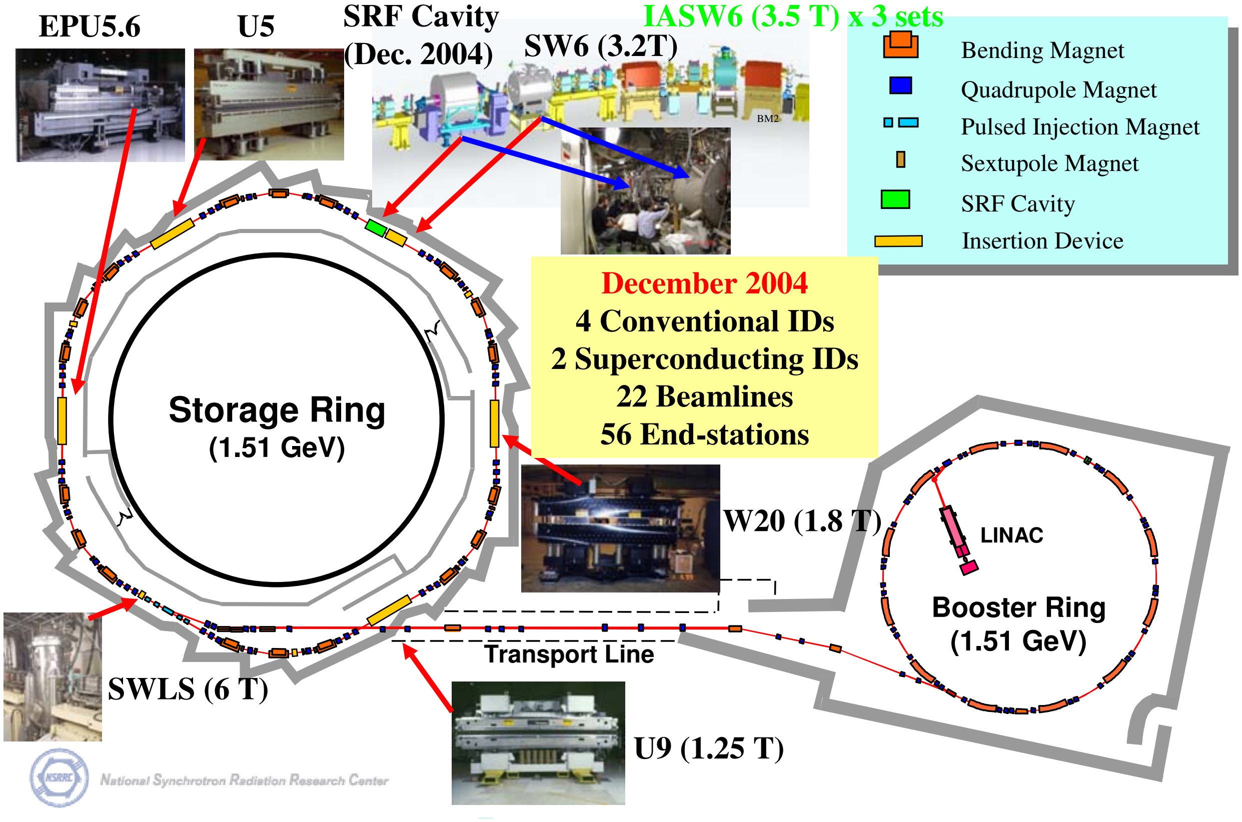
3rd International Workshop on Beam Orbit Stabilization - IWBS2004
December 6-10, 2004
Hotel Kirchbühl, Grindelwald, SWITZERLAND

Orbit Stabilization at Taiwan Light Source

Kuo-Tung Hsu

December 6, 2004

NSRRC Accelerator



▬	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

Major Parameters of the Storage Ring

Lattice type	**Combined function Triple Bend Achromat (TBA)**
Operational energy	**1.5 GeV**
Circumference	**120 m**
RF frequency	**499.654 MHz**
Harmonic number	**200**
Natural beam emittance	*25.6 nm-rad*
Natural energy spread	*0.075%*
Momentum compaction factor	*0.00678*
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	**$1.06*10^{-2}$ (SRF, $1.52*10^{-2}$)**
Bunch length	**9.2 mm (Doris Cavities, 800 kV)** **6.5 mm (SRF, 1.6 MV)**
Radiation loss per turn (dipole)	**128 keV**
Nominal stored current (multibunch)	**200 mA (~2004), 300~400 mA (2005~)**
Number of stored electrons (multibunch)	**$5*10^{11}$ (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

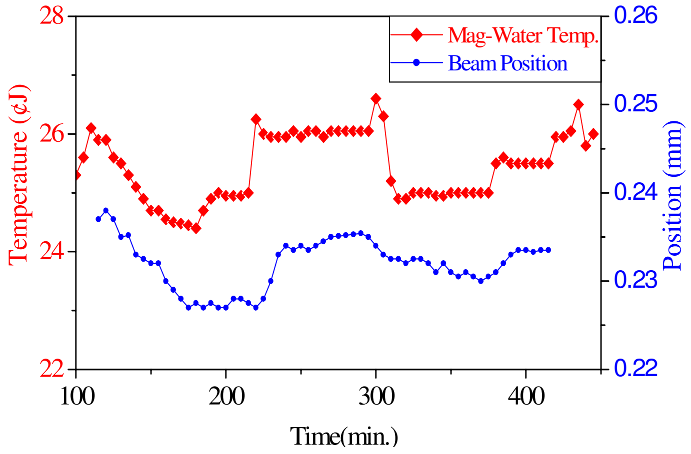
Top-up injection

Mechanical Related Source Elimination

Program initiation	1997	1998	1999	2000	2001	2002	
Performance, T **orbit** **Io/Io**	> 1 (drift>50 m) >1%	~ 0.25	< 0.2 (drift~20 m)	~ 0.15 <3 m rms ~0.5%	< 0.1 (drift<5 m)	< 0.1 <1 m rms <0.3%	(2003) ~ 0.06%
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		Floor meas.	Piping improv.	
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

