Design and Testing of the Girder Support System of the SSRF

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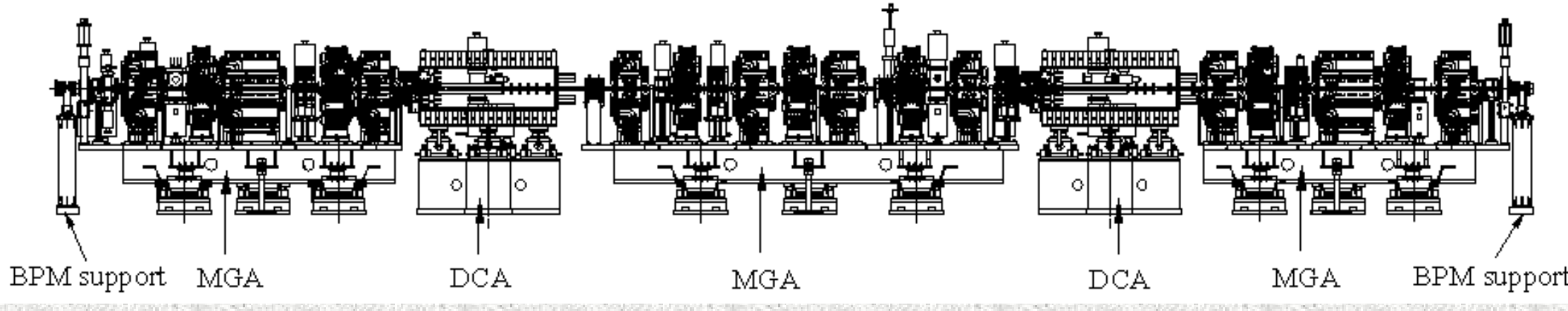
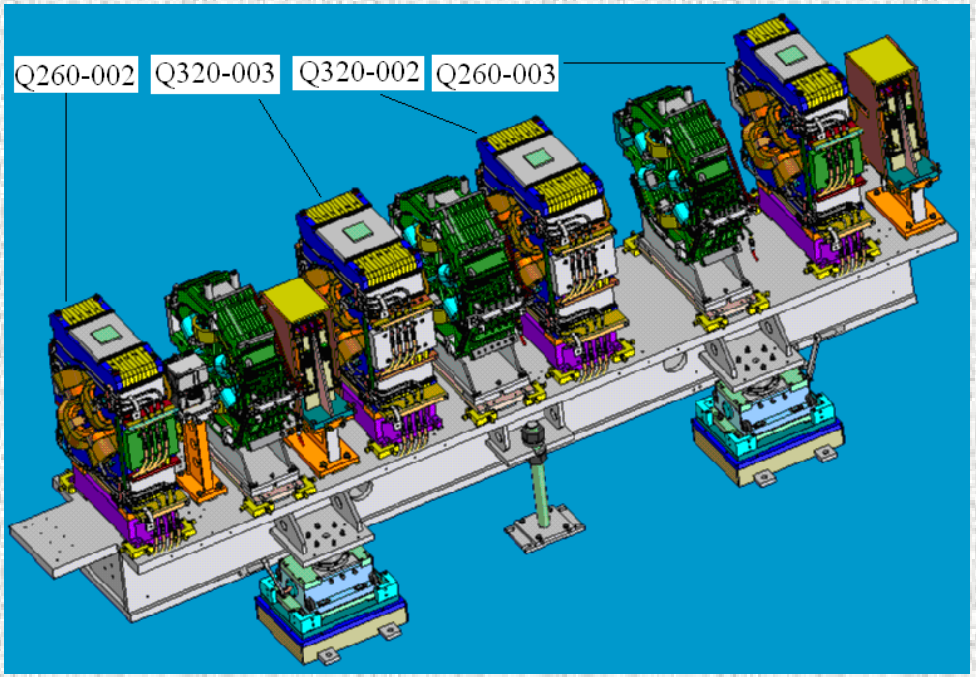
A cell of the storage ring



MGA prototype



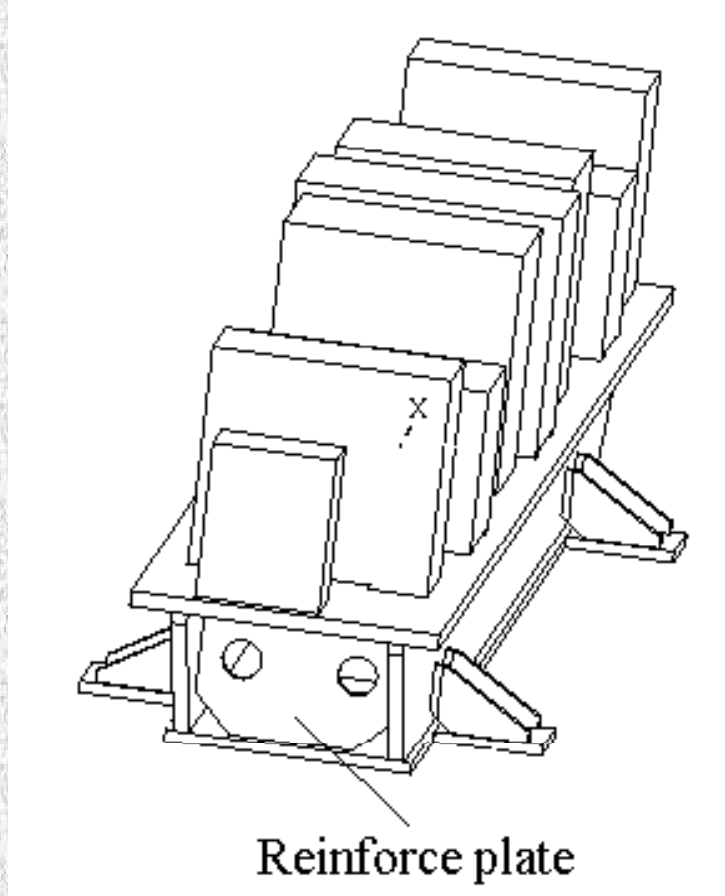
Weight: 8.8 ton with 6.0 ton magnets
Dimension:4100mm length, 800mm wide, 590mm high
Sensitivity: 0.01mm in three directions

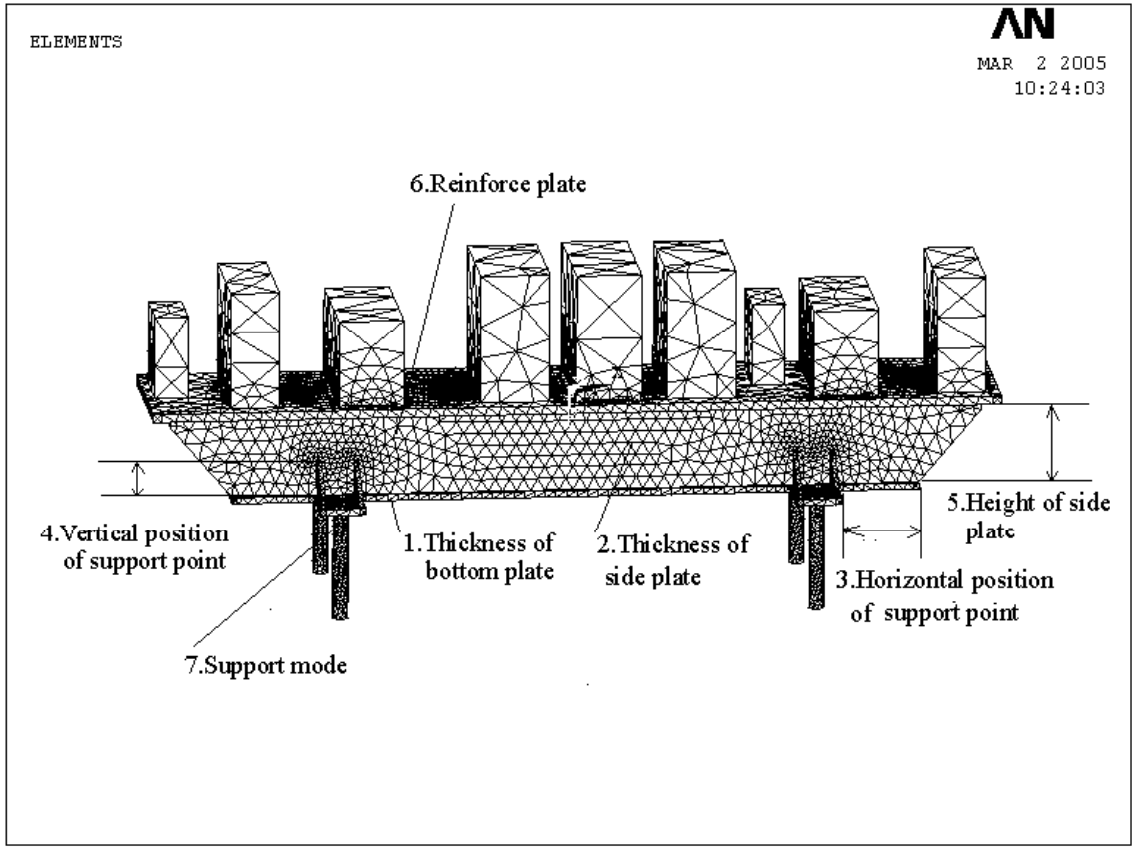
Weld scene and vibration treatment

Orthogonal design of girder body

- 1.There are many influencing factor and FEA model is complexity, it will spent much time for full optimization. Orthogonal design can get the optimal result and the amount of calculation repetition is decreased from 128 to 8.
- 2.The influencing degree is different to the dynamic performance of the girder under different influencing factor.Orthogonal design can find out the law and give some instructional idea for the girder design.

The diagram of influencing factor





The meaning and level of every influencing factor

Influcing factor		A	B
1	Thickness of bottom plate	40mm	30mm
2	Thickness of side plate	40mm	30mm
3	Horizontal position of support point	0mm	400mm
4	Vertical position of support point	Align with bottom plate	Leaning against top plate
5	Height of side plate	250mm	400mm
6	Reinforce plate	Add	None
7	Support manner	Rigid	Flexible

Calculation result

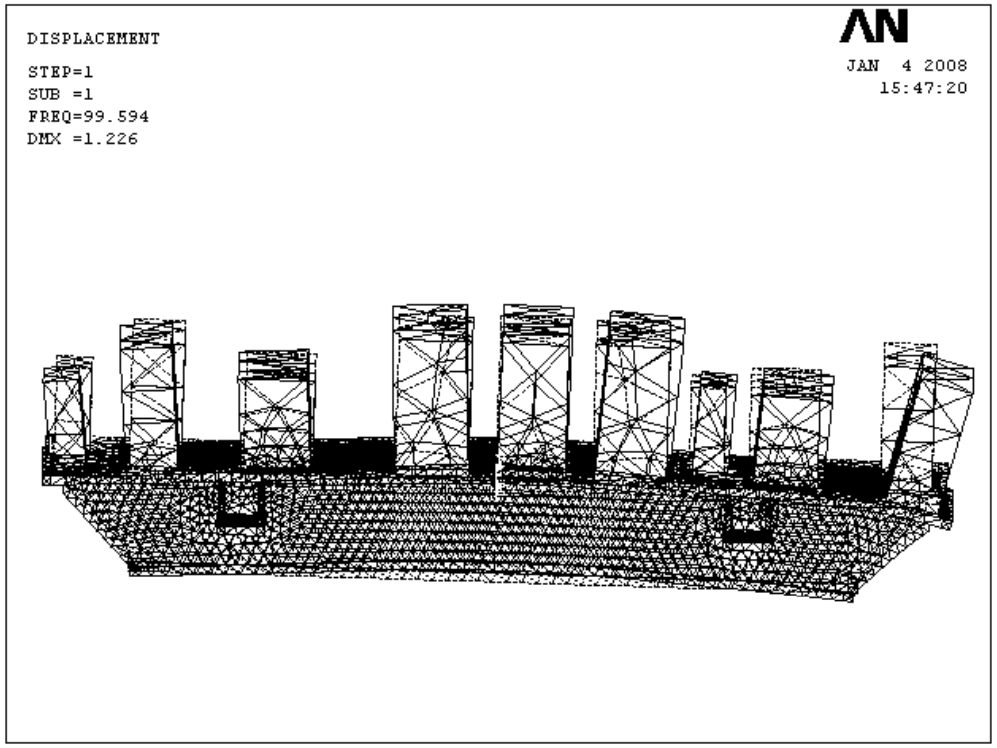
	1	2	3	4	5	6	7	result
1	A	A	A	A	A	A	A	68.594
2	A	A	A	B	B	B	B	13.066
3	A	B	B	A	A	B	B	13.284
4	A	B	B	B	B	A	A	99.594
5	B	A	B	A	B	A	B	12.601
6	B	B	B	B	A	B	A	82.689
7	B	B	A	A	B	B	A	43.417
8	B	B	A	B	A	A	B	13.849
S	220.3	5.79	599.3	635.5	11.85	222.4	7290	

