tr>
<td>Bending-section</td>
<td>x 12</td>
</tr>
<tr>
<td>Emittance</td>
<td>&lt; 2 nm·rad at 3 GeV (Distributed dispersion)</td>
</tr>
<tr>
<td>Coupling</td>
<td>1 %</td>
</tr>
<tr>
<td>RF Frequency</td>
<td>500 MHz</td>
</tr>
<tr>
<td>RF Max. Voltage</td>
<td>4.8 MV (4 SRF cavities)</td>
</tr>
<tr>
<td>RF Max. Power</td>
<td>720 kW (4 SRF cavities)</td>
</tr>
<tr>
<td>Site</td>
<td>NSRRC in Hsinchu Science Park, Taiwan</td>
</tr>
<tr>
<td>Building</td>
<td>223 m OD (700 m circumference)</td>
</tr>
<tr>
<td></td>
<td>139 m ID (437 m circumference)</td>
</tr>
</tbody>
</table>

Sub-μm orbital performance is one of a design goal.
Summary

* To achieve µm (sub-µm) orbital performance is a short term goal at TLS.
* Further develop of fast orbit feedback system is needed in following area:
  • Corrector PS improvement
  • High sampling rate (~ 2 KHz/4 KHz)
  • PS control interface
  • BPM system improvement in engineering as well as software functionality.
* Top-up operation mode is scheduled, beam orbit stability will be improve further.
* Sub-µm orbital performance is one of a challenge for the newly proposed 3 ~ 3.3 GeV Taiwan Photon Source
Thank you for your attention.