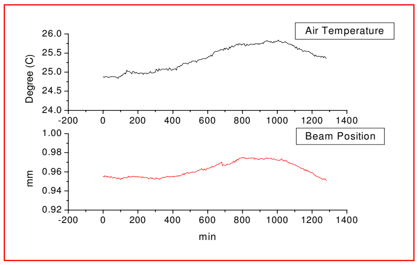
Magnet deformed ~ 10 m/

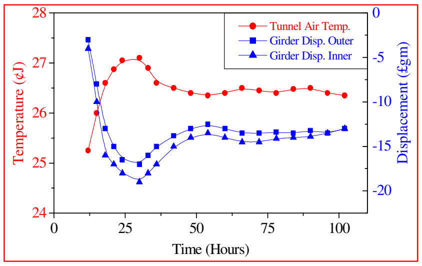
Induced beam orbit drift: 5 ~ 50 m /

Current status

Cooling water temp.: ~ 0.1

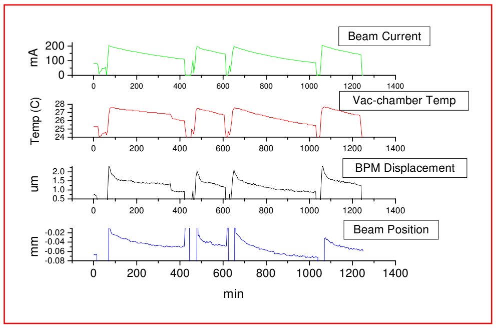
Girder Displacement

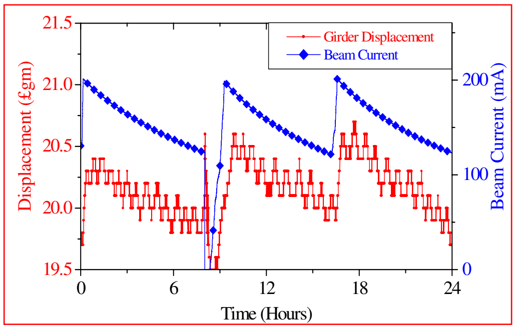




- Main cause: air temperature
  Sensitivity to air temp.: ~10   m /
  Induced beam orbit drift: 20-100   m /
- Current status: <   0.1   m per 8 hr shift
  Air temp. : <   0.1
  (utility control system improved)
  Thermal insulator jacket

Expansion of Vacuum Chamber

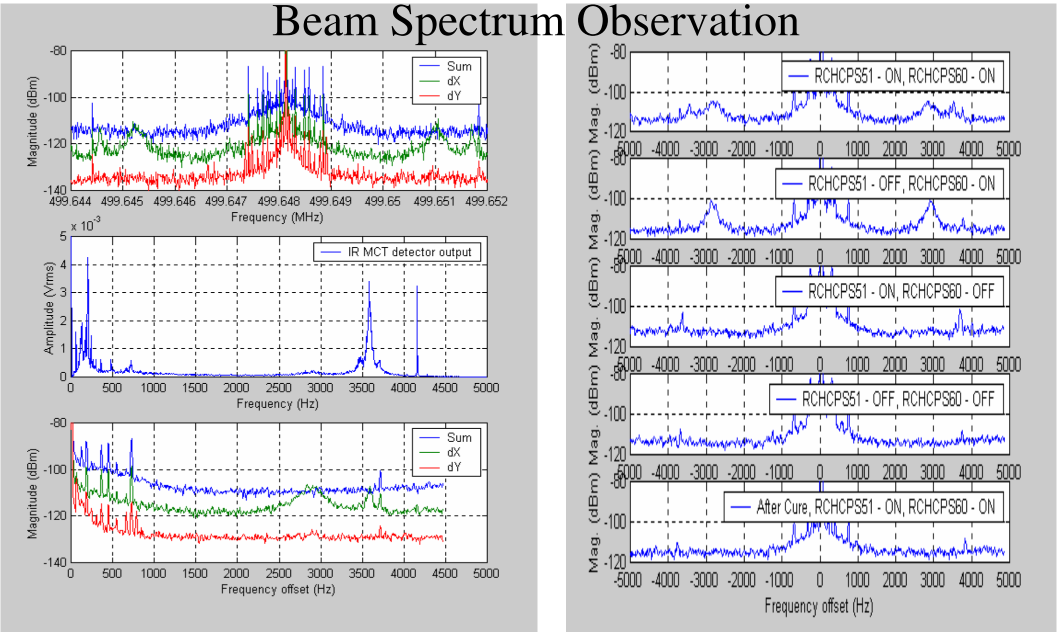




- Caused by synchrotron light irradiation.
  Sensitivity to water temp.: ~ 10   m /
  Move the girder (~ 0.3   m/   ) and BPM (~ 1   m/   )
  Induced beam orbit drift: ~10-30   m /
- Current status
  Vacuum cooling water temp.: ~   0.5

Power Supply Related High Frequency Orbital Noise (Source Elimination)

