Highlights of the 2nd 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

Users' Requirements for Orbit Stabilization - T. Ishikawa (SPring-8 user)

Extreme Sensitivity to Electron Beam Position

- Photon spectrum dependence on incoming beam position

  Notable shift with ~mm change in position

- Crystal monochromator

  $$\lambda = 2\,d\,Sin(\vartheta) \rightarrow \Delta\lambda = 2\,d\,Cos(\vartheta)\,\Delta\vartheta$$

- Thomson Scattering (slide of T. Ishikawa)

$$E^{distribution}_{radiation} = E^{point\ charge}_{radiation} \iiint \rho(\boldsymbol{x}) \exp\left[-i(\boldsymbol{K}_s - \boldsymbol{K}_o)\cdot\boldsymbol{x}\right] d^3\boldsymbol{x}$$

3D Fourier Transform of Charge Density

Scattered Intensity

$$I = I^{single} \left| \iiint \rho(\boldsymbol{x}) \exp\left[-i(\boldsymbol{K}_s - \boldsymbol{K}_o)\cdot\boldsymbol{x}\right] d^3\boldsymbol{x} \right|^2$$

$$= \frac{r_o^2 \sin^2\alpha}{r^2} I_o \left| \iiint \rho(\boldsymbol{x}) \exp\left[-i(\boldsymbol{K}_s - \boldsymbol{K}_o)\cdot\boldsymbol{x}\right] d^3\boldsymbol{x} \right|^2$$

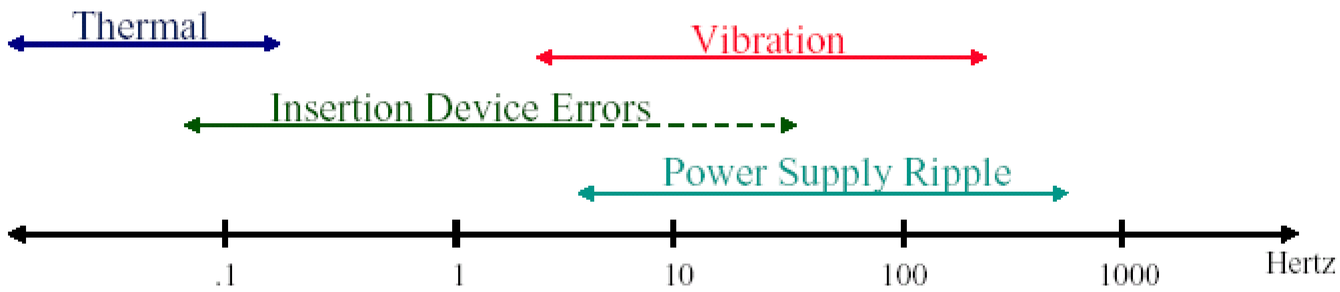
Photon Users Can Provide Feedback on Electron Beam Quality

- 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



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

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

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

Evolution of Orbit Spectrum at SPring8

Super Photon Ring - 8 Accel. Div.

4. Stabilization of F. O. V.

Fast (0.1Hz ~ several kHz)

97'~02': Precise correction of gap & ϕ 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)

at IWBS2002@SPring-8 2002/12/4~6

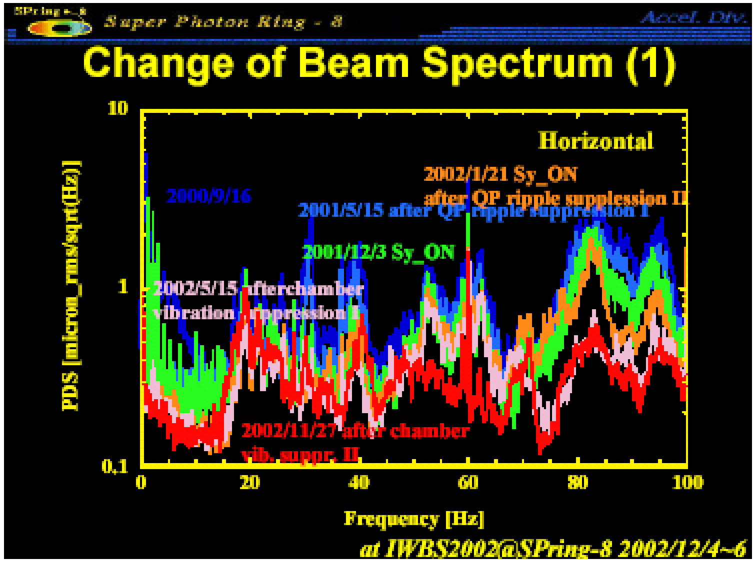
Super Photon Ring - 8 Accel. Div.

