Design and Alignment Accuracy of HEPS Storage Ring Magnet Adjustment Mechanism

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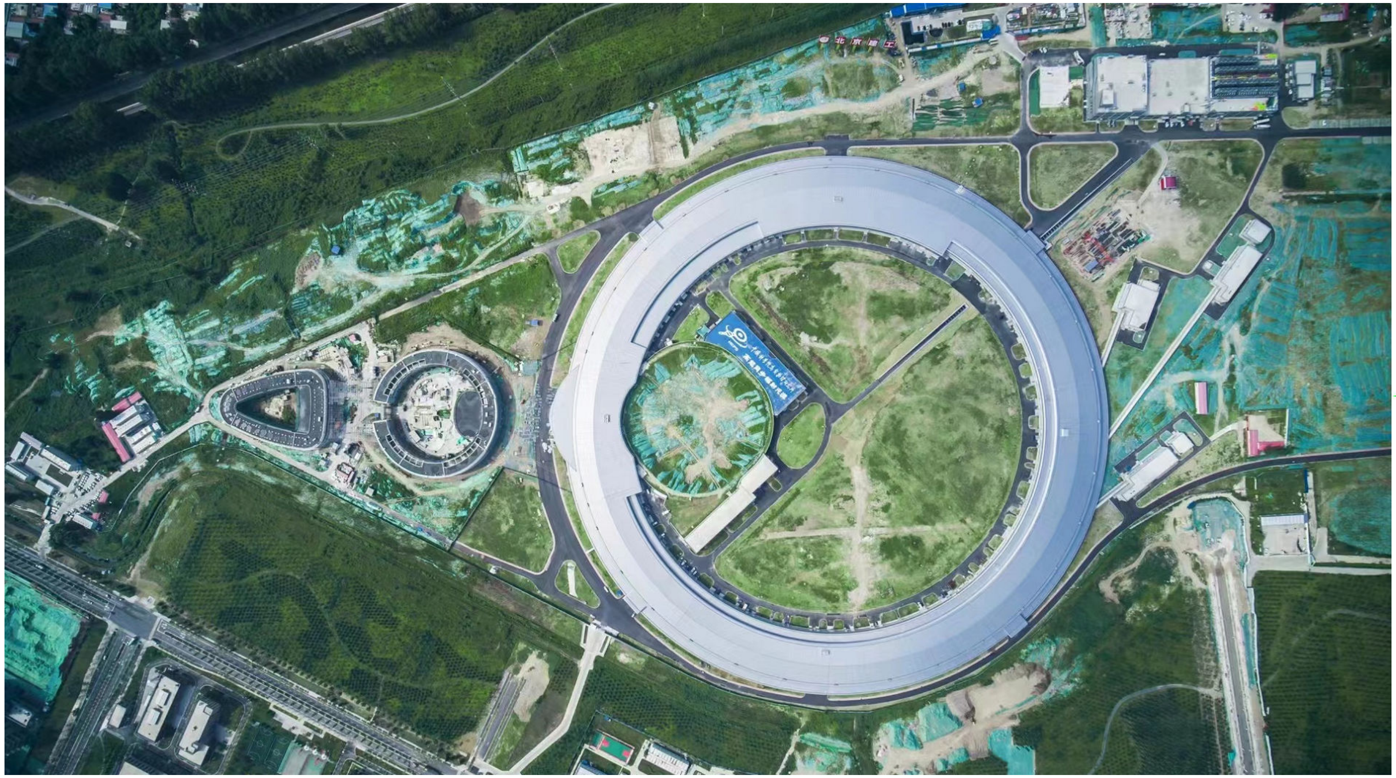
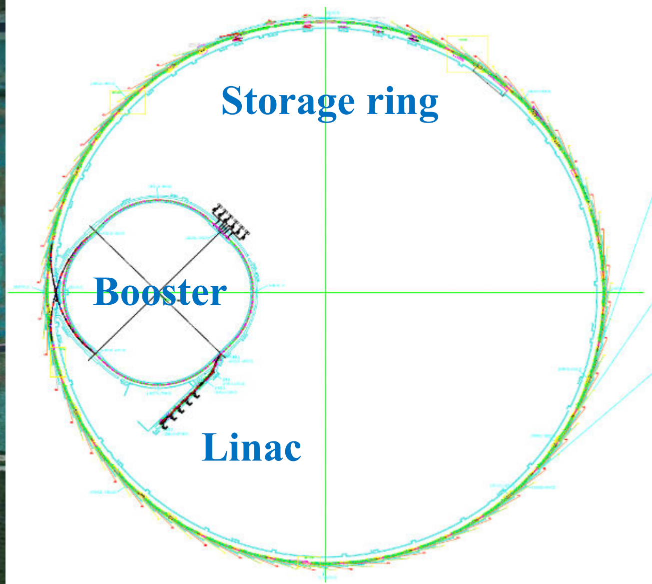
Outline

Introduction

HEPS: High Energy Photon Source, 2019.6-2025.12, Huairou, Beijing



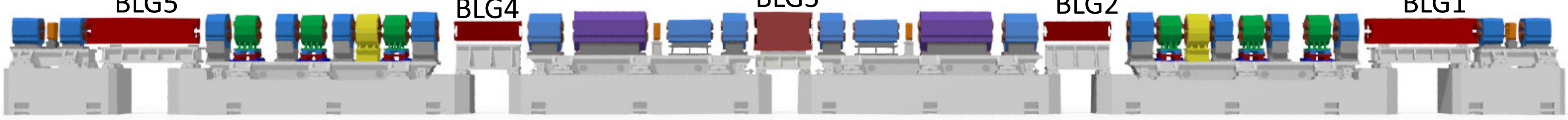


- High energy: 6GeV
- low emittance： 60pm·rad
- circumference: 1360.4m
- Lattice： 48-7BA

Introduction

- Multi-pole magnets will be pre-aligned on girders and then installed in the tunnel.
  - 6 pre-alignment M&G modules of 3 types.
    - FODO * 2, MP * 2, DQ * 2
  - 5 dipole(BLG) separate girders supported on the concrete plinths

Parameters		Requirement
Alignment tolerance between girders	Transverse (X)	±0.05mm
	Vertical (Y)	±0.05mm
	Longitudinal(Z)	±0.15mm
Natural frequency of M&G assembly		54Hz
➢ Sextupoles be capable of being aligned online, for correction of beam optical parameters.		