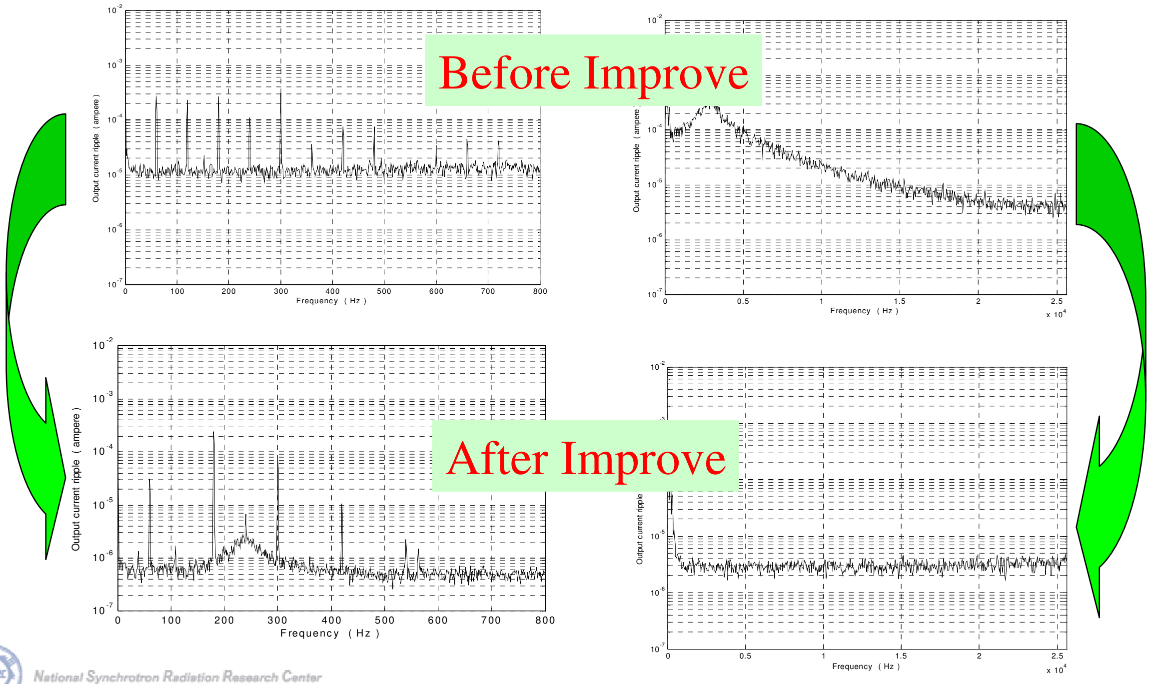
Beam Spectrum Observation



@ 136 mA (August 22, 2001)

High Frequency Corrector Power Supply Noise

Typical Corrector Spectrum

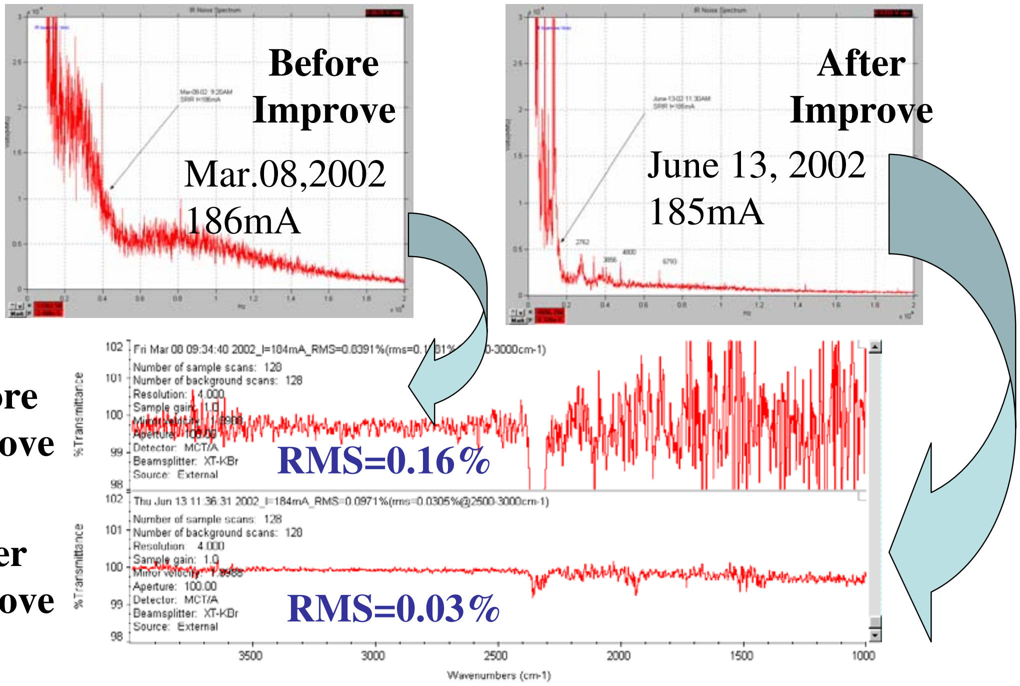


Before Improve

After Improve

(K.B. Liu et al.)

