IWBS 2002, 4-6 Dec. 2002, Spring-8

Study of Orbity Stability at SSRF

DAI Zhimin, LIU Guimin and HUANG Nan

Shanghai National Synchrotron Radiation Center, CAS

Contents

Introduction

- SSRF: Shanghai Synchrotron Radiation Facility

  An intermediate energy 3rd SR light source
- Concept Design phase from 1995 to 1998
- Approval of the 80M Yuan R&D Program in 1998
- Two year's R&D from Jan. 1999 to March 2001
- Site selection for the SSRF in 1999

Zhang-Jiang High-Teche Park

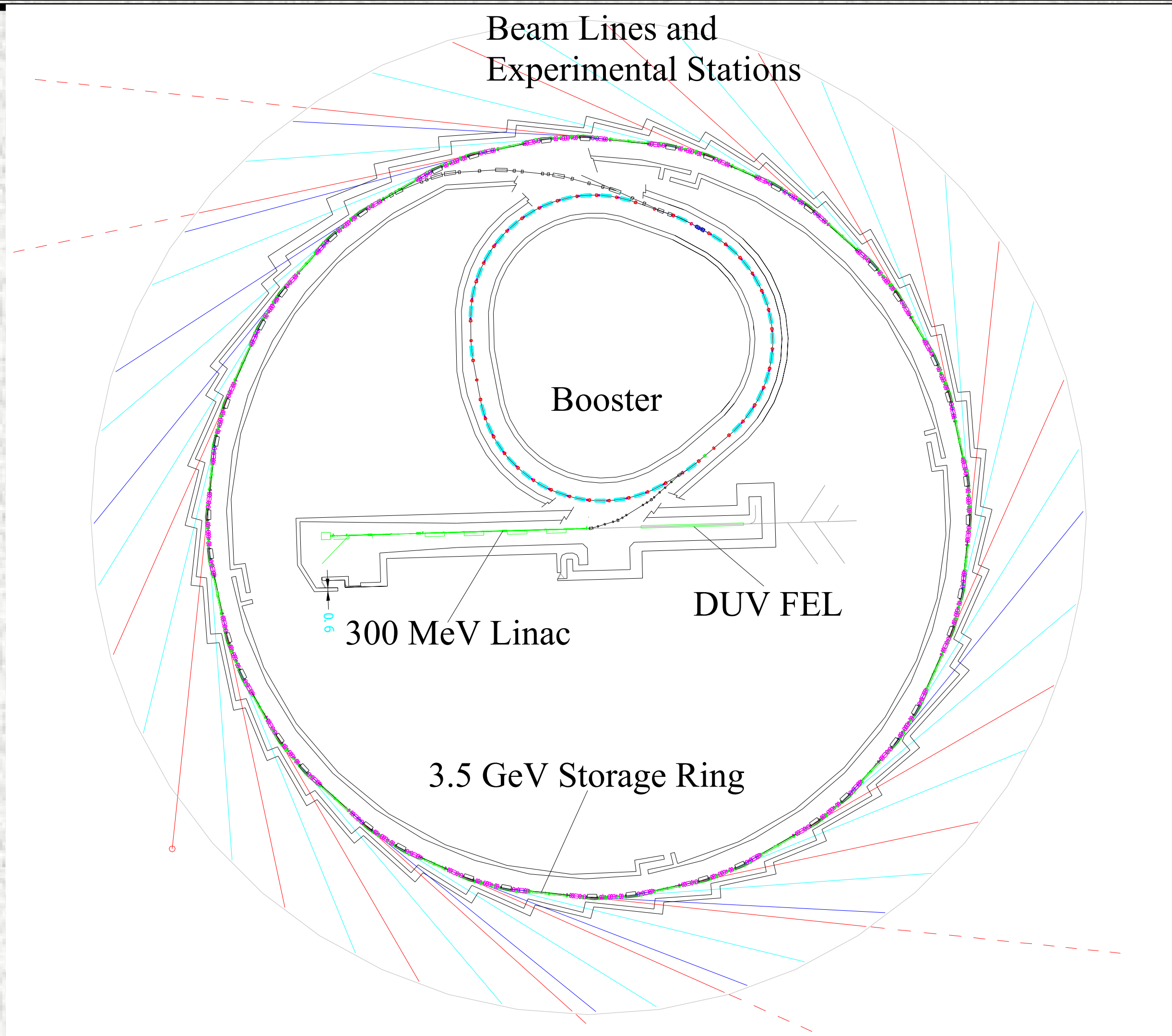
- Construction of 100MeV Linac (pre-injector) from 2002 to 2004