DESIGN OF SUPPORT SYSTEM

Mechanical design requirements:

- Ensure alignment accuracy → Resolution
- Compensate construction error of infrastructure & Foundation settlement → Adjusting range
- Reduce amplification of ground vibrations → Natural frequency

Parameters		Values
Resolution	Transversal	≤5μm
	Vertical	≤5μm
	Longitudinal	≤15μm
Adjusting range	Horizontal	±10mm
	Vertical	±7mm
Natural frequency		≥54Hz

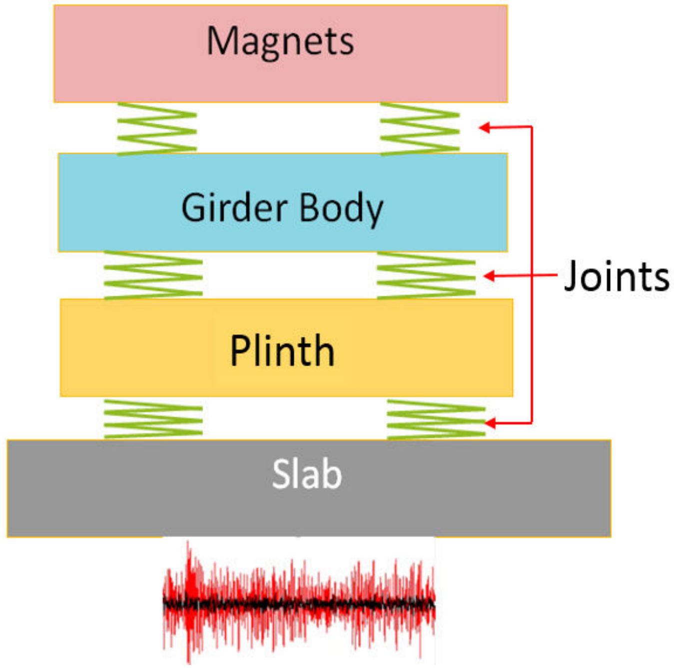
- Sensitive frequency range of HEPS beam: 5-54Hz

Other considerations：

- Uneven deformation of the girder with load: <20μm
- As less residual internal stress as possible, to ensure the dimensional stability and keep alignment accuracy in a long term.

DESIGN OF SUPPORT SYSTEM

- Stability is the first priority in design
- Magnet support system： magnet, girder body, plinth
- The stiffness of components connect with each other and contribute to the system stability.
  - Parallel stiffness: $\frac{1}{K} = \frac{1}{k1} + \frac{1}{k2} \dots + \frac{1}{kn}$
  - Serial stiffness: $K = k_1 + k_2 + \cdots + k_n$



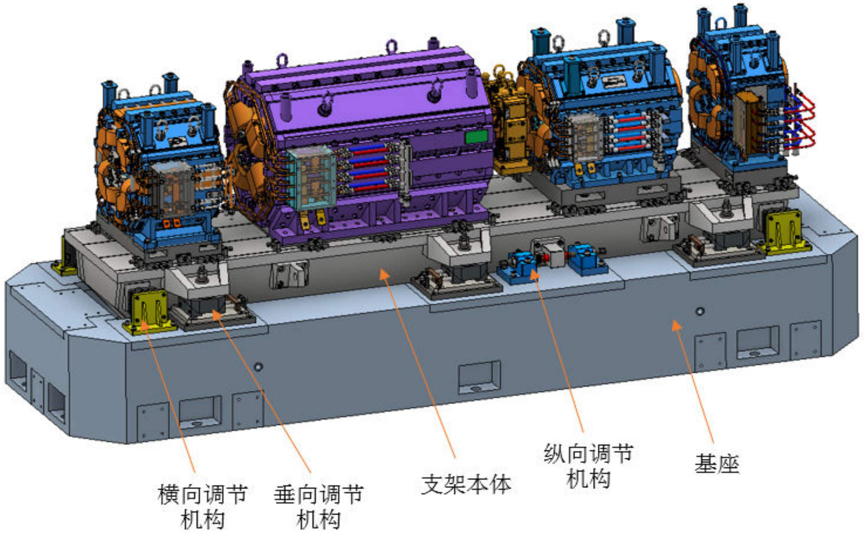
- The connection is a weak part → high stiffness adjustment mechanism

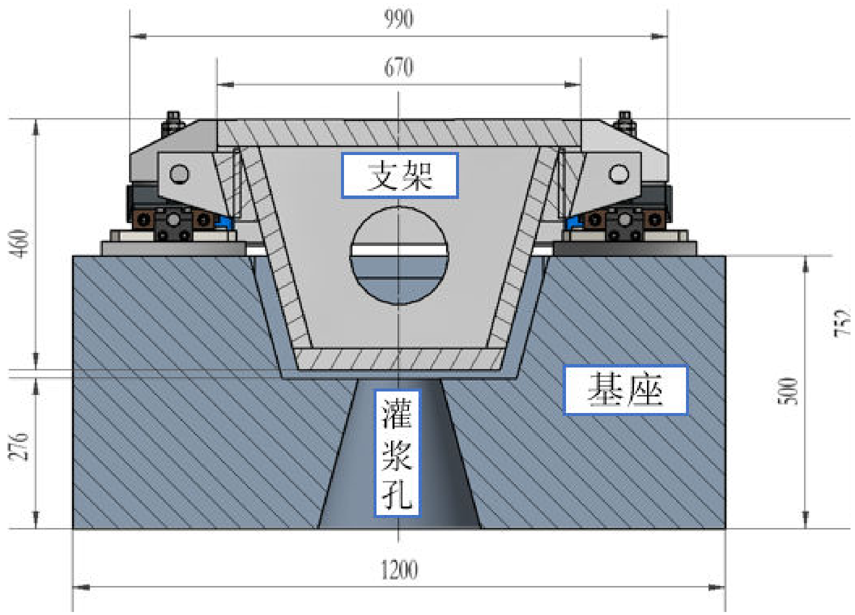
$$K = \frac{F}{\Delta L} = \frac{EA \cdot \Delta L / L}{\Delta L} = \frac{EA}{L}$$

- The flatness and roughness has a significant effect on the stiffness → Machining accuracy
- Fixation of the plinth → grouting

DESIGN OF SUPPORT SYSTEM

- Support system structure program:
- Six-point support，Wedge Adjustment
  - Increase contact area to improve connection stiffness
- Ear shape support
  - The pivot point should be close to the magnetic center
  - Enlarge the transverse span of the pivot point
- Box structured girder body
  - Matched girder and plinth
  - stiffness