Observation at Infrared Beamline



Before Improve

Mar.08,2002
186mA

After Improve

June 13, 2002
185mA

Before Improve

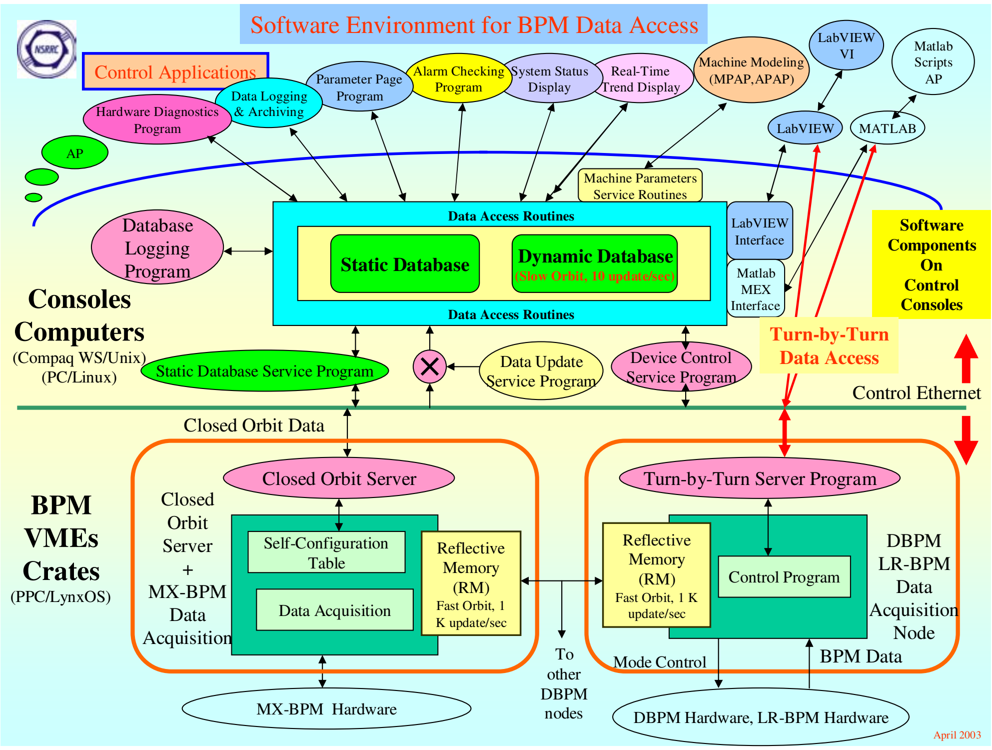
RMS=0.16%

After Improve

RMS=0.03%

(Y. C. LO, et al.)

Environment of BPM System



Software Environment for BPM Data Access

Control Applications

AP

Hardware Diagnostics Program

Data Logging & Archiving

Parameter Page Program

Alarm Checking Program

System Status Display

Real-Time Trend Display

Machine Modeling (MPAP,APAP)

LabVIEW VI

Matlab Scripts AP

LabVIEW

MATLAB

Machine Parameters Service Routines

Data Access Routines

Static Database

Dynamic Database (Slow Orbit, 10 update/sec)

Data Access Routines

LabVIEW Interface

Matlab MEX Interface

Software Components On Control Consoles

Database Logging Program

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

Static Database Service Program

Data Update Service Program

Device Control Service Program

Turn-by-Turn Data Access

Control Ethernet

Closed Orbit Data

BPM VMEs Crates
(PPC/LynxOS)