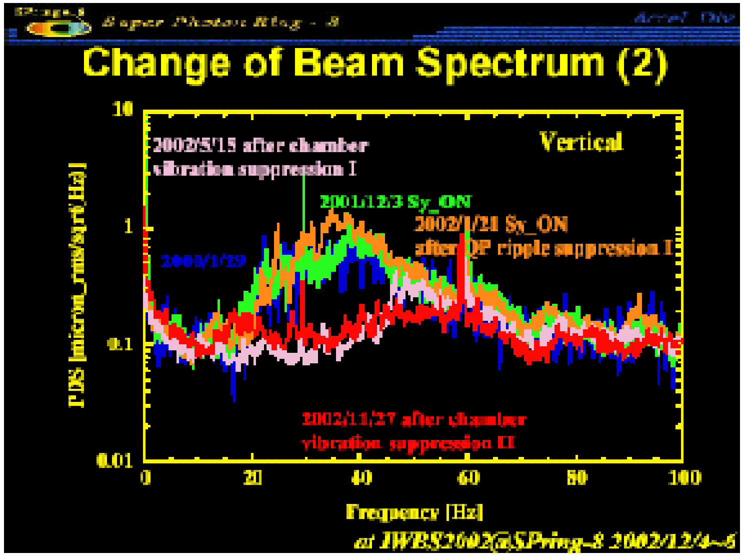
Fast (0.1Hz ~ several kHz)

00'~01': Suppression of Quad. Mag. PS current ripple II (by Takebe)

01'~02': Suppression of Chamber Vibration in Quad. Mag. (by Matsui/Oishi)

at IWBS2002@SPring-8 2002/12/4~6

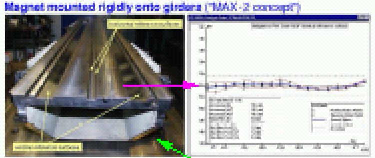


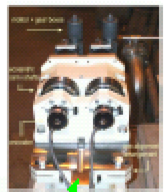


Alignment / Monitor Methods at SLS (M. Boege)

SR - Innovative Subsystems - Magnet Girders

Magnet mounted rigidly onto girders ("MAX-2 concept")



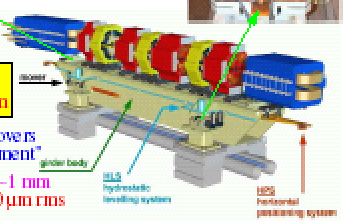


Girders movable in 5 degrees of freedom
Position monitoring systems on girders

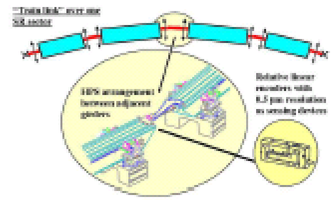
Girder Rail Precision: 15 μm
Magnet Axis Calibration: 30 μm

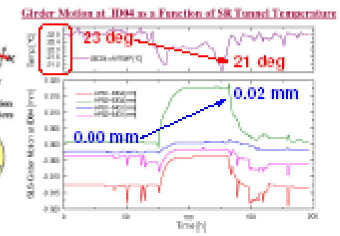
Remotely Controlled Girder Movers
-> " Beam-Based Girder Alignment"

Null Orbit: xrms ~2 mm, yrms ~1 mm
-> Magnet Misalignments < 50 μm rms



SR - Innovative Subsystems - HPS

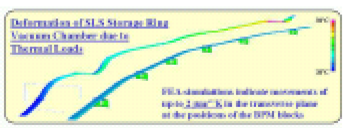




Tunnel Temperature stabilized to <0.5 deg peak-peak

- 4 girders per sector connected through "virtual joints" established by HPS with 0.5 μm precision (→ "Train link")
- Girders of sector self-contained with 2 reference points at the beginning of straight sections (→ ×)
- Absolute girder positions reconstructed from reference points and "virtual joints"

SR - Innovative Subsystems - POMS



POMS System

- Dial gauges sense transverse movements of BPM block in reference to adjacent quadrupole magnets.
- Linear encoders of type Renishaw RGH24Z50A00A with 0.5 μm resolution are used as sensing devices.
- Complete integration into EPICS control system through serial SSI-interface and 32 channel VME-SSI card.

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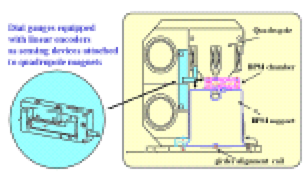
Dial gauges equipped with linear encoders as sensing devices attached to quadrupole magnets



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 girder alignment rail)
- BPM supports serve as supports for the vacuum system (→ BPM chamber)