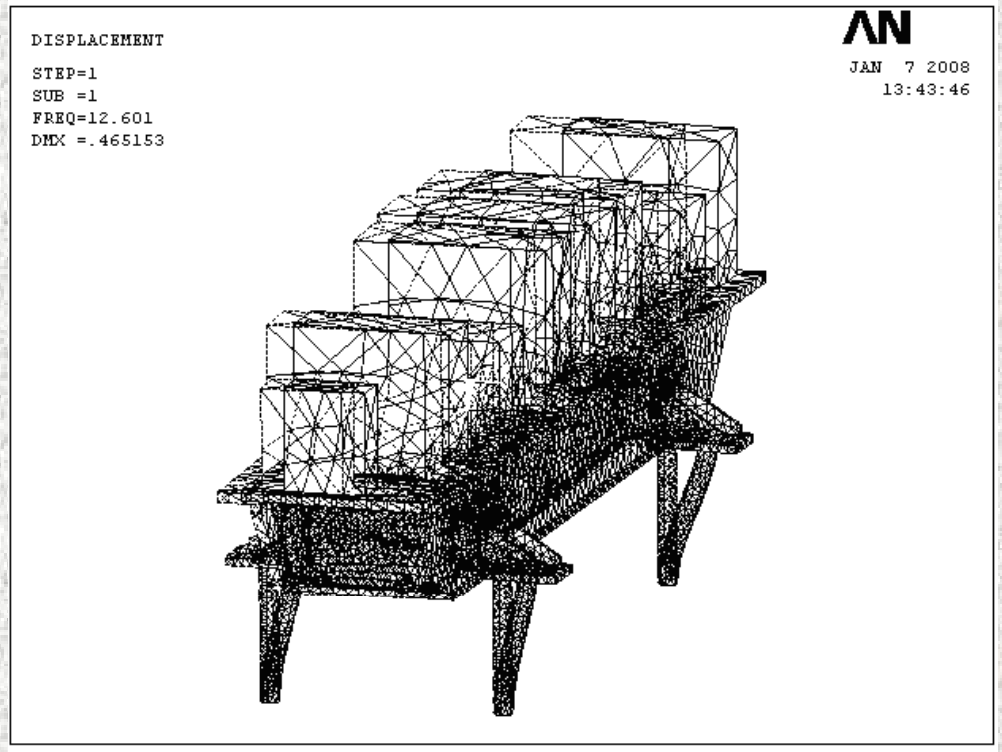
1.Order 4 is adopted at last.

2. Stiffness of the alignment system is the key factor.

3. Vertical and Horizontal position of support point should be paid attention too

Modal shape





Order 4

Order 5

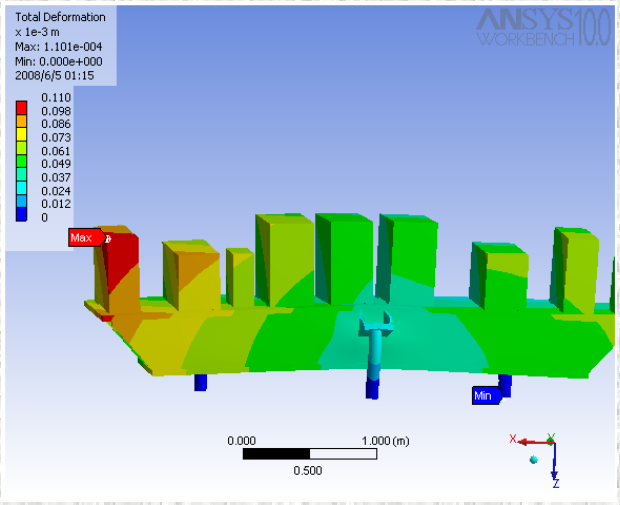
Four types of support structure

- The following four kinds of support structures are considered:
- Type A is a three points support with two of them near both ends along one long side and the other in the middle of the other long side.
- Type B is also a three points support with two of them near both ends along one long side and the other at one end of the other long side.
- Type C is also a three points support with two of them in two long sides respectively and the other in the middle of the short side.
- Type D is a four points support, which is located near both ends of the two sides.

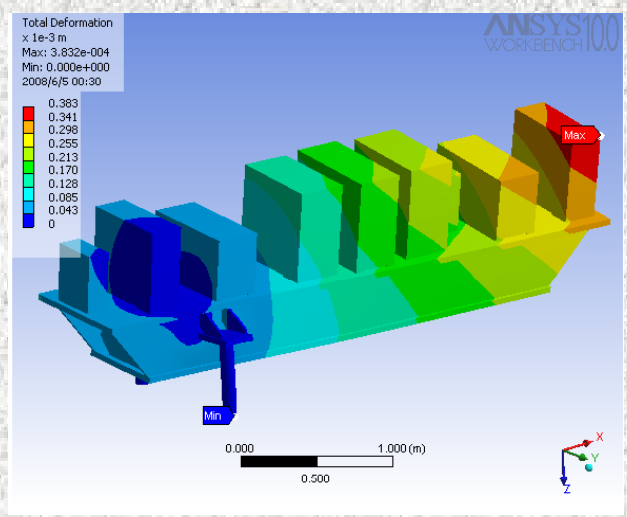
FE calculation result of girder*

Support manner	Maximal deformation (mm)	The first eigen-frequency (Hz)
R&D	0.2	5.9
Support A	0.110	15.9
Support B	0.383	13.6
Support C	0.202	16.8
Support D	0.042	20.6

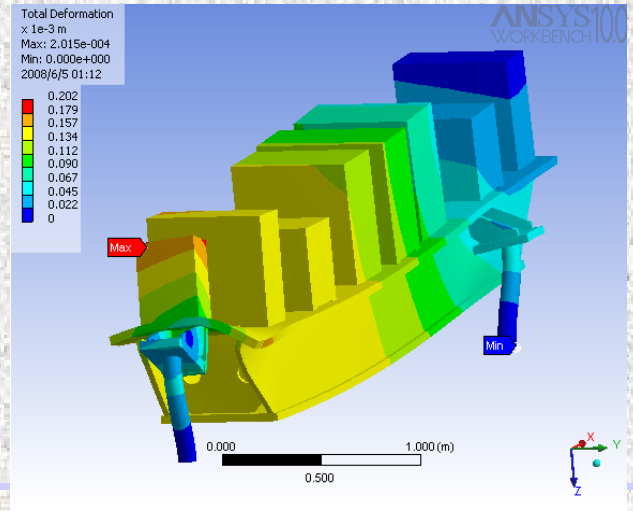
Static deformation



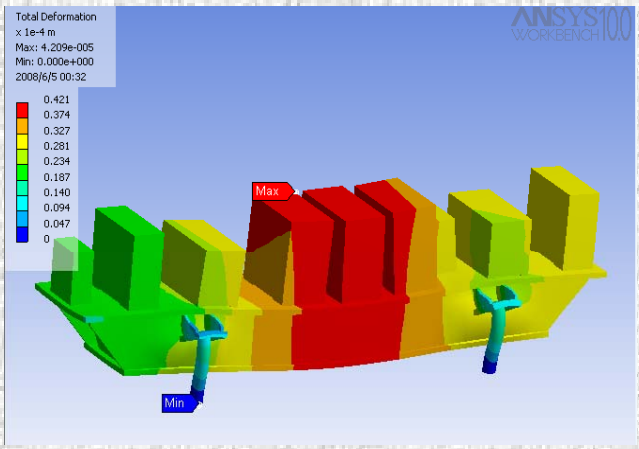
Type A



Type B

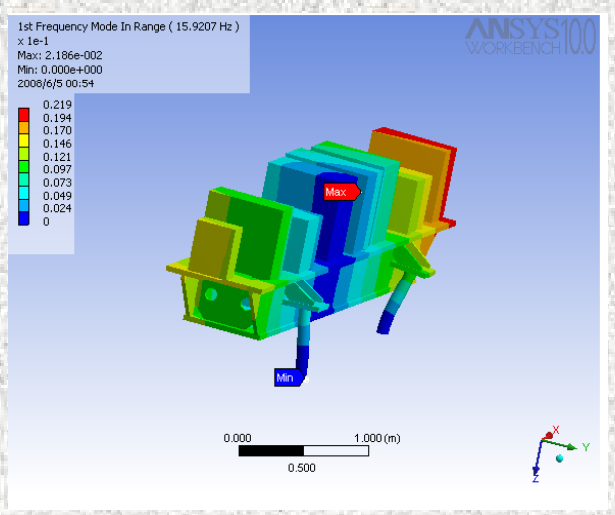


Type C

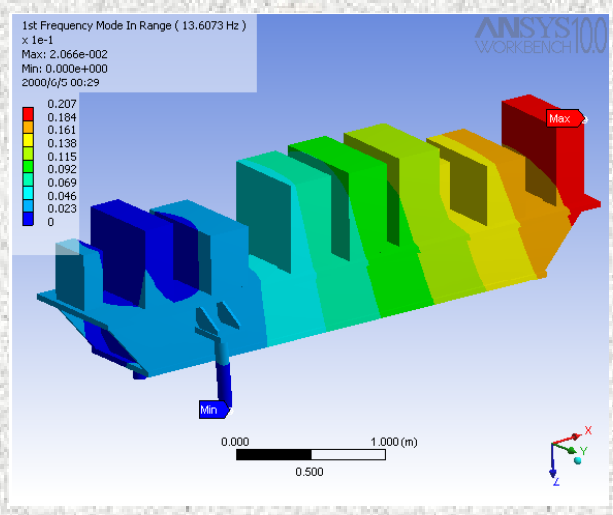


Type D

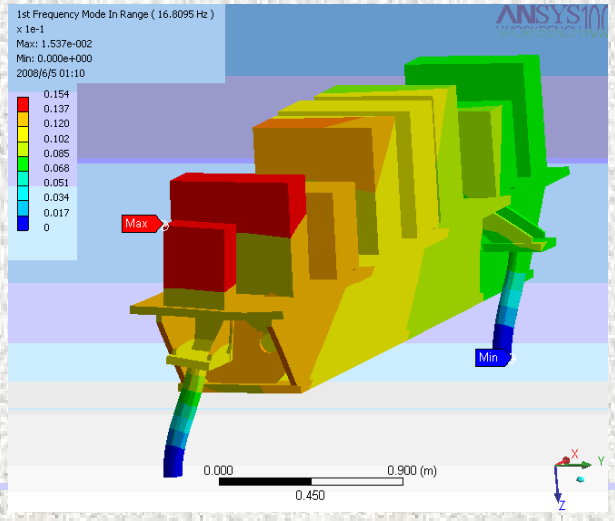
Modal shape



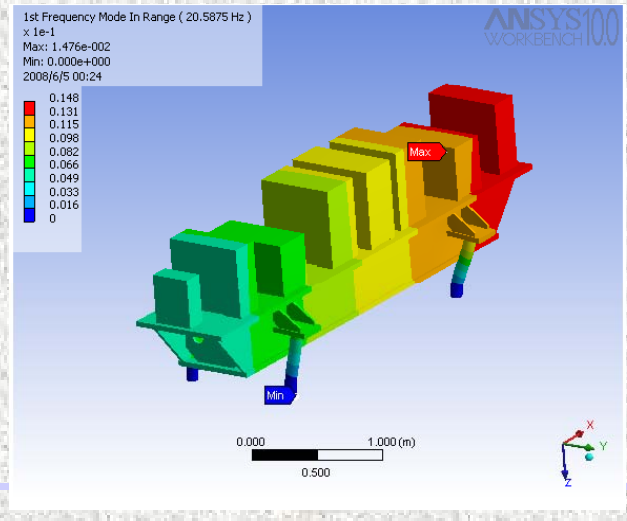
- Type A



- Type B



Type C

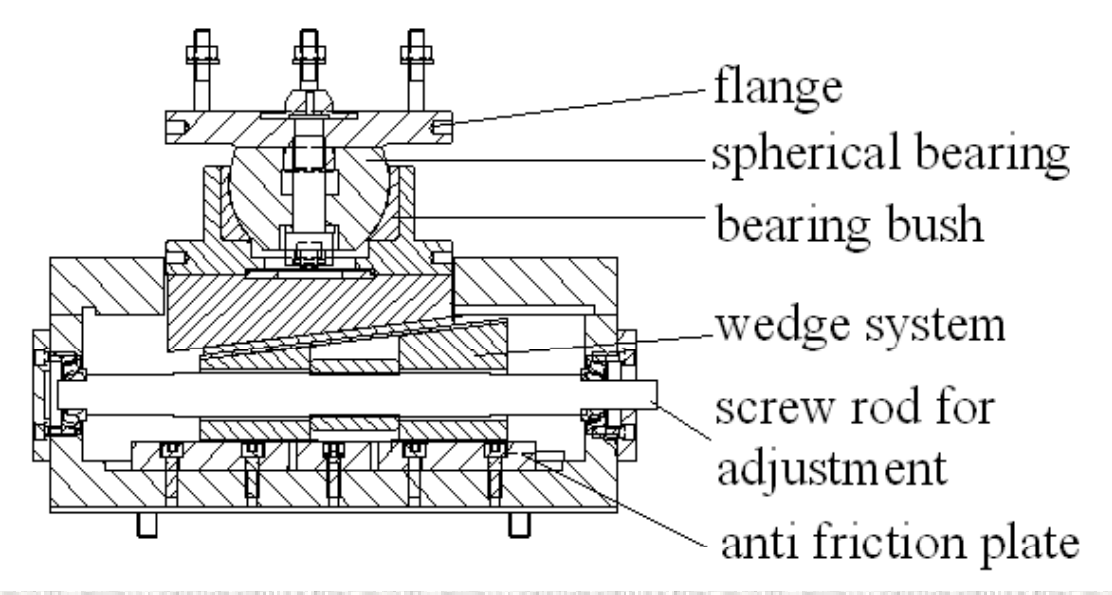


Type D

Conclusion of FEA results

- 1.The dynamic and static performance of four point support is better than three point support.
- 2.If one point of four point support system is free,the dynamic and static performance of the girder will become worse remarkably.
- 3.According to FEA results, the synthetical performance of type A is better than by type C.