Closed Orbit Server

Closed Orbit Server + MX-BPM Data Acquisition

Self-Configuration Table

Data Acquisition

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

MX-BPM Hardware

To other DBPM nodes

Turn-by-Turn Server Program

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

Control Program

DBPM LR-BPM Data Acquisition Node

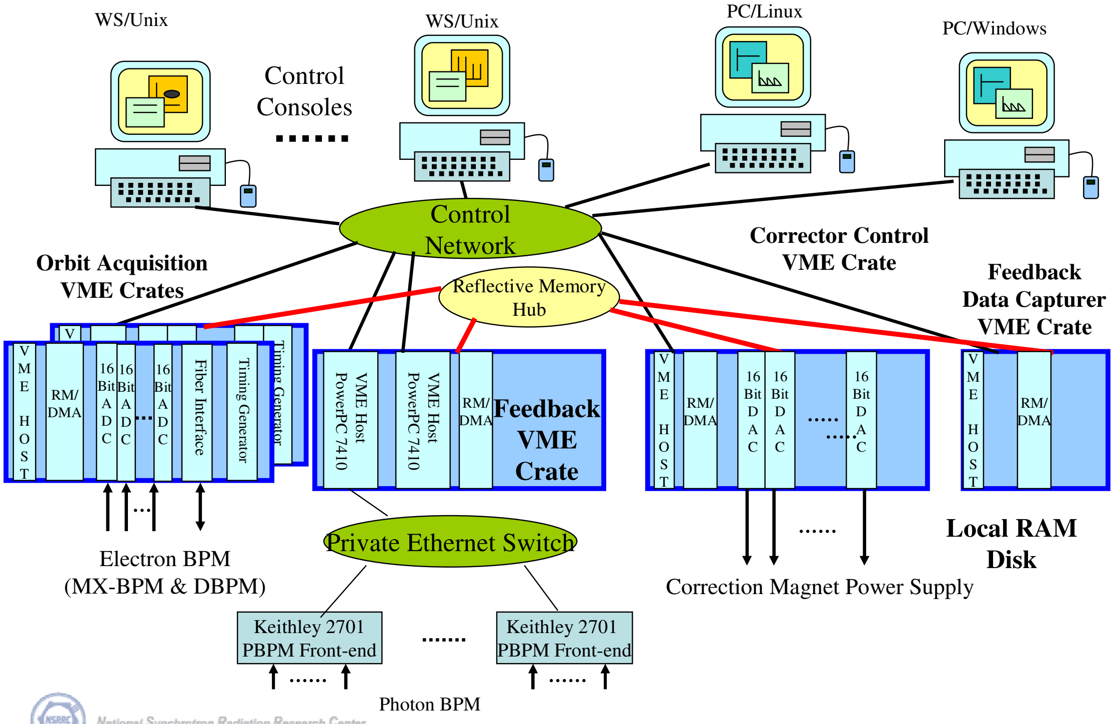
Mode Control

BPM Data

DBPM Hardware, LR-BPM Hardware

April 2003

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

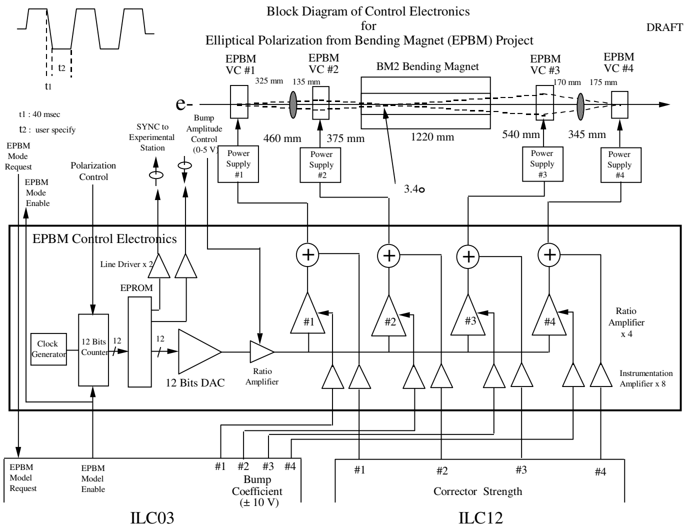
Closed Orbit and Orbit Stability

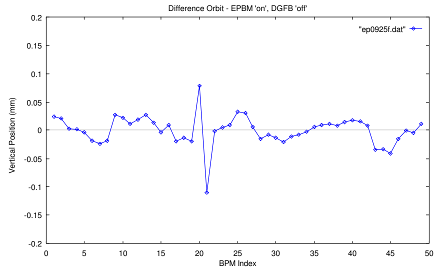
Closed Orbit : ~10 µm rms with DC correction schemes. (Peace Chang et al.)

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

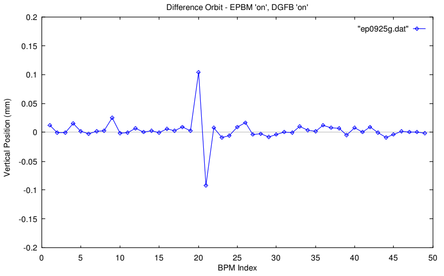
Beam orbit stability: *a few* µm *level (peak-to-peak)* with a global feedback system. (C. H. Kuo et al.)

Eliminated Orbit Leakage for EPBM Operation





EPBM flip bump without feedback



* EPBM dynamic bump with feedback

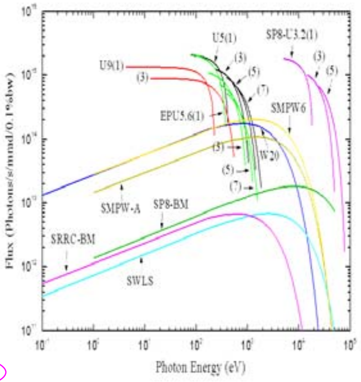
(C.H. Kuo et. al.)

Insertion Devices in the TLS Storage Ring

Insertion Device		SWLS	EPU5.6	U5	SW6	W20	U9	IASW
Location Section		S1	S2	S3	S4/RF	S5	S6	Arc 2,4,6
Type		SC	Pure	Hyb.	SC	Hyb.	Hyb.	SC
Magnet Length (M)		0.835	3.9	3.9	1.404	3.0	4.5	0.85
Period Length (cm)		25	5.6	5	6	20	9	6
(Min.) Gap (mm)		55	18	18	18	22	18	18.5
Number of Periods		1.5	66	76	16	13	48	7.5
Maximum By (Bx) Field (Tesla)		6	0.67 (0.45)	0.64	3.2	1.8	1.25	3.5
Photon Energy (eV) [Used Range]	Min.	4000	80	60	5000	800	5	5000
	Max.	38000	1400	1500	14000	15000	100	14000
Defection Parameter Ky (Kx)		190.5	3.52 (2.37)	2.99	17.9	33	10.46	19.6
Vertical Tune Shift (Horizontal Tune Shift)		0.0504 (-0.014)	0.011 (-0.012)	0.008	0.036	0.036	0.033	0.05
Installation Date		Apr. 2002	Sep. 1999	Mar. 1997	Dec. 2003	Dec. 1994	Apr. 1999	2005

without
Feed-forward
Tune
Correction

with
Feed-forward
Tune
Correction



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

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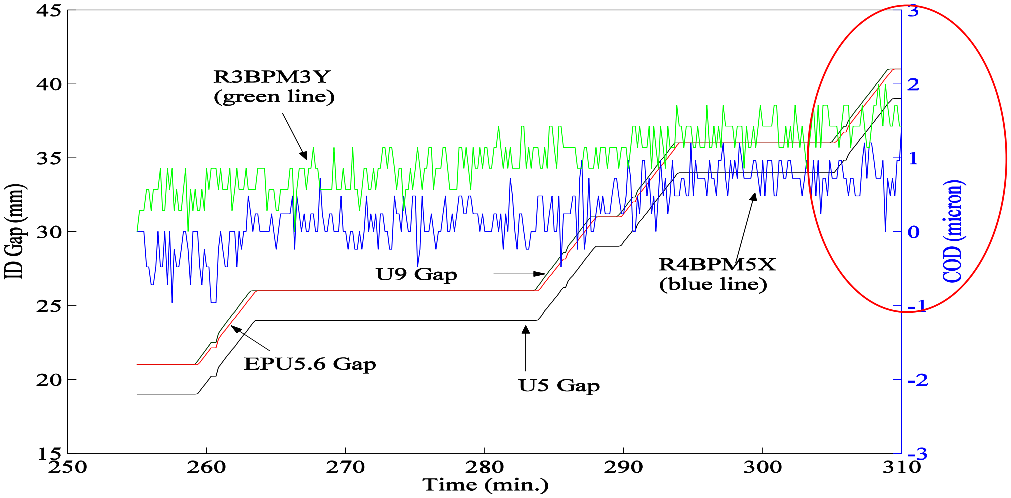
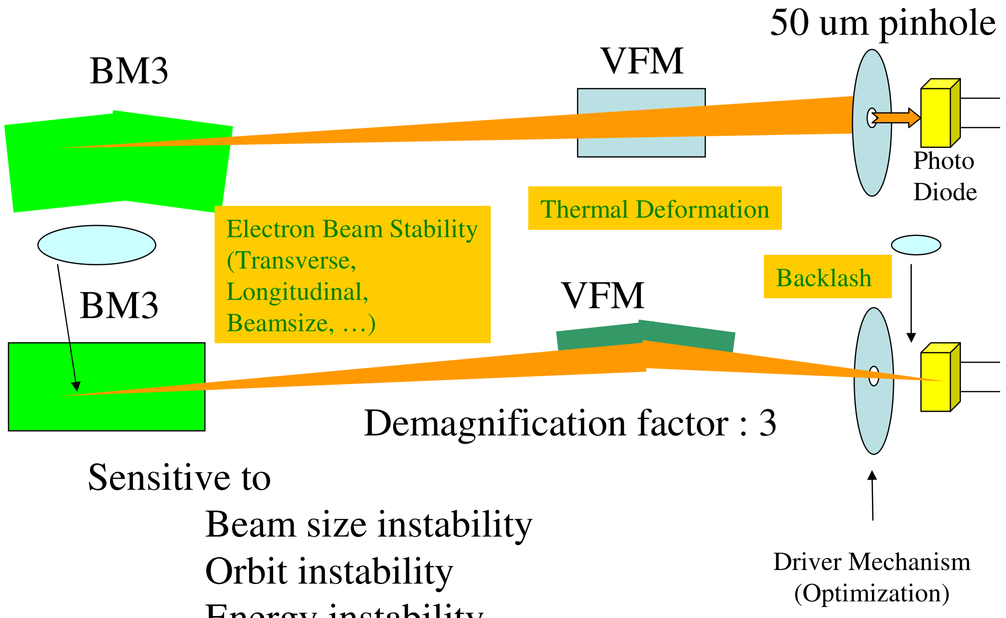
Orbit stability of the NSRRC Storage Ring