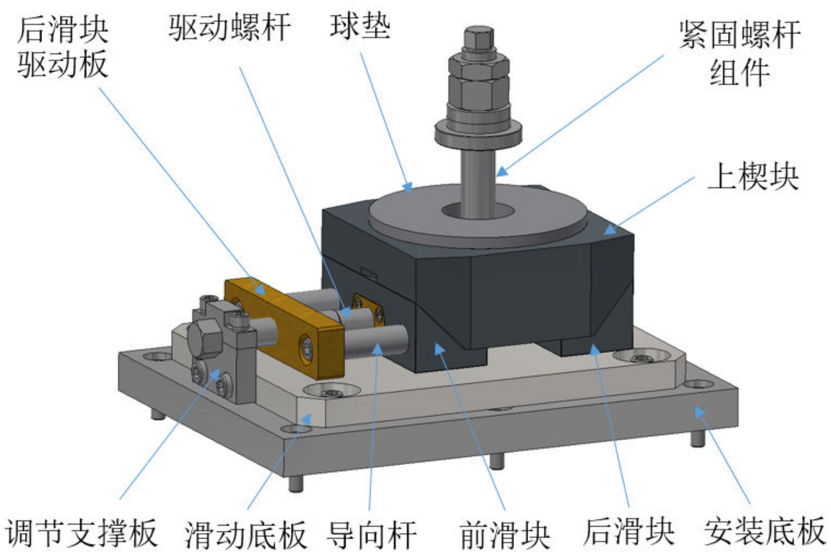


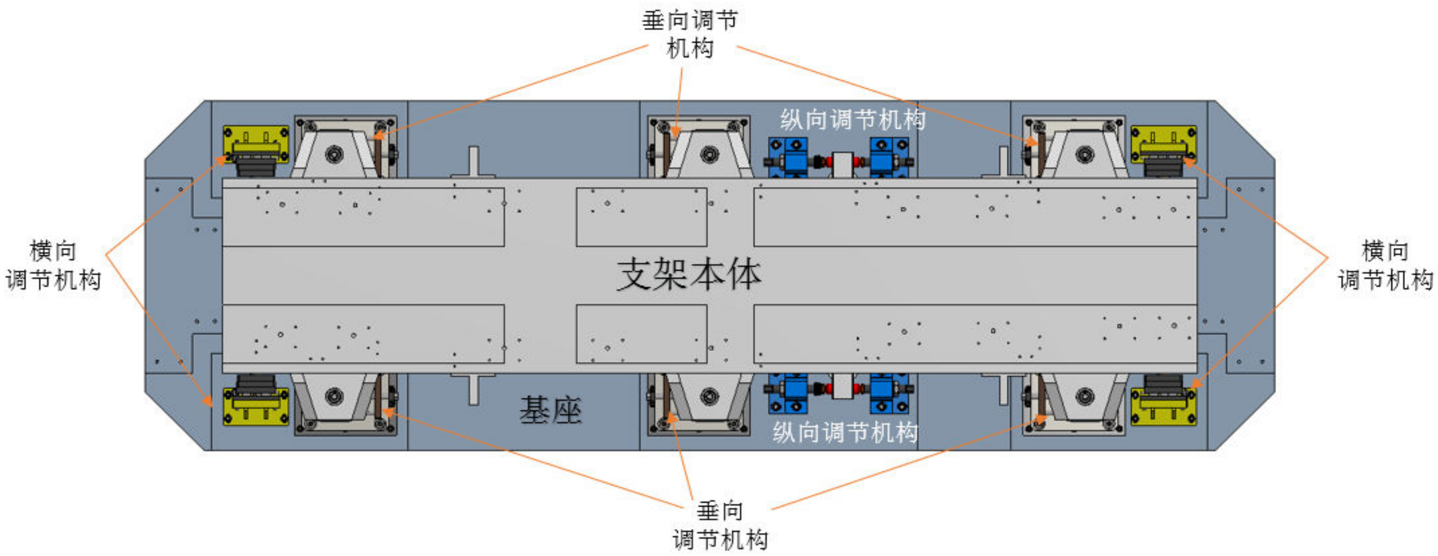


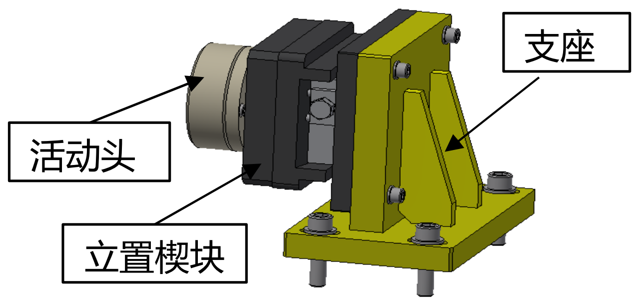
MP/FODO支撑系统截面图

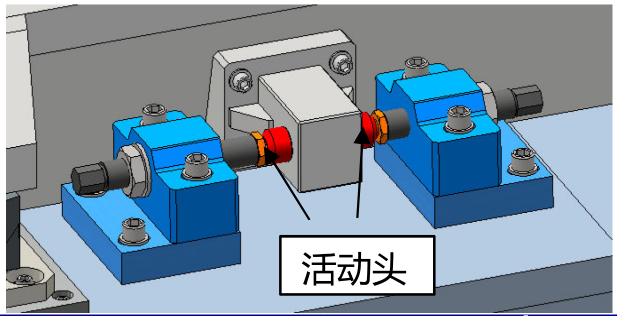
DESIGN OF SUPPORT SYSTEM

- Location of adjustment mechanism
  - vertical： 6 sets， Double-wedge
  - transversal/ longitudinal： 2 sets each， mutual-push structure， fine thread， movable top