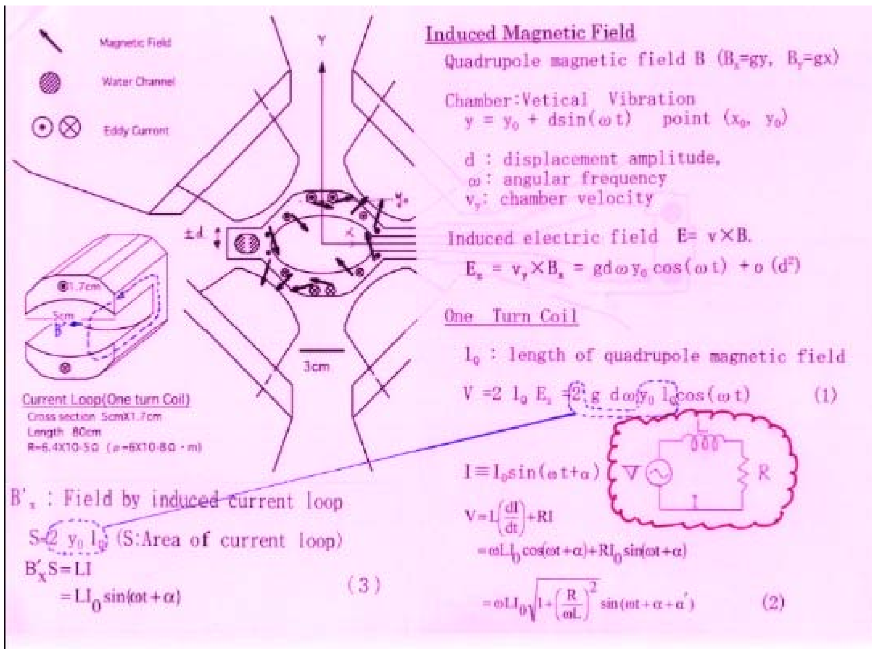
SR - Stability - Worst Case Estimate

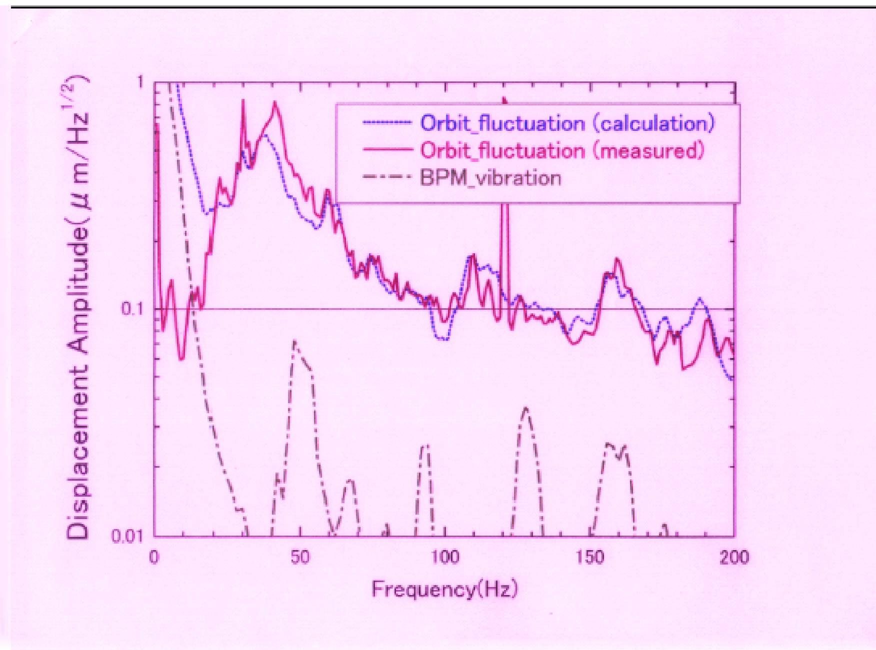
- $\beta_x = 1.4$ m, $\beta_y = 0.9$ m at **ID** position of section nS →
  $\sigma_x = 84\ \mu$m, $\sigma_y = 7\ \mu$m assuming emittance coupling $\epsilon_y/\epsilon_x = 1$ %
- With stability requirement $\Delta\sigma = 0.1 \times \sigma$ →

Requirement: Orbit jitter < 1 μm at insertion devices

	Worst case Noise estimate	30	60	Hz
	Seismic measurements	300	30	nm
	Damping by hall's concrete slab	neglected		
	Girder resonance max amplification	< 10	< 10	
	Closed orbit amplification hor./vert.	8/5	25/5	
→	Maximum Orbit jitter hor./vert	24/15	7.5/1.5	μm
	Attenuation by orbit feedback	-55	-35	dB
→	**Maximum Orbit jitter hor. /vert.**	**40/30**	**130/30**	**nm**

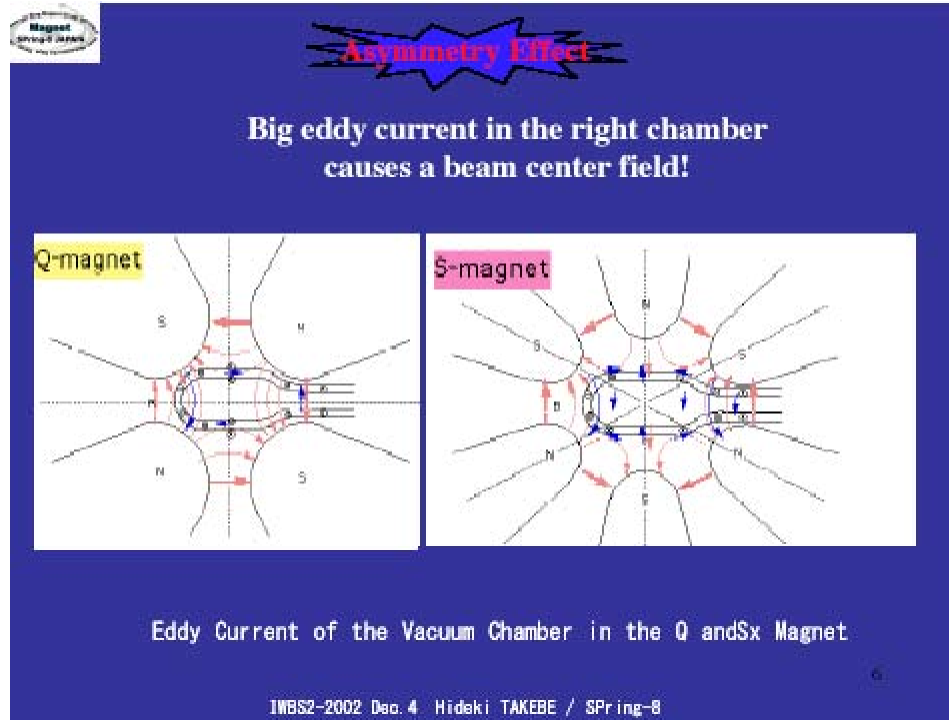
Excitation due to Vacuum Chamber Vibration (through Induced Eddy Current) S. Matsui & M Oishi, Spring-8