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 ($\Delta I_o / I_o$)



50 um pinhole

BM3

VFM

Photo
Diode

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

Thermal Deformation

Backlash

BM3

VFM

Demagnification factor : 3

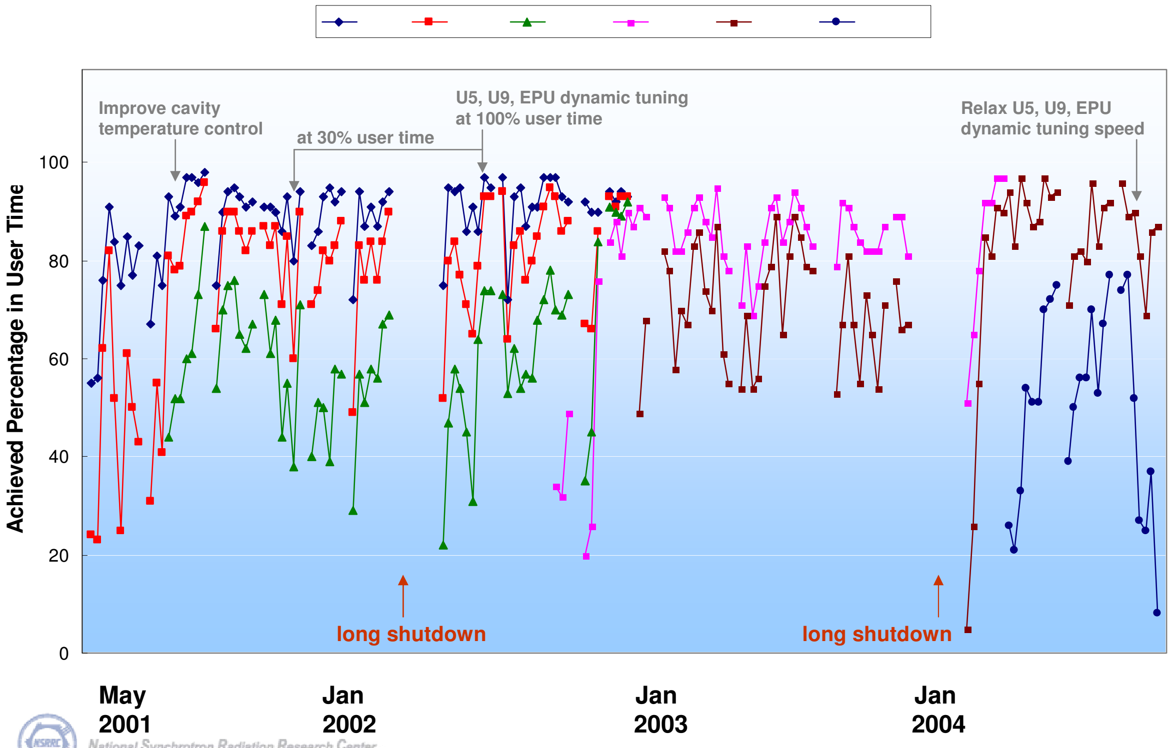
Driver Mechanism
(Optimization)

Sensitive to

- Beam size instability
- Orbit instability
- Energy instability

Signpost of overall beam stability form users' viewpoints

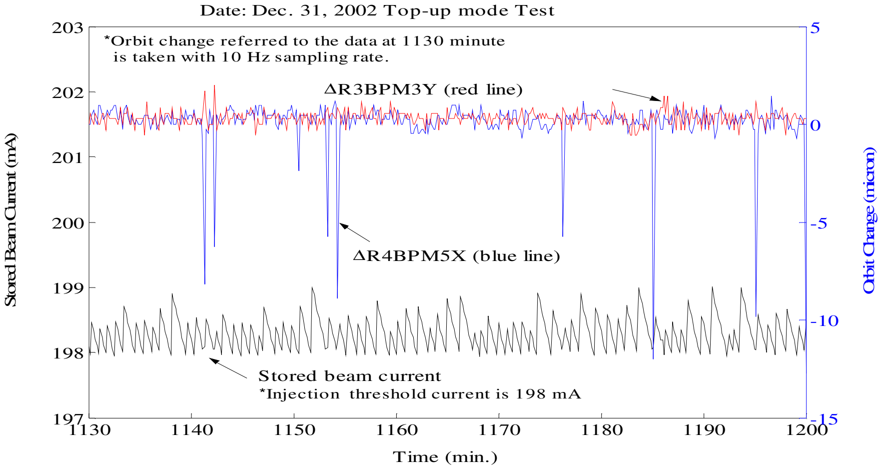
History of the Photon Beam Stability ($\Delta I_0/I_0$)



(K.K. Lin et. al.)

