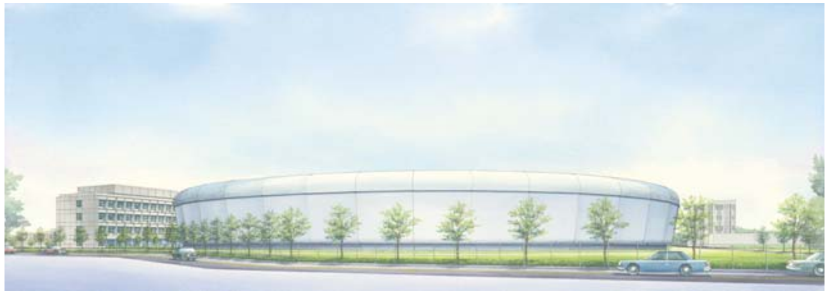
Activities on the Orbit Feedback System for the Super-SOR Light Source



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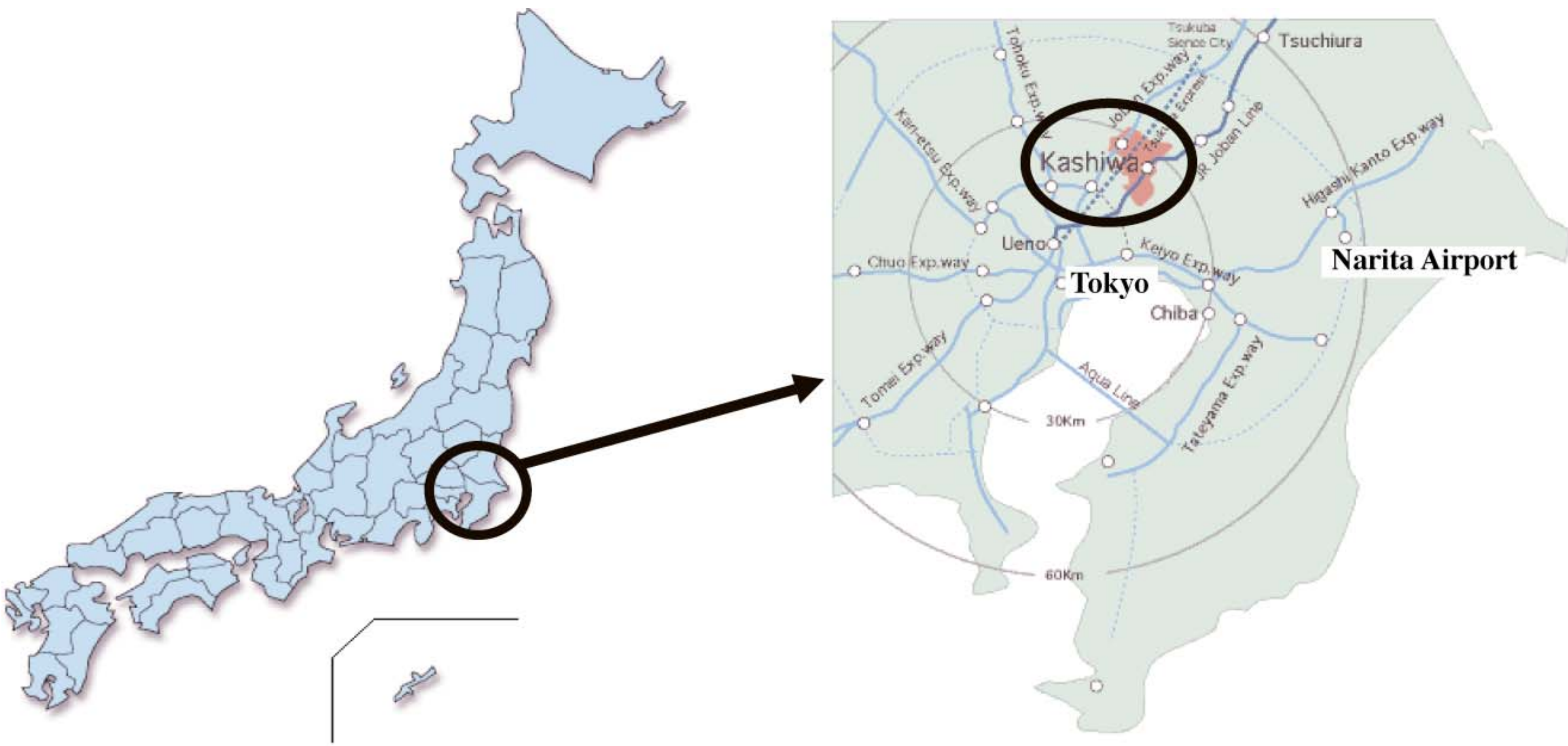
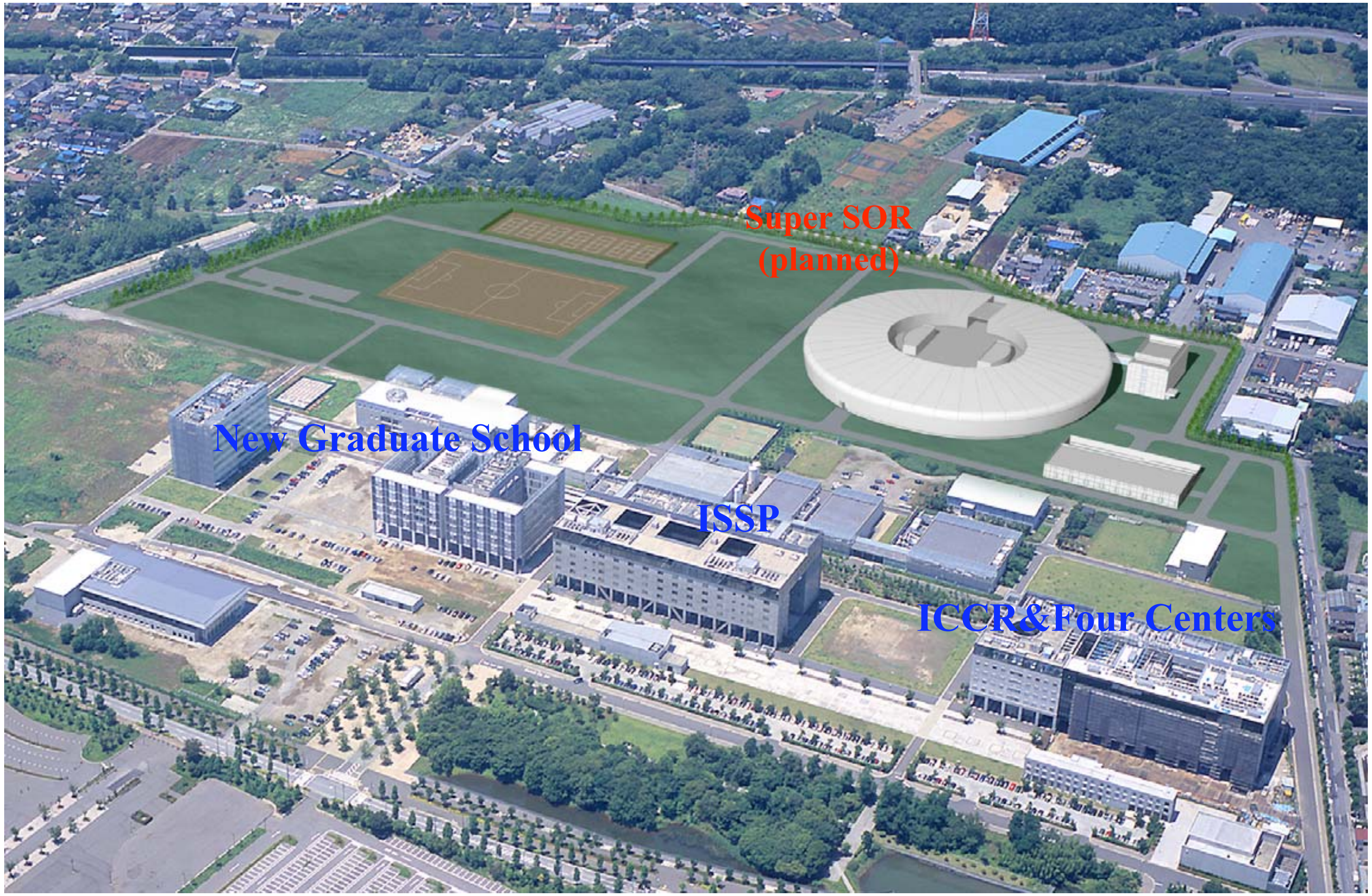
3rd International Workshop on Beam Orbit Stabilization - IWBS2004,
Hotel Kirchbühl, Grindelwald, Switzerland, December 6-10, 2004