IWBS 2002, 4-6 Dec. 2002, Spring-8

The SSRF Site in Shanghai

SSRF Main Building Layout

The SSRF Layout



The SSRF Storage Ring

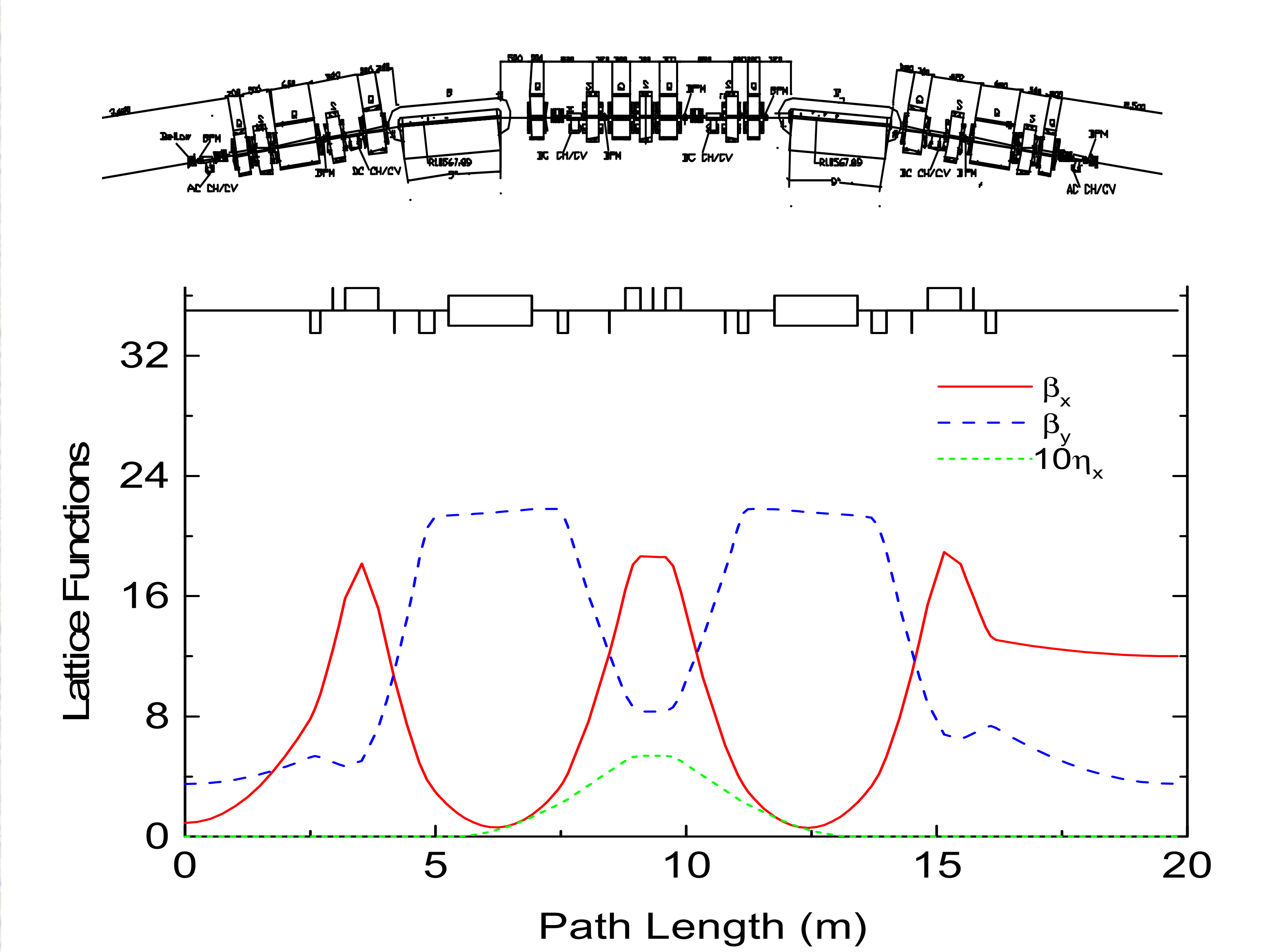
Magnetic Lattice

- Operation Energy: 3.5GeV
- Circumference: 396 m
- 20 cells DBA structure with 10 of 5m and 10 of 7.24m straight sections
- High Flexibility in operation
  - High β_x and hybrid β_x configurations
  - Dispersion free and finite dispersion modes
  - Emittance: 4.8~12.1nm·rad

Main Parameters of SSRF

Energy (GeV)	3.5
Circumference (m)	396
Harmonic Number	660
Nature Emittance (nm·rad)	4.8~12.1
Beam Current, Multi-Bunch (mA) Single-Bunch (mA)	200~300 >5
Straight Lengths (m)	10×7.24, 10×5
Betatron tunes, Q_x/Q_y	18.81/8.77, 22.19/8.23
Momentum Compaction	6.9×10^{-4}
RF Frequency (MHz)	499.654
RF Voltage (MV)	4
Dipole Radiation per Turn (MeV)	1.256
Bunch Length (mm)	4.59
Beam Lifetime (hrs)	>20

The SSRF Magnet Lattice



Electron beam Parameters

at photon source points

	Beam size			
	Coupling 5%		Coupling 1%	
	σ_x (μm)	σ_y (μm)	σ_x (μm)	σ_y (μm)
BM(1°)	144	110	145	50
BM(3°)	103	110	105	50
Long Straights	367	44	374	20
Short Straights	101	44	103	20

Orbit stability requirements

$\sim 0.1\sigma_{x,y}$

	Horizontal stability (rms)	Vertical stability (rms)
Straight section	<30 μm	<5 μm
Mid-girder	<30 μm	<5 μm
Dipole	<15 μm	<5 μm

Final goals for orbit stability in vertical plane will be smaller than 1μm

Sources of orbit motion

- Thermal motion
- Magnet power supply's stability and ripples
- Vibration
- Others, such as ground settlement

Effects of ground settlement of a few hundred microns may be compensated by COD correction. But larger motion must be corrected by realigning the magnet girder

Orbit Stability Analysis

Thermal Motion

- Variation of tunnel air temperature
- Variation of magnet cooling water temperature
- Variation of vacuum chamber cooling water temperature
- Synchrotron radiation power variation due to beam current decreasing.
- Lead to
- Magnet's motion
- Beam orbit motion
- BPM's motion

Orbit Stability Analysis

Thermal Motion

Temperature stability specifications for storage ring

	Tunnel Air	Magnet cooling water	Vacuum chamber cooling water
First Stage	±1.0°C	±0.5°C	±1.0 °C
Final goal	±0.2°C	±0.1°C	±0.2 °C

Temperature stability of RF cavity cooling water is ±0.1°C

Orbit Stability Analysis

- Thermal Motion

Magnet and BPM's Thermal Motion

Element	Horizontal drift	Vertical drift
Magnet	~± 2μm	~± 7μm
Normal BPMs	~± 11μm	<± 15μm
High precise BPMs at ID straights	~± 2μm	~± 2μm

Orbit Stability Analysis

Thermal Motion

Components	Temperature variation	Vertical position variation
Magnet girder（ L=39cm）	±0.4 °C	±1.9μm
Magnet girder stands（ L=42cm）	±0.4 °C	±2.0μm
Magnet（ L=49cm， to girder）	±0.5 °C	±3.0μm
Normal vacuum chamber（ L=2.5cm）	±3.0 °C	±1.8μm
Vacuum chamber stands 1(normal BPM)（ L=46.5cm， to girder）	±1.0 °C	<±5.6[a]μm (±0.5[b]μm)
Stainless steel vacuum chamber (L=2.5cm)	±1.0 °C	±0.4μm
Vacuum chamber stands 2(high stable BPM) (L=127.5cm， to floor)	±1.0 °C	±1.3μm
Magnet position to floor		±6.9μm
Normal BPM position to floor		±11.3[a]μm (±6.2[b]μm)
High precise BPM position to floor		±1.7μm