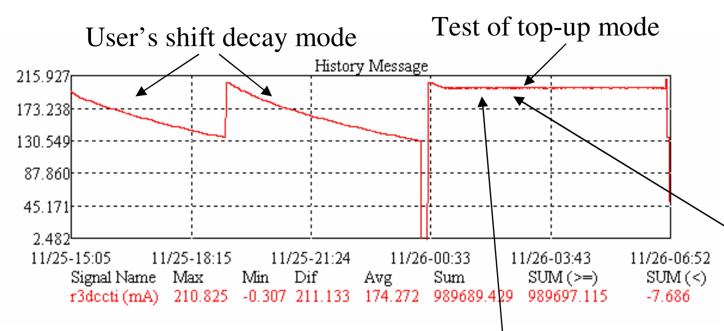
Top-up Injection Project

Top-up injection scheme planned.
Feasibility demonstrated.

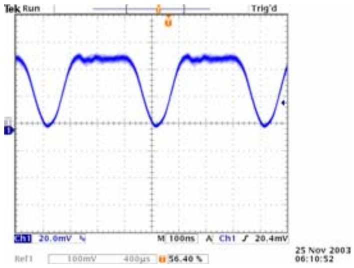


(G.H. Luo et. al.)

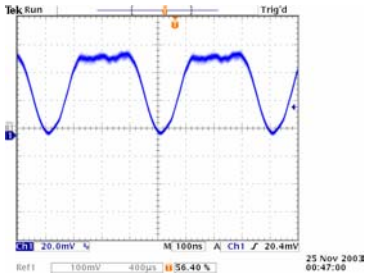
Experiment of Top-up injection



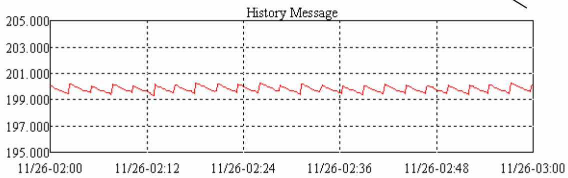
Signal Name	Max	Min	Dif	Avg	Sum	SUM (>=)	SUM (<)
r3dccti (mA)	210.825	-0.307	211.133	174.272	989689.429	989697.115	-7.686



Filling pattern at the end of top-up injection



Filling pattern at the beginning of top-up injection

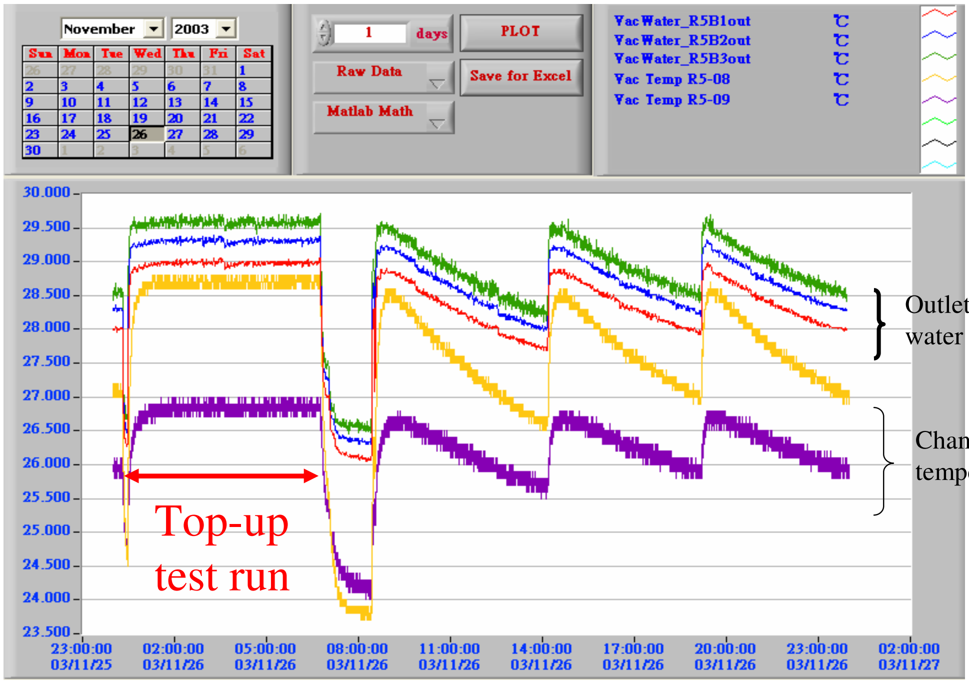


Signal Name	Max	Min	Dif	Avg	Sum	SUM (>=)	SUM (<)
r3dccti (mA)	200.255	199.354	0.901	199.801	71928.302	71928.302	0.000

Zoom in, injection interval 2 min.

(G.H. Luo et. al.)

