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

EPU5.6

U5

SRF Cavity (Dec. 2004)

SW6 (3.2T)

IASW6 (3.5 T) x 3 sets

Bending Magnet

Quadrupole Magnet

Pulsed Injection Magnet

Sextupole Magnet

SRF Cavity

Insertion Device

December 2004

4 Conventional IDs

2 Superconducting IDs

22 Beamlines

56 End-stations

SWLS (6 T)

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>
</tbody>
</table>
| Damping time:
  Horizontal                                  | 6.959 ms                    |
  Vertical                                      | 9.372 ms                    |
  Longitudinal                                  | 5.668 ms                    |
| Betatron tunes horizontal/vertical            | 7.18/4.13                   |
| Natural chromaticities:
  Horizontal                                   | -15.292                     |
  Vertical                                      | -7.868                      |
| Synchrotron tune                              | $1.06 \times 10^{-2}$ (SRF, $1.52 \times 10^{-2}$) |
| Bunch length:
  Doris Cavities, 800 kV                      | 9.2 mm                      |
  SRF, 1.6 MV                                  | 6.5 mm                      |
| Radiation loss per turn (dipole)              | 128 keV                     |
| Nominal stored current (multibunch)           | 200 mA (~2004), 300–400 mA (2005~) |
| Number of stored electrons (multibunch)       | $5 \times 10^{11}$ (SRF cavity, $10^{12}$) |

**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**
**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.: ~ 10 m/
  Move the girder (~ 0.3 m/) and BPM (~ 1 m/) 
  Induced beam orbit drift: ~10-30 m/
- Current status
  Vacuum cooling water temp.: ~ 0.5
Power Supply Related High Frequency Orbital Noise (Source Elimination)

@ 136 mA (August 22, 2001)

High Frequency Corrector Power Supply Noise

Typical Corrector Spectrum

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

Before Improve
Mar. 08, 2002
186 mA

After Improve
June 13, 2002
185 mA

RMS = 0.03%
RMS = 0.16%

(Y. C. LO, et al.)

Environment of BPM System

Software Environment for BPM Data Access

Consoles Computers
(Compaq WS/Unix) (PC/Linux)

BPM VMEs Crates
(PPC/LynxOS)

BPM Data Acquisition

Closed Orbit Data

Control Applications

Machine Diagnostics Program

Data Logging & Archiving Program

Parameter Page Program

Parameter Checking Program

System Status Display

Real-Time Trend Display

Machine Modeling Service Routines

MATLAB Interface

MATLAB Scripts AP

Software Components On Control Consoles

Turn-by-Turn Data Access

Control Ethernet

DBPM LR-BPM Hardware

DBPM Hardware

BPM Data

Mode Control

Control Program

Reflective Memory (RM) Fast Orbit, 1 K-samples/sec

Reflective Memory (RM) Fast Orbit, 1 K-samples/sec

MX-BPM Hardware

Closed Orbit Server

Self-Configuration Table

Data Acquisition

MX-BPM Data Acquisition

To other DBPM nodes

DBPM Hardware

Environment of BPM System

April 2003

National Synchrotron Radiation Research Center
Orbit Feedback System Architecture

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: ~10 µm rms with DC correction schemes. (Peace Chang et al.)

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

Beam orbit stability: a few µm level (peak-to-peak) with a global feedback system. (C. H. Kuo et al.)

Eliminated Orbit Leakage for EPBM Operation

* 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>LASW</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</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>3.6</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</td>
<td>0.64</td>
<td>3.2</td>
<td>1.8</td>
<td>1.25</td>
<td>3.5</td>
</tr>
</tbody>
</table>

| Vertical Tune Shift (Horizontal Tune Shift) | 0.011 | 0.008 | 0.036 | 0.036 | 0.003 | 0.05 |
| (Horizontal Tune Shift) | (-0.012) | (-0.014) |


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.

Orbit stability of the NSRRC Storage Ring

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 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 ($\Delta I_0 / I_0$)

BM3

VFM

50 um pinhole

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

Thermal Deformation

Backlash

Driver Mechanism (Optimization)

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

Demagnification factor : 3

Signpost of overall beam stability form users’ viewpoints

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

Achieved Percentage in User Time

May 2001
Jan 2002
Jan 2003
Jan 2004

Improve cavity temperature control at 30% user time
U5, U9, EPU dynamic tuning at 100% user time
Relax U5, U9, EPU dynamic tuning speed

long shutdown

(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.

Stored beam current
Injection threshold current is 198 mA

Top-up Injection Project

Experiment of Top-up injection

User’s shift decay mode
Test of top-up mode
Filling pattern at the end of top-up injection
Filling pattern at the beginning 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

Compound Displacement of the of 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

Stored beam current in mA

R1 BPM3 X displacement in µm

R1 BPM3 Y displacement in µm

Top-up test run
Vertical Beam Position Variation

- **R1BPM1Y**: 20 µm
- **R2BPM7Y**: Top-up test run
- **R6BPM4Y**: 20 µm

Horizontal Beam Position Variation

- **R1BPM1X**: 20 µm
- **R3BPM8X**: Top-up test run, 9 µm
- **R4BPM3X**: 5 µm
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>Value</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 = 2^5·3^3, dia.= 165.0 m)</td>
</tr>
<tr>
<td>BR Circumference</td>
<td>499.2 m (h = 832 = 2^7·13, 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 you attention