Super-SOR Project

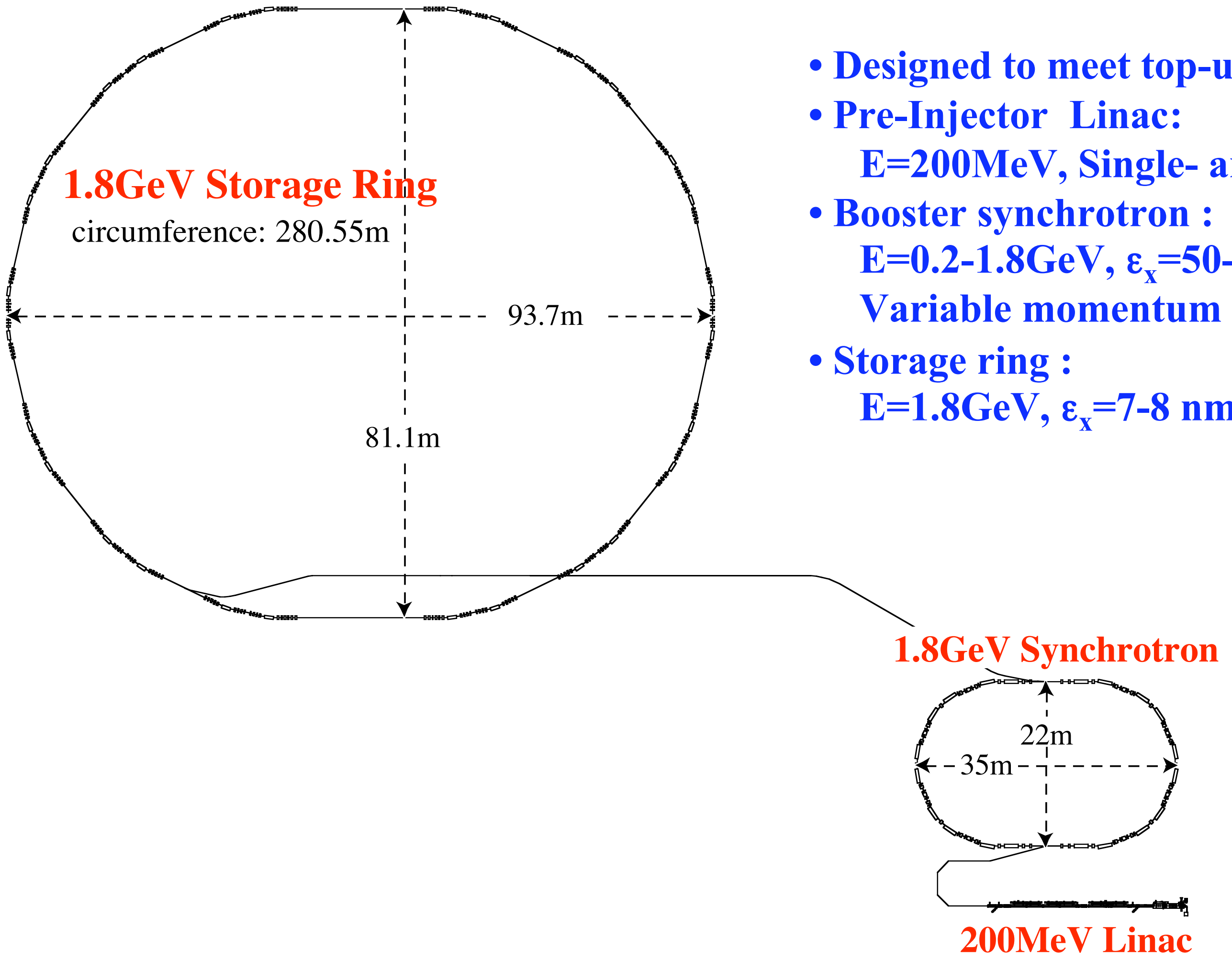
- The Super-SOR project aims to construct a 3rd-generation VUV and soft X-ray synchrotron radiation source in Japan.
- Proposed site is in the new campus of the University of Tokyo (Kashiwa campus).



Plan View of Super SOR Light Source

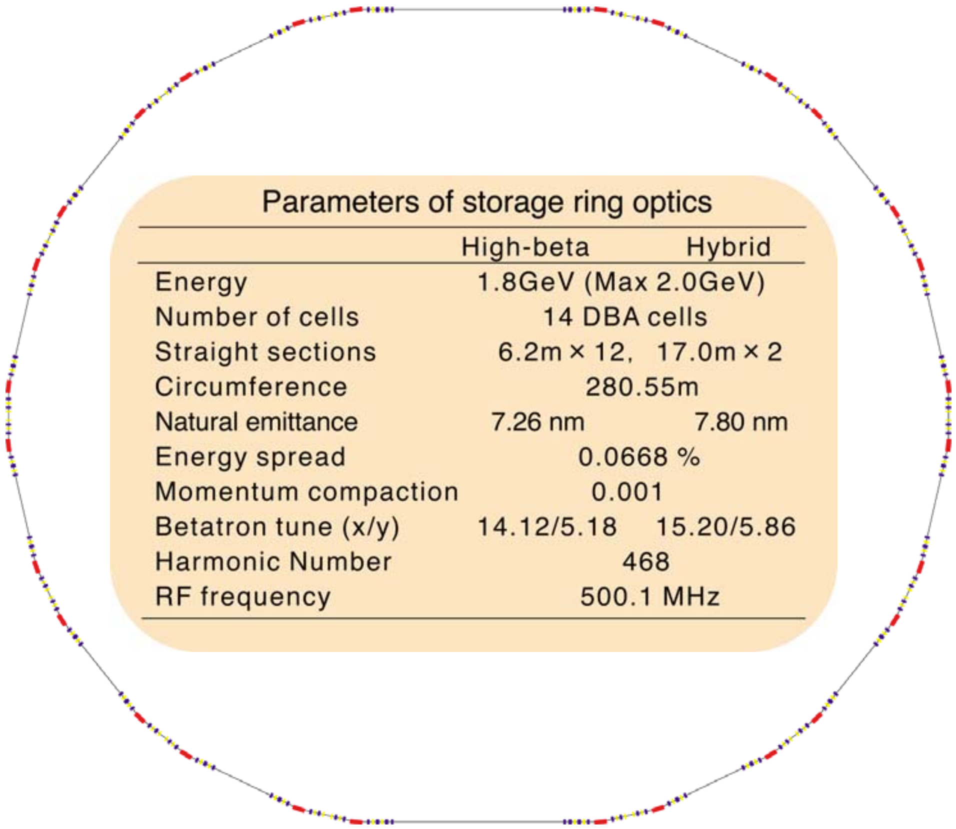


Super-SOR Accelerators



- **Designed to meet top-up injection**
- **Pre-Injector Linac:**
  E=200MeV, Single- and Multi-bunch modes
- **Booster synchrotron :**
  E=0.2-1.8GeV, ε_x=50-100 nm rad
  Variable momentum compaction (α=0.003-0.01)
- **Storage ring :**
  E=1.8GeV, ε_x=7-8 nm rad, I=400mA

Super-SOR Storage Ring

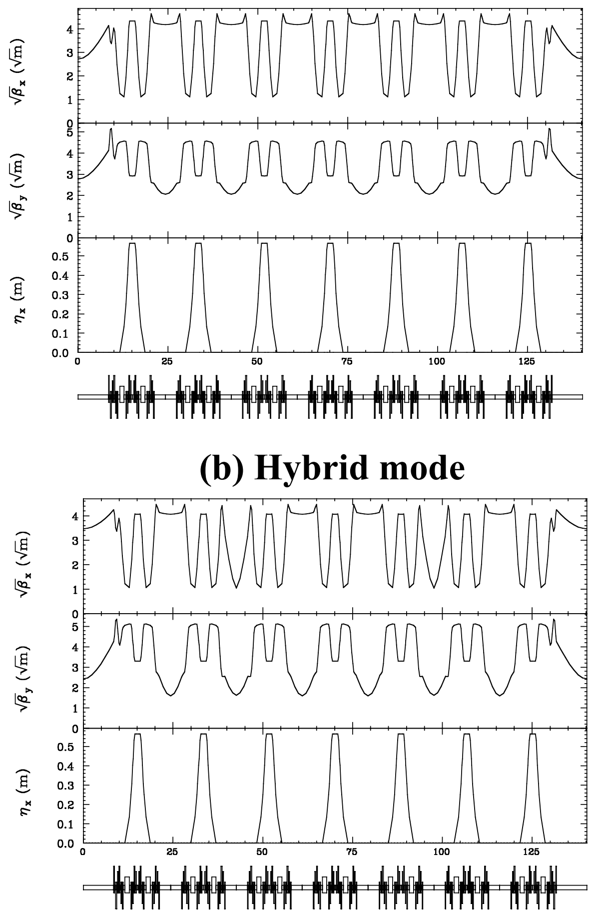


Parameters of storage ring optics

	High-beta	Hybrid
Energy	1.8GeV (Max 2.0GeV)	
Number of cells	14 DBA cells	
Straight sections	6.2m × 12, 17.0m × 2	
Circumference	280.55m	
Natural emittance	7.26 nm	7.80 nm
Energy spread	0.0668 %	
Momentum compaction	0.001	
Betatron tune (x/y)	14.12/5.18	15.20/5.86
Harmonic Number	468	
RF frequency	500.1 MHz	

(a) High-beta mode

(b) Hybrid mode



Optics of half ring

- **14 DBA cells with 2 x 17m and 12 x 6.2m long straight sections**
- **Flexible optics with high- and low-beta straight sections**
- **Vertical beam size at insertion devices : σ_y = 10 - 30 μm**