[a] Mounted vacuum chamber with stainless steel、

[b] Mounted vacuum chamber with low thermal expansion stands

Orbit Stability Analysis

- Thermal motion

Beam orbit motion due to global temperature variation

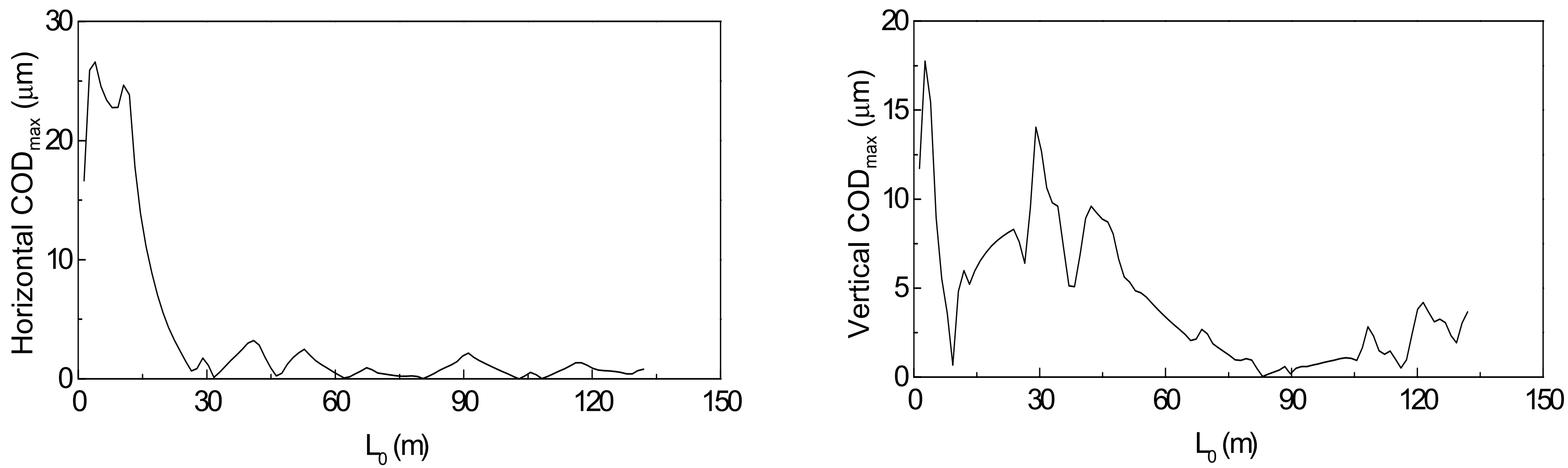
Photon Source Ponits	Horizontal drift	Vertical drift
BM	~± 4μm	~±7μm
Straight Section (without dispersion)	~± 2μm	~±7μm
Straight Section (with dispersion)	~± 10μm	~±7μm

Orbit Stability Analysis

Thermal Motion

Beam Orbit Motion due to local temperature variation

$\Delta T = \Delta T_{max} \cos[\pi(S_n - S_0)/L_0]$, $L_C - L_0 < 2(S_n - S_0) < L_C + L_0$, $\Delta T_{max} = \pm 1°C$



Orbit Stability Analysis

- Power Supply's Stability and Ripples

Specifications of magnet Power Supplies

Elements	Long time Stability	Ripples
BM	$\pm 5.0\times 10^{-5}$	$\pm 5.0\times 10^{-5}$
Quadruple	$\pm 1.0\times 10^{-4}$	$\pm 1.0\times 10^{-4}$
Sextupole	$\pm 1.0\times 10^{-3}$	$\pm 1.0\times 10^{-3}$
Correctors	$\pm 2.0\times 10^{-4}$	$\pm 2.0\times 10^{-4}$

Orbit Stability Analysis

Power Supply's Stability and Ripples

- **Effects of BM, Quadruploe and Sextuploe power supplies on the beam orbit stability is very small, e.g., leads to orbit motion within 1μm.**

- **Effect of corrector power supplies on beam orbit stability is strong, and it should not cause a problem for horizontal beam orbit stability, but produce vertical beam orbit motion larger the 5μm limit.**

The static horizontal and vertical correctors's maximum strength are respectively 1.2mrad and 0.8mrad in vertical plane, and rms value for COD correction are respectively 0.24mrad and 0.16mrad

Orbit Stability Analysis

Effects of Correctors Power Supplies

$$\sigma_{x,y}(s) = A_{x,y}\sigma_{errors}$$

Photon Source Ponits	Amplification factors		Long time stability		Ripples	
	A_x	A_y	σ_x(μm)	σ_y(μm)	σ_x(μm)	σ_y(μm)
BM	15.8	85.7	3.8	13.7	0.8	2.7
ID in 7.0 straight	54.7	34.4	13.1	5.5	2.6	1.1
ID in 5.0 straight	15.0	34.4	3.6	5.5	0.7	1.1

Orbit Stability Analysis

Vibrations

- The vibration sources include external or internal sources, which can be considered as plane wave vibrations and random vibrations, respectively.
- External sources are seismic ground motion, traffic and equipment such as pumps and compressors in the site at large distances from the storage ring.
- Internal vibration sources are those close to the storage ring in the experimental area or the inner area of the machine. They include the linac and booster and associated equipment, such as vacuum pumps working in this area.

Orbit Stability Analysis

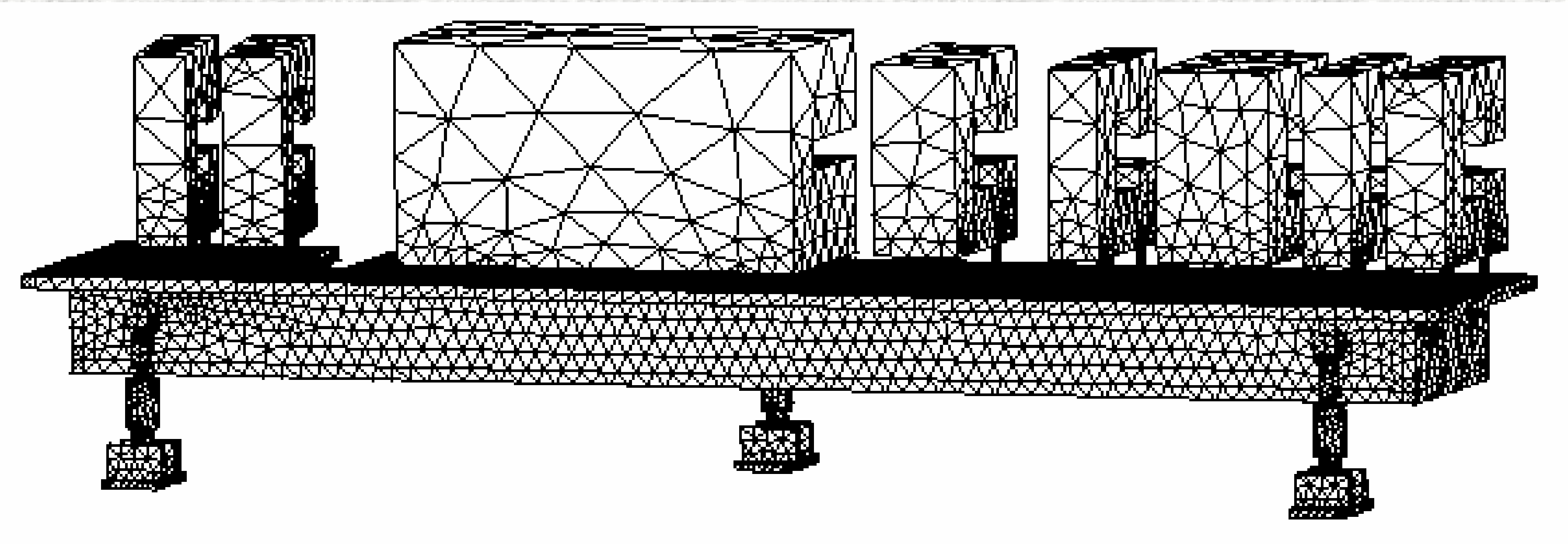
Vibrations

Photon Source Points		Amplification factors $A_{x,y}$ Random vibrations	Amplification factors $A_{x,y}$ Plane vibrations	Beam Orbit Motion (μm)
BM	Horizontal	16.7	29.4	7.7
	Vertical	51.8	141.3	32.3
ID in 7m straight	Horizontal	57.9	101.7	26.7
	Vertical	20.8	56.7	12.9
ID in 5m straight	Horizontal	15.8	27.9	7.3
	Vertical	20.8	56.7	12.9

