國家同步輻射研究中心
National Synchrotron Radiation Research Center

THE AUTO-ALIGNMENT GIRDER SYSTEM OF TPS STORAGE RING

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NSRRC

Outline

- Girder system design briefing
- Preparations at a rental plant
- Girders Installation at TPS tunnel
- Survey alignment works
- Auto alignment preparation and implementation
- Conclusions

TPS Girder System Timeline

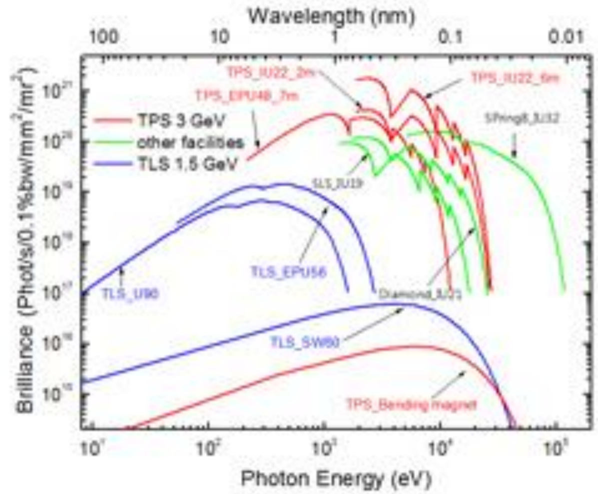
Date	Event
2004 June	TPS feasibility study started
2005 Dec.	A preliminary study prototype bending section with 3 girders established
2009 Oct.	A nearly real size testing mock-up system was set up in NSRRC lab .
2010~2013	Parts manufacturing, sub-systems assembling and calibration in a rental factory
2012 May	A third mock-up system was set up
2013 Jan.	Pedestals were to be set out, anchor bolts drilling and installed
2013 July	2 bending sections installed as an on-site mock-up testing system
2013 Oct.	Entire system installation began
2014 Mar.	The Last girder was craned
2014 Aug.	A whole ring girder automatic alignment was really performed
2014 Aug.	Phase I accelerator system test and commissioning started
2014 Oct.	A second automatic alignment was performed
2014.12.31	First synchrotron light from TPS

Taiwan Photon Source

Parameters of TPS Synchrotron Facility

Energy	3 GeV
Beam Current	500 mA at 3 GeV
C of the Storage Ring	518.4 m (h = 864)
C of the Booster	496.8 m (h = 828)
Cells	24-cell DBA
Straight Sections	12 m x 6 (σ_v = 9.8 μm, σ_h = 165.1 μm) 7 m x 18 (σ_v = 5.1 μm, σ_h = 120.8 μm)
Emittance	1.6 nm·rad at 3 GeV (Distributed dispersion)
RF frequency	499.654 MHz
Critical Energy	7.13 keV (dipole)
Energy Loss/turn	853 keV (dipole)

Brightness of Synchrotron Light Sources



Design goals of the girder system for TPS

- **Firm support and precise positioning of magnets (30μm RMS), Vacuum Chamber & BPM**
- **Higher nature frequency (above 30 Hz is better)**
- **Alignment accuracy between girders within 0.1mm(relative)**

  Traditional alignment network simulation reveals an accuracy of 0.3mm typically. It needs to be iterated several times to reduce to 0.1mm
- **Precise resolution (μm)**

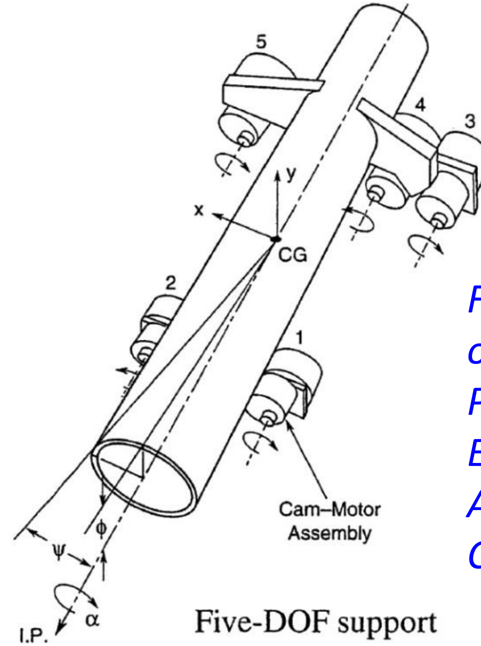
  Manual adjustment mechanism is of poor resolution and time consuming
- **Toward whole ring automatic alignment (optional)**

  How to align the girders precisely and quickly with less manpower? Considering the deformation of the floor and limited space in the tunnel also frequent earthquakes in Taiwan .

A 6-axes motorized adjusting mechanism was thus proposed!