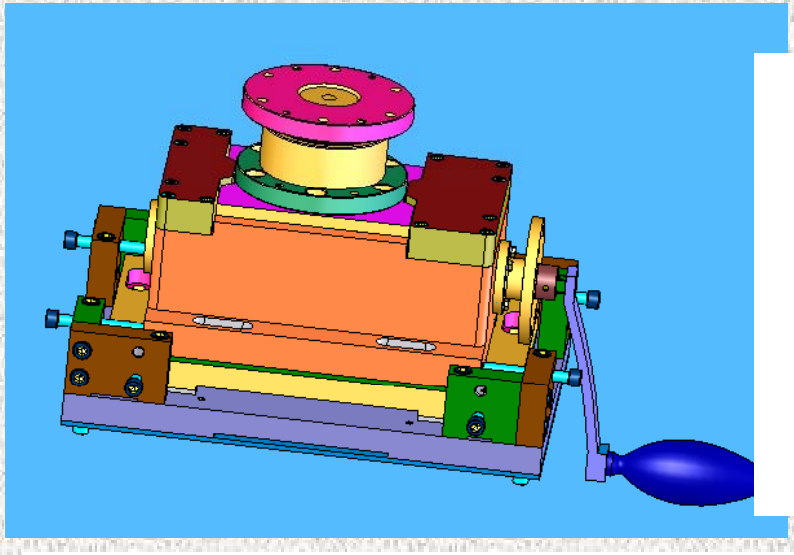
Alignment system

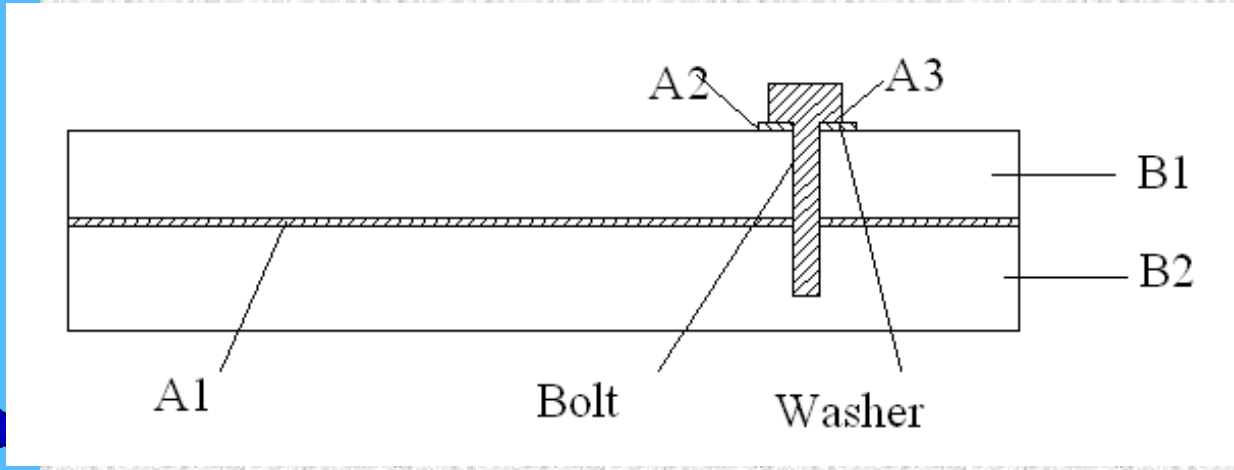


Adjustment range: ±7mm and ±10mm in the vertical and horizontal directions, respectively.

The spherical bearing in the wedge jack mechanism can rotate around the bearing bush only when the external moment exceeds 16 Nm

Finite element analysis for a bolt connection





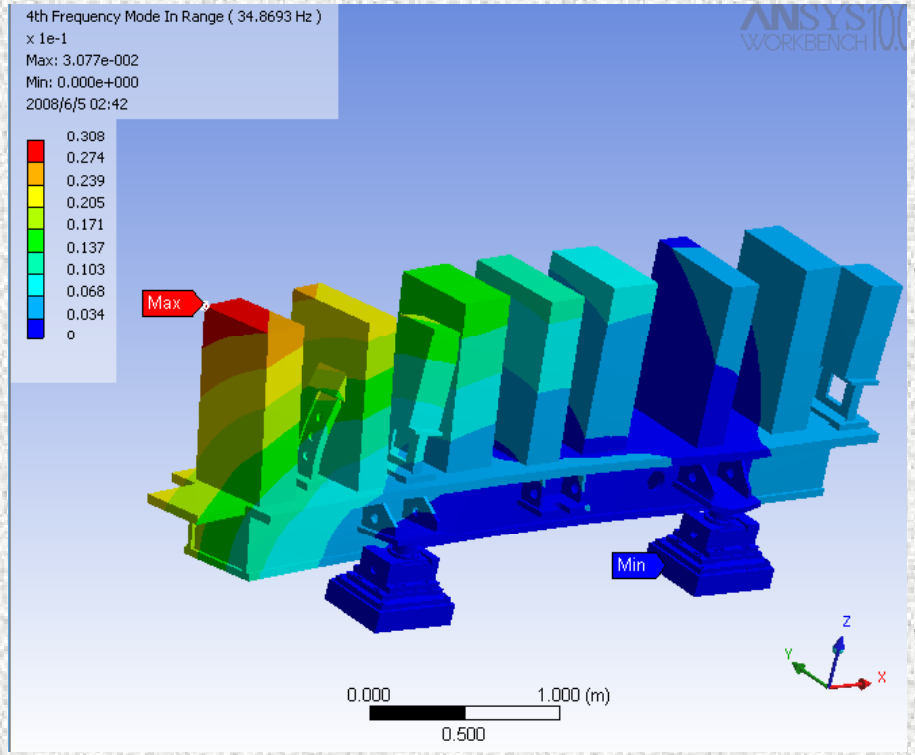
Way A (usual)			Way B (modification)		
components	Contact type	Contact area	components	Contact type	Contact area
B1, B2	Bond	A1	B1, B2	No separation	A1
Bolt, washer are elimimated for simplification			Bolt， washer	Bond	A3
			Washer, B1	Bond	A2
			Bolt, B2	Bond	A4

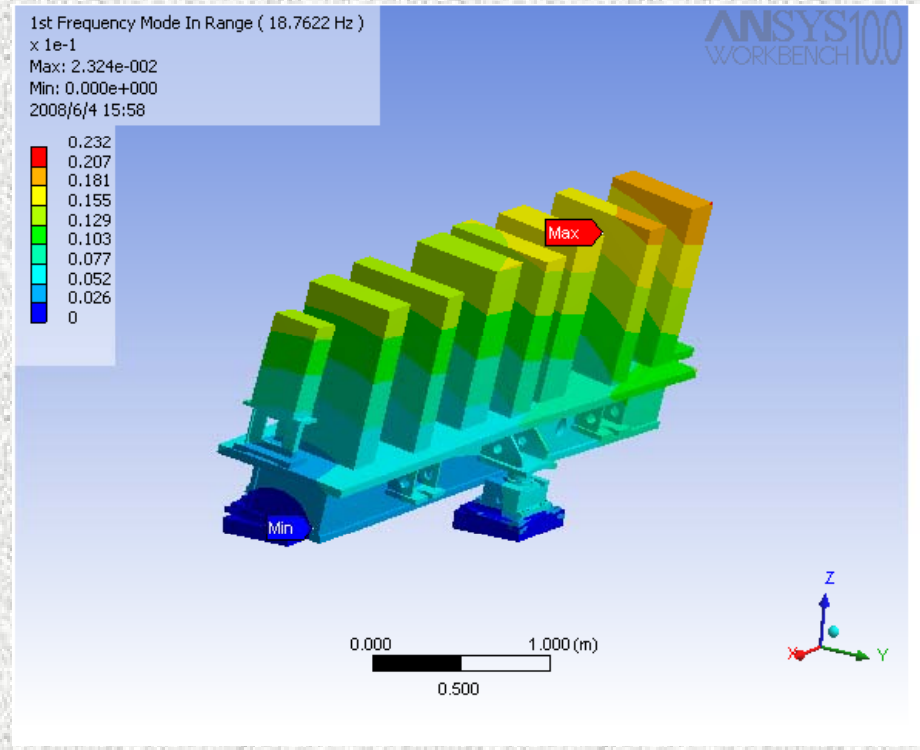
Results of two ways

	Measurement	Way A		Way B	
		value	relative error	value	relative error
Lateral first eigenfrequency	21.9	34.9	60%	18.8	14%
Vertical first eigenfrequency	22.5	38.1	69%	22.4	1%

Way B are suitable for FEA

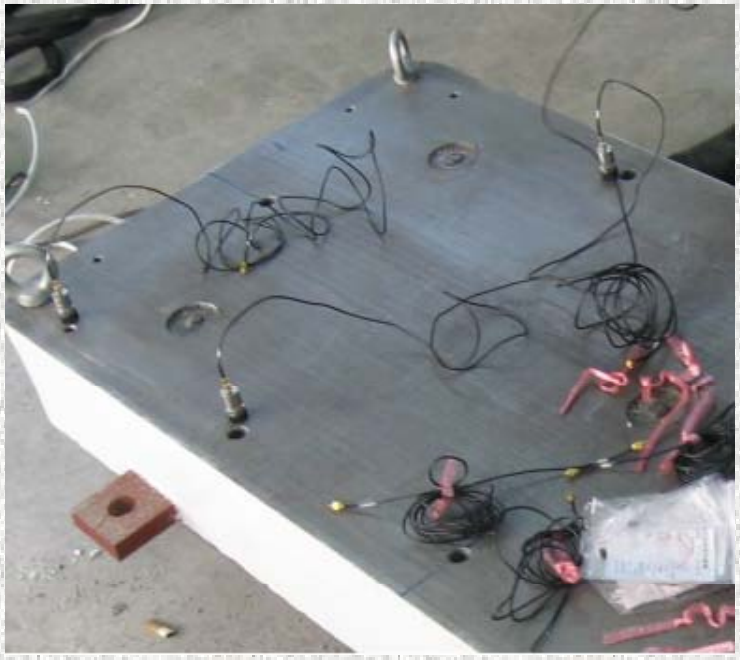
FEA dynamic results for girder support system





- Way 1
- Way 2

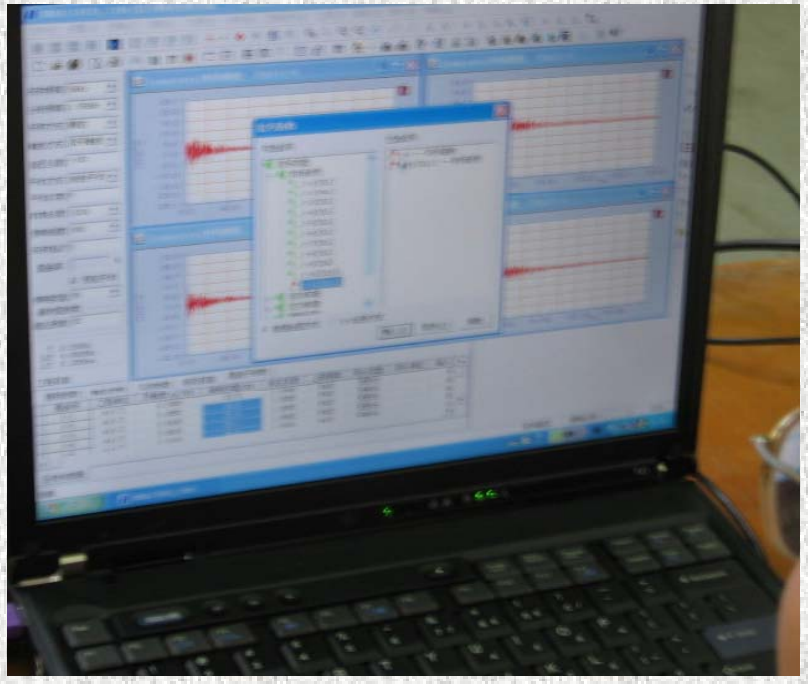
Sensor used in the dynamic test



Seismometer 941-B, produced by Institute of Engineering Mechanics,China Earthquake Administration

accelerometer DH103 , produced by Jiangsu Donghua Co.Ltd. of test technology.

Analysis software



Data signal analysis:
DH5920-11,

Modal analysis:
DHMA2.0

Produced by Jiangsu Donghua Co.Ltd. of test technology.

DH5920 data acquisition system

Produced by Jiangsu Donghua Co.Ltd. of test technology.

Dynamic test on prototype girder A3

Location: SINAP, CAS, Jiading

Modal test

In order to understand the character of girder A3 in detail,the following 12 different manner is measured.

1.four-point support with impaction by screw,without anti-vibration and anti-friction plates,with normal concrete base,vertical direction.

2.four-point support with impaction by screw,with anti-vibration and anti-friction plates, with normal concrete base, vertical direction.

3.four-point support with impaction by screw,with anti-vibration and anti-friction plates with normal concrete base,lateral direction.