Design Goal of Orbit Feedback System

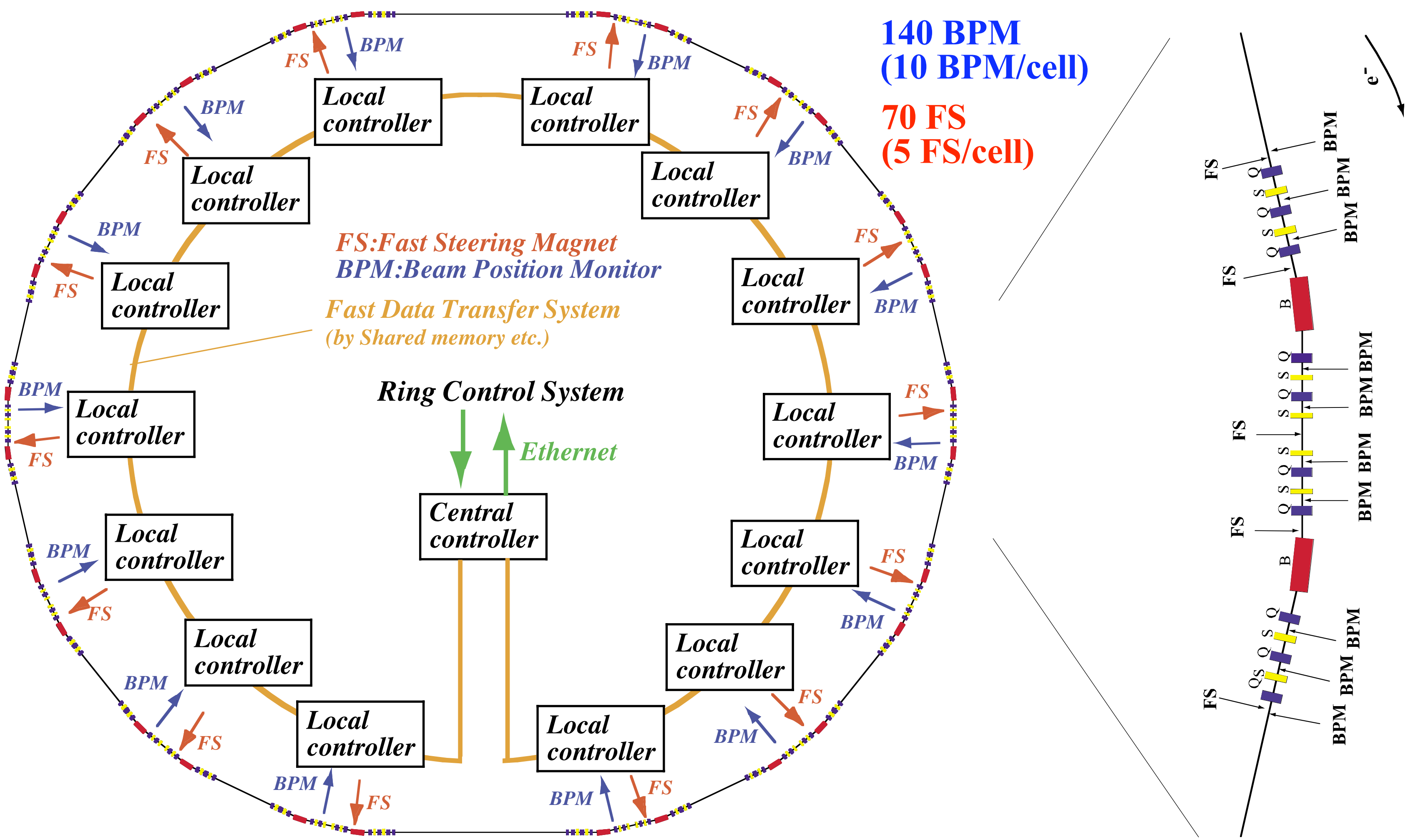
- **Fast and High-resolution Beam Position Measurement**
  Resolution < 1 μm @ sampling rate > 2 kHz

- **Wide Frequency Range**
  BW > 100Hz (Noise attenuation: < -20dB @ 10Hz)

- **High Position Stability at Insertion Devices**
  New orbit correction scheme

⇒ Submicron Stability

Outline of Orbit Feedback System



New Orbit Correction Scheme

Principle of eigenvector method with constraints (call "EVC" or "SVDC" here)

Vector of residual COD:

$$\vec{\Delta} \equiv R\vec{\theta} + \vec{y} \qquad (1)$$

y : beam position before correction (M)
θ : kick angle of steering magnet (N)
R : Response matrix (M x N)

Constraint conditions:

$$\overrightarrow{C_i^T} \cdot \vec{\theta} + z_i = 0 \; (i = 1, \cdots\cdots, N_C) \qquad (2)$$

Minimize the norm of Δ under the constraint conditions by introducing the following function of S (Lagrange's method of indeterminate multipliers).

$$S = \frac{1}{2}(R\vec{\theta} + \vec{y})^2 + \sum_i^{N_c} \mu_i (\overrightarrow{C_i^T}\overrightarrow{\theta} + z_i) \qquad (3)$$

Set derivatives of the function S with respect to θ and μ to zero.

$$R^T R\vec{\theta} + R^T\vec{y} + C\vec{\mu} = 0 \qquad (4)$$

$$C^T\vec{\theta} + \vec{z} = 0 \qquad (5)$$

Solution of the above equations:

$$\vec{\theta} = B\vec{y} - D\vec{z} \qquad (6)$$

where

$$B = (-A^{-1} + A^{-1}CP^{-1}C^T A^{-1})R^T \qquad (7)$$

$$D = A^{-1}CP^{-1} \qquad (8)$$

$$A = R^T R \quad P = C^T A^{-1} C \qquad (9)$$

Definition of the matrix A^{-1} :

$$A^{-1} = \sum_{i=1}^{N_V} \frac{\vec{v}_i \vec{v}_i^T}{\lambda_i} \quad (N_V \leq N), \qquad (10)$$

v_i : i-th eigenvector of the matrix A
λ_i : i-th eigenvalue of the matrix A

For λ_i~0, $1/\lambda_i$ in the matrix A^{-1} is replaced with zero to avoid very large kick angles. The condition of $N_V \geq N_C$ is required for the existence of the inverse matrix P^{-1}.

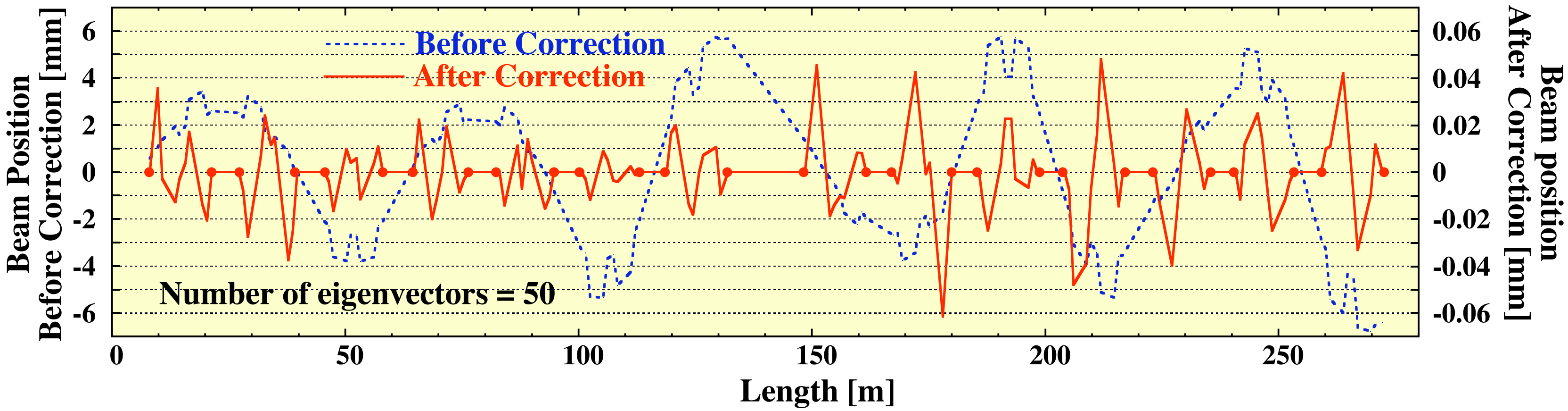
If z is taken as the electron (or photon) beam positions measured at arbitrarily selected BPMs (or photon BPM) and C as the corresponding response matrix, the beam positions at the selected BPMs are fixed at zero by this correction. For the electron beam and BPMs, Eq. (6) can be rewritten in a simplified form.