Cam mover type adjustment mechanism

Girder of Swiss Light Source

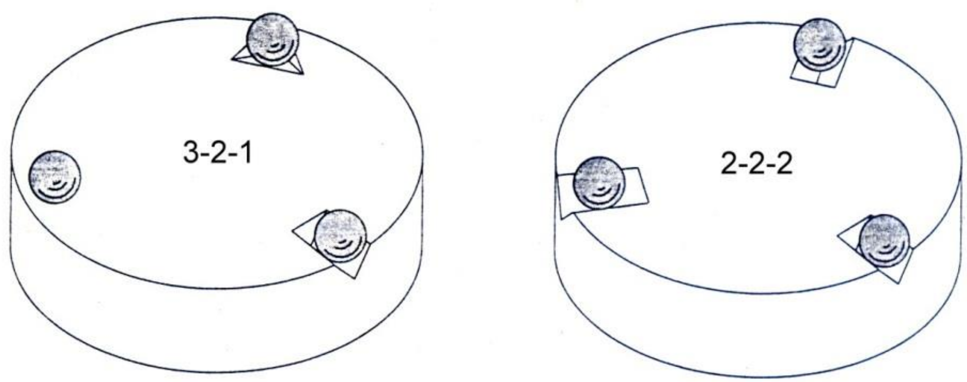


Five-DOF support

From "Handbook of Accelerator Physics and Engineering" Alexander Wu Chao, P377.

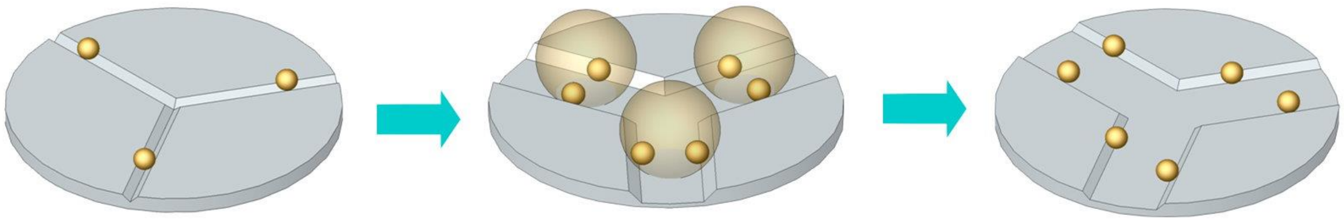
Types of kinematic mounting

From "Precision Machine Design" Alexander H. Slocum, P377.



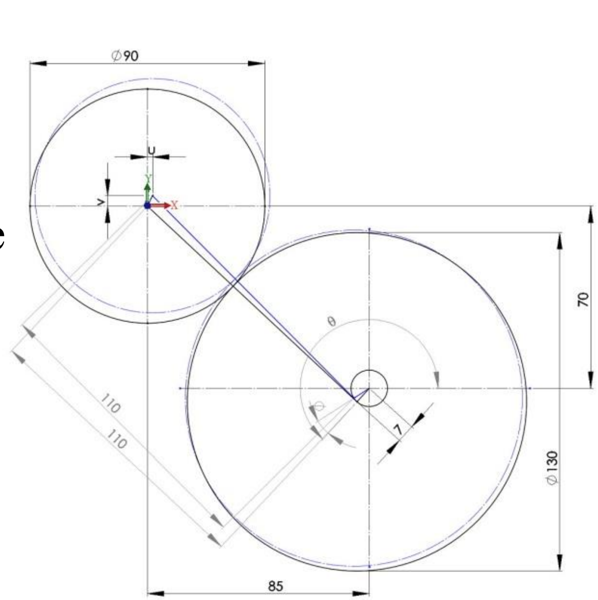
Flat-groove-tetrahedron (Kelvin clamp) and three-vee-groove kinematic couplings. In both cases, the balls should be mounted in tetrahedrons formed in an upper plate.

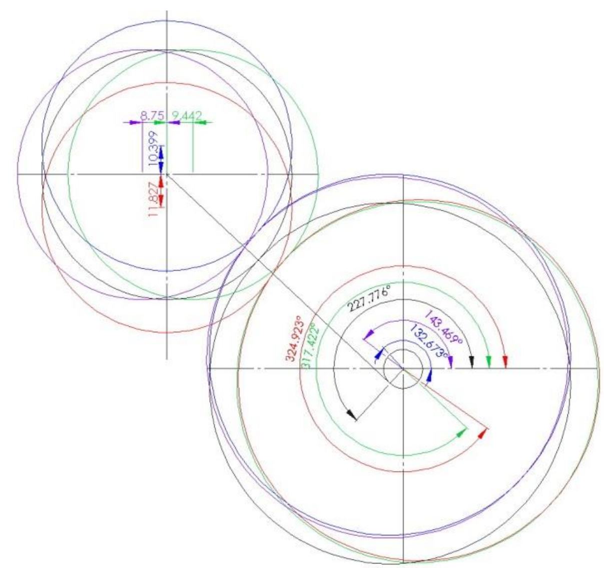
Cam mover type mechanism modification and adjusting algorithm