4.four-point support with impaction by screw,with anti-vibration and anti-friction plates, with normal concrete base,longitudial direction.

5. Four-point support without impaction by screw, with anti-vibration and anti-friction plates, with normal concrete base,vertical direction.

6. Four-point support without impaction by screw, with anti-vibration and anti-friction plates, with anti-vibration concrete base,vertical direction.

Modal test(continue)

7.Three-point support with impaction by screw,without anti-vibration and anti-friction plates, with normal concrete base,vertical direction.

8. Three-point support without impaction by screw,without anti-vibration and anti-friction plates, with normal concrete base,vertical direction.

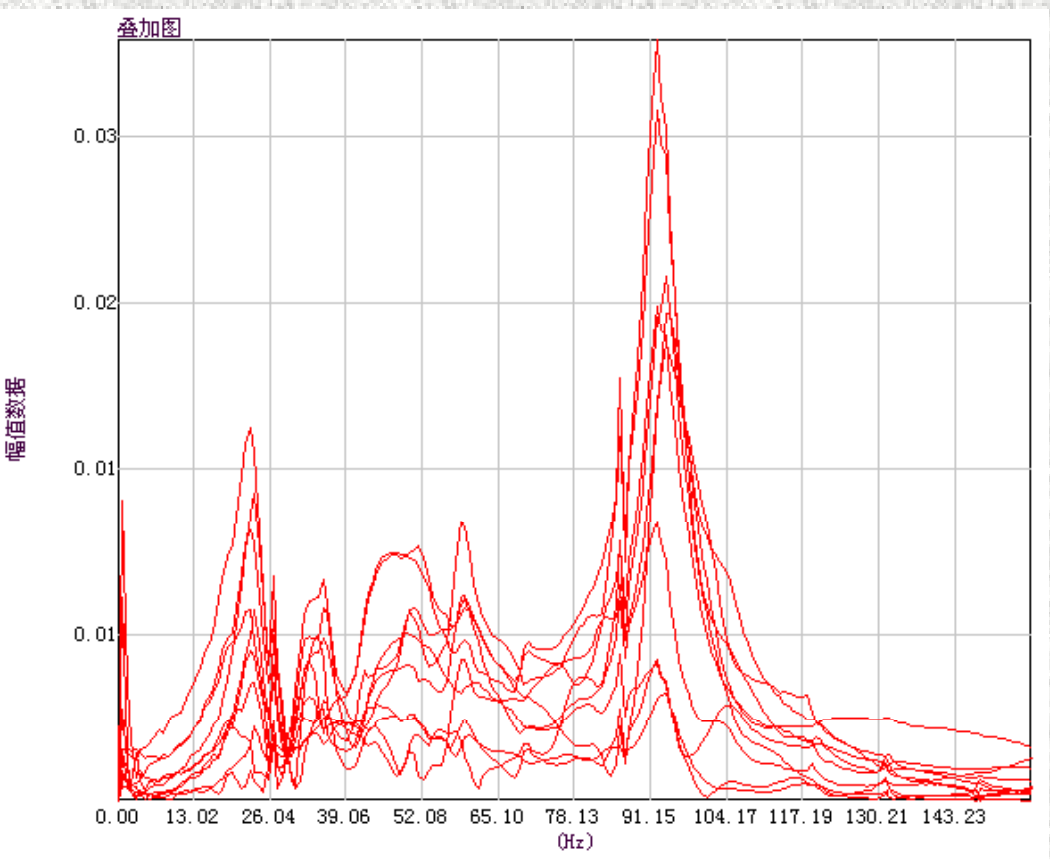
9. Three-point support with impaction by screw,with anti-vibration and anti-friction plates, with normal concrete base,vertical direction.

10. Three-point support without impaction by screw, with anti-vibration and anti-friction plates, with anti-vibration concrete base,vertical direction.

11.Five-point support with three of them impaction by screw,with anti-vibration and anti-friction plates, with anti-vibration concrete base,vertical direction.

12. Bad four-point support without impaction by screw (one point is free) , with anti-vibration and anti-friction plates, with anti-vibration concrete base,vertical direction.

Frequency response function of four-point support with impaction by screw,without anti-vibration and anti-friction plates,with normal concrete base,vertical direction



The influence of support ways on the lowest eigenfrequency

	impaction by screw, without anti-vibration and anti-friction plates		without impaction by screw, with anti-vibration and anti-friction plates	
	The lowest eigenfrequency (Hz)	Damping ratio	The lowest eigenfrequency (Hz)	Damping ratio
Four-point support	23.06	10.13%	20.07	6.52%
	23.03	9.4%		
Three-point support	19.53	6.54%	18.69	9.23%
The bad four-point support			13.5	
Five-point support	23.5	6.85%		

The influence of impaction by screw on the lowest eigenfrequency

	Three-point support,without anti-vibration and anti-friction plates		Four-point support,with anti-vibration and anti-friction plates	
	The lowest eigenfrequency (Hz)	Damping ratio	The lowest eigenfrequency (Hz)	Damping ratio
Without impaction	18.58	6.68%	20.1	6.52%
	18.79	6.84%		
With impaction	19.53	6.54%	21.5	6.76%

The influence of anti-vibration and anti-friction plates on the lowest eigenfrequency

	Three-point support,with impaction by screw		Four-point support,without impaction by screw	
	The lowest eigenfrequency (Hz)	Damping ratio	The lowest eigenfrequency (Hz)	Damping ratio
Without anti-vibration and anti-friction plates	18.58	6.68%	23.1	10.13%
	18.79	6.84%		
With anti-vibration and anti-friction plates	18.69	9.23%	21.5	6.76%

The influence of anti-vibration concrete base on the lowest eigenfrequency

	Four-point support		Three-point support	
	The lowest eigenfrequency (Hz)	Damping ratio	The lowest eigenfrequency (Hz)	Damping ratio
anti-vibration concrete base	20.00	10.3%	18.75	11.84%
normal concrete base	20.07	6.52%	18.69	9.23%

Result of modal test on girder A3

1.The first eigenfrequency of the four-point support is higher about 1.5~3.5Hz than the three-point,the bad four-point support is only 13.5Hz which is much lower than the normal three-point (18.7Hz).five-point support is higher about 4Hz than the three-point with compaction by screws.

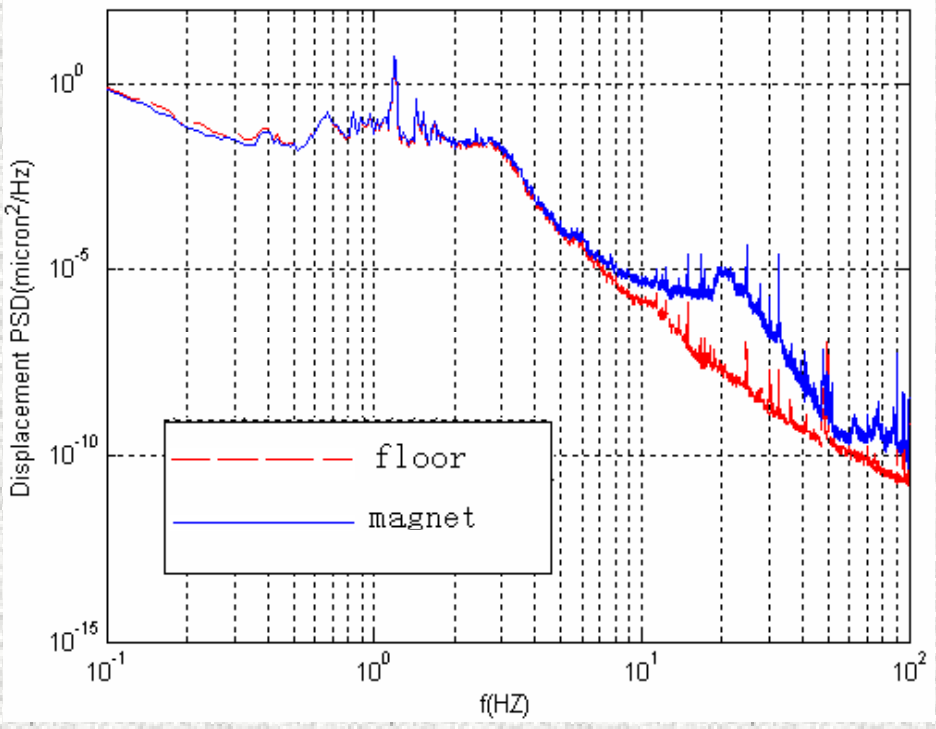
2.Impaction by screw can improve the first eigenfrequency about 1 Hz。

3.The anti-vibration and anti-friction plates has less effect on the three-point support,while can decrease about 1.5 Hz on the four-point support.

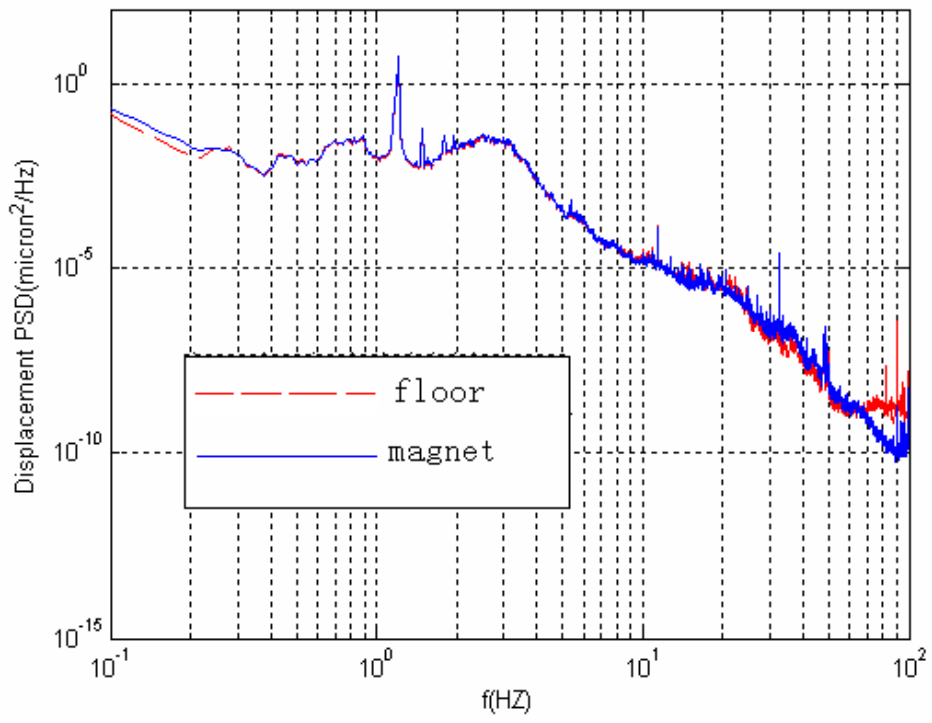
4.Compare with the normal concrete base,the anti-vibration's has less effect on the first eigenfrequency,while can increase the damping ratio .

5. It is difficult to adjust the four support point bear the force evenly and it will be converted into the bad point support under uneven settlement of the ground, so three point support is adopted at last.