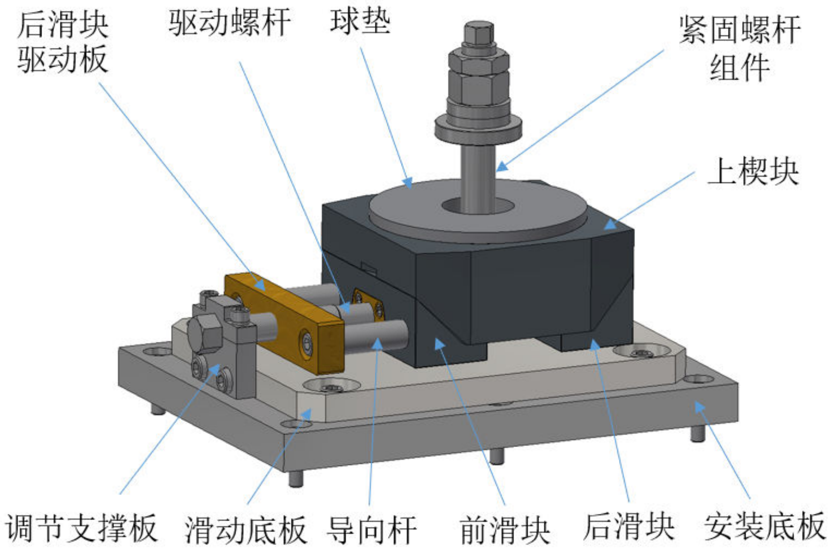


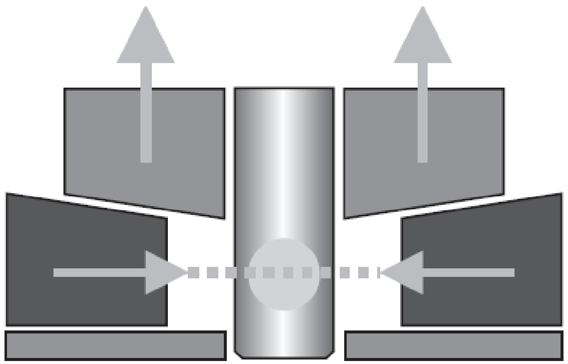




Design of Vertical Adjustment Mechanism

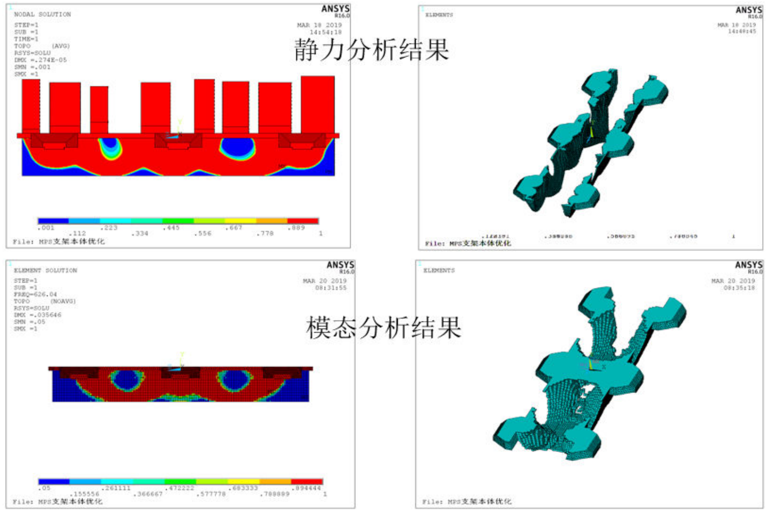
- Vertical adjustment mechanism： key parts
  - ■Double-wedge, reduce torque for better motion performance.
  - ■Spherical washer, adaptable to the angle of adjustment to ensure surface fit and avoid locking stress.
- ◆ Advantage：
  - ■Fulfill motion performance and support stiffness simultaneously
- ◆ Disadvantage：
  - ■Smaller adjustment range

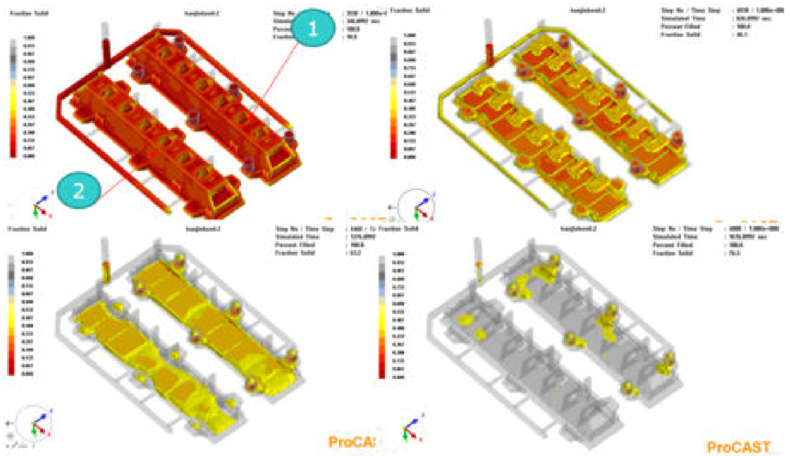




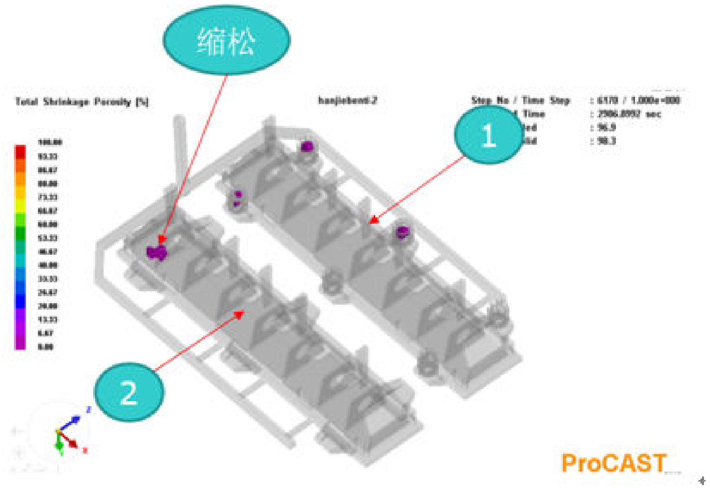
Design of Girder Body

- Structural optimisation： stiffness
  - Cross-section shape and rib plate distribution optimisation
- Material： cast iron HT350
  - Excellent long-term stability of dimensions; high efficiency in batch production；
  - Quality control is difficult





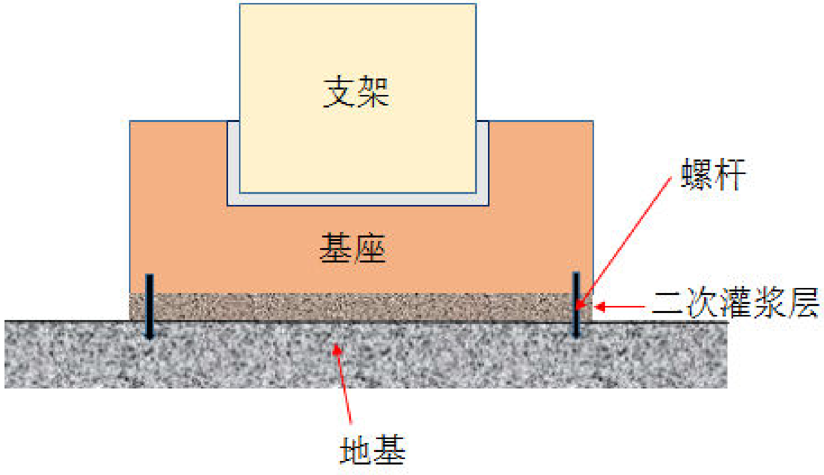
液态收缩过程

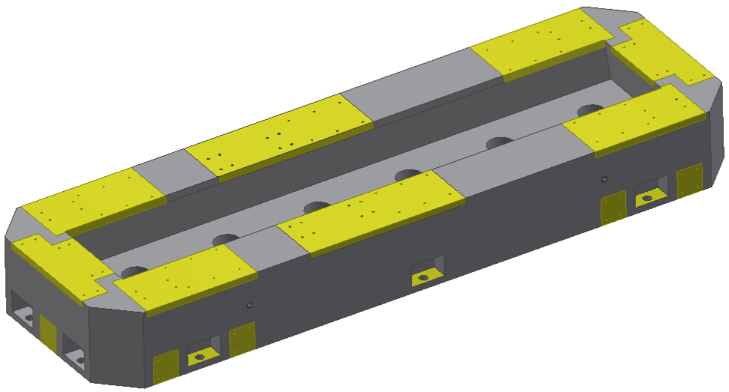


缩松现象

Design of Plinth

- Design proposal：
  - reinforced concrete precast，
    - good overall stiffness.
    - modulus of elasticity can be increased >50GPa
  - grouting
    - seamless connection
    - improve the stiffness of the system