A 3 grooves type kinematic mounting modification to 6 stands girder design

- Two coordinate systems are to be established at girders and movers separately, from the rigid body assumption, the adjustment of center position of each ball can be calculated.
- Due to the kinematic V groove type arrangement, the girder moving range in horizontal direction is only ½ of the mover range in horizontal(X) direction (4.5mm) and √3/2 in longitudinal(Z) direction (7mm)





prototype ,mock-up fabrication and testing

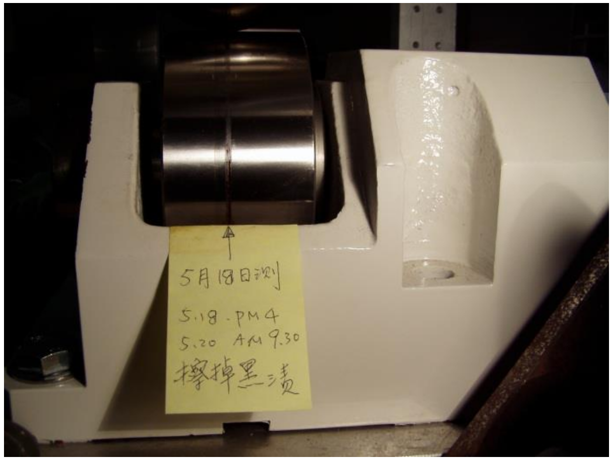
Studying prototype installed in 2005 Dec.

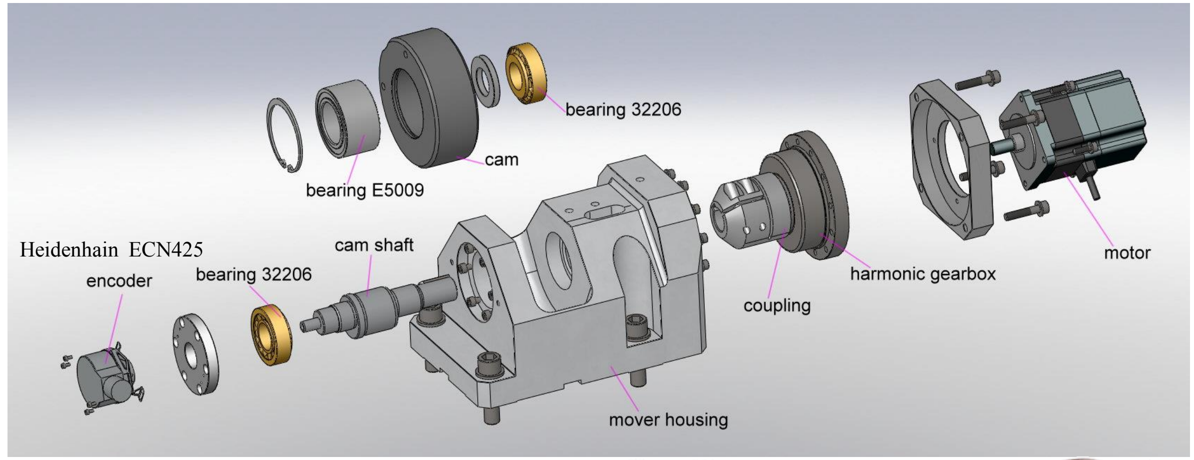
- Machining accuracy and ability testing
- Vibration testing
- Adjustability testing

First real size mock-up installed in 2009 Oct.

- Interfaces check
- Vibration testing
- Adjustability testing

Modification of point contact type cam to line contact to reduce stress

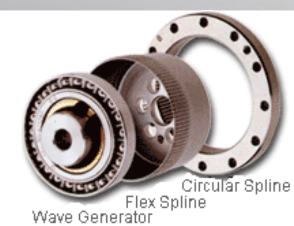




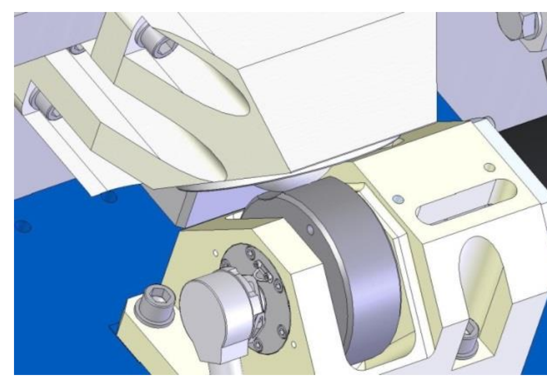
- Kinematic mounting situation preserved.
- The contact position of the ball and the cam remains the same for adjusting algorithm.
- the contact situation changes from point contact to line contact.
- the stress is reduced drastically to 12.4% and far below the elastic limitation of the cam.