Displacement PSD of Q320 under four-point support

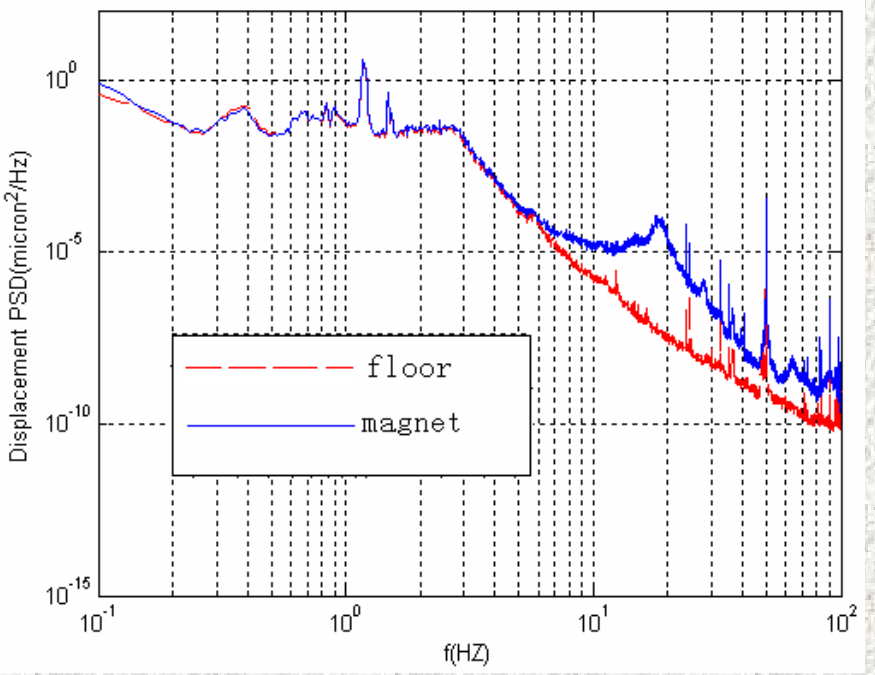


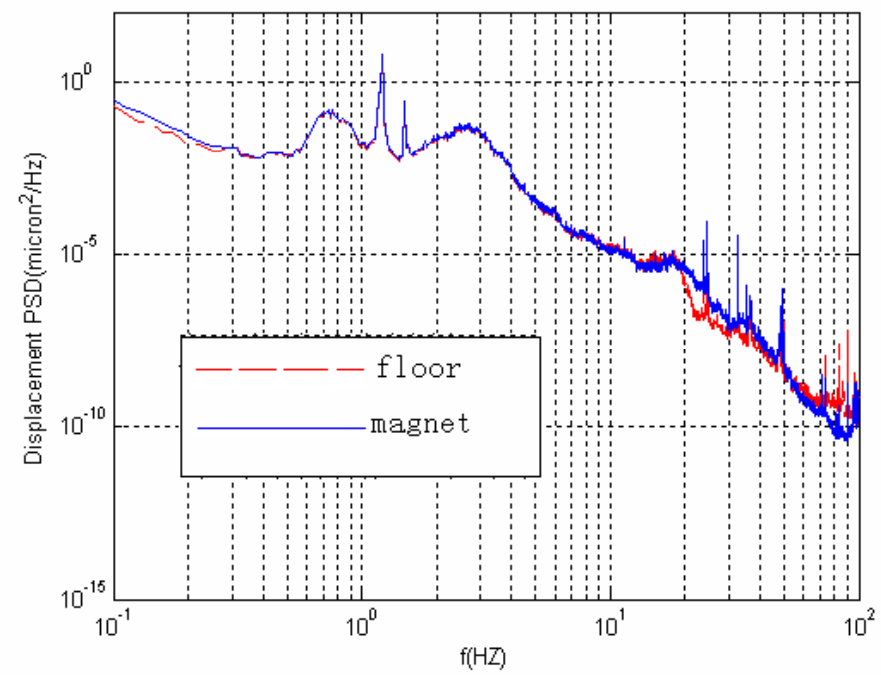
Lateral direction



Vertical direction

Displacement PSD of Q320 under three-point support





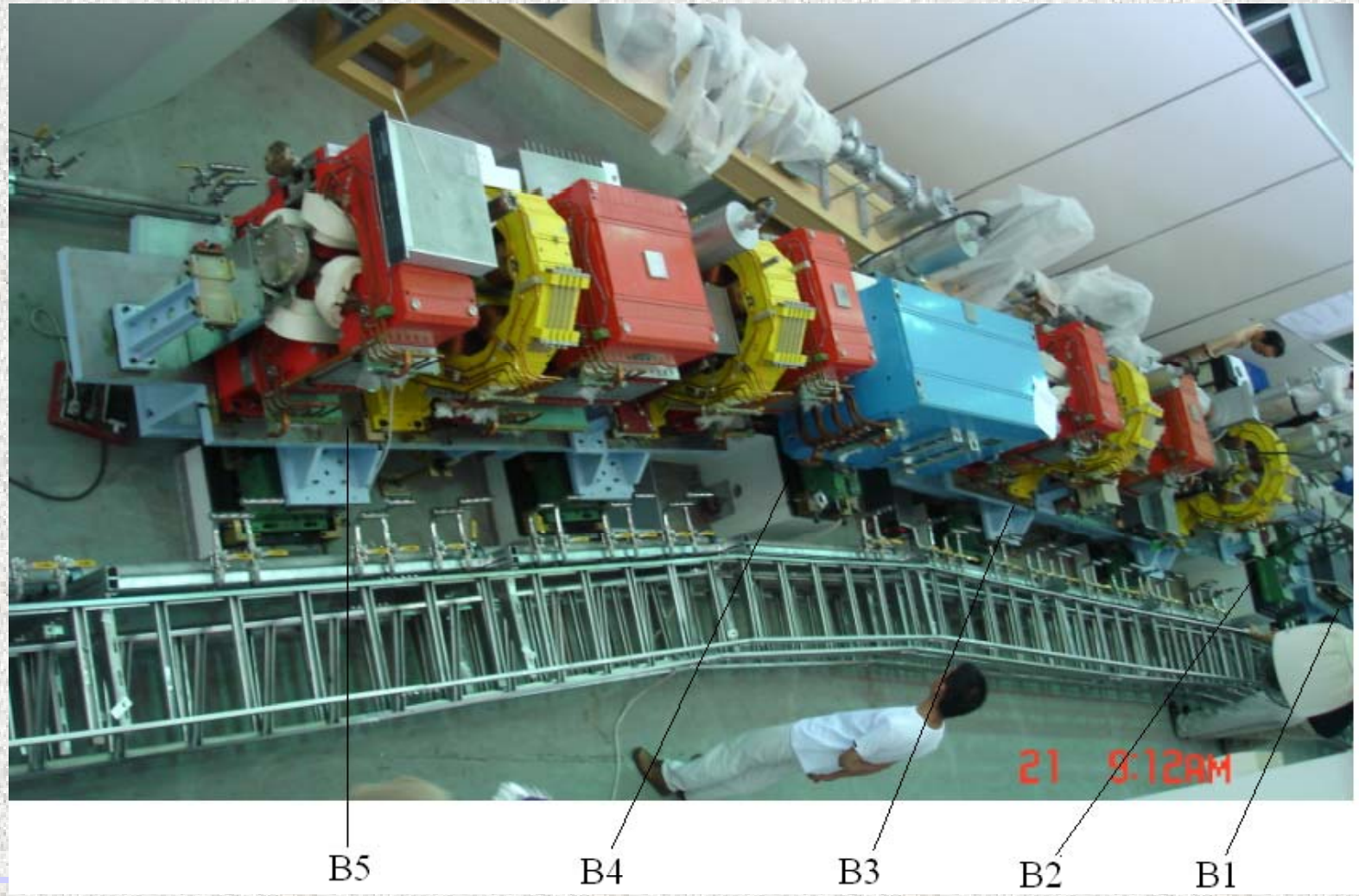
Lateral direction

Vertical direction

RMS Displacement(4~50Hz) （micron）

		Floor	Quadrupole magnet	Ratio
Three-point support	Lateral	0.01411	0.01828	1.30
	vertical	0.02738	0.03267	1.19
Four-point support	Lateral	0.01845	0.02273	1.23
	vertical	0.03081	0.03464	1.12
Bad four-point support	Lateral	0.02885	0.06532	2.26
	vertical	0.03201	0.04508	1.41
Five-point support	Lateral	0.02681	0.03195	1.19
	vertical	0.02828	0.03058	1.08

Dynamic test on B cell

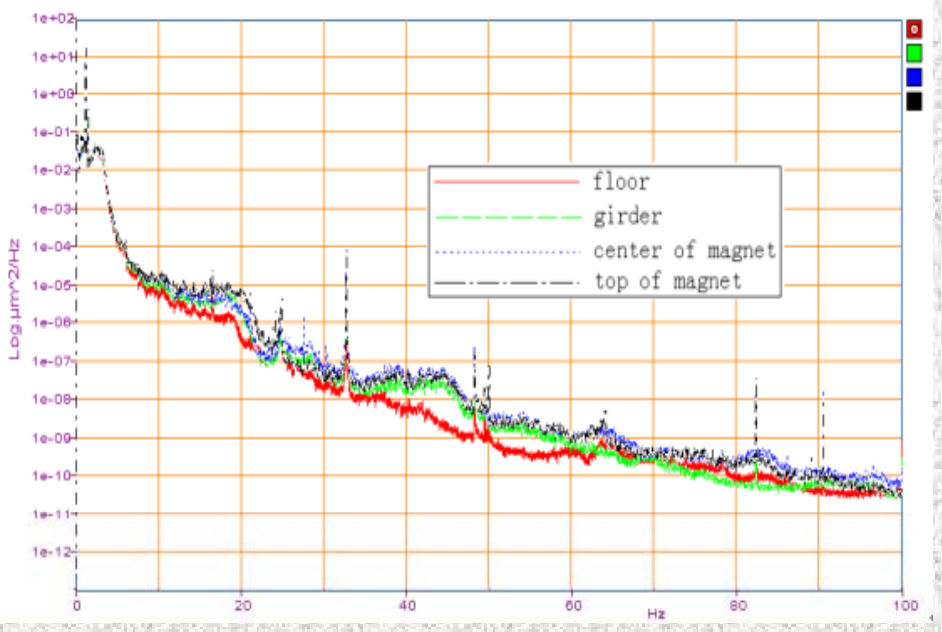


Location: SINAP, CAS, Jiading

PSD in lateral direction of B1 girder

Frequency	causer	Character of the peak		Grade should be attentive
		width	height	
19.1Hz	Modal of girder	widest	highest	*****
24.7Hz	Floor vibration	narrow	higher	**
27.6 Hz	Modal of girder	wider	higher	***
32.8 Hz	Floor vibration	narrow	higher	**
36.3Hz	Modal of girder	wider	lowest	*
48.4Hz	Floor vibration	narrow	higher	**
50Hz	Floor vibration and modal of girder	wider	higher	***
60.8Hz	Modal of girder	wide	lower	**
69.4Hz	Modal of girder	wide	lower	**
81.4Hz	Modal of girder	narrow	lower	**
92Hz	Floor vibration	narrowest	higher	*

PSD in vertical direction of B1 girder



Frequency	Causer	Character of the peak		Grade should be attentive
		width	height	
19.1Hz	Modal of girder	wider	higher	*****
24.7Hz	Floor vibration	narrower	higher	**
27.6 Hz	Modal of girder	narrower	higher	**
30.2 Hz	Modal of girder	narrowest	lower	*
32.8 Hz	Floor vibration	narrower	highest	***
38.8Hz	Modal of girder	wider	lower	**
42.8Hz	Modal of girder	wider	lower	***
48.4Hz	Floor vibration	narrowest	higher	*
50Hz	Floor vibration	narrowest	higher	*
63.9Hz	Floor vibration	narrower	lower	**
82Hz	Floor vibration	wider	higher	**
92Hz	Floor vibration	narrowest	higher	*

RMS displacement of girder B1 in 4~50Hz

			RMS displacement(um)	RMS displacement magnification of center of magnet vs floor	Difference ratio
Horizo -ntal	The first	Floor	0.01707	1.256	
		Center of magnet	0.02144		
	The second	Floor	0.01394	1.291	2.78%
		Center of magnet	0.01799		
	The third	Floor	0.01382	1.283	2.15%
		Center of magnet	0.01773		
Vertic -al	The first	Floor	0.05895	1.013	
		Center of magnet	0.05974		
	The second	Floor	0.03756	1.026	1.28%
		Center of magnet	0.03854		
	The third	Floor	0.03701	1.024	1.1%
		Center of magnet	0.03788		