Cooling Water and Chamber Temperature



Top-up test run

Outlet cooling water temperature

Chamber's temperature

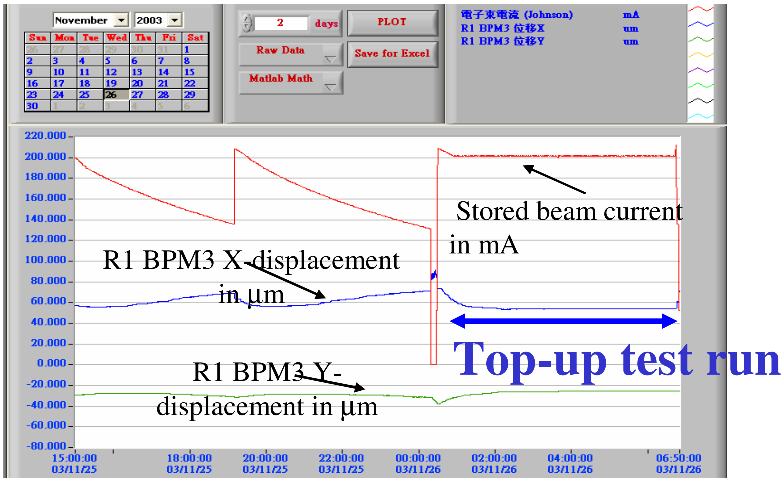
(G.H. Luo et. al.)

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

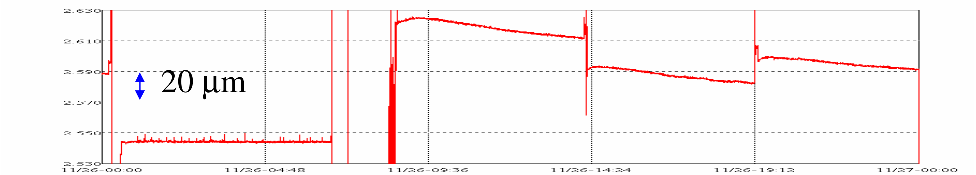
Top-up test run

R1 BPM3 Y-displacement in μm

(G.H. Luo et. al.)

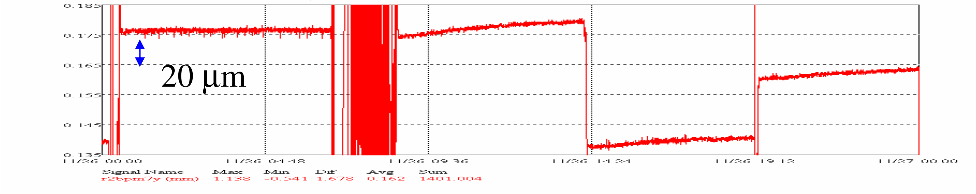
Vertical Beam Position Variation

R1BPM1Y

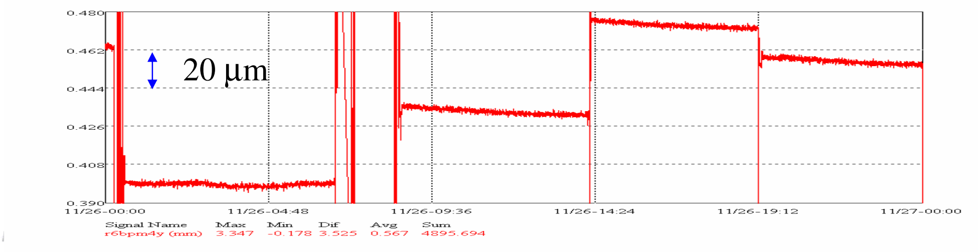


Top-up test run

R2BPM7Y



R6BPM4Y

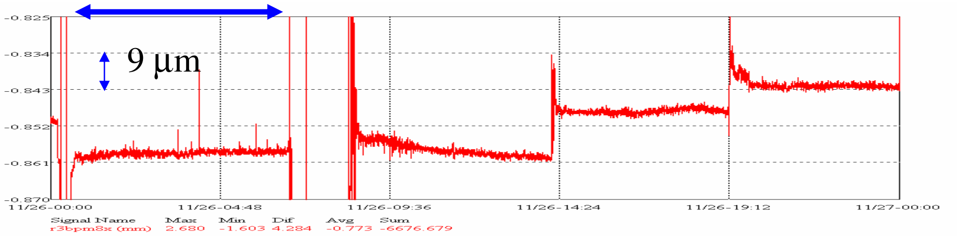


Horizontal Beam Position Variation

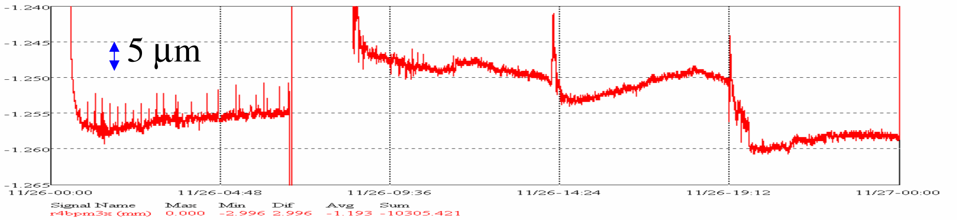
R1BPM1X

Top-up test run

R3BPM8X



R4BPM3X



Top-up Injection Plan

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

Electron Energy	3 ~ 3.3 GeV
Current	400 mA at 3 GeV or 300 mA at 3.2 GeV (Top-up injection)
SR Circumference	518.4 m (h = 864 = $2^5 \cdot 3^3$, dia.= 165.0 m)
BR Circumference	499.2 m (h = 832 = $2^6 \cdot 13$, dia.= 158.9 m)
Lattice	24-cell DBA
Straight-section	10.5 m x 6 ($_v$ = 10.5 m, $_h$ = 160 m) 6 m x 18 ($_v$ = 8 m, $_h$ = 110 m) 3 m x 12 ($_v$ = 4.5 m, $_h$ = 250 m; In-achromat)
Bending-section	x 12
Emittance	< 2 nm·rad at 3 GeV (Distributed dispersion)
Coupling	1 %
RF Frequency	500 MHz
RF Max. Voltage	4.8 MV (4 SRF cavities)
RF Max. Power	720 kW (4 SRF cavities)
Site	NSRRC in Hsinchu Science Park , Taiwan
Building	223 m OD (700 m circumference) 139 m ID (437 m circumference)

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

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Thank you for you attention