Steps of the stepping motor is 5000 and plus with the gearbox ratio of 160, it comes with a resolution of 800000 per turn and also refers to a step resolution of at least 0.03um in girder coordinate system

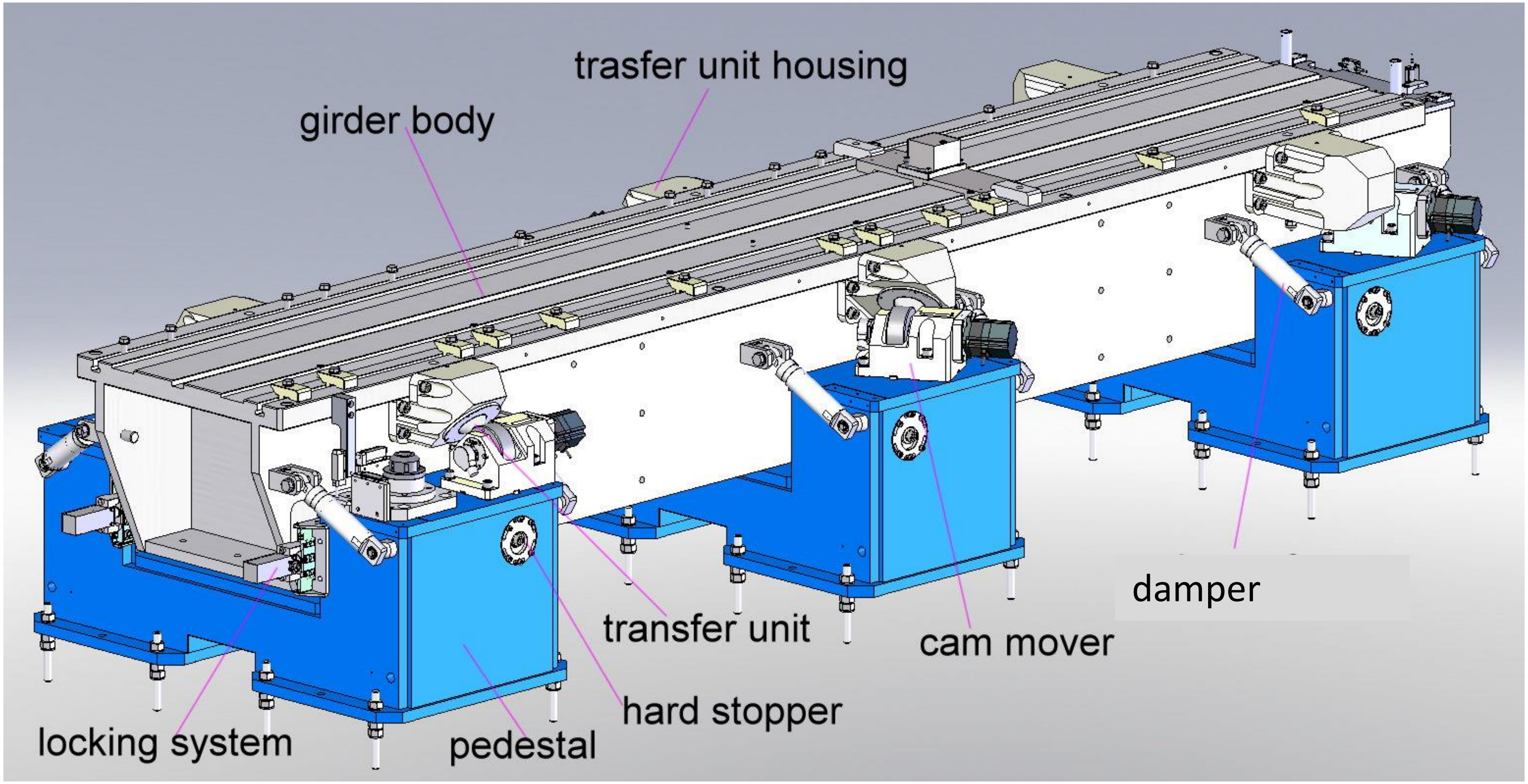
Heidenhain ECN425 rotary encoder



harmonic drive 1: 160
constant torque : 35 kg.m

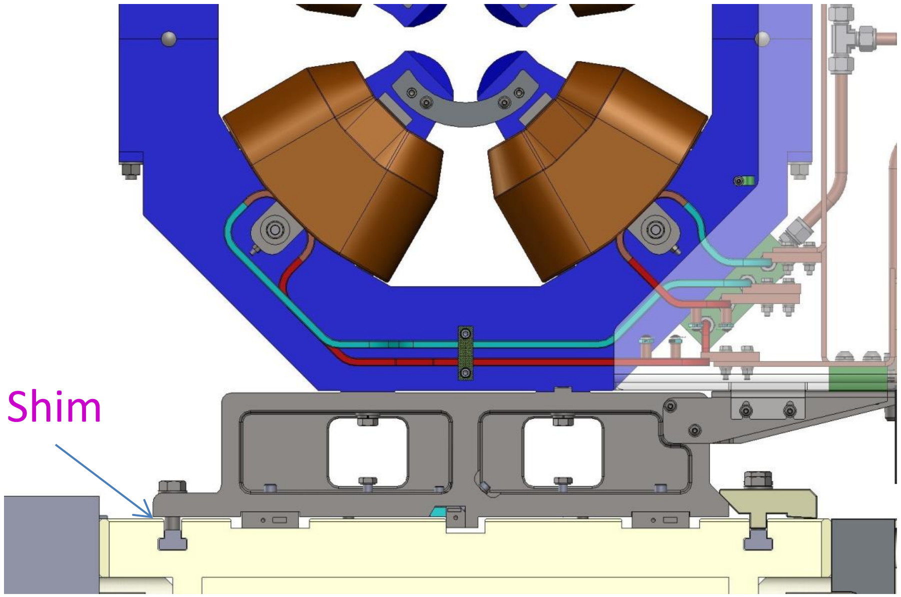