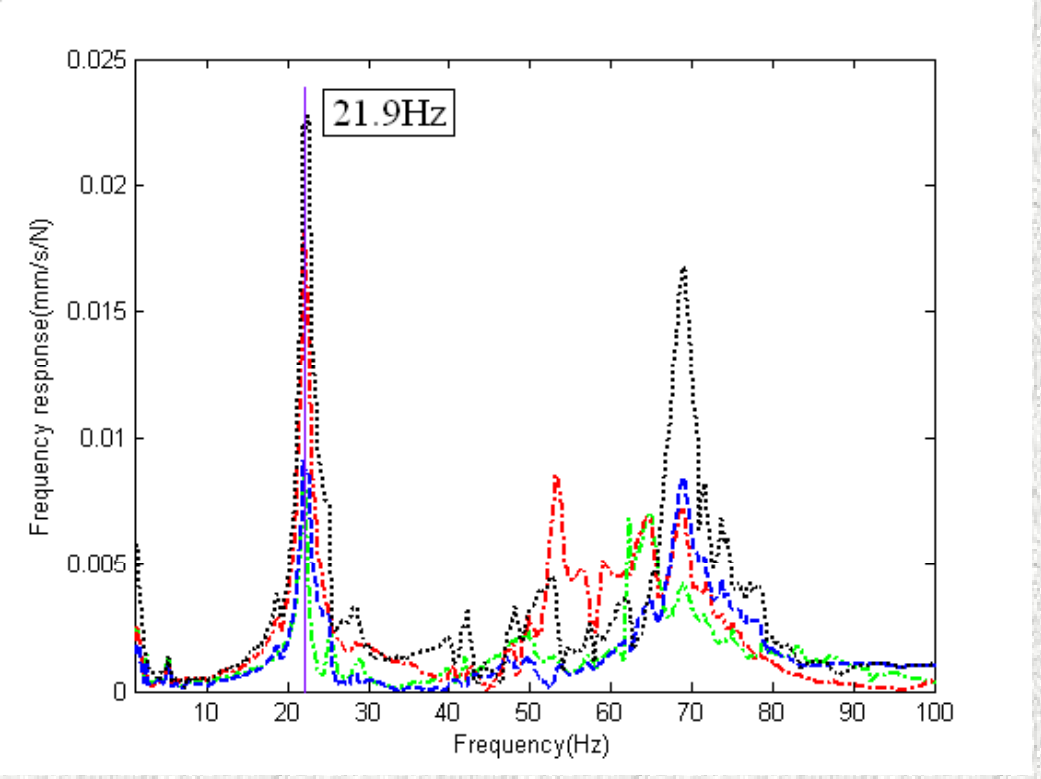
Three times in three days

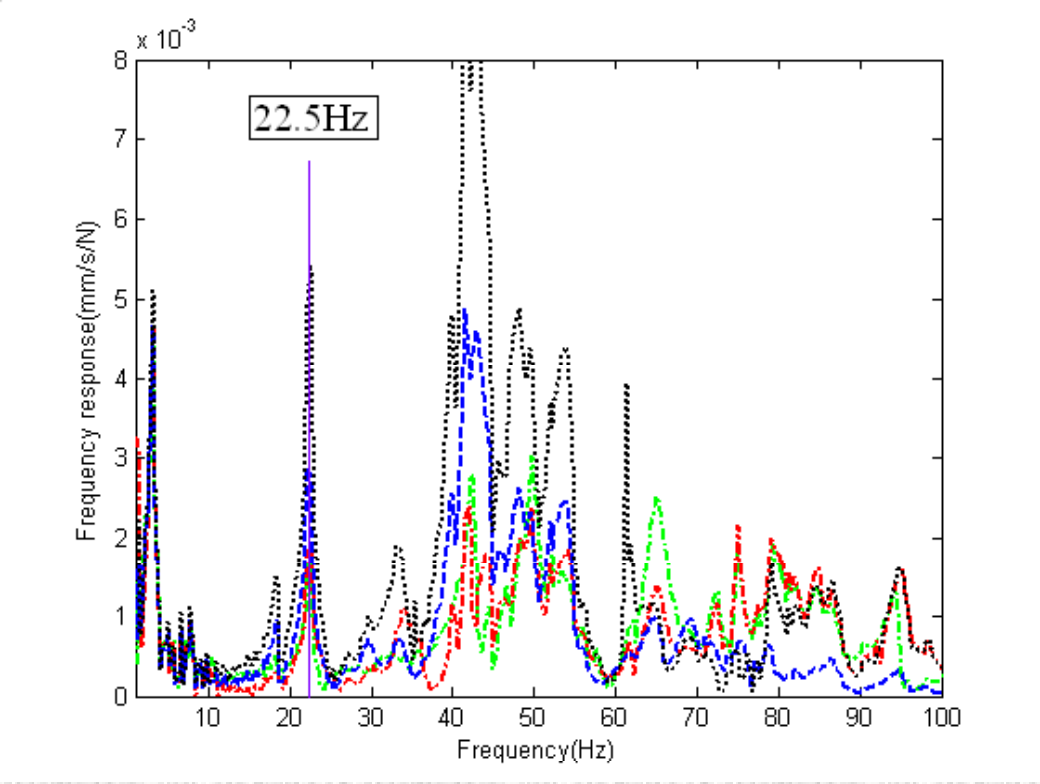
Five measurement ways for C10

- A. Excited measurement
- B. Magnet Q320-003, vacuum chamber, girder, floor
- C.Q260-002, Q320-003, Q320-002, Q260-003, floor
- D. With and without cooling water
- E. Comparison between adding damping pad and auxiliary support

Location: the storage ring tunnel

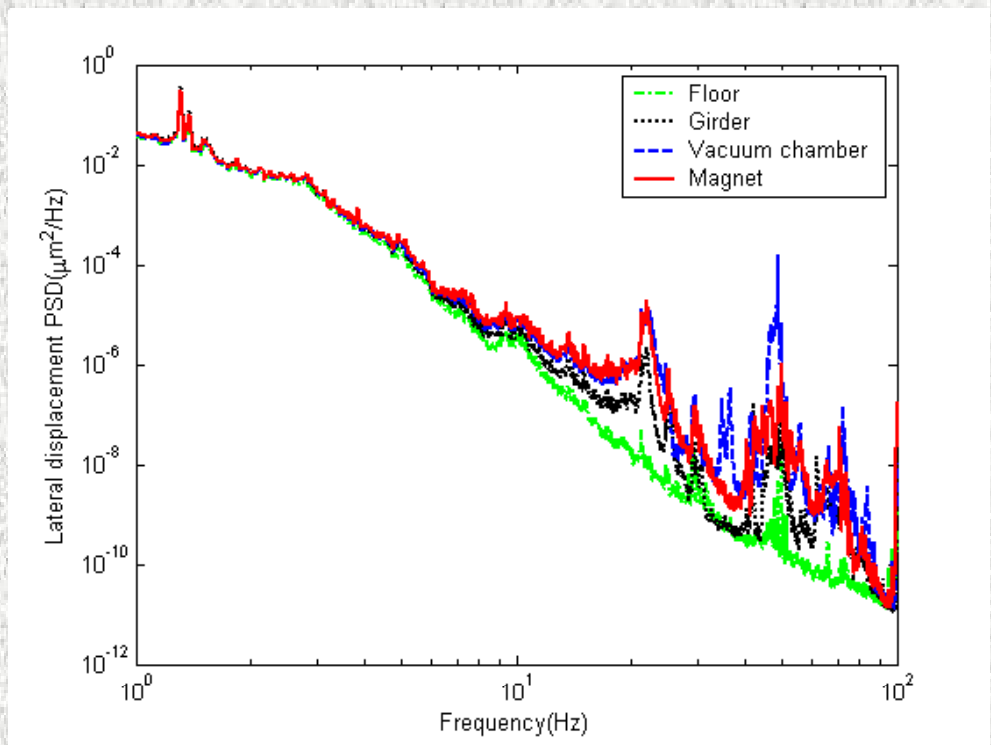
Frequency response of measurement A

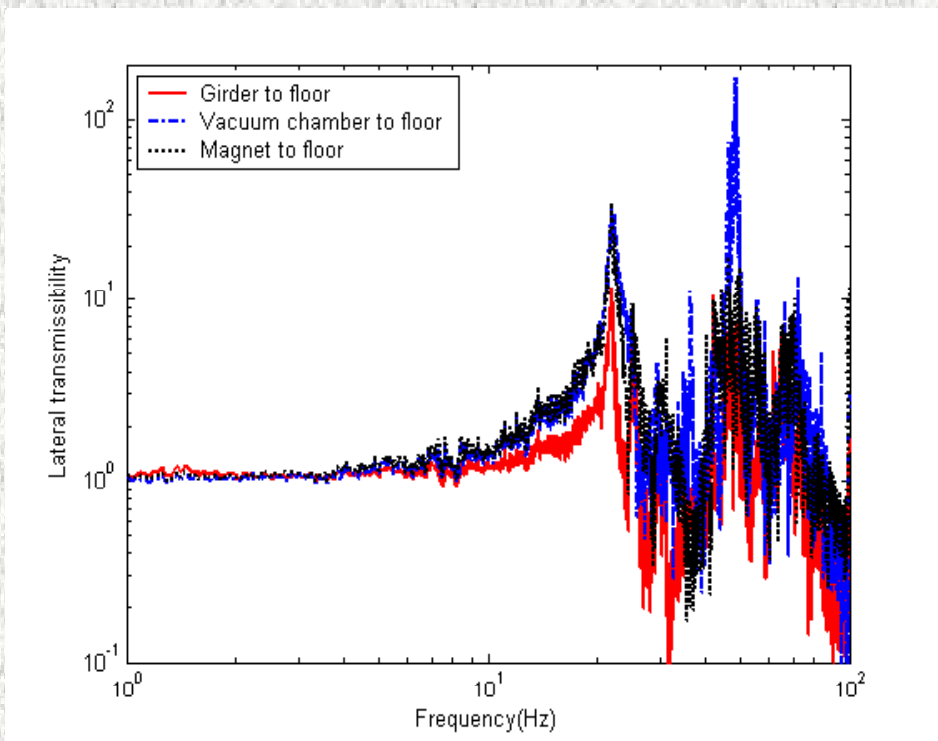




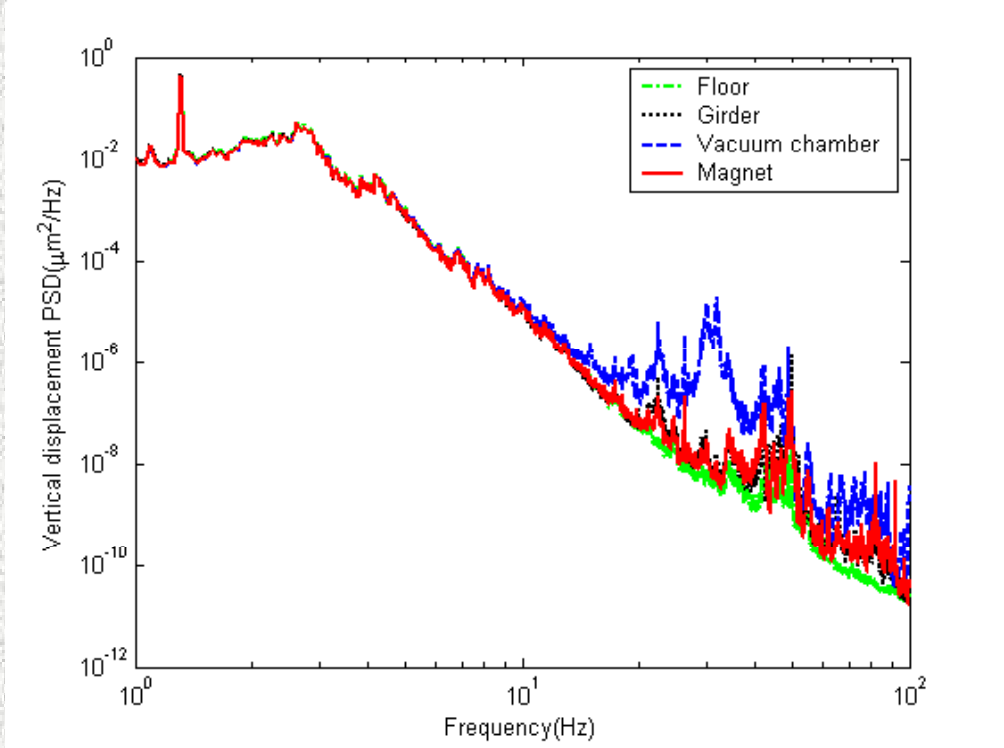
- The first eigenfrequency: lateral 21.9 Hz, vertical 22.5 Hz.