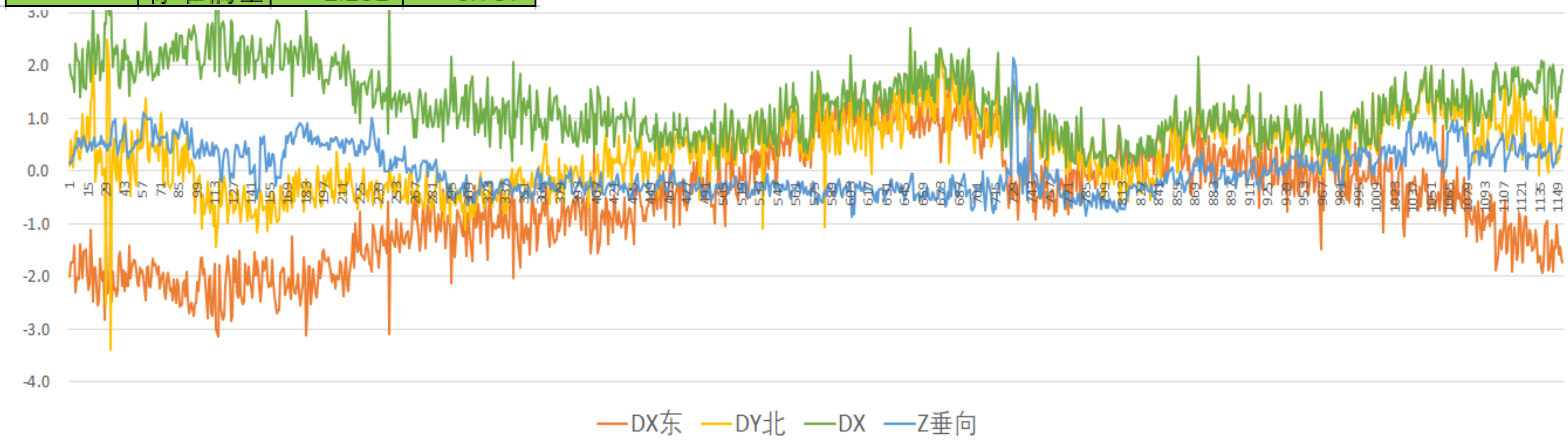
Design of Plinth

- Displacement after grouting
  - ✓ adjustment error,
  - ✓ alignment control network measurement error
  - ✓ foundation settlement,
  - ✓ plinth movement during grouting
  - ✓ grout solidification

- Results
  - ➢ the maximum deviation of the horizontal was 3.5mm;
  - ➢ in the vertical direction, the deviation of 5 plinths was >1mm, the maximum deviation was 2.14mm, and the rest were ＜1mm.

		东X	北Y
平面方向基座位置偏差	最大偏差	1.977	2.614
	最小偏差	-3.149	-3.372
	平均偏差	-0.566	0.380
	标准偏差	1.191	0.787

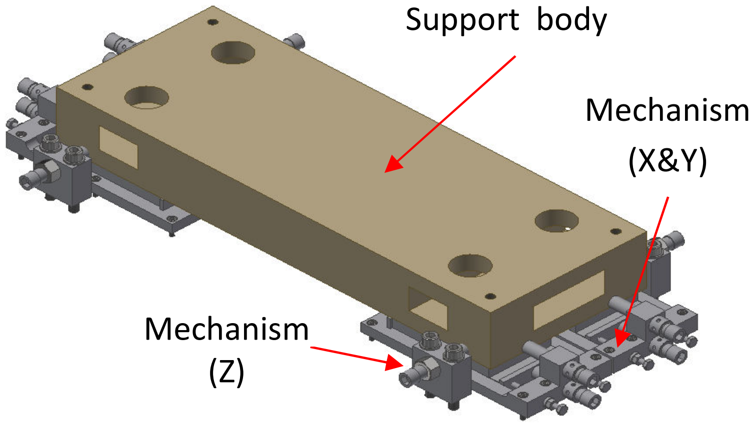
垂直方向基座位置偏差	最大偏差	2.139
	最小偏差	-0.880
	平均偏差	0.005
	标准偏差	0.429

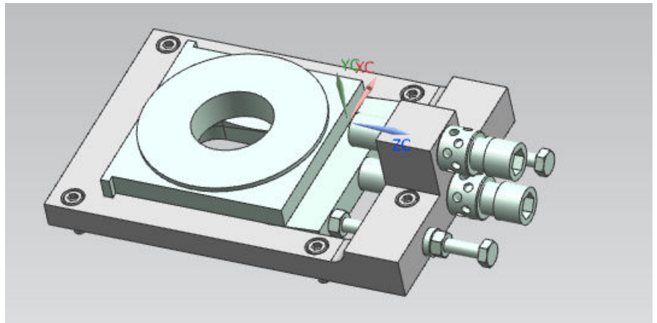


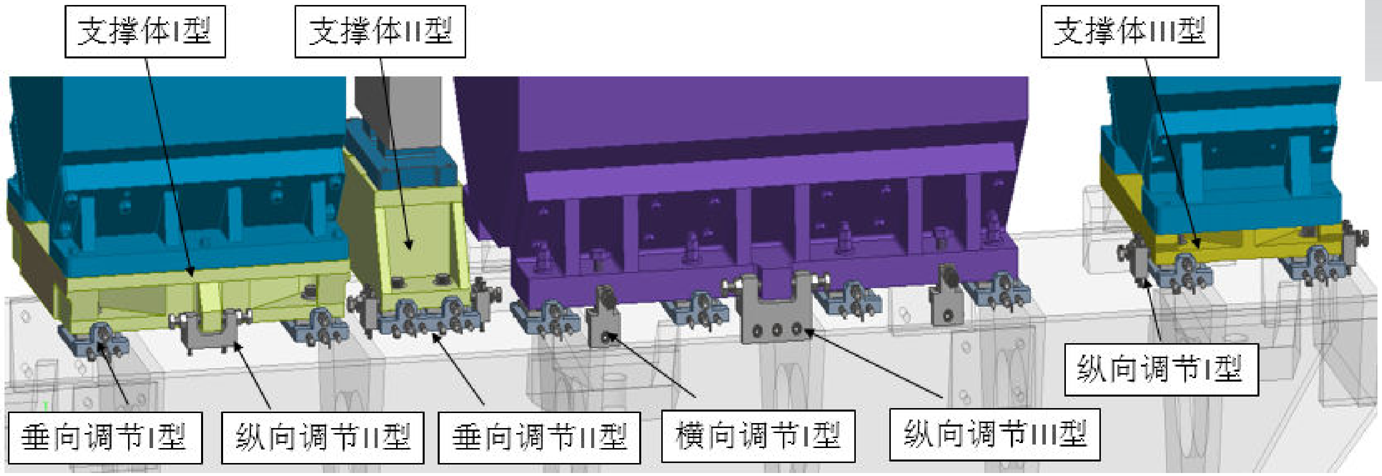
理论值点名	偏差Z垂向
R03F1H2	1.100
R03F1H3	1.030
R03F1H4	1.009
R03F2H3	1.014
R10M1H2	1.003
R31D2H4	1.456
R31F1H1	2.139
R31F1H2	1.971
R31F1H3	1.480
R31M1H4	1.328
R31M2H3	1.227