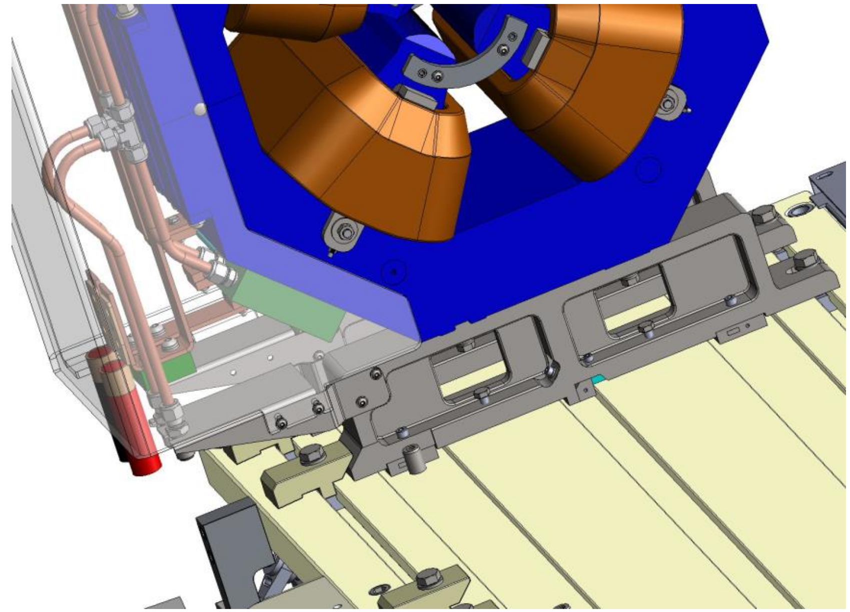
One girder system configuration



- More contact points with locking system to raise natural frequency and reduce deflection.
- All contact points persist rolling contact condition when adjusting to reduce friction and remain high mobility .
- Contact stress less than elastic limitation to reduce friction wear and keep high reliability