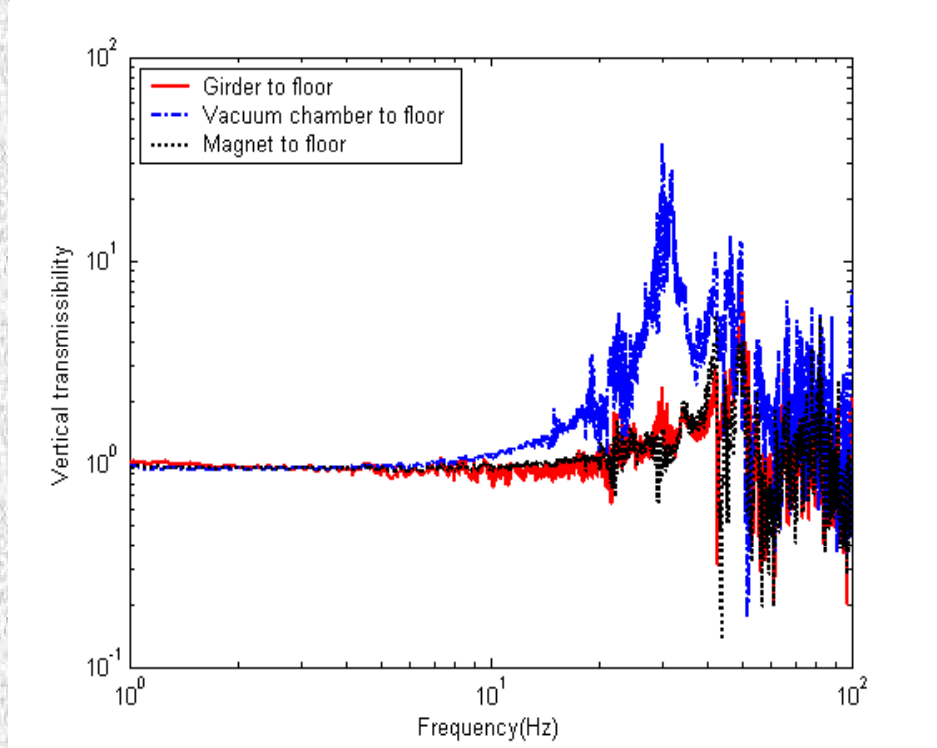
Lateral spectra of measurement B





Vertical spectra of measurement B

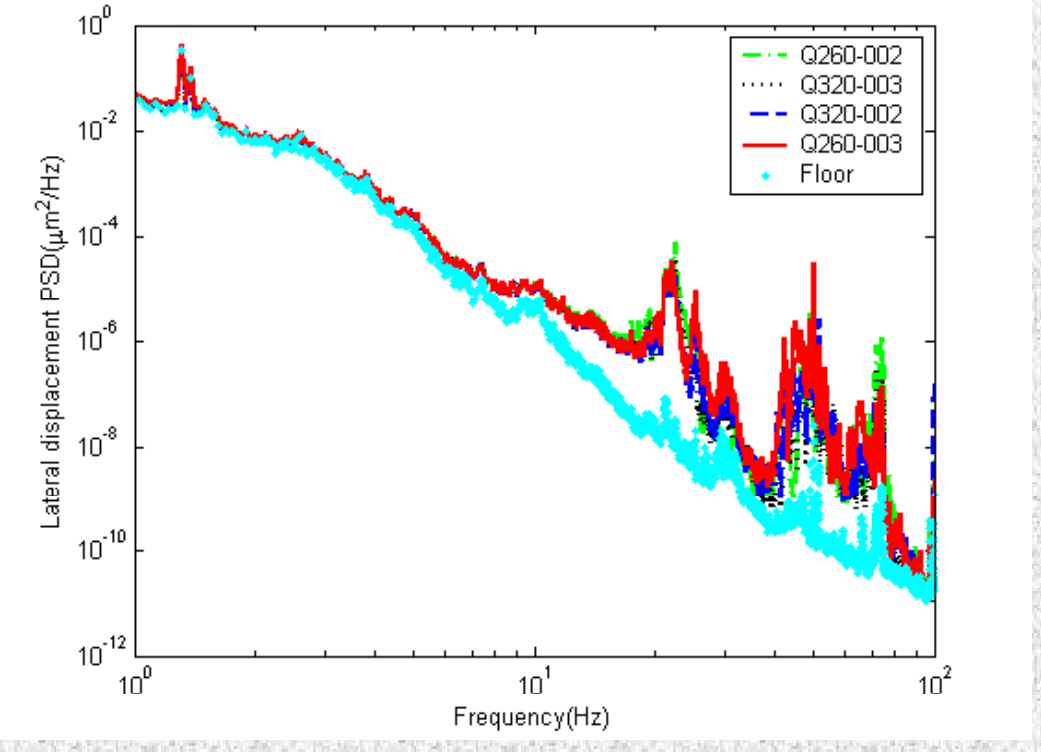


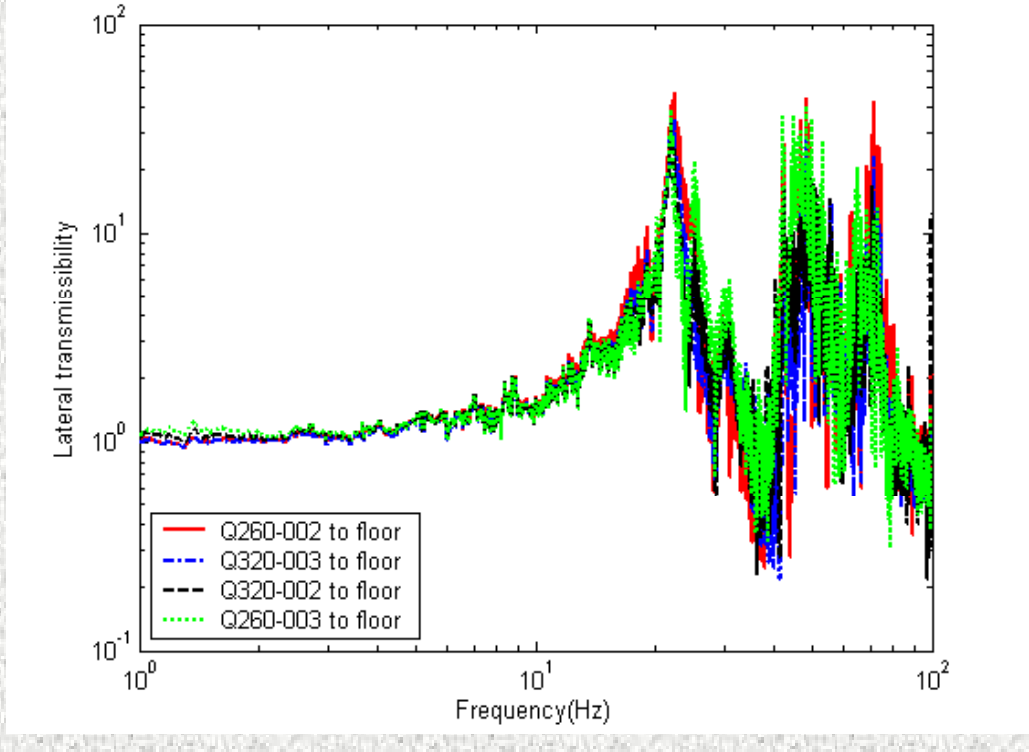


Result of measurement B

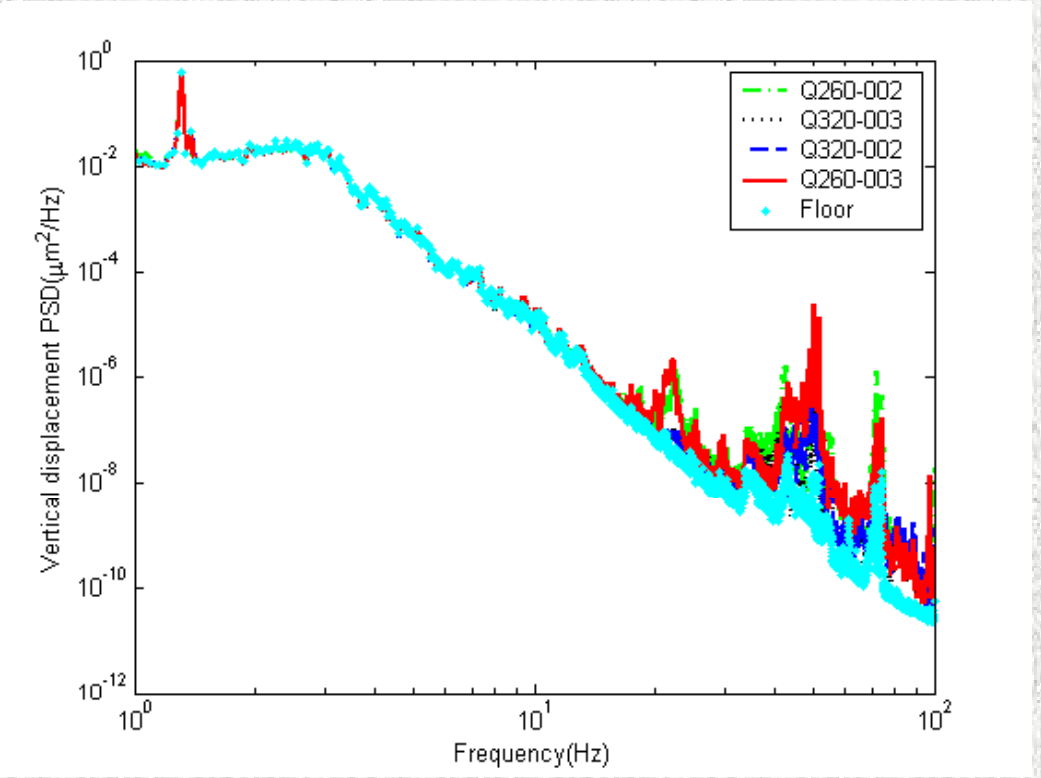
		Lateral				Vertical			
		Daytime		Night		Daytime		Night	
Frequency range (Hz)		2-50	4-50	2-50	4-50	2-50	4-50	2-50	4-50
Floor	Displacement	81.1	19.5	49.5	11.9	18.8	52.5	79.5	14.9
Girder	Displacement	88.1	22.1	54.8	13.5	18.9	52.6	80.4	15.0
	Ratio	1.09	1.13	1.11	1.13	1.00	1.00	1.01	1.02
	Q value	11.9		10.3		1.8		1.1	
Vacuum	Displacement	87.6	24.6	53.1	14.6	19.0	54.1	80.5	15.5
chamber	Ratio	1.08	1.26	1.07	1.23	1.00	1.03	1.01	1.04
	Q value	35.3		25.3		5.7		5.8	
Magnet	Displacement	89.8	25.2	55.2	14.9	19.9	55.2	84.4	15.7
	Ratio	1.11	1.29	1.12	1.25	1.06	1.05	1.06	1.05
	Q value	34.8		28.2		1.6		1.1	
Measurement time									
(Mar. 6th, 2007)		Daytime: 15:41:11 - 16:01:11				Night: 22:01:12 - 22:21:12			

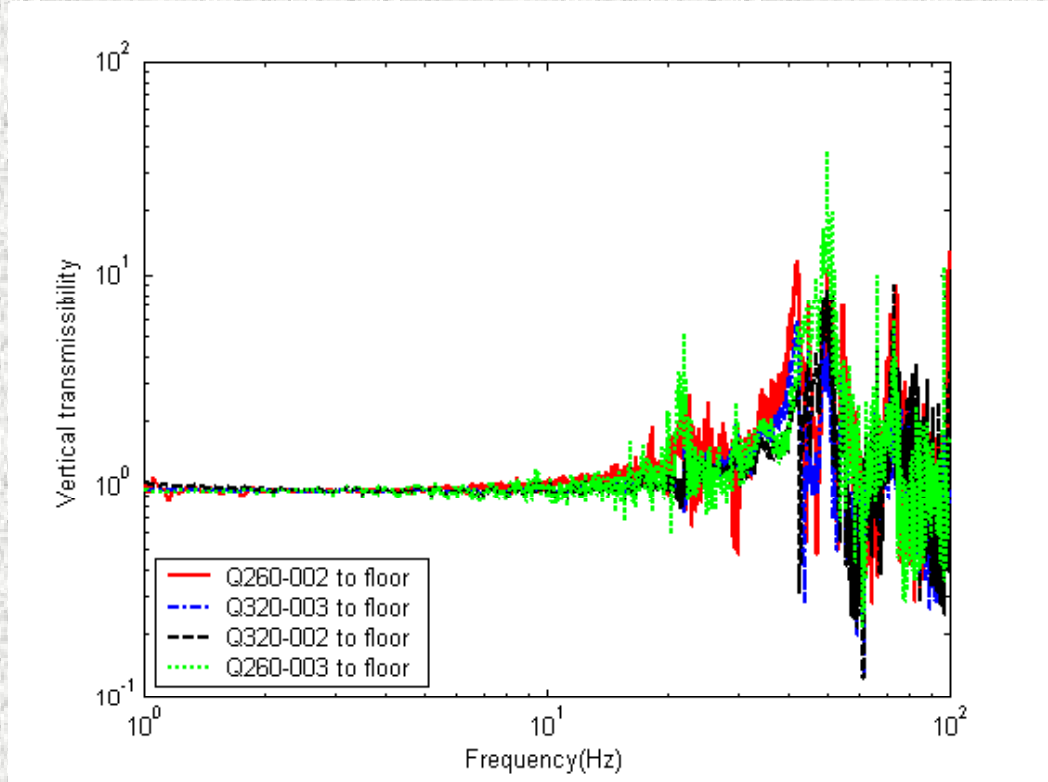
Lateral spectra of measurement C





Vertical spectra of measurement C





Result of measurement C

		Lateral			Vertical	
Frequency range (Hz)		2-50	4-50	6.5-100	2-50	4-50
Floor	Displacement	81.4	18.8	5.3	163.1	39.0
Q260-002	Displacement	88.5	25.1	11.6	173.0	41.1
	Ratio	1.09	1.34	2.19	1.06	1.05
	Q value		47.3		4.7	
Q320-003	Displacement	87.6	24.2	10.3	163.5	39.7
	Ratio	1.08	1.29	1.94	1.00	1.02
	Q value		35.1		1.5	
Q320-002	Displacement	91.1	24.7	10.1	165.2	39.2
	Ratio	1.12	1.31	1.91	1.01	1.01
	Q value		34.4		1.2	
Q260-003	Displacement	93.5	25.1	10.8	164.2	40.0
	Ratio	1.15	1.34	2.04	1.01	1.03
	Q value		38.8		5.2	
Measurement time		14:57:45 - 15:17:45, Mar. 6th, 2007				

Horizontal Motion Band Power (2-50 Hz) and Band Power Amplification

Facility	Floor (nm)		Quad (nm)		Amp. Undamped	Amp. Damped
	Undamp.	Damp.	Undamp.	Damp.		
ALS	16		201		12.6	
APS	37 (1)	25	291 (1)	51	7.9	2.0
ESRF	47 (2)	30	102	40	2.2	1.3
SPRING-8	25 (3)		48 (3)		1.9	
SRRC	71 (3)	73	126	92	1.8	1.3

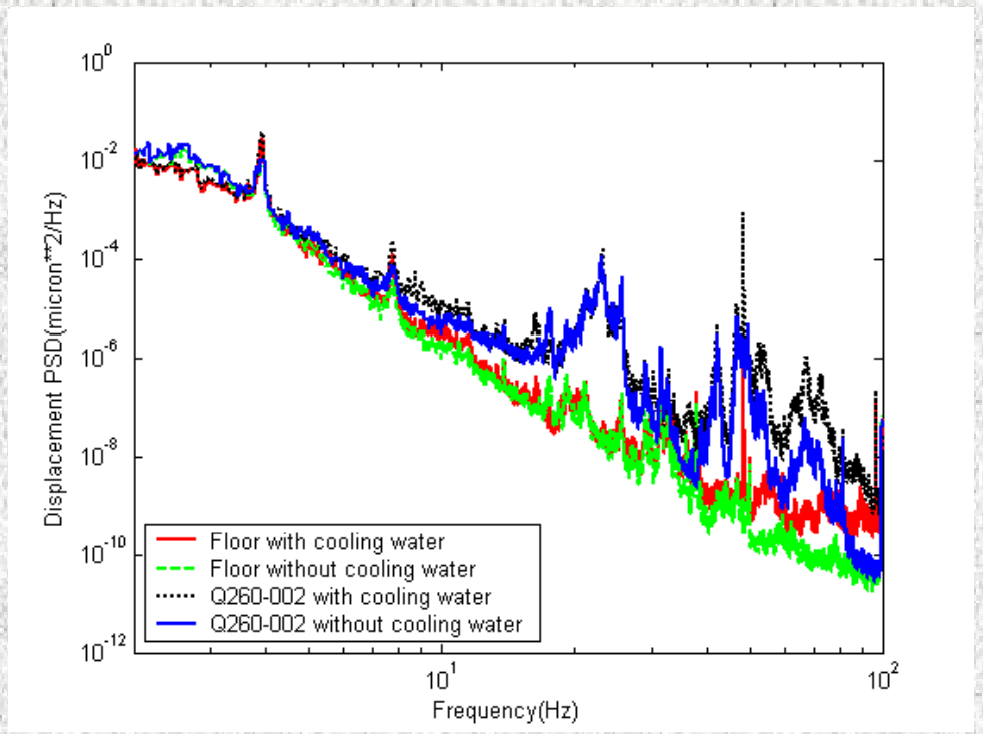
Notes:

(1) Location close to shutdown activities.