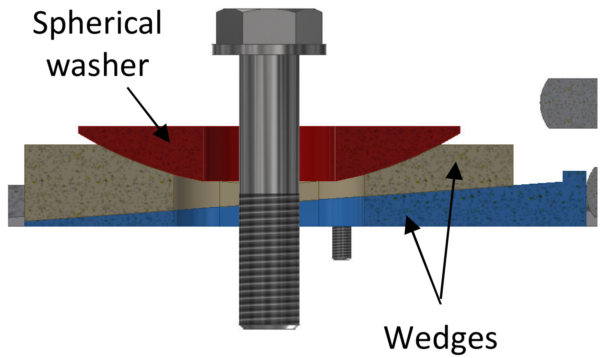
Magnet alignment mechanism

- Requirement： Align the magnets on one girder precisely with the motion resolution of 1μm.
- Mechanical design：
  - Cast steel support body, good dimensional stability, easy to shape.
  - Vertical adjustment: Wedges with spherical, adjustable range of ±1mm；
  - Horizontal adjustment: Screws, ±4mm.



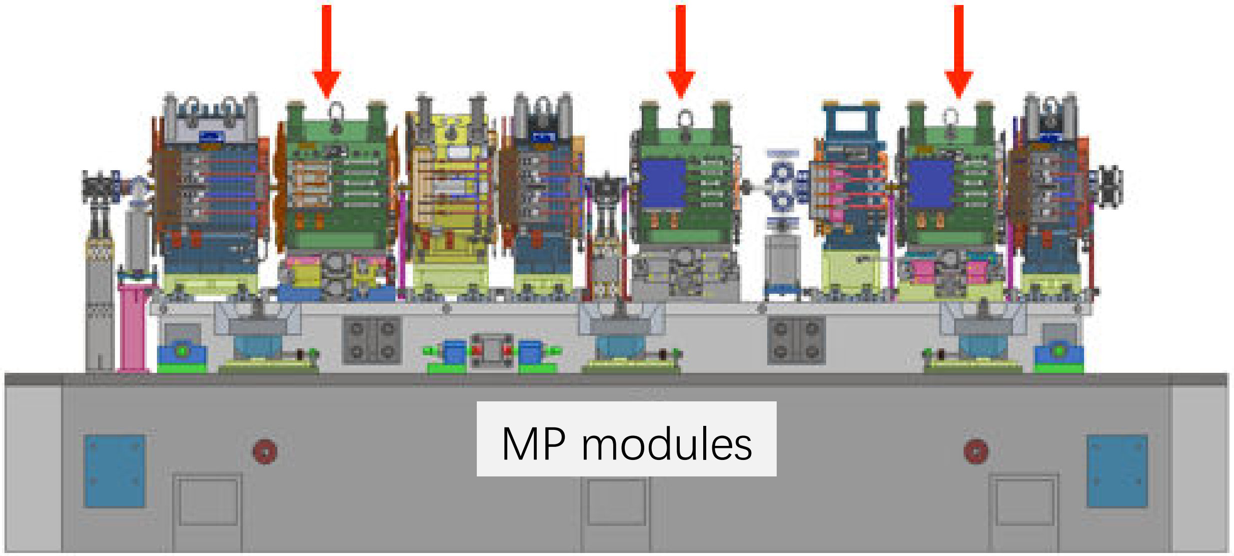


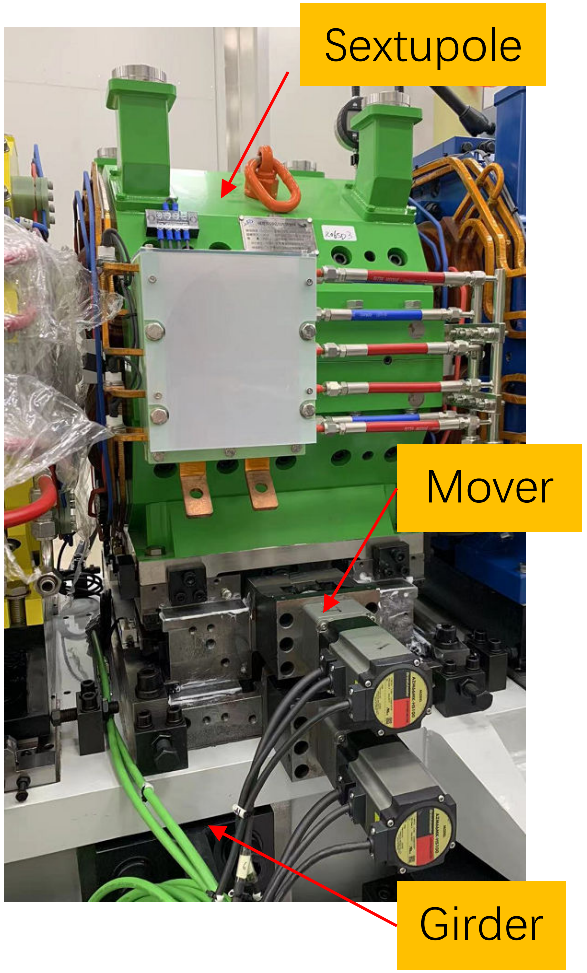




Magnet alignment mechanism

- Remote Mover is proposed specially for the sextupole position adjustment online, and for optical parameters correction.
  - Located on the MP modules, 288 in total
- Physical requirements:
  - Transversal & vertical motion accuracy: 5μm, at the magnet center.
  - Adjustable range online: ±0.3mm
  - No influence on the magnet support system stability.





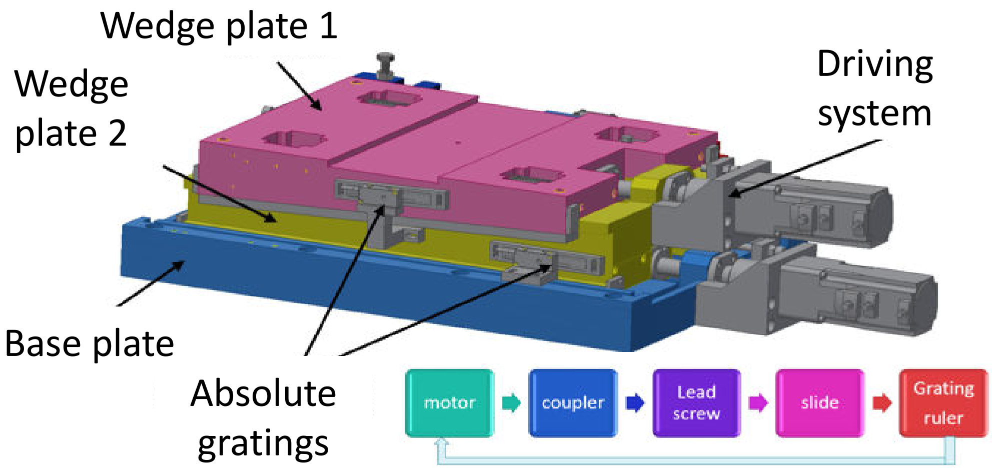
Magnet alignment mechanism

➢ Difficulties:

- Heavy load, limited space
- High stiffness & motion accuracy

➢ Mechanical Design:

- Wedge mechanism
- Drive system: Ball-screw +Step motors
- Absolute gratings for feedback



Parameters		Values
Displacement errors	X/Y	2μm
Angular errors	Pitch	2”
	Yaw/roll	3”
Moving range		±1mm
1st natural frequency		54Hz
Load		450kg

For detailed design, machining and experimental content, see article “Aligment scheme of sextupole and Mover in the pre-alignment MP module of HEPS” by Wu Lei

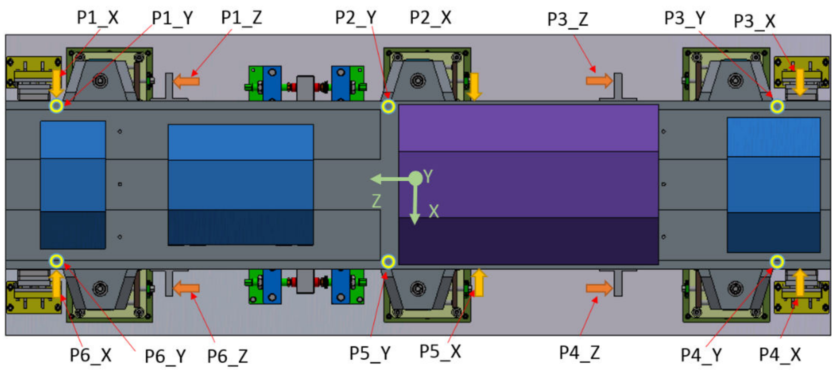
Alignment accuracy study of the support system

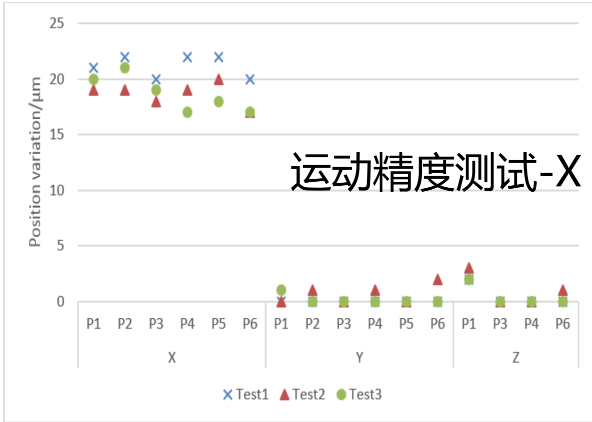
Final Accuracy /mm		Stage Accuracy /mm		Fundamental accuracy /mm	
Total	0.047	Pre-alignment	0.029	Magnetic center of magnet leads to calibration accuracy	0.01
				measurement error	0.01
				adjustment deviation	0.015
				magnet lock	0.01
				Magnet open and close	0.01
				transport	0.015
		Tunnel alignment	0.036	Adjustment of displacement measurement accuracy	0.005
				adjustment deviation	0.02
				Relative control measurement accuracy	0.03

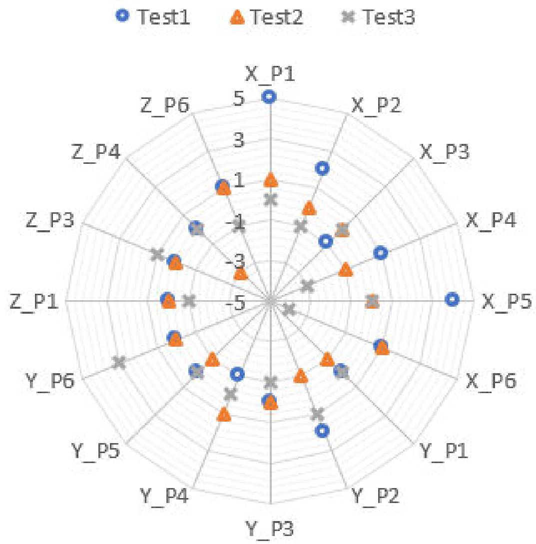
- Motion performance test
  - Adjustment resolution and motion accuracy test
  - Locking test
- Magnet opening and closing repeatable test
- Girder transportation reliable test

Motion test

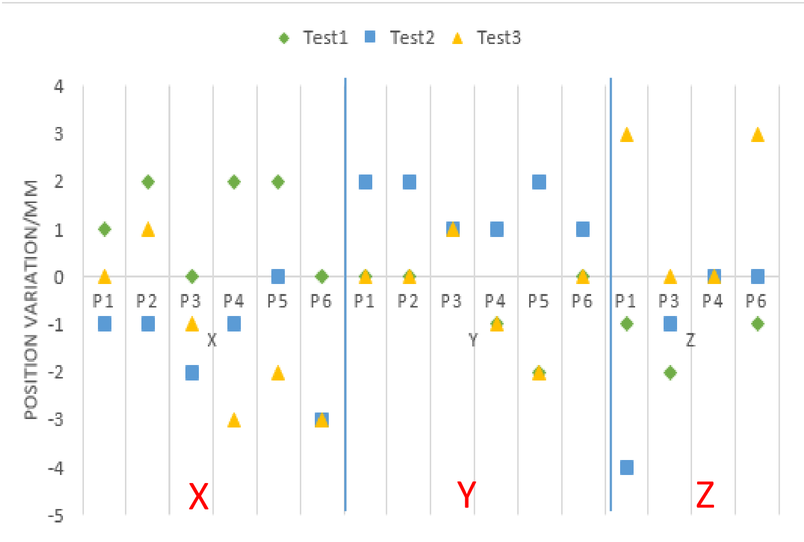
- Method: dial gauge
  - ①Adjustment Resolution~ 1μm
  - ②Motion precision< 5μm。
    - ◆motion coupling < 3μm。
  - ■Locked offset <5μm