Magnets assembling on girder design

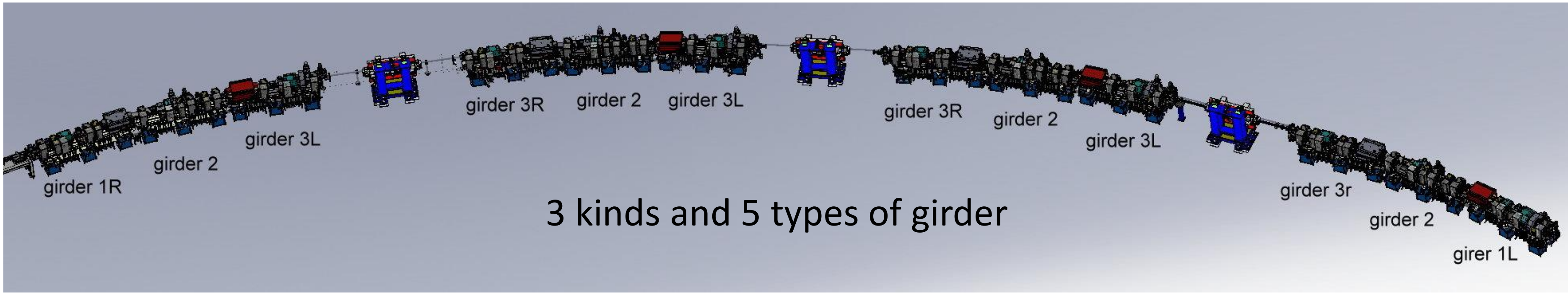




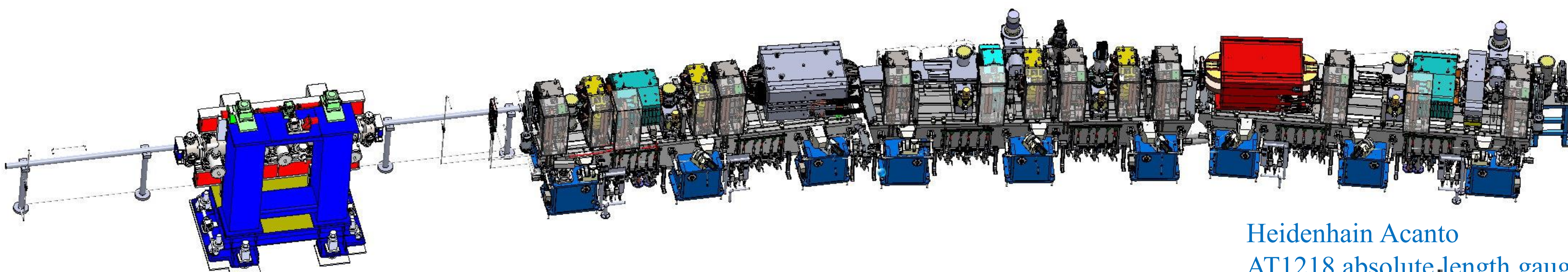
- 3 magnet installation referencing channels precisely machined within 15μm tolerance
- The magnet mounting base also precisely machined within 15μm tolerance ∗
- two side channels can keep the magnets on the same height with minimized rotation
- the mounting base will be pushed to closely touch the side of center channels with an inclined clamper
- The clamper produces a horizontal pushing force to make sure the magnet base contact with the certer reference channel
- The right screw for the clamper is locked with a constant 1400 kg.cm torque, while the left screw 1000 kg.cm (with a shim underneath)

∗ ***TUAD1, J. C. Jan, et al., "Magnet Design and Control of Field Quality for TPS Booster and Storage Ring", IPAC'15***.

TPS storage ring girder system design

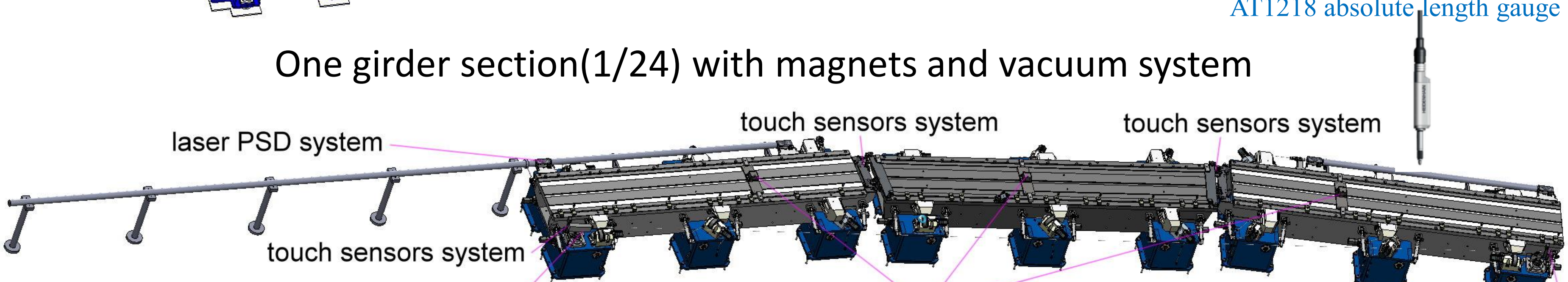


1/6 ring symmetry super-period configuration



Heidenhain Acanto
AT1218 absolute length gauge

One girder section(1/24) with magnets and vacuum system



No sensor for length measurement of straight section

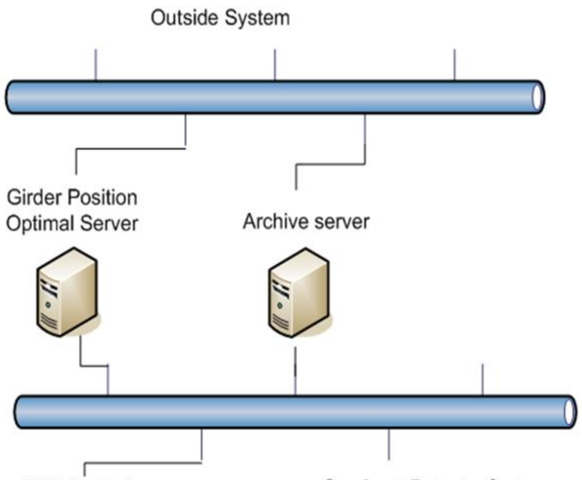
One girder section

Leica Nevil220 tilting sensors

Control system Architectures

- Each local control system controls 3 girders of a bending section.
- A NI PC-based PXI platform
- Consists of 6 sub-systems:

1. cam mover control(18)
2. rotational encoder (18)
3. touch sensor reading(16)
4. tilting sensor reading(3)
5. PSD reading(4)
6. locking control(18)



PXI Controller

Name	Quantity	Desciption
PXI Computer	1	Compute the argrthm of girders
RS232 Port	1	Read data from Nivel 220
Encoder Card	4	Read Endata 2.2 signals of rotary and linear encoders
Digital I/O Card	2	For limit switches
Motion Card	1	Control Stepping Motor

Quadrant Detector System

Name	Quantity	Desciption
Sever	2	Operation System
Quadrant Detector card	2	Read the voltage of a quadrant detector

Total quantity of local side computers is 24

** H.S. Wang et al, "Design and testing of a girder control system at NSRRC", ICALEPCS(2011)*

Features of the girder system

1. Precisely grinding reference channel Δ_{max} < 15μm/4m
2. 6 supporting point → 6 DOF adjustment
3. Line contact cam mover → Heavy load (16 tons)
4. Stepping motor with harmonic gearbox → submicron step
5. Damper + locking system → Higher NF and stability
6. Hard-stop → motion and earthquake security
7. Sensors system → auto–alignment and deviation monitor