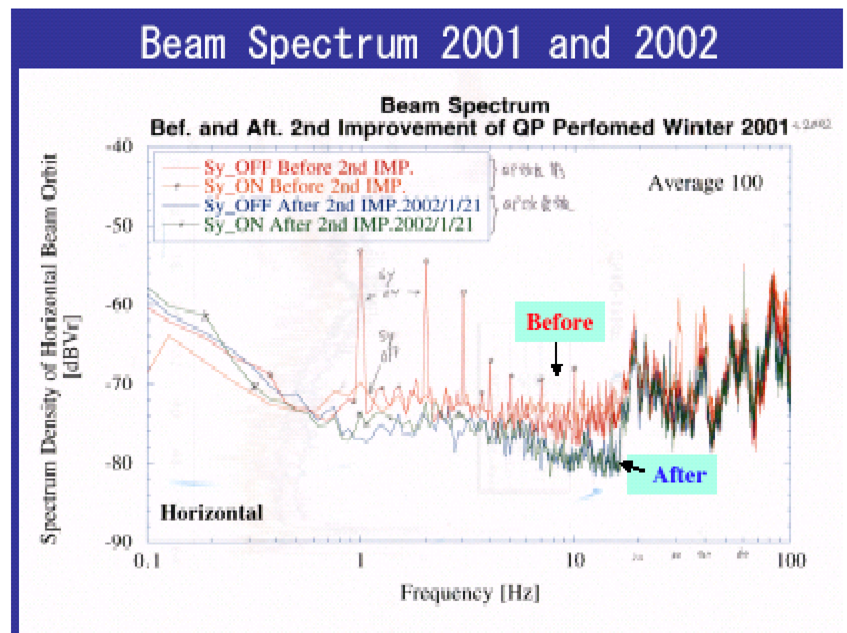
Magnet Ripple Induced Field due to Chamber Asymmetry,

H. Takebe, Spring-8



Q magnet Power Supply Tuning and Modification History

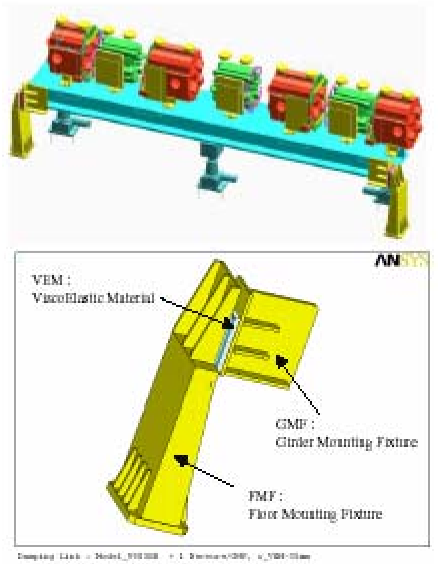
- 2000 Aug. 23-30 : Thyrister Phase Tuning
- 2000 Sep. 8-10 : Input Transformer adopted
- 2000 Oct. 2- 3 : Phase Timing Circuit Modify
- 2001 May 8-10 : DCCT exchange
- 2002 Jan. : Phase Control Circuit Modify



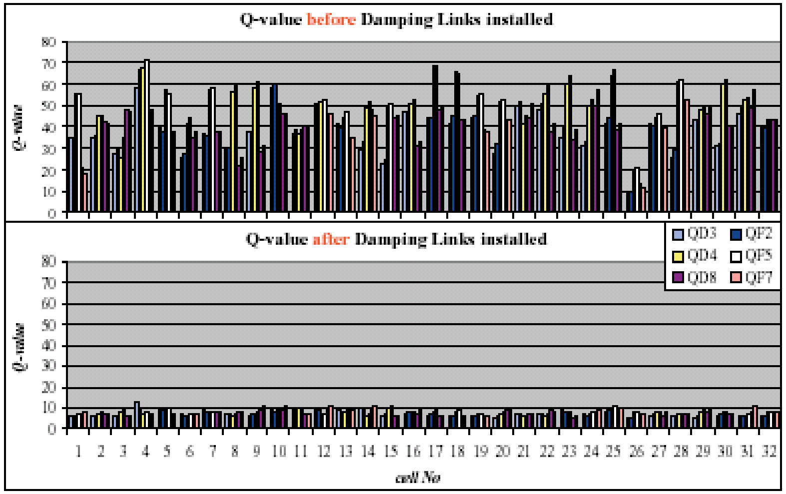
Damping Links at ESRF

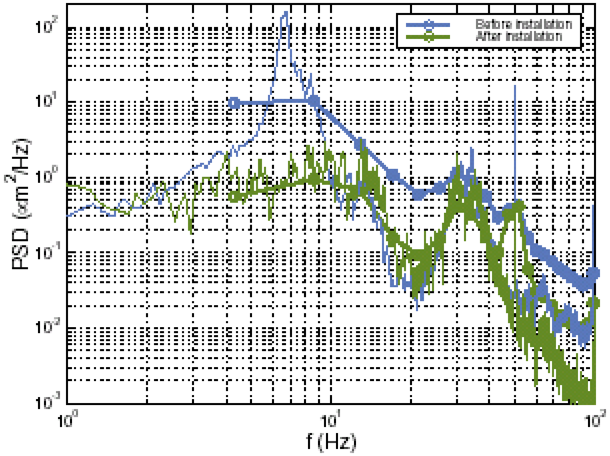
(L. Farvacque & L. Zhang)