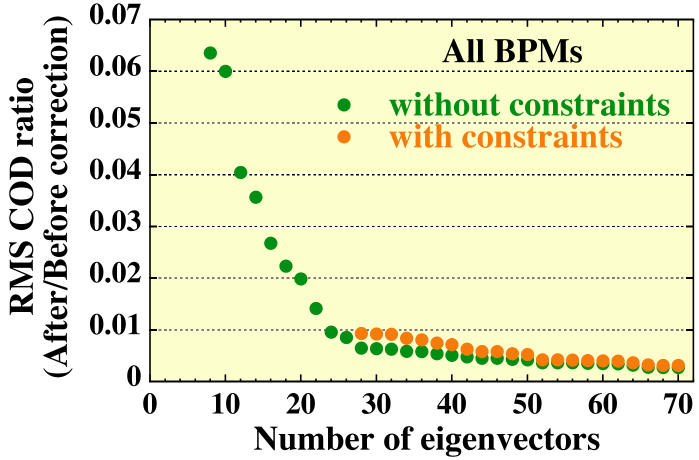
$$\vec{\theta} = B^* \vec{y} \qquad (11)$$

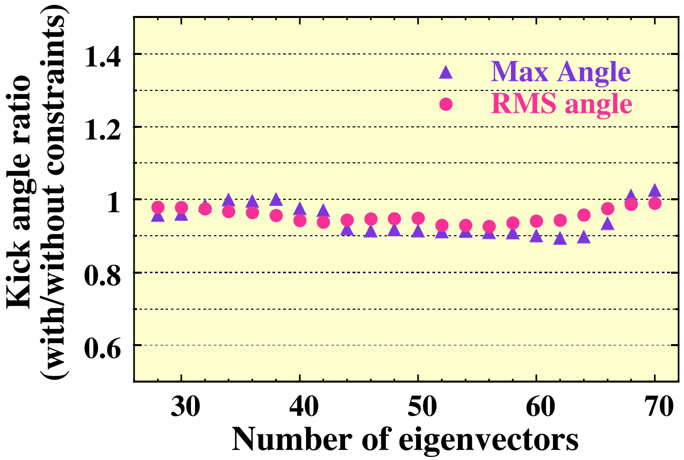
→ See Proceedings of EPAC98 and PAC99

Orbit Correction Simulation

(1) COD sources are all the quadrupole magnets with vertical position errors of σ=50 μm.
(2) Constraint conditions are that positions at 28 BPMs on both sides of 14 long straight sections are zero.
(3) 140 BPMs and 70 fast steering magnets are used for correction simulations.



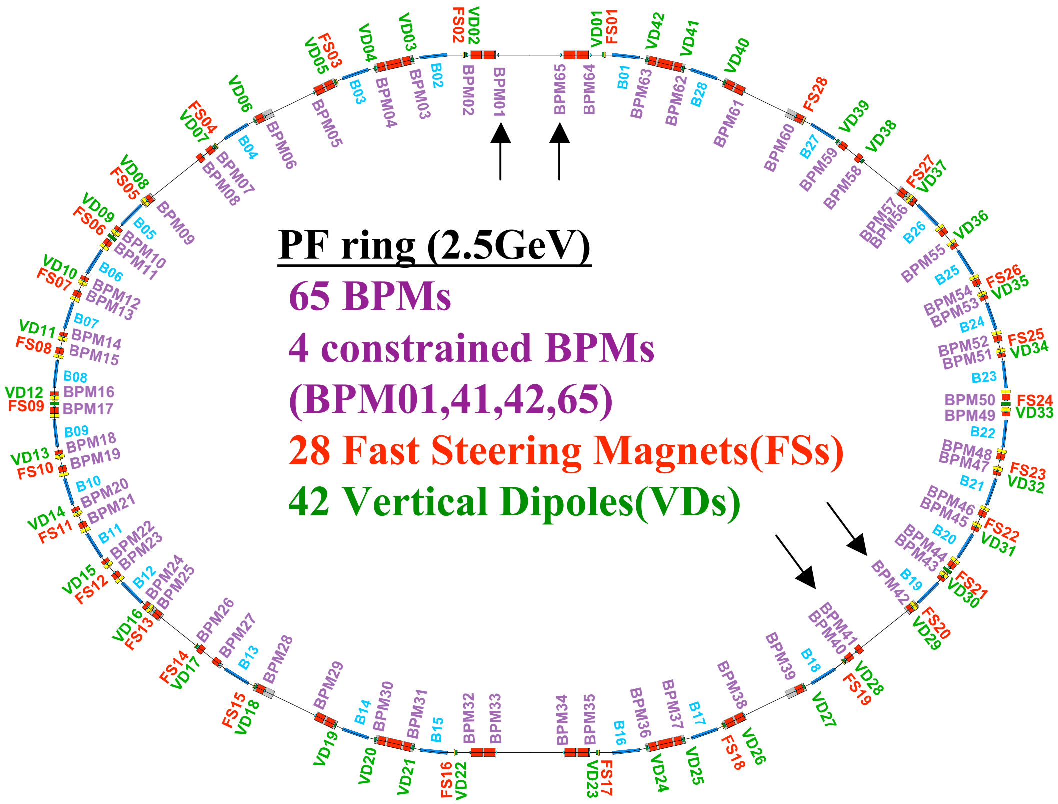




⇒ Simulations confirm that the global and local corrections are compatible in the new method.

Orbit Correction Study at PF ring (1)

Experimental study of the new orbit correction method at PF ring



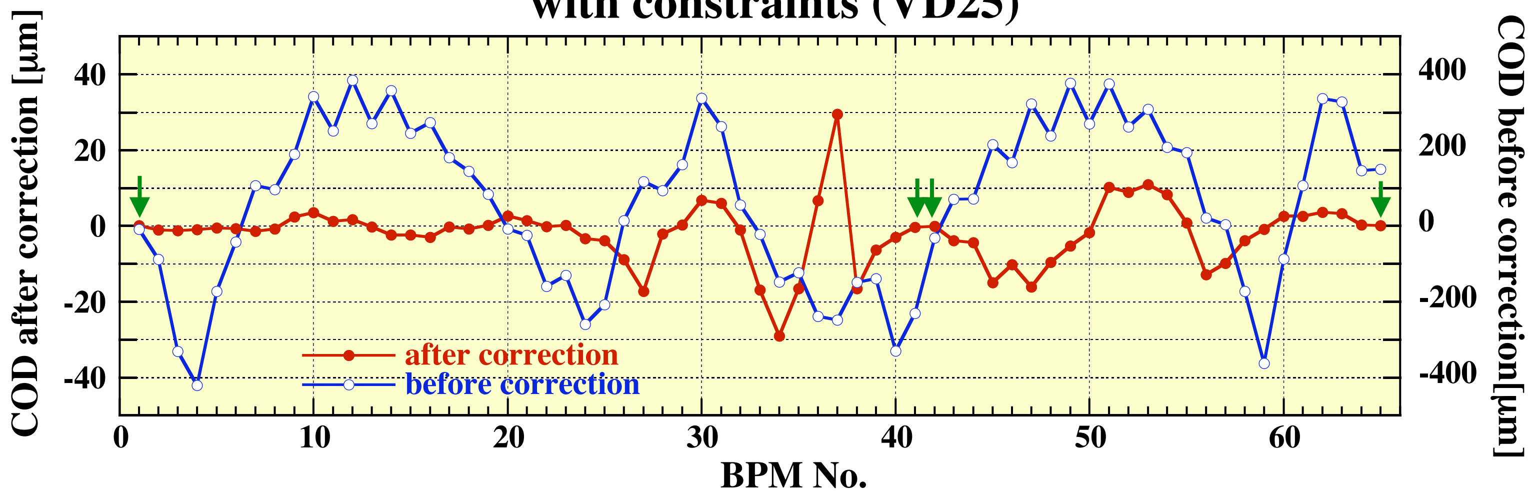
Outline of correction study

1. Vertical COD is artificially generated by each vertical dipole and then several times corrected by 28 fast steering magnets using eigenvector methods with and without constraints. The number of the used eigenvectors is 14.
2. Constraint conditions are that beam positions at 4 BPMs on both sides of the two long straight sections are zero.
3. Measured response function is used.
4. RMS CODs for the constrained 4 BPMs and for all the BPMs are obtained for the two kinds of correction methods.

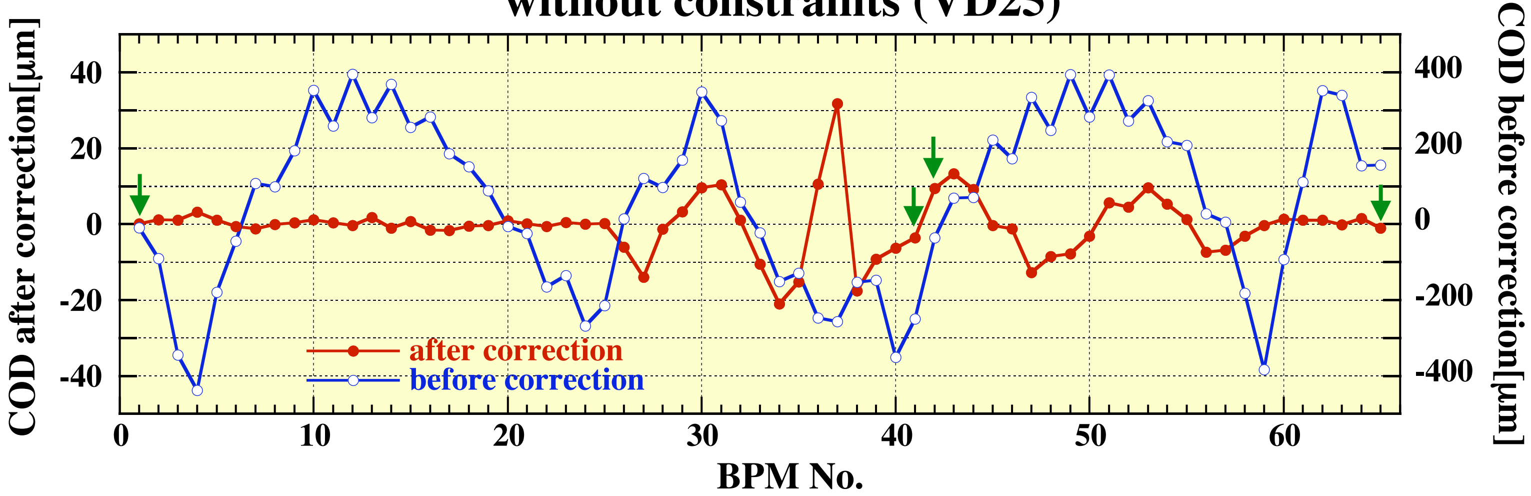
Orbit Correction Study at PF ring (2)