Manufacturing inspection

Girder welding

Preliminary machining

Reference plane grinding

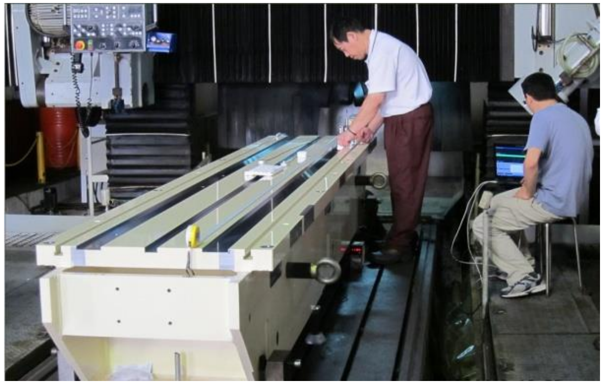
Pedestal welding toolkit

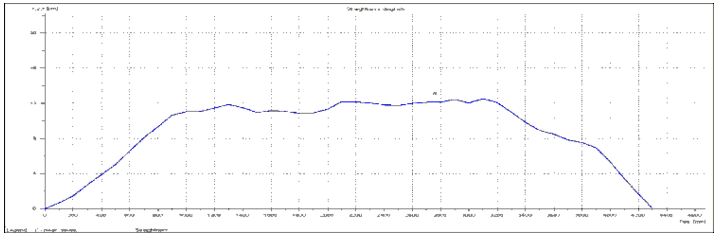
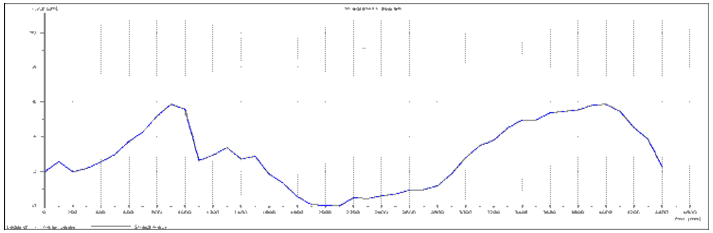
Welding inspection

Pre-measurement

Fully annealing after welding and the girders were vibrated for stress release after preliminary machining

Girder measurement and assembly at the rental plant



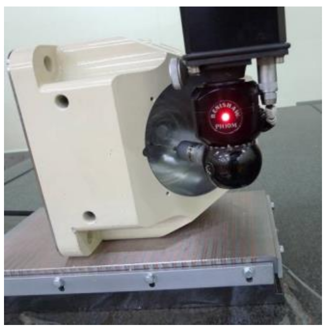


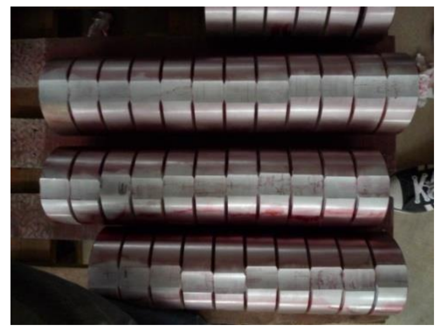
- All the girders are examined by using laser interferometer, autocollimator and laser tracker
- Straightness measurement of assembling reference channel on each girder is around 8~15μm
- The deviation of the ball center of transfer unit is less than 0.3mm

Pedestal and manufacturing parts measurement and assembly








- All components were measured with CMM stage and arms, laser tracker and precision gages to make sure within spec before assembling.
- The movers also being performed with life cycling test

Control system assembly





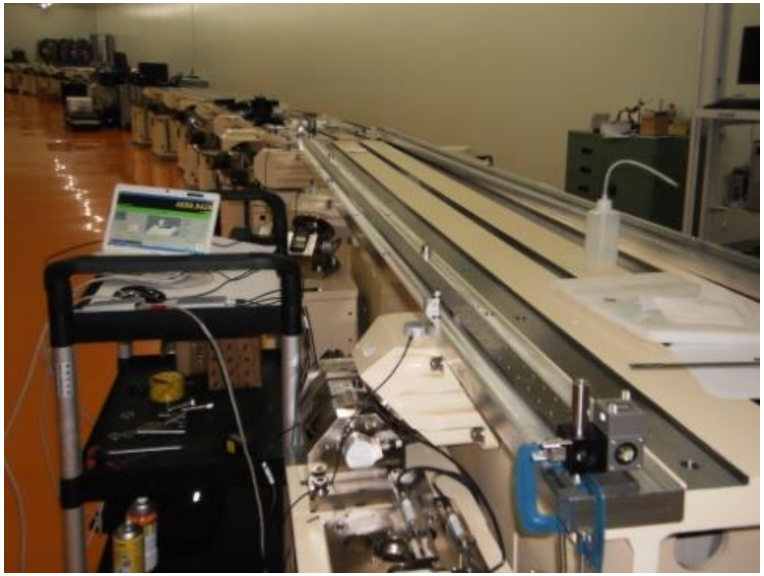
NI controller Delivered and assembled into the Racks