*To calculate beam orbit motion, it is assumed that
300nm random vibrations and 200nm plane vibrations in 0-100Hz

Dynamic Analysis of Magnet Girder

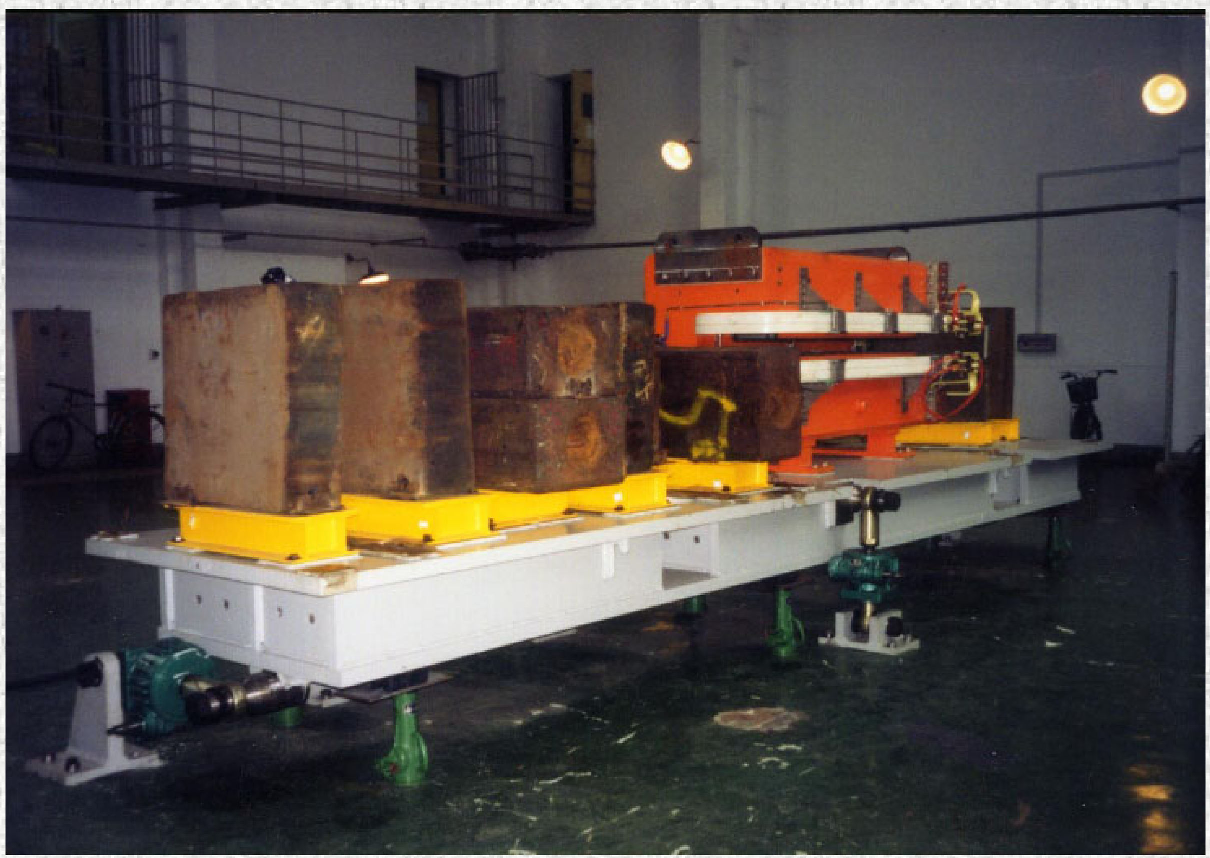
- Girder's resonant frequency



ANSYS Model with load

Dynamic Analysis of Girder

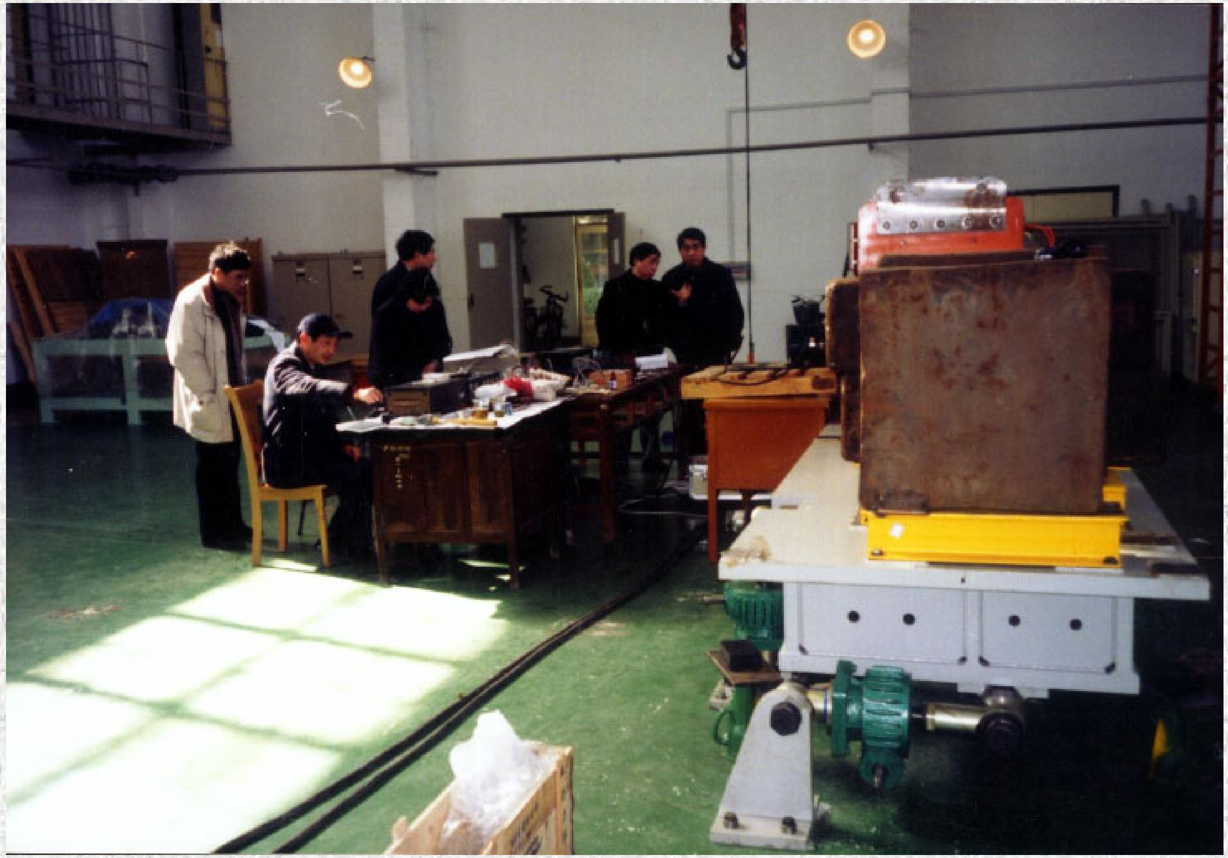
- Girder's resonant frequency



Experimental Model with load

Dynamic Analysis of Girder

- Girder's resonant frequency



Experimental measurements with acceleration sensors

Dynamic Analysis of Girder

- Girder's resonant frequency

Resonant frequency of magnet girder with load

	ANSYS Results (Hz)	Experimental Results (Hz)
Horizontal (X)	6.322	6.875
Longitudinal (Z)	5.816	5.875
Vertical (Y)	26.851	23、25、27.00*