Example of vertical COD before and after correction

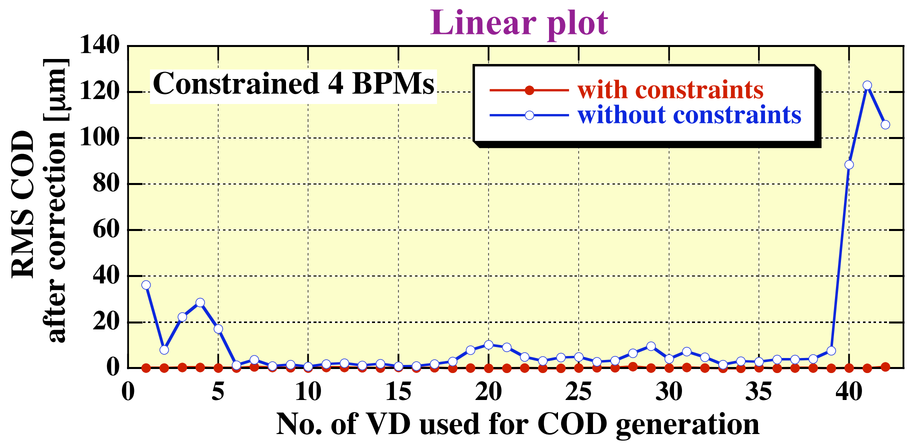
with constraints (VD25)

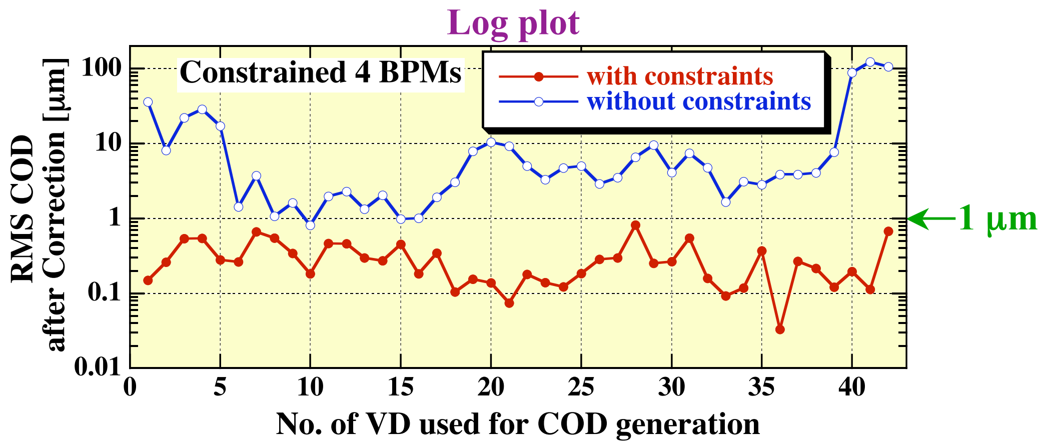


without constraints (VD25)

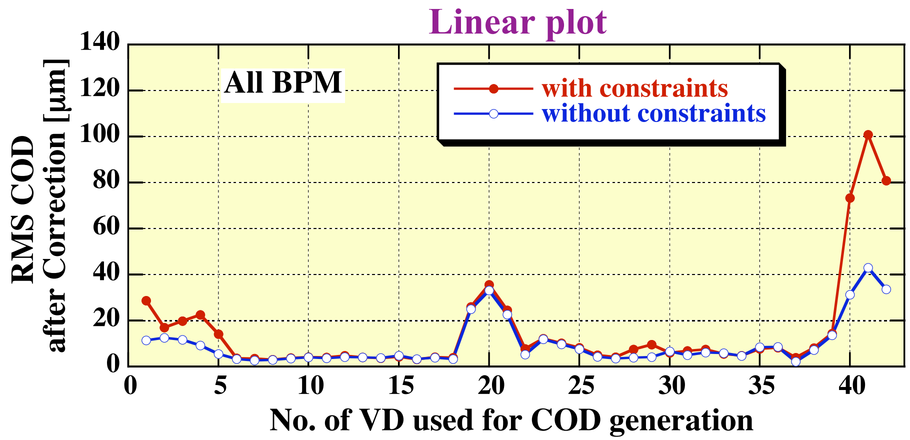


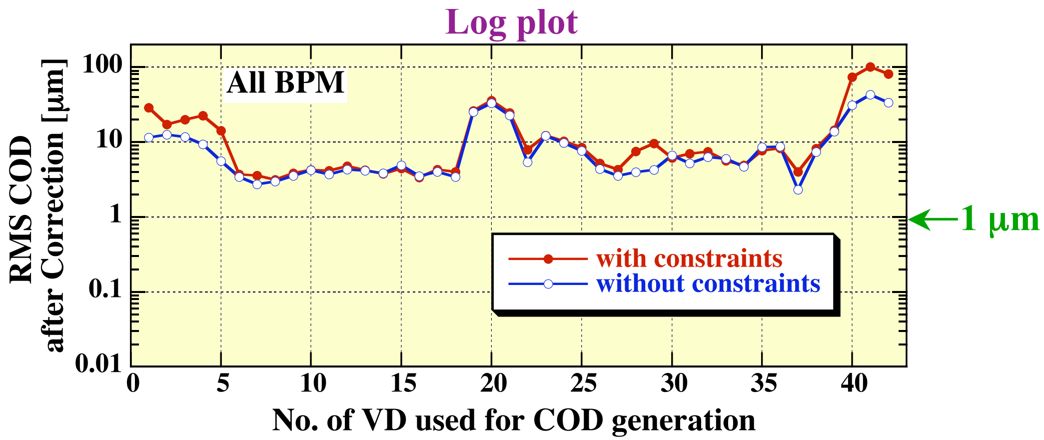
Orbit Correction Study at PF ring (3)





⇒ **Local correction performance of the new method is a sub-micron level !**



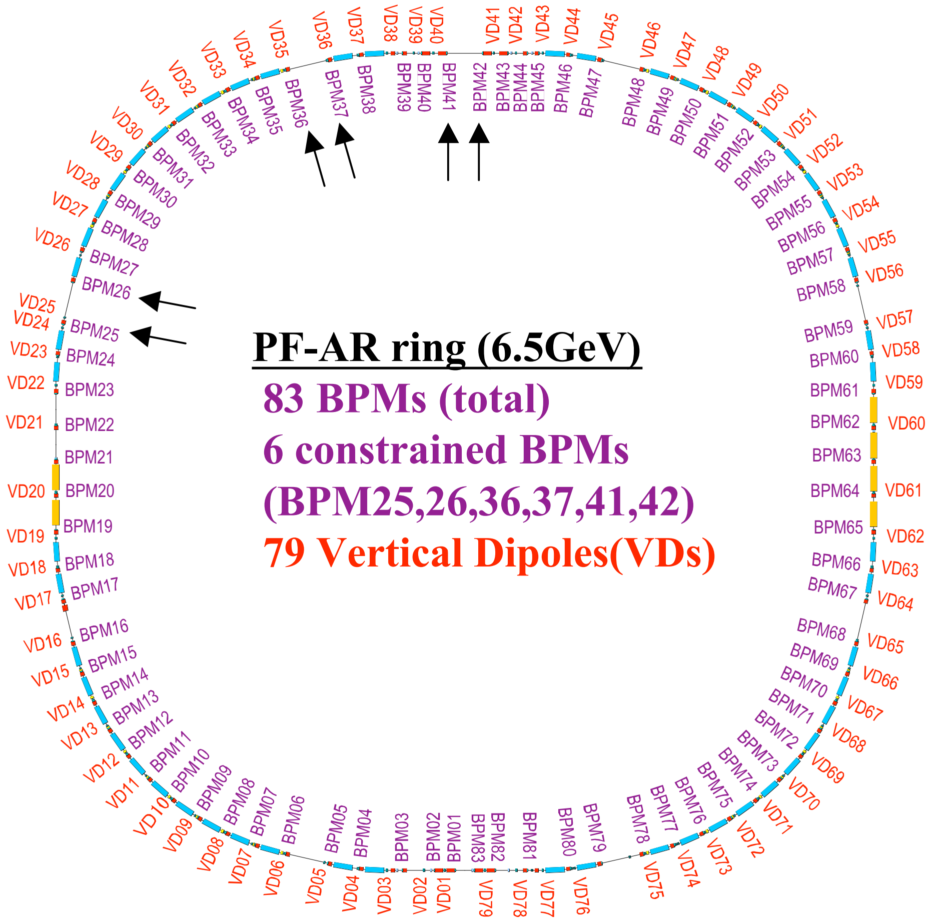


⇒ **Global correction performances of the two methods are almost the same.**

(The global correction performance for VD 40 - VD05 can easily be compensated by adding 1 or 2 steering magnets in the section.)