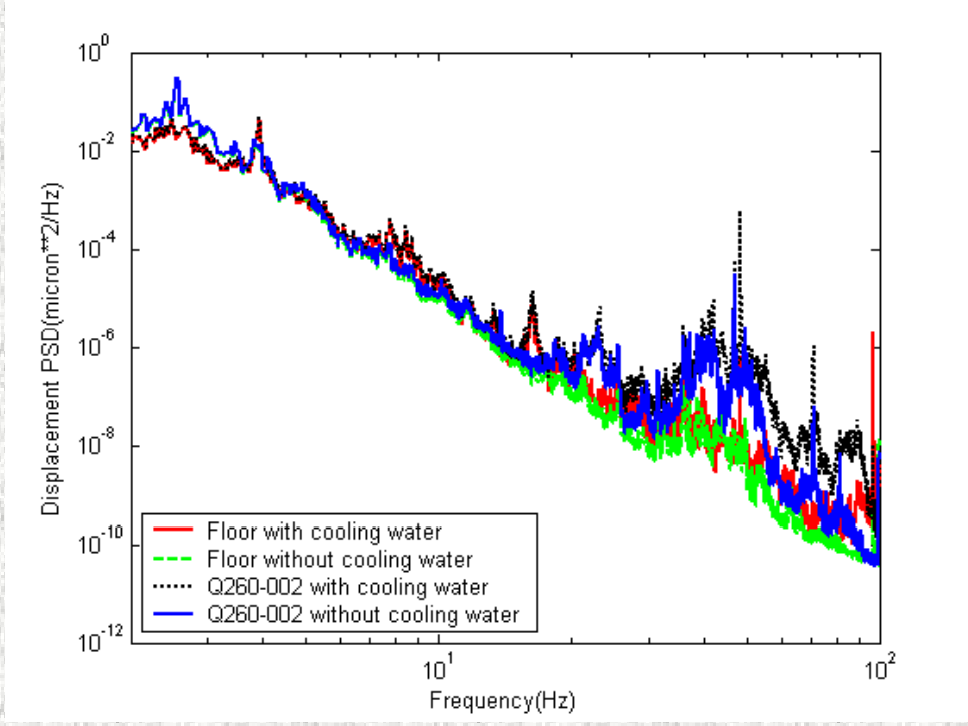
(2) Vacuum pumping operation during vibration tests.

(3) Location close to mechanical equipment room.

Spectra of measurement D

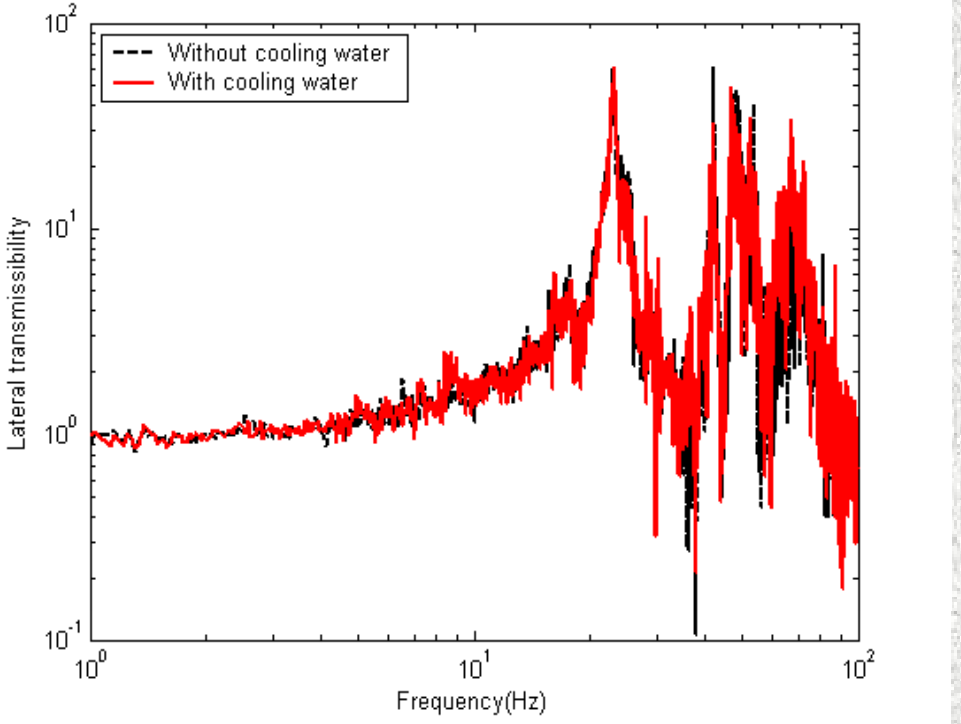


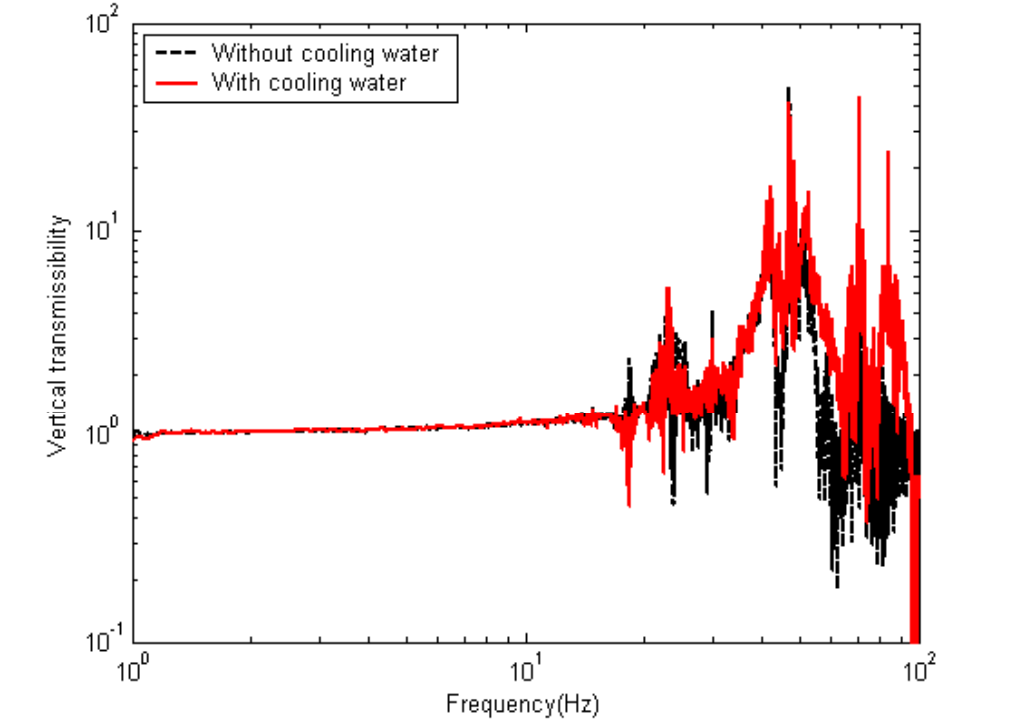
Lateral



Vertical

Spectra of measurement D

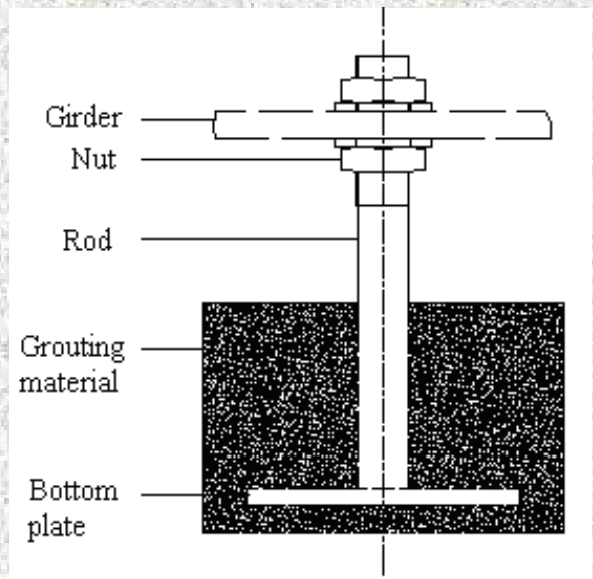


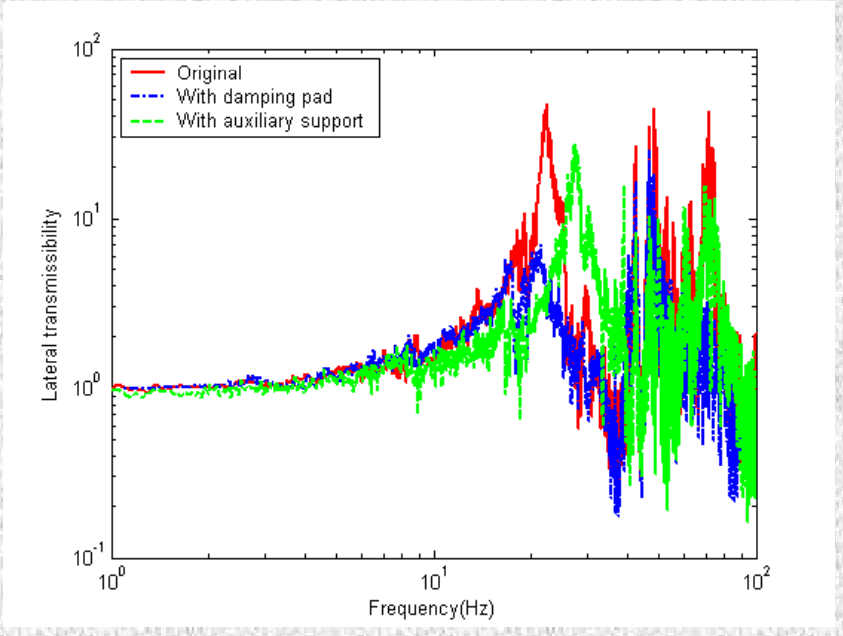


The influence of cooling water: < 4%, less than the ground vibration variety.

	Without cooling water	With cooling water	Ratio
Floor	25.1	27.1	1.08
Q260-002	32.2	35.7	1.11
Ratio	1.28	1.32	
Measurement time (Apr. 5th, 2007)	15:20:51 - 15:30:58	15:43:20 - 15:53:42	

Spectra of measurement E





	Ground	Magnet	Ratio
Original	18.8	25.1	1.34
With damping pad	26.9	35.1	1.30
With auxiliary support	17.0	21.1	1.24

The first eigenfrequency can be improved to 27.7 Hz

Dynamic comparisons with other light source

Project	First eigenfrequency	Project	First eigenfrequency
BESSY-II	5.6	DIAMOND	16.3
ALS	6.4	SPEAR3	17.2
ESRF	6.9	AS	17.3
APS	9.5	SPring-8	18.9
KEK	13.0	SSRF (R&D)	5.9
TLS	15.0	SSRF (modification)	21.9

Project	Without damping devices	With damping devices	Damping devices
AS†	43.2	7.4	Damping plates
SSRF	47.3		
ESRF	50	10	Damping links
TLS	50	12	Damping pads
APS	100	10	Damping pads

† For the dipole girder.

		Without damping devices			With damping devices†		
Project	Frequency range (Hz)	Ground	Magnet	Ratio	Ground	Magnet	Ratio
SSRF	2–50	81.4	93.5	1.15			
	4–50	18.1	25.1	1.34			
	6.5–100	5.3	11.6	2.19			
TLS	2–50	71	126	1.77	73	92	1.26
SPring-8	2–50	25	48	1.92			
ESRF	2–50	47	102	2.17	30	40	1.33
AS	6.5–100	6.3	21.4	3.40	4.9	12.4	2.53
BESSYII	2–315	150	500	3.33	150	250	1.67
APS	2–50	37	291	7.86	25	51	2.04
DIAMOND	1–100	14	134	9.57			
ALS	2–50	16	201	12.56			

† BESSY-II: damping plates, others are the same as those in Table 4.

Conclusion

- 1. The first eigenfrequency: Lateral 21.9 Hz, Vertical 22.5 Hz, Q value: Lateral 47.3, vertical 5.2, Ratio of RMS displacement from magnet to floor: 1.15 in 2~50Hz, 1.34 in 4~50 Hz, 2.19 in 6.5~100 Hz.
- 2.After adding auxiliary, the lateral first eigenfrequency can be improved 27.7 Hz, Ratio of RMS displacement from magnet to floor in 4~50 Hz can arrive 1.24.
- 3. The influence of cooling water: < 4%, less than the ground vibration variety.
- 4. The ground has important influence on the dynamic performance of the MGA.

Thank you for your attention !