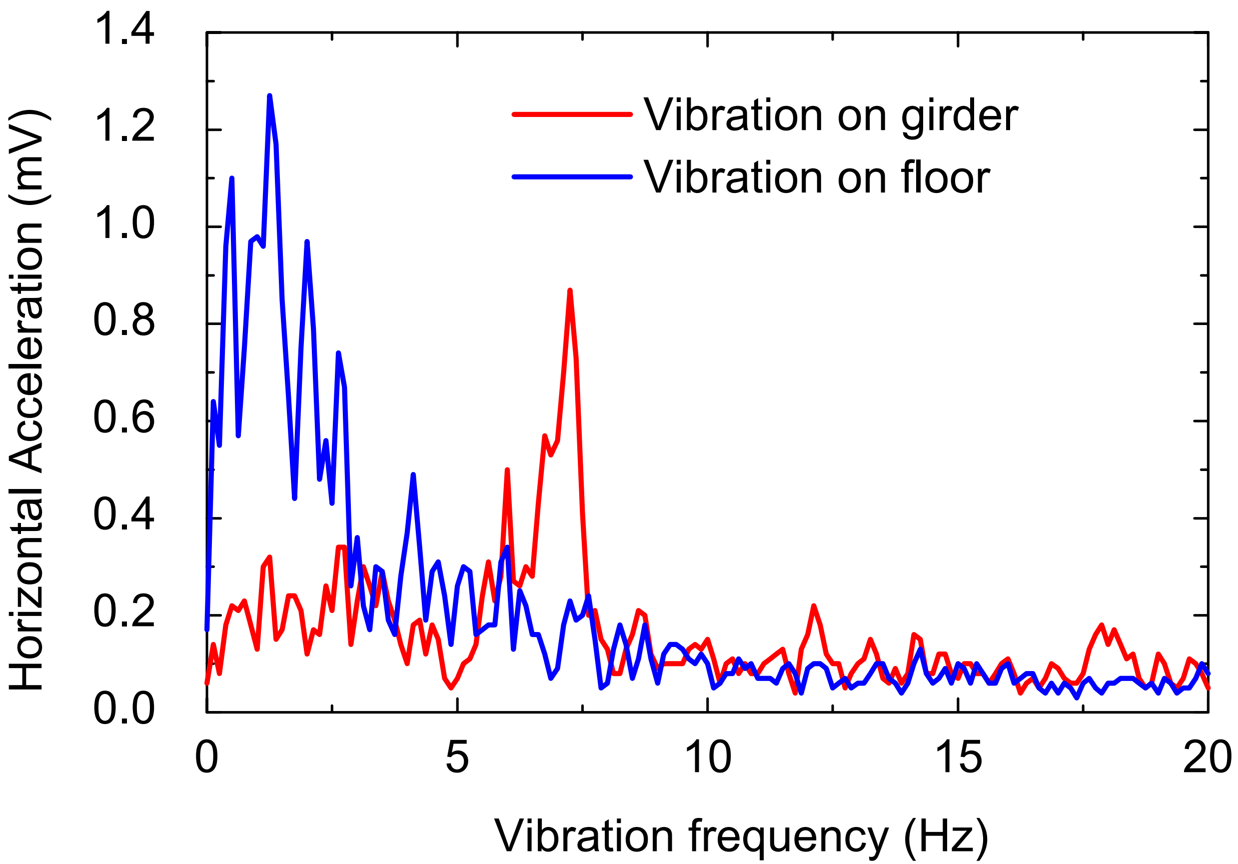
* At different points

Dynamic Analysis of Girder

Acceleration spectrum

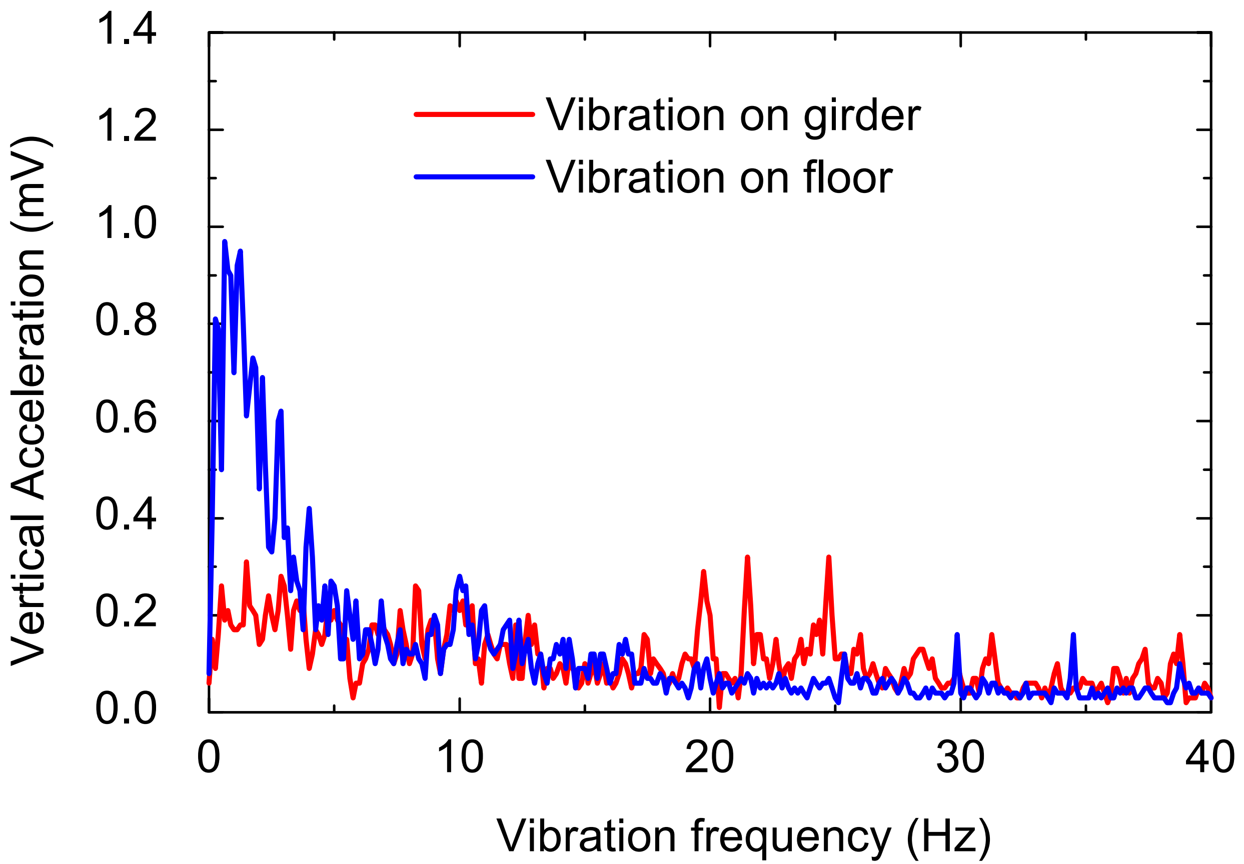
- Measure the acceleration response at different points on girder.
- Study the girder's vibration modes experimentally, which are consistent with the ANASYS results.
- Measure the acceleration spectrum on floor and on girder under peaceful condition, respectively. It shows that the magnet girder can damping vibrations far from the resonant frequencies but amplify the vibrations near the resonant frequencies, and the maximum amplification factors are 8 and 4 for horizontal direction and vertical direction, respectively.
- Measure the acceleration spectrum on girder with and without magnet cooling water, respectively. It shows that the effects of magnet cooling water flow on acceleration spectrum is weak, and can be neglected.