Damping link design



The FMF is glued on the Storage Ring floor





Effect of damping links on the horizontal beam motion

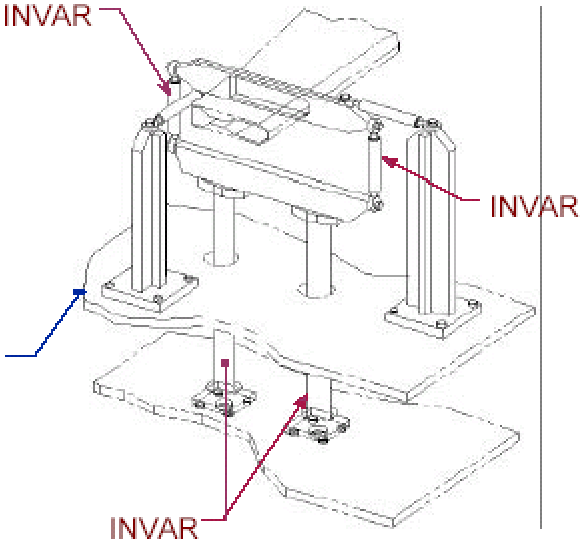
Invar Strut Support for BPMs

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.



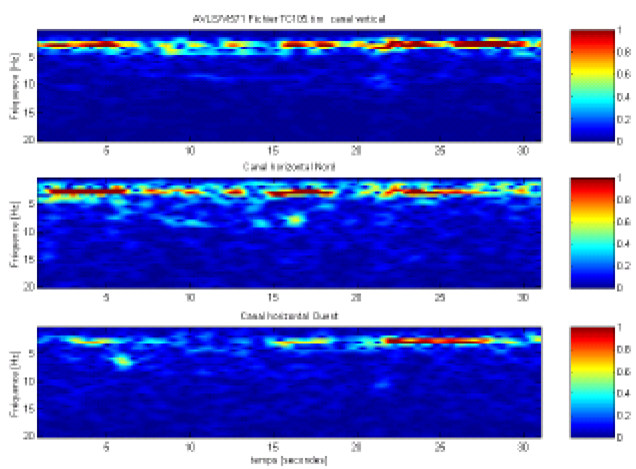
SPEAR 3 chamber/BPM supports

3 µm/°C vert, 15 µm/°C hor

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)

Marie-Paule LEVEL *IWBS December 4-6, 2002, Spring-8, japan*

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……

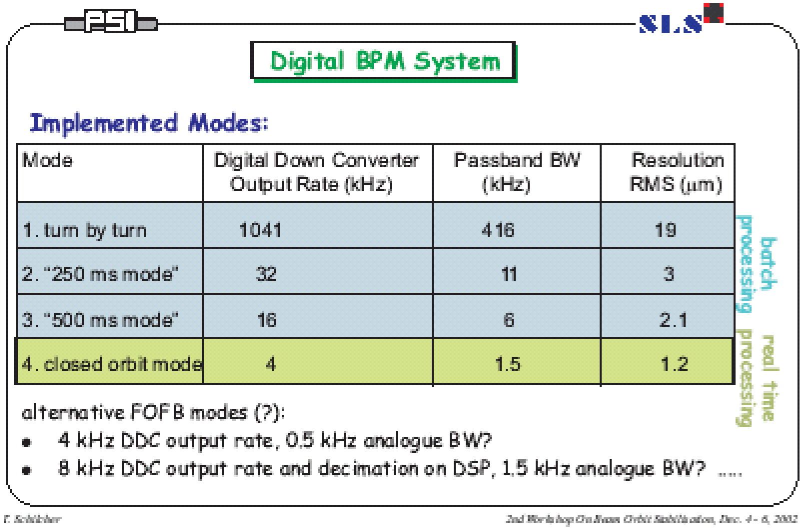
Fast Feedback

- 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


Digital BPM System

Implemented Modes:

Mode	Digital Down Converter Output Rate (kHz)	Passband BW (kHz)	Resolution RMS (μm)
1. turn by turn	1041	416	19
2. "250 ms mode"	32	11	3
3. "500 ms mode"	16	6	2.1
4. closed orbit mode	4	1.5	1.2

alternative FOFB modes (?):

- 4 kHz DDC output rate, 0.5 kHz analogue BW?
- 8 kHz DDC output rate and decimation on DSP, 1.5 kHz analogue BW? .....