Including: mover motors and locking system controller
all the sensor's interfaces
vibration monitoring system
i/o with the ring control system

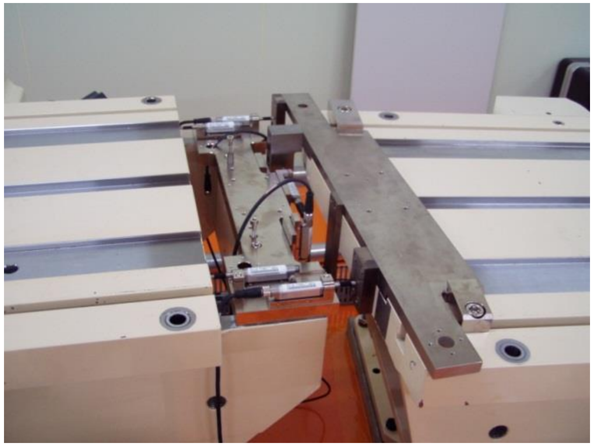
Girder system assembling processes

- **Almost all components have been delivered and sub-assembled then the girder with sensors system assembly start.**
- **The procedures include:**

1. Measure distances between reference holes on one girder with a laser interferometer
2. Measure distances between reference holes on adjacent girders with a encoder rule
3. Touch sensor module assembling
4. PSD module assembling, partially auto-alignment processing and sensor's data acquisition

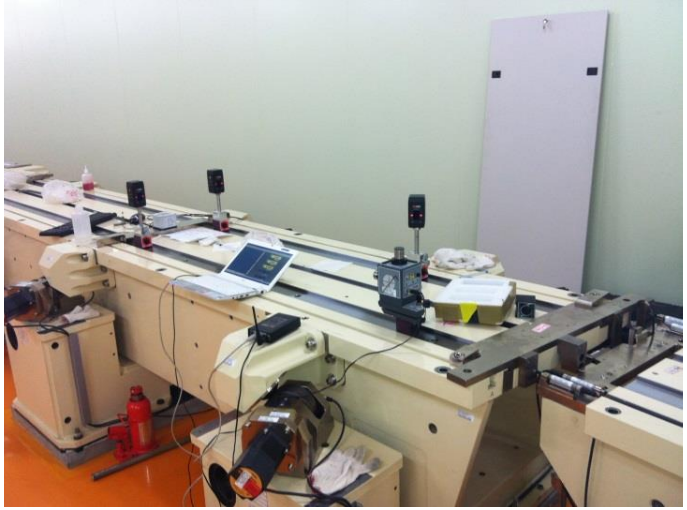


Inflatable mandrel



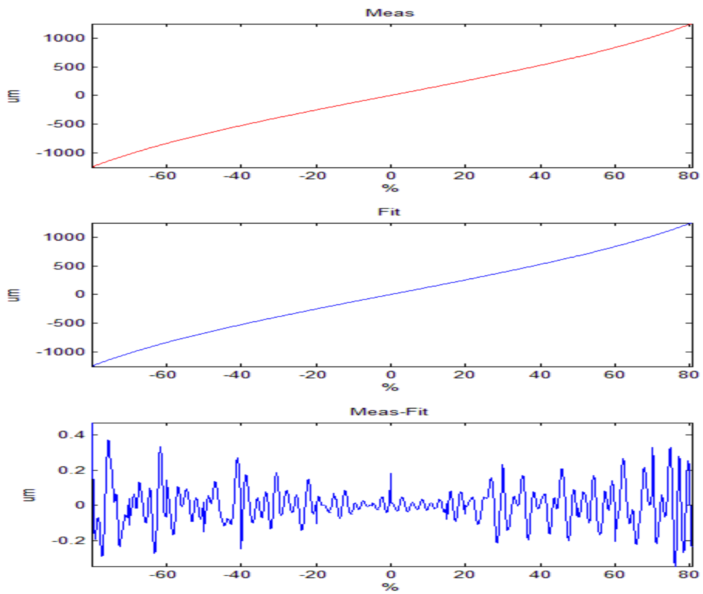
Sensors calibration at the rental plant



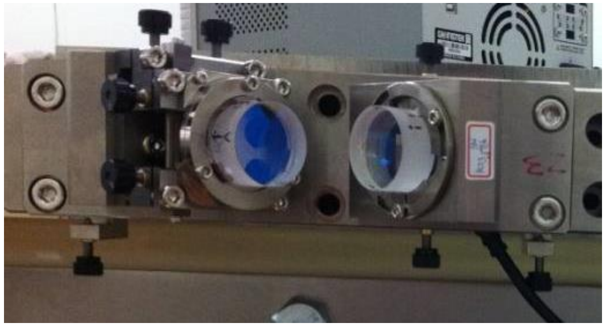