Orbit Correction Study at PF-AR Ring (1)

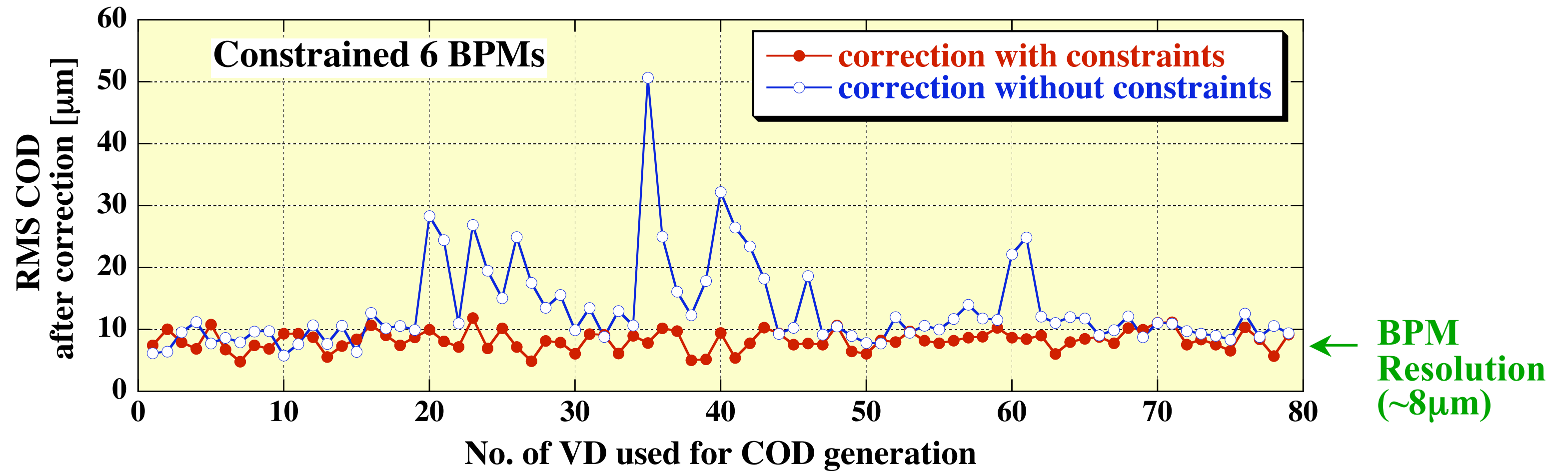
Experimental study of the new orbit correction method at PF-AR ring



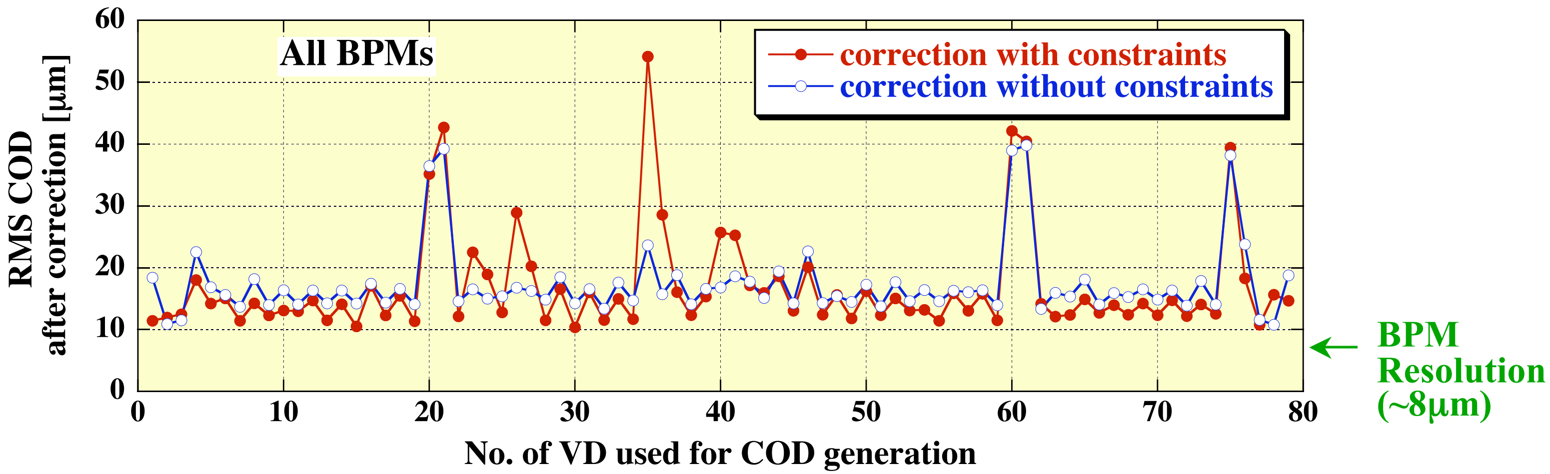
Outline of correction study

1. Vertical COD is artificially generated by each vertical dipole (VD) and several times corrected by the other 78 VDs using eigenvector methods with and without constraints. The number of the used eigenvectors are 40.
2. Constraint conditions are that positions at 6 BPMs on both sides of the three long straight sections are zero.
3. Measured response matrix is used.
4. RMS CODs for the 6 BPMs and all the BPMs are obtained for the two kinds of correction methods.

Orbit Correction Study at PF-AR Ring (2)

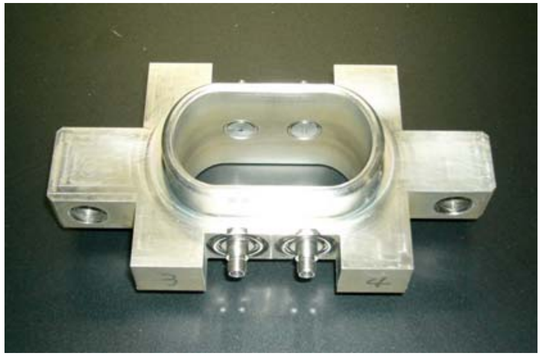


⇒ Local correction performance of the new method is better than BPM resolution.

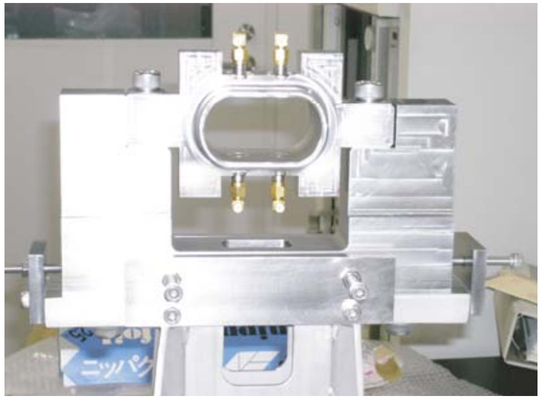


⇒ Global correction performances of the two methods are almost the same.

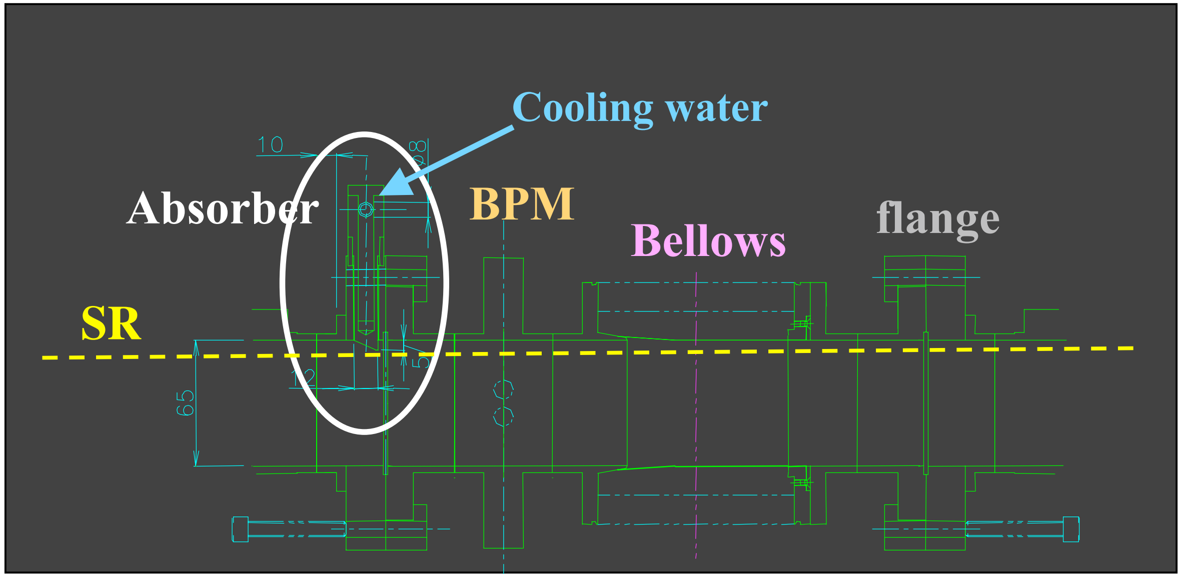
BPM System (1)