Dynamic Analysis of Girder



Acceleration spectrum on floor and on girder under peaceful condition (100V=1 g)

Dynamic Analysis of Girder



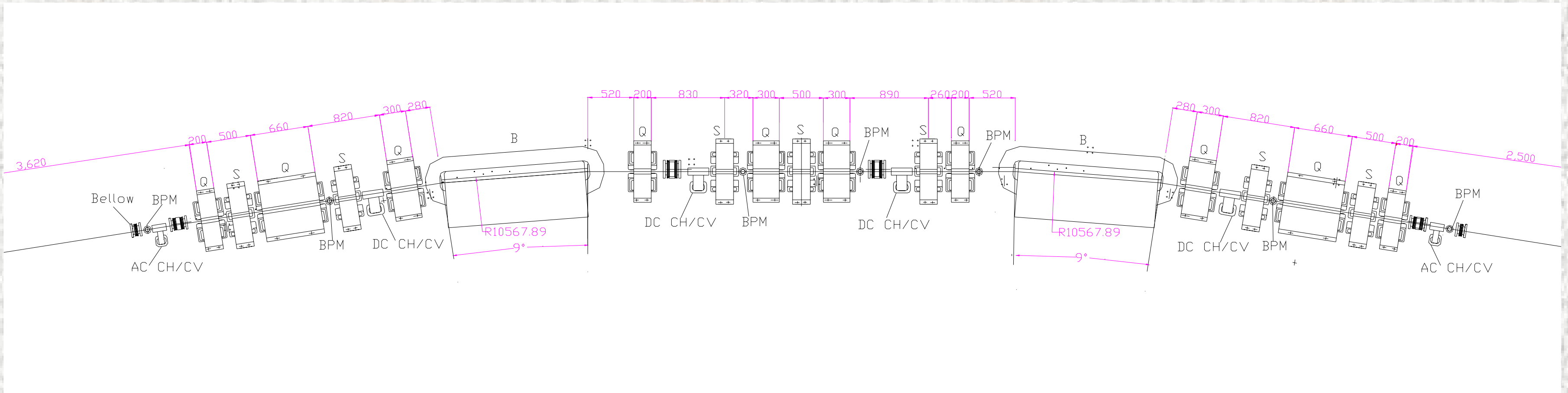
Acceleration spectrum on floor and on girder under peaceful condition (100V=1 g)

Orbit Control

- Global Static COD Corrections
- Local Orbit Bump
- Global Orbit feedback

Orbit Control

- **BPM and corrector locations**



- 5 Normal BPMs and 2 High-precise BPMs per DBA Cell
- 4 Normal Correctors and 2 Coil Correctors per DBA Cell

Orbit Control

BPM and corrector locations

- The two AC correctors at both ends of straight section are air-coil type, which surround stainless vacuum chambers, which have significantly higher effective bandwidth and its magnetic field penetration roll-off frequency is >1kHz.
- The two high precise BPMs at both ends of the DBA cell will be have larger button and smaller vertical gap, and mechanically isolated by vacuum bellows located on the outside and mounted on mechanically stable stands with low thermal expansion coefficients and are much more stable than others.

Orbit Control

Static Orbit Correction

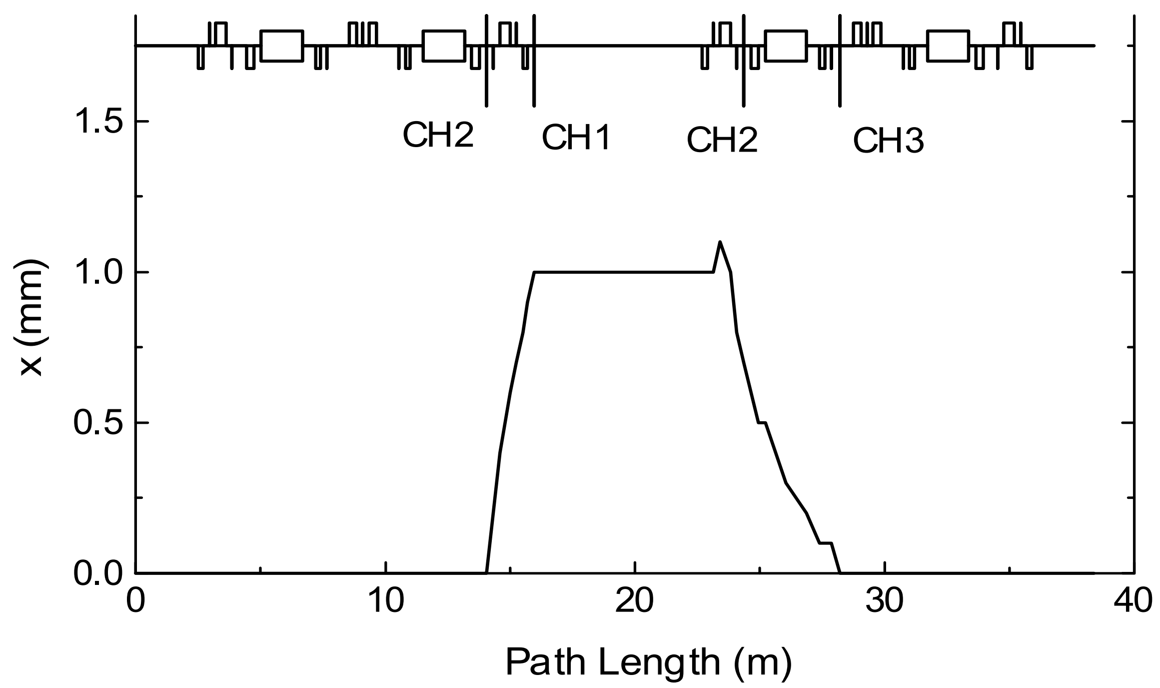
Corrected CODs (100 randomly aligned machines)