Strategy toward Sub-Micron Stability

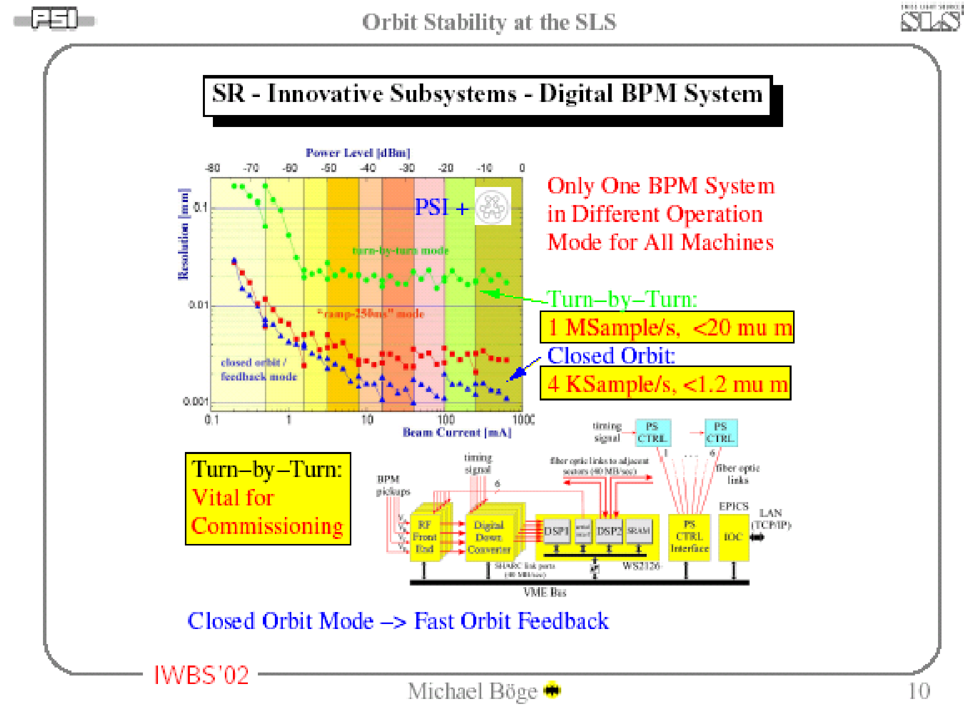
- Electrical power systems
- BPMs (resolution & stability)
- Feedback on X-rays
- ID improvements
- Building stability

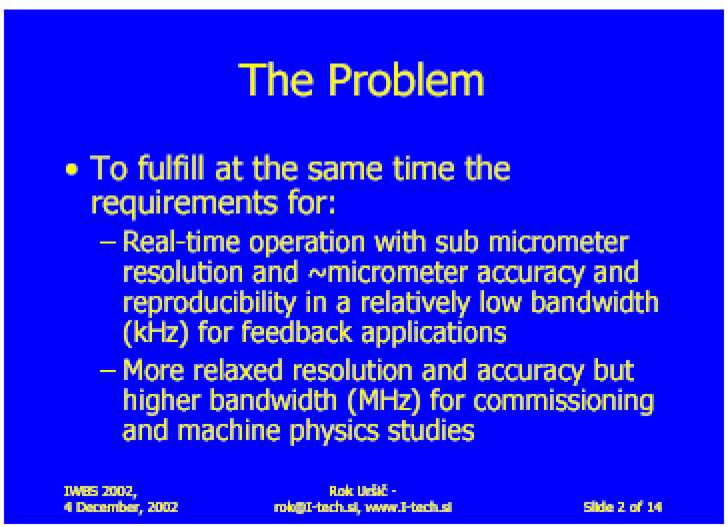
Digital BPM's

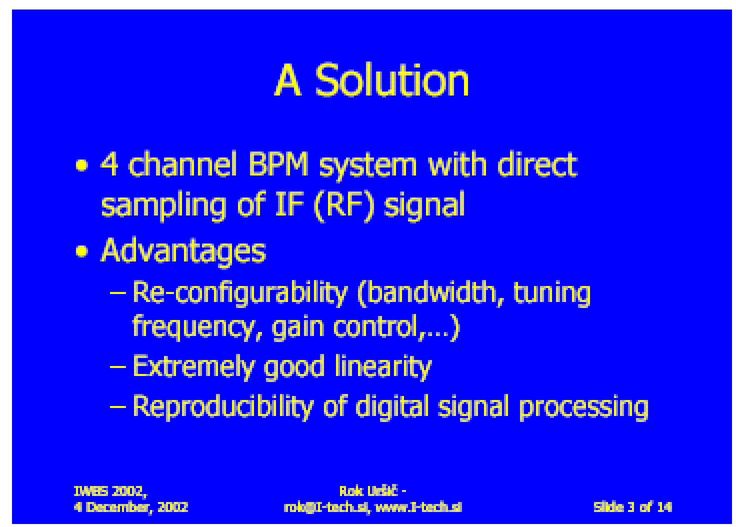
Configurable for both high bandwidth (turn by turn) and low bandwidth (closed orbit correction)

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

Multiplexed Electrodes BPM system: pros and cons

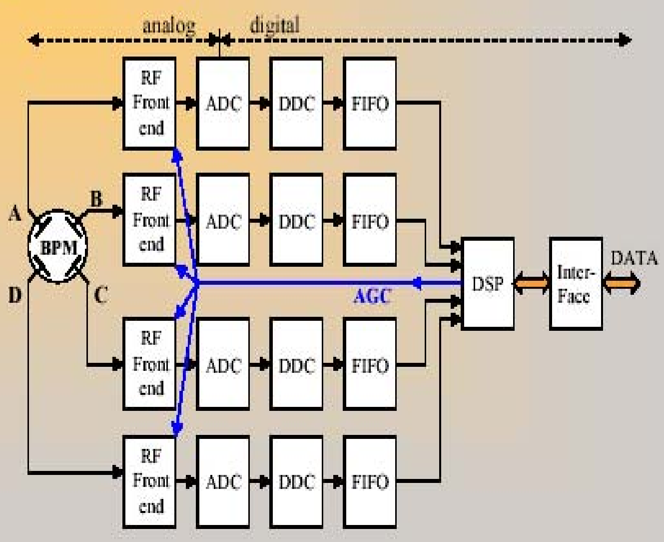
Pros

- Single electronics → single gain & offset for the 4 electrodes
- Excellent position stability
- Excellent current dependence
- Commercially available from Bergoz company

Cons

- Resolution issues
  - Synchrotron oscillations → noise increase due to aliasing
  - Difficulty to get low noise
    - Signal available ¼ of the time
    - Front end matching for low current dependence
    - Preamplifier with AGC capability
- No turn-by-turn acquisition

Digital BPM system



Digital BPM system: Pros and Cons

Pros

- Programmable → turn-by-turn as well as stored beam
- Excellent resolution
  better resolution = lower beam noise OR wider bandwidth with fast feedback
- Large dynamic range (AGC)
- Digital Down Conversion has no offset
- Commercially available from i-tech (see i-tech talk at this workshop).