Prototype of BPM block



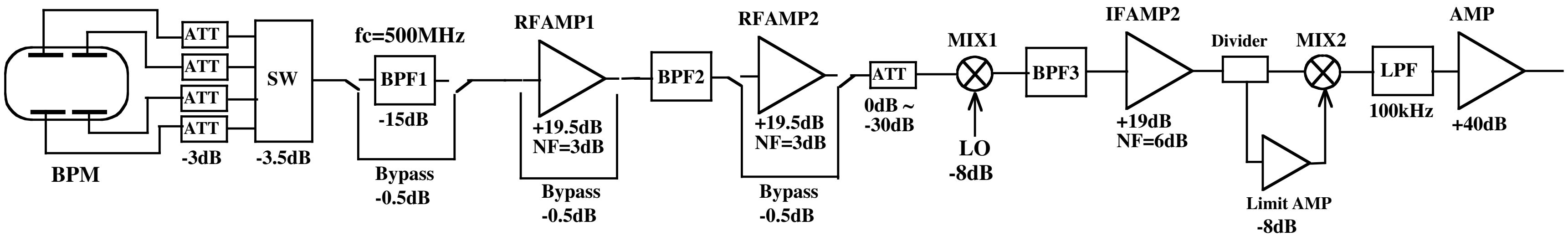
Prototype of BPM support



Example of BPM location

- BPM block (SUS) with SMA feedthroughs
- Fixed on the girder by BPM support
- Reduction of vacuum chamber stress by bellows
- Protection from SR irradiation by absorber

BPM System (2)



Design of BPM Electronics using Multiplexing & Heterodyne method

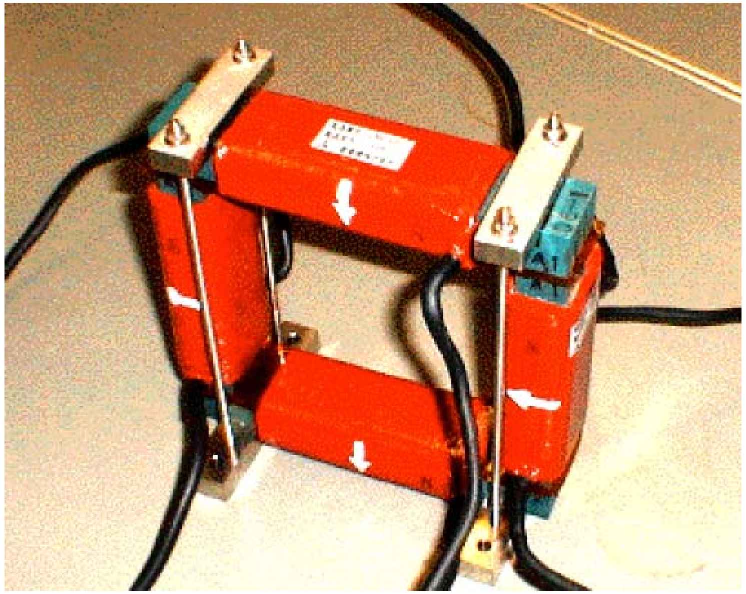
- S/N is more than 90dB at 200mA (< 0.3μm in resolution).
- Single-bunch operation is also considered.
- BPM signals can be switched to another system for turn-by-turn measurement.

PROBLEMS

- Position error by coherent synchrotron oscillations
- Cost effectiveness

⇒ Another type of BPM electronics is also under consideration.

Fast Steering Magnet System (1)



Prototype of Fast Steering Magnet

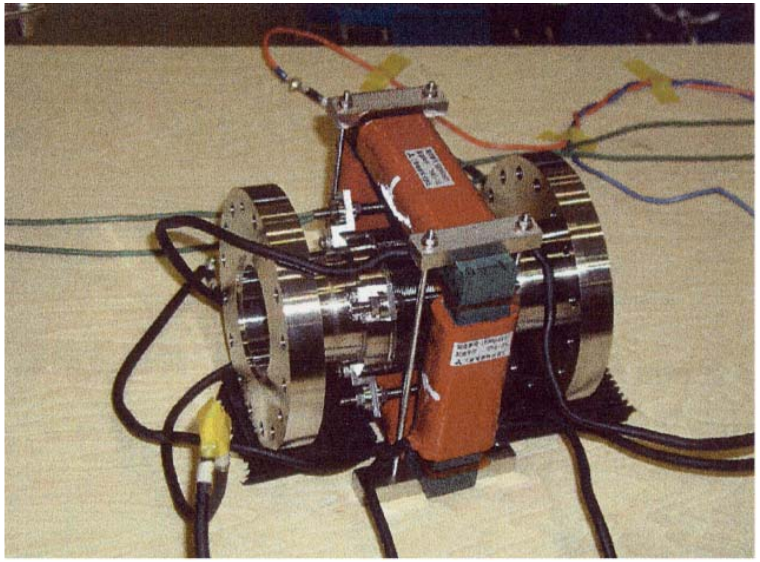
Power Supply Models for Fast Steering Magnets

Upper : Switching type

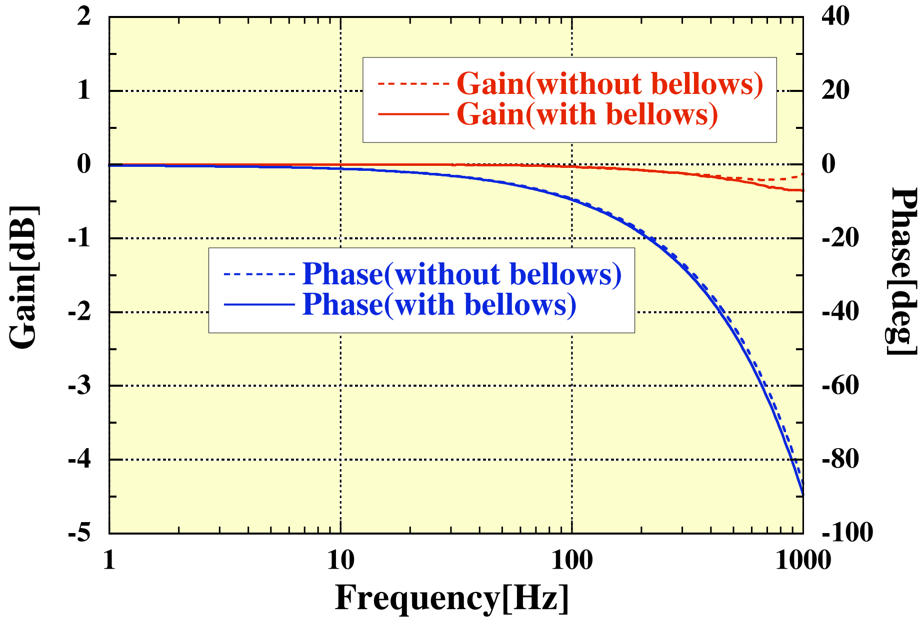
Lower : Linear amp. type

- Fast steering magnet is made of 0.5-mm silicon steel laminations.
- Two types of power supply (linear amp. and switching types) are tested.
- Linear amp. type is superior to switching type in ripple noise.

Fast Steering Magnet System (2)



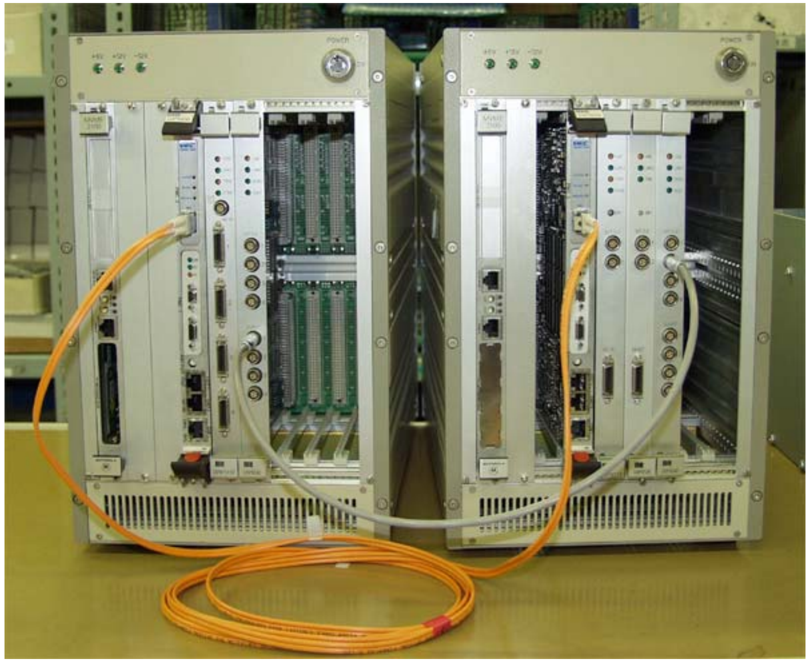
Steering magnet + Bellows duct



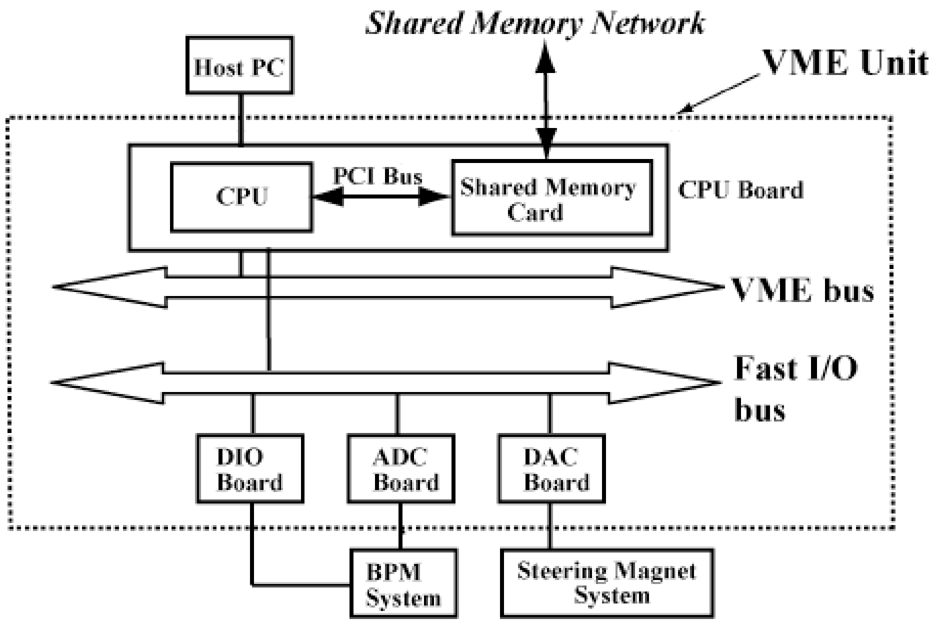
Measured frequency response

- All the fast steering magnets are installed on the RF-shielded bellows ducts.
- Bellows duct is made of stainless steel and RF shields of 0.4mm-thick BeCu.
- Effects of bellows on frequency response are negligibly small.