COD	X_{max} (mm)	0.6
	Y_{max} (mm)	0.65
	X_{rms} (mm)	0.1
	Y_{rms} (mm)	0.1
Correctors	CH_{max} (mrad)	1.2
	CV_{max} (mrad)	0.8
	CH_{rms} (mrad)	0.24
	CV_{rms} (mrad)	0.16

- Global Static COD Correction with 140 BPMs and 80 normal Correctors

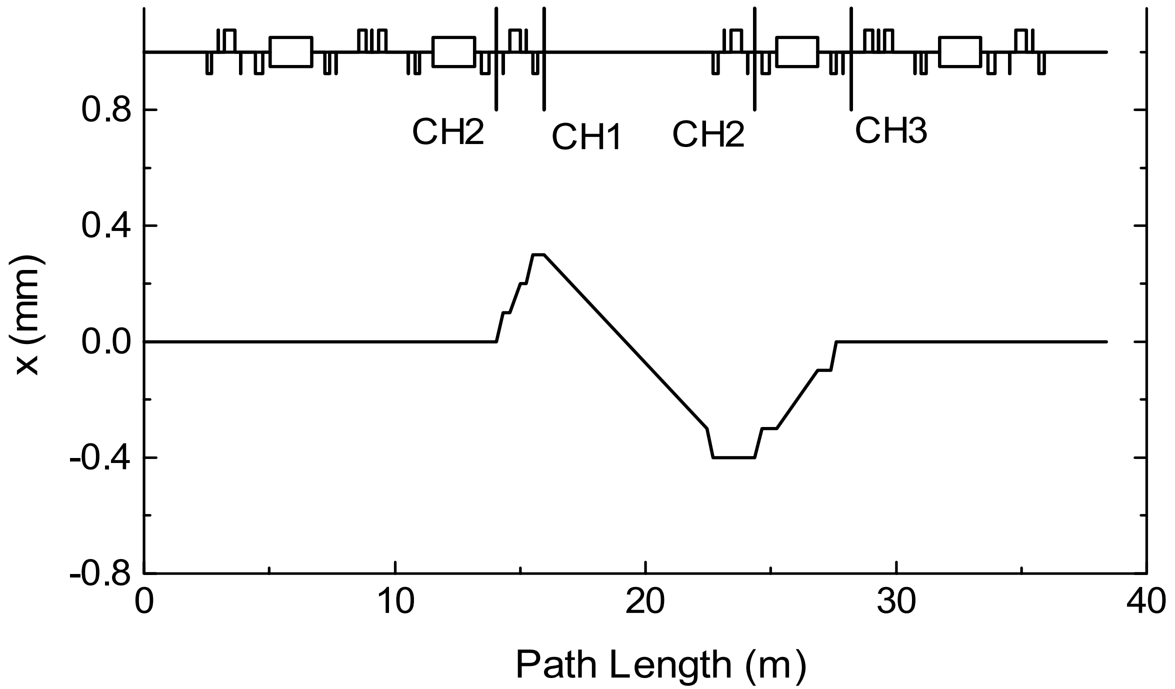
Orbit Control

- **Symmetrical local orbit bump**



Orbit Control

- **Asymmetrical local orbit bump**



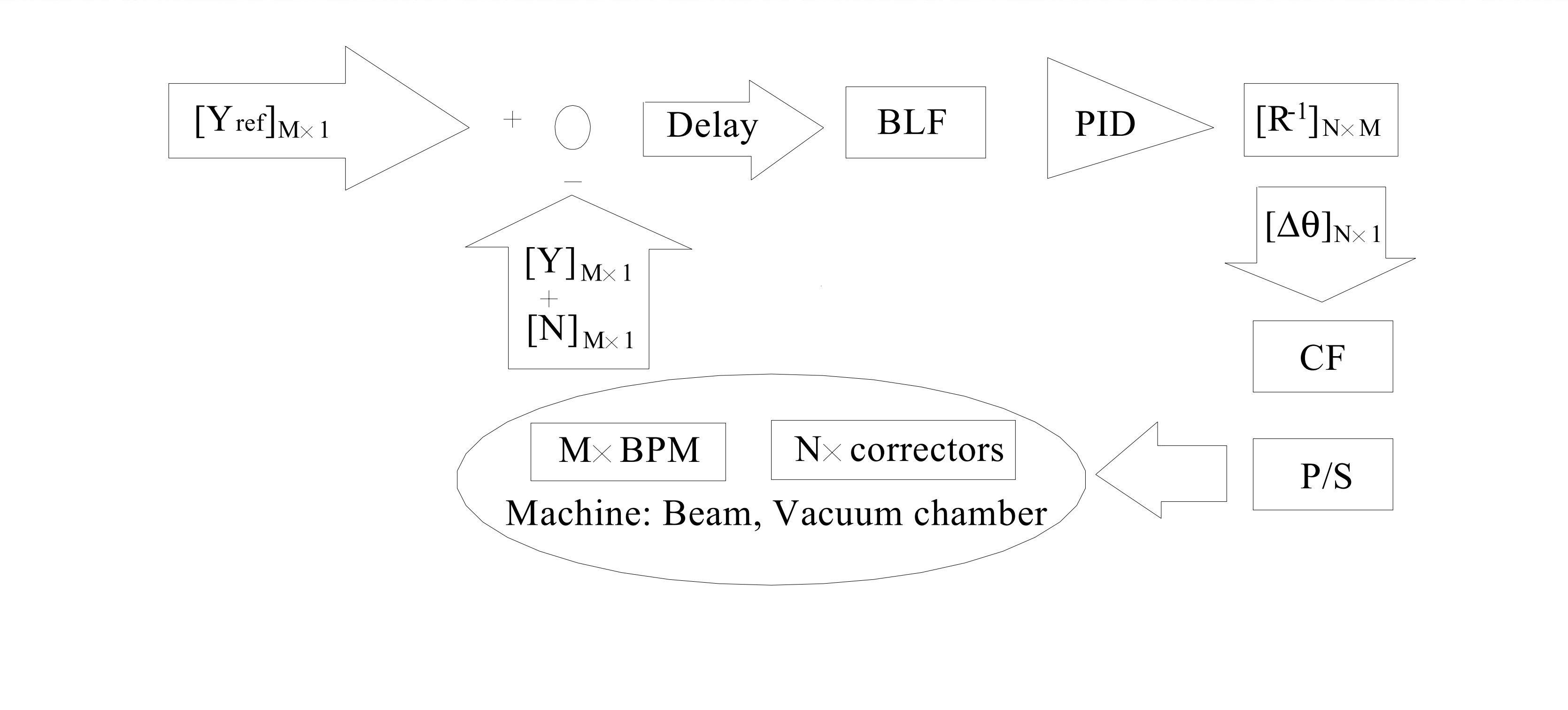
Orbit Control

Global Orbit Feedback

- Global orbit feedback using many BPMs has then the advantage of minimizing BPM errors and correcting only "physical" disturbances.
- A global orbit feedback system is proposed to reduce the vertical orbit motion in SSRF storage ring.
- 40 high precise BPMs and 38 high bandwidth air-coil correctors will be employed for global orbit feedback in SSRF storage ring.