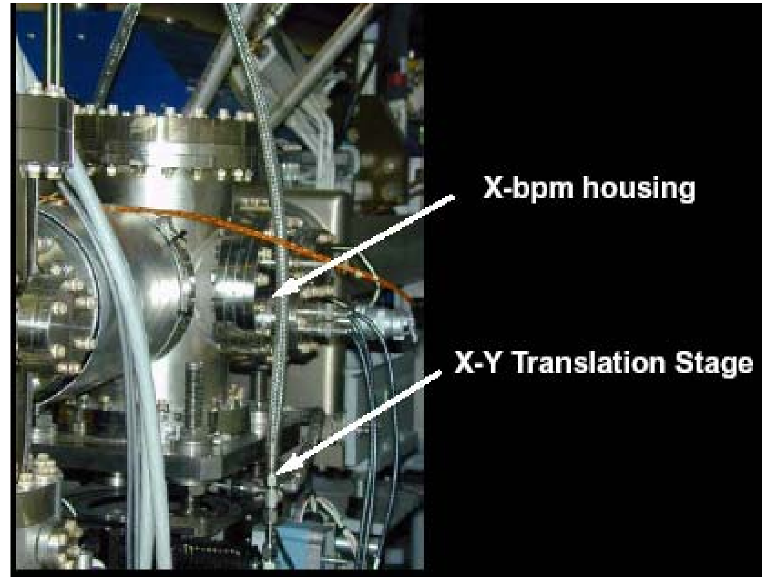
Cons

- Need elaborate calibration scheme (gain ratios vary with AGC voltage)
- Current dependence and stability rely on excellent calibration performance for beam stabilization at the submicron level

X-BPM

Example: APS XBPMs used in insertion devices

Metalized CVD diamond blades

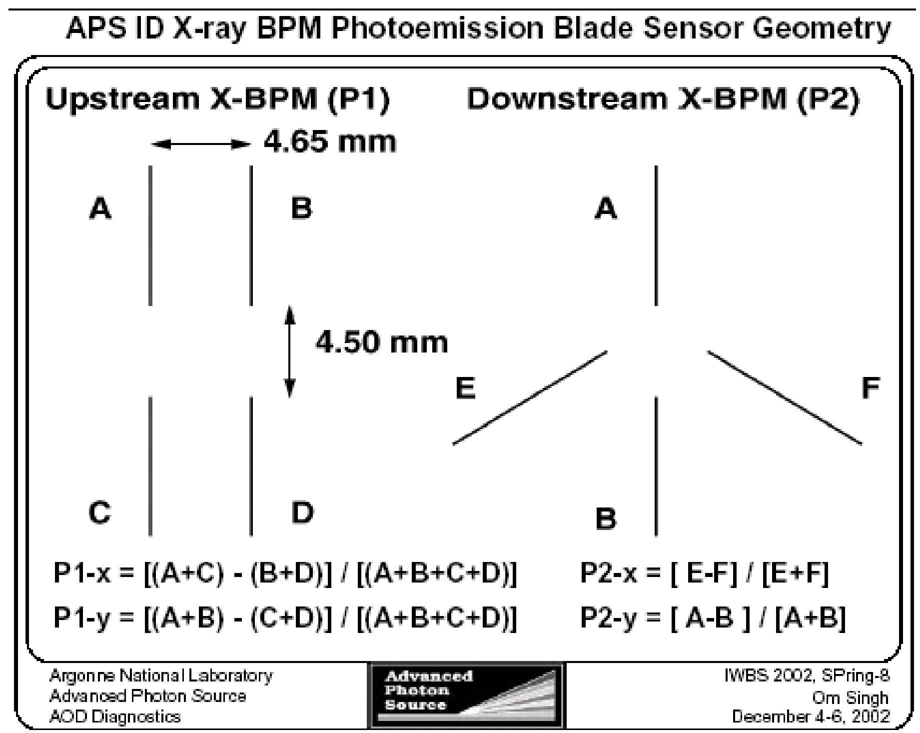


Provides additional accuracy needed in the ID

Integrated into the global orbit control system

0.2 μrad over 24 hrs.