Feedback Control System (1)



Local controller x 2 (prototype model)

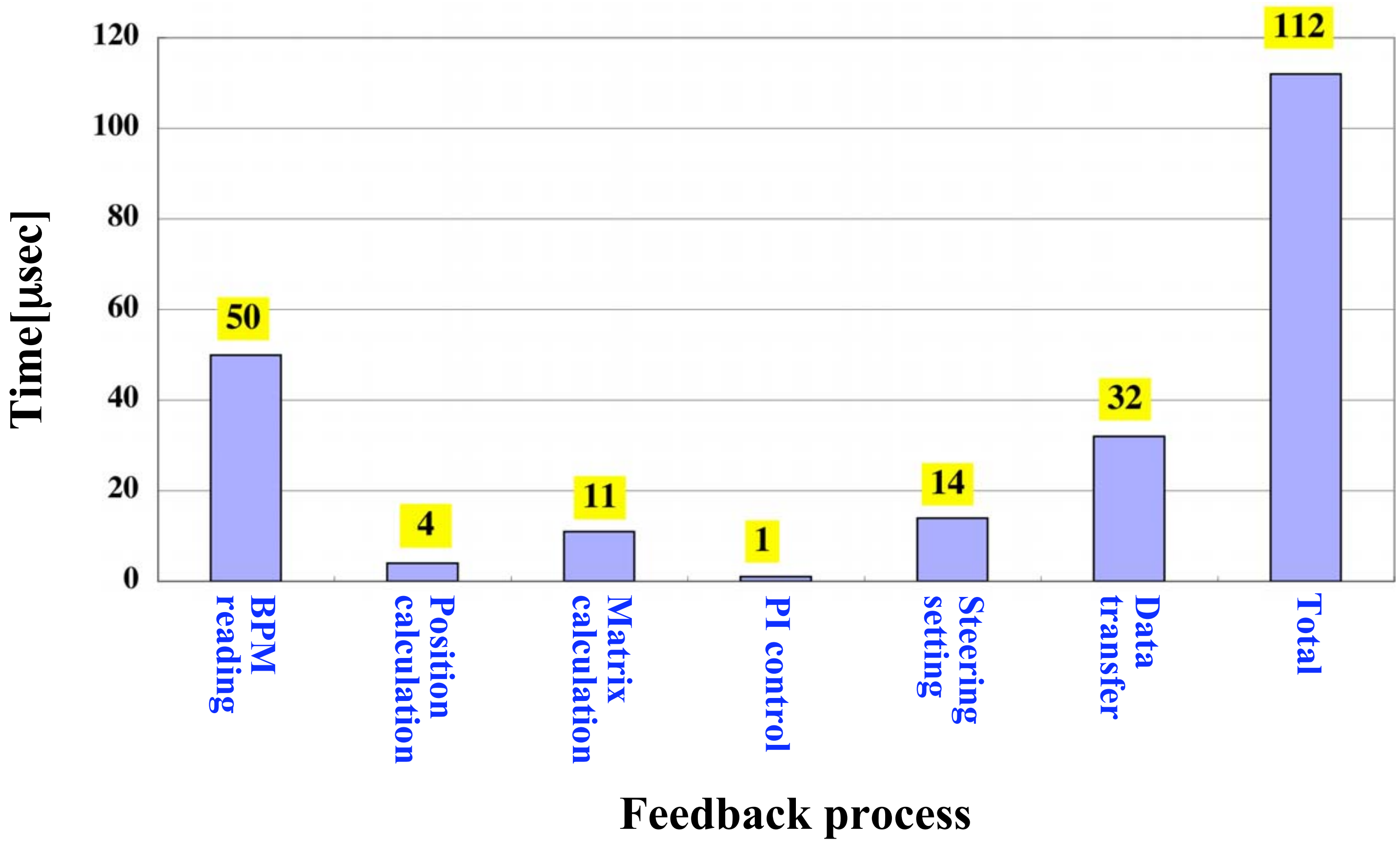


Block diagram of local controller

- Target feedback period T_S < 0.5ms (sampling rate > 2 kHz)
- 140 BPM data are shared with all the controllers by a shared memory network.
- CPU board computes beam positions at 10 BPMs and coil currents of 5 FSs.

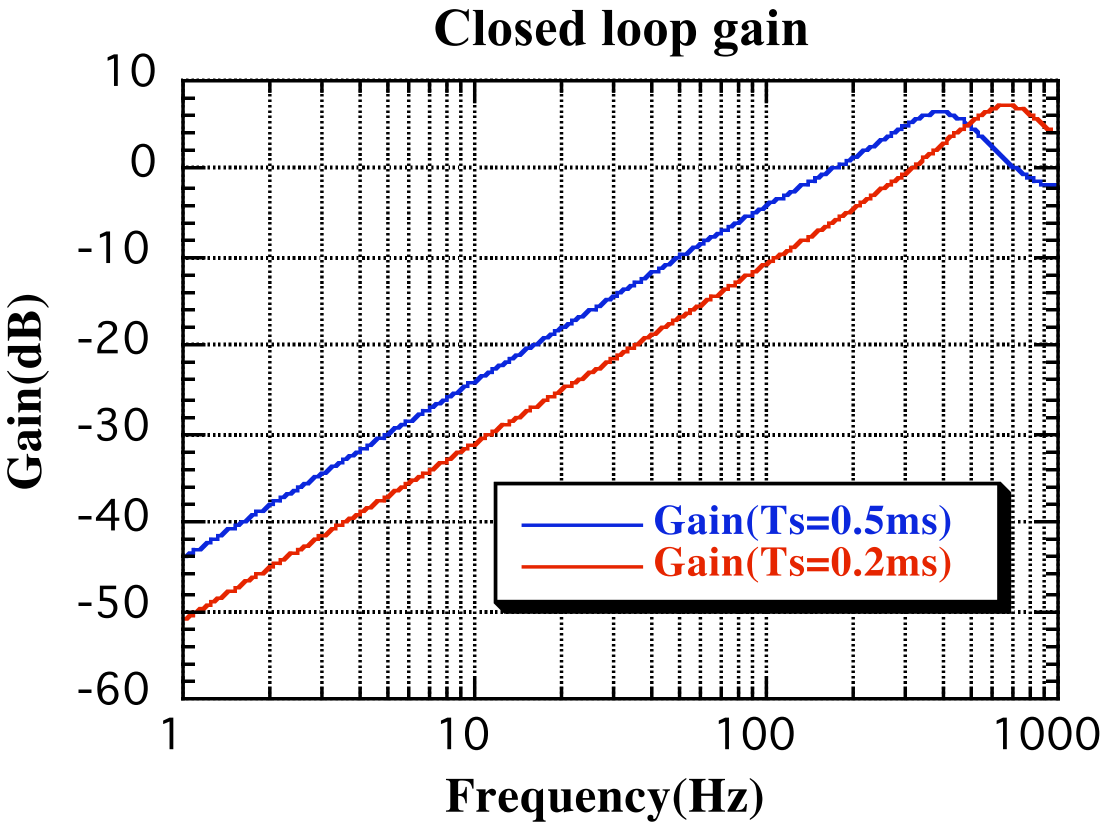
Feedback Control System (2)

Measurement result of consumed time for each feedback process



⇒ Feedback period of less than 0.2 ms can be achieved.

Noise Attenuation



⇒ **Frequency Bandwidth > 100Hz**

Summary

- An orbit feedback system is planned for the Super-SOR project to suppress the brilliance reduction due to orbit drifts and vibrations. Final goal is sub-micron stability at the source points and at the experimental stations.
- A new orbit correction method, the eigenvector method with constraints ("EVC" or "SVDC"), can unite global and local orbit feedbacks and enhance the beam stability at insertion devices up to a sub-micron level. We will try to stabilize photon beams using this correction method and photon BPMs.
- Design and R&D of the BPM, fast steering and feedback control systems are in progress. The feedback system can achieve position resolution of less than 1μm and the frequency bandwidth of more than 100 Hz.