Orbit Control

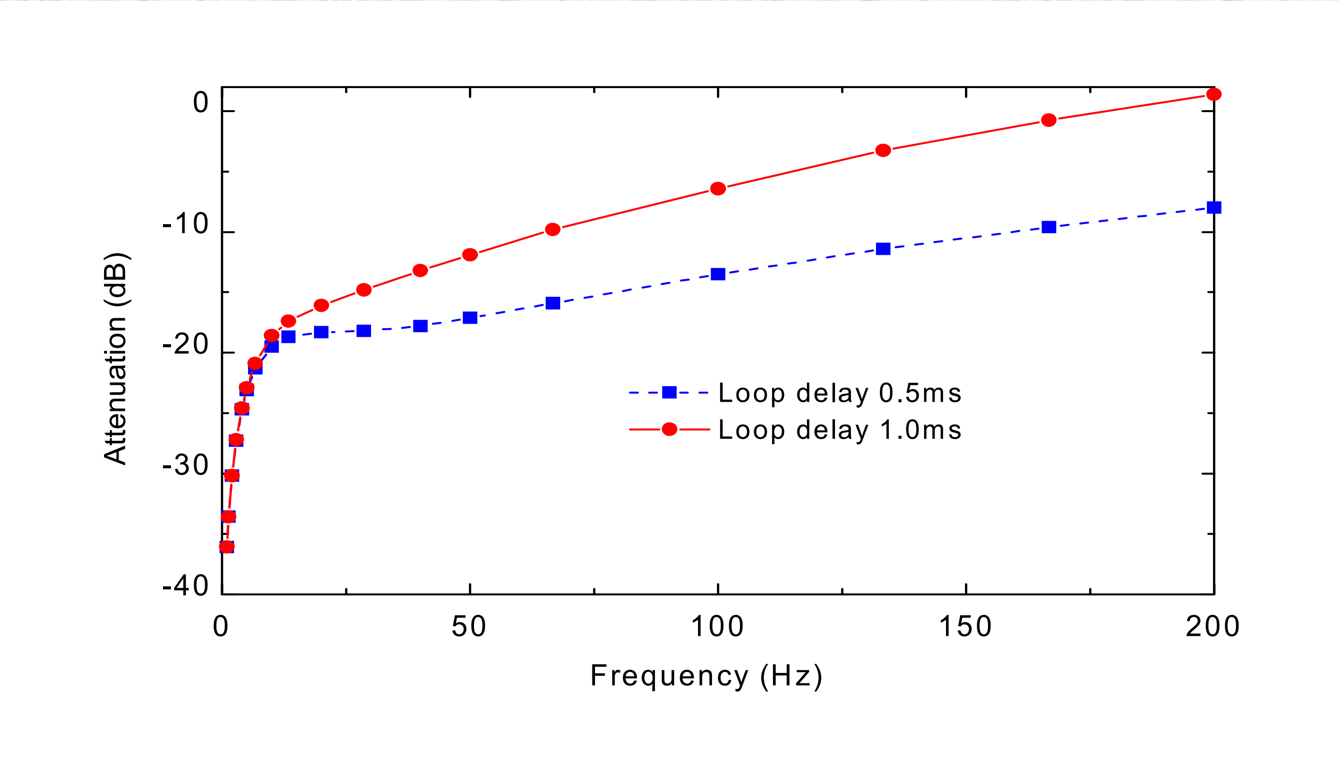
Global Vertical Orbit Feedback



- Block diagram of orbit feedback loop
- Simulation by use of SIMULINK of MATLAB

Orbit Control

Global Vertical Orbit Feedback



Dynamic response of orbit feedback loop

Orbit Control

Global vertical orbit feedback

Simulation results with 40 BPMs and 38 vertical correctors

Parameters			Quadrupole displacement (rms)				
			1.0µm	2.0µm	3.0µm	4.0µm	5.0µm
Before Correction	COD	Y_{MAX}(µm)	194.8	385.9	578.0	770.9	967.2
		Y_{RMS}(µm)	37.9	75.5	113.1	150.8	189.0
	BPM Readings	Y_{MAX}(µm)	104.7	208.6	312.4	416.3	522.3
		Y_{RMS}(µm)	26.2	51.9	77.8	103.6	129.5
After Correction	COD	Y_{MAX}(µm)	32.4	47.8	63.2	81.3	122.7
		Y_{RMS}(µm)	5.4	8.0	11.1	14.3	19.9
	BPMs Readings	Y_{MAX}(µm)	13.9	23.5	33.9	45.3	69.8
		Y_{RMS}(µm)	1.4	2.2	3.2	4.2	10.3
Corrector (µrad)	Vertical $KICK_{MAX}$		9.1	16.3	23.6	30.8	38.0
	Vertical $KICK_{RMS}$		1.9	3.1	4.4	5.7	7.6

Orbit Control

Orbit feedback system specifications

Number of electron BPMs	40
Number of correctors	38
Correction algorithm	SVD
Feedback processor	DSP or Powerful PC
Feedback filter	BLF ,　CF and PID
Cycle time	<1ms
Bandwith (3dB closed-loop)	100Hz
Orbit stabilization goal (ID)	5μm rms (Vertical direction)
BPM resolution	1μm
Corrector maximum strength	50μrad
Corrector power supply stability	10^{-3}

Orbit Control

Orbit feedback system specifications

Bandwidth of the orbit feedback components

Component	3 dB Bandwith
Corrector magnets (air coil)	>1kHz
Corrector supplies	500Hz
BPM Processor (2kHz orbit rate)	500Hz(ϕ=-45°)
Vacuum chamber (Stainless Steel)	>1kHz
Beam (damping τ_x=7.35ms, τ_y=7.36ms)	>>1kHz

Conclusion

- Analysis shows that horizontal beam orbit motion resulted from the thermal drift, vibrations and variations in magnet power supplies is smaller than the horizontal orbit stability requirement, but vertical orbit motion caused by these sources exceeds the vertical orbit stability requirement.
- A mechanical damping links of girder should be added.
- A dynamic vertical orbit feedback is required.
- The proposed dynamic global vertical orbit feedback system includes 38 high bandwidth air-coil AC correctors and 40 high-precise BPMs.
- Numerical simulations show that this dynamic orbit feedback system can stabilise orbit motion in the frequency up to 100 Hz.

Thank you for your attention！

谢谢！