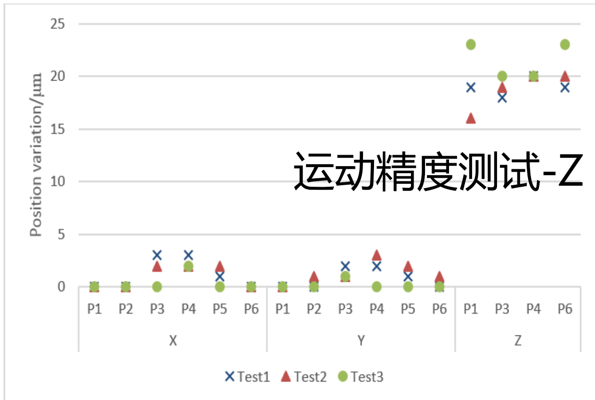




三方向锁紧跑动量

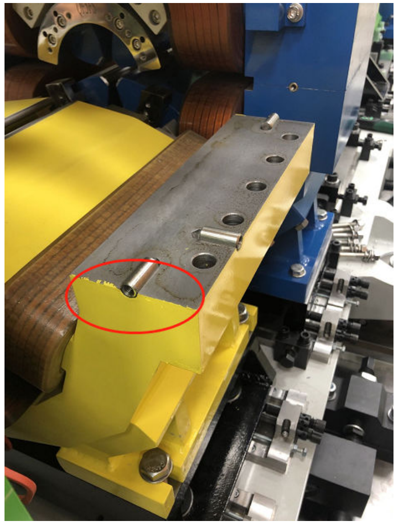


三方向定位误差



Magnet opening and closing repeatable test

- The position of the magnet after opening and installing the vacuum chamber needs to meet the pre-alignment accuracy requirements.
- Tolerance： 0.01mm
- Subjects : MP & FODO module
- Repeatable positioning structure: pin





Magnet opening and closing repeatable test

- Results: magnet position change <0.01mm
- Error analysis： The main contribution is the change in position of the ABF and BD magnet, most likely due to stress relief from magnet disassembly, with iron chipping residue in the BD magnet pin.
- Batch Production Notes：
  - disassembly and assembly parts stowage；
  - the order and torque requirements of tightening bolt；
  - the pin position and angle remain unchanged;

Type	standard deviation/mm		
	DX	DY	DZ
MP	0.006	0.008	0.005
FODO	0.006	0.003	0.004
	0.006	0.003	0.004

Transportation Reliable Test

- After completing the pre-alignment, the magnet girder needs to be transported to the HEPS tunnel for installation via the sinking channel, and the magnet position after transportation needs to meet the pre-alignment accuracy requirements.

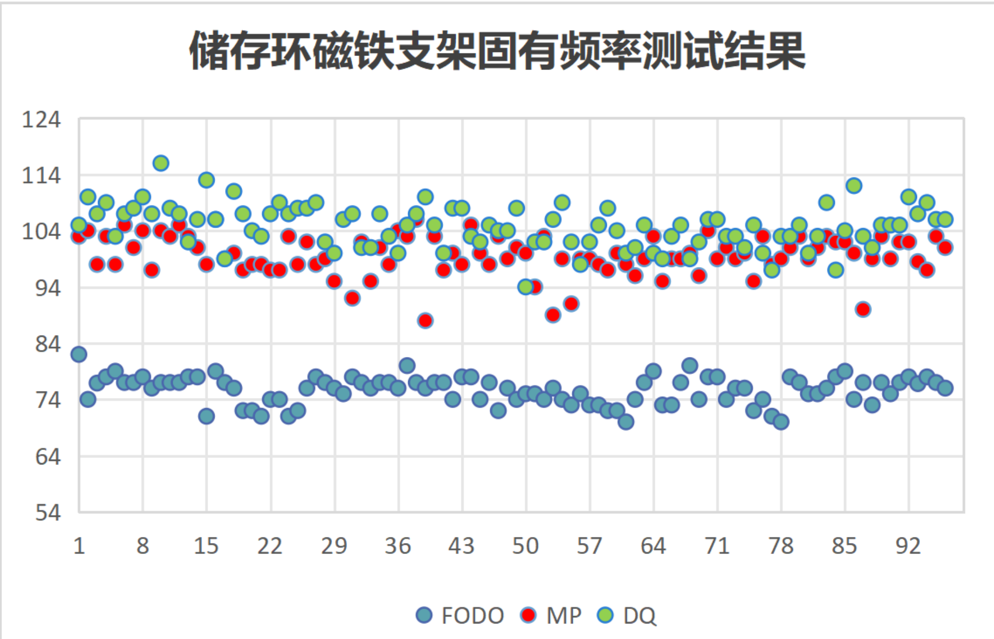
- Tolerance： 0.015mm
- Toute： pre-alignment thermostat room to the tunnel installation hall.
- Security measure：
  - the self-leveling vibration damping transportation platform
  - transportation speed is 10-20km/h
  - Uniform force on the 6 support points of the girder during transportation

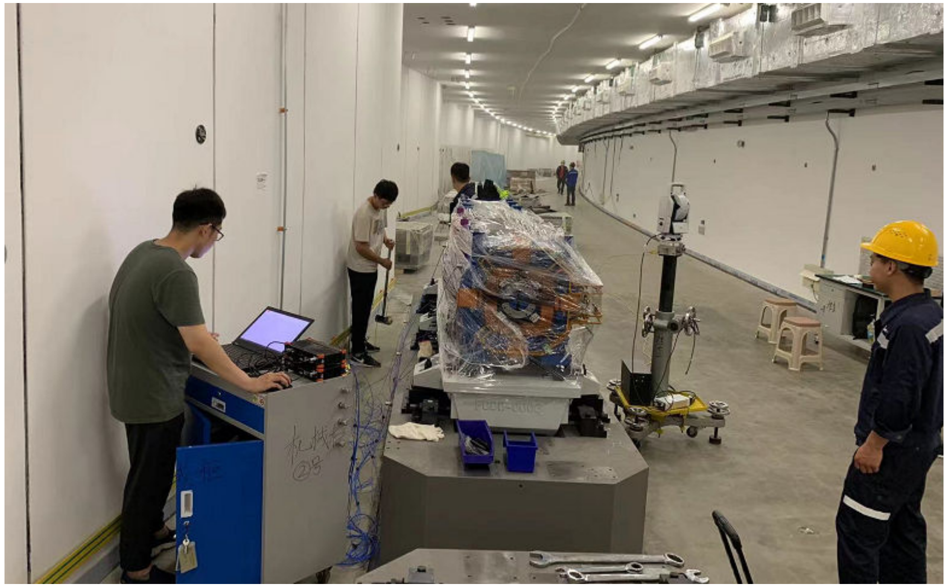
- Results: magnet position change <0.01mm, meet the error requirements

Type	standard deviation/mm		
	DX	DY	DZ
MP	0.005	0.004	0.005
FODO	0.006	0.006	0.010

Modal test

- Test the stability of the system in tunnel
  - ■MP: 86Hz， mover @159Hz
  - ■FODO: 70Hz
- All greater than the requirements





Summary

- General design of magnet support system based on alignment accuracy and stability is presented.
- The design solution for the magnet support system was validated in batch installations and tests, and a number of problems were identified and solved.
- Through the motion performance test of the prototype, magnet opening/closing repeatable test, transportation test and modal test, the technical solutions and accuracy of magnet pre-alignment and tunnel alignment have been verified, all test results meet the design requirements proposed.

Thanks for your attention！