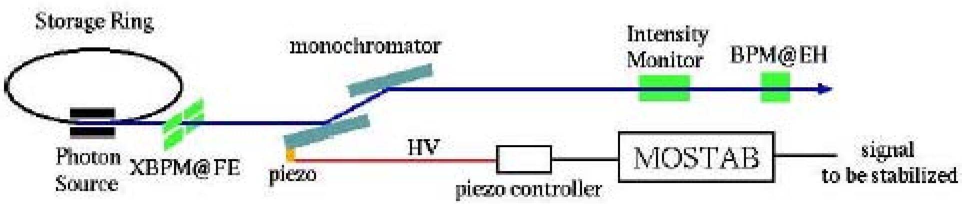
Variable ID gap calibration



MOSTAB

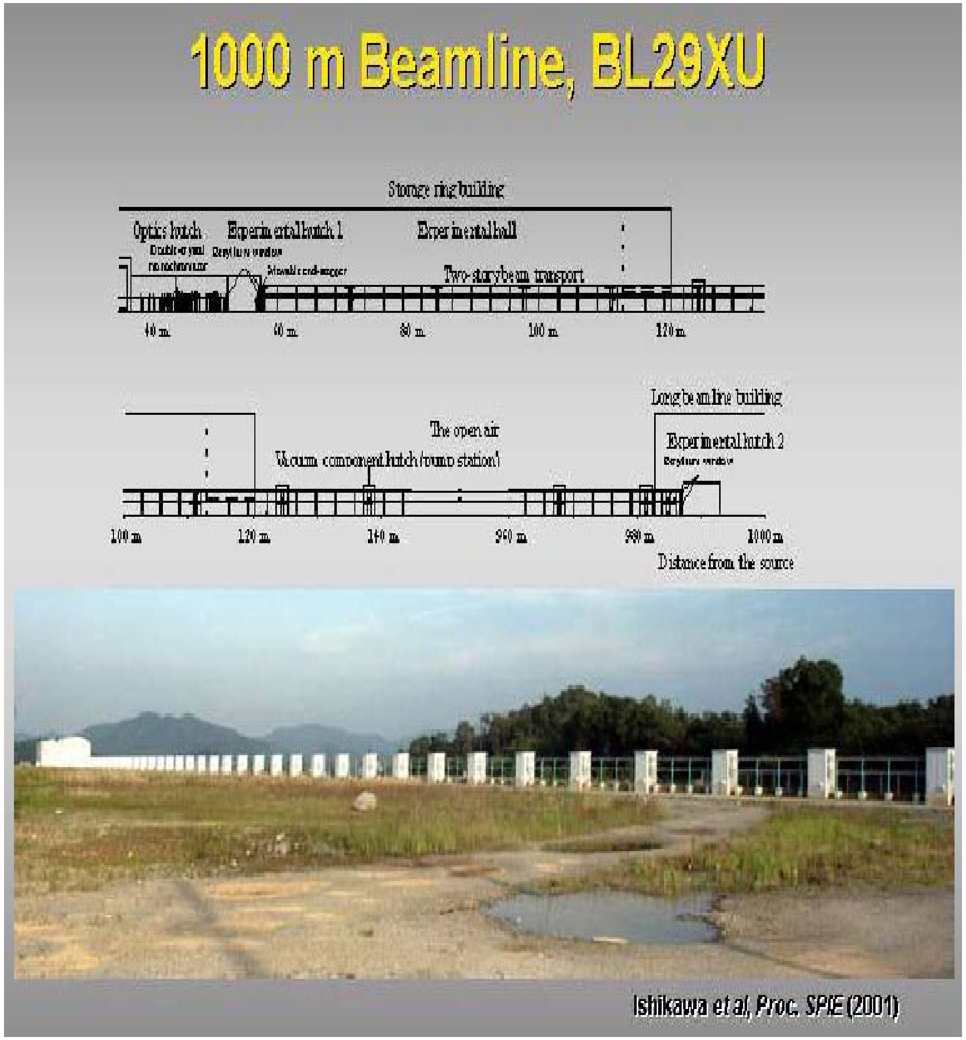
User keeps complaining!

MOSTAB



MOSTAB (Monochromator Stabilization) module applies a feedback voltage to the piezo actuator of DCM.

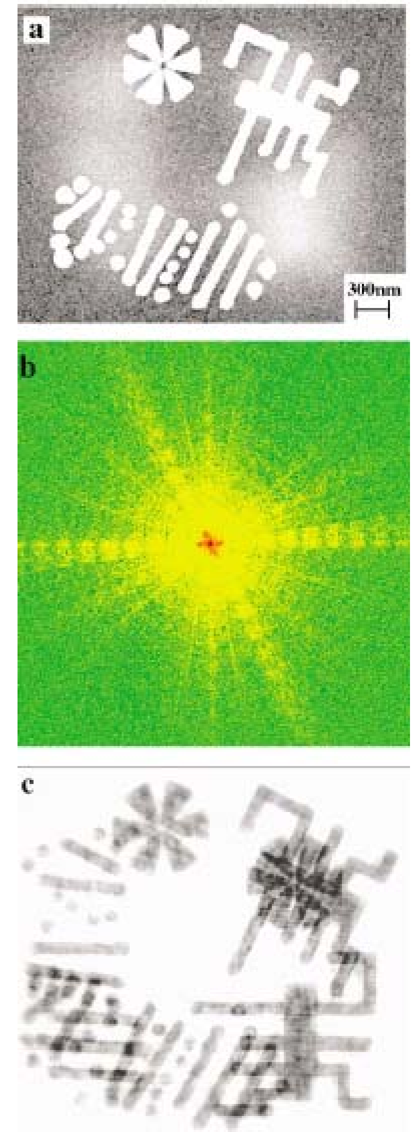
Tour of SPring8 & 1 km Beamline



3D reconstruction of non-crystalline structure

50 nm 3D

8 nm 2D



Conclusion

- Very interesting progress has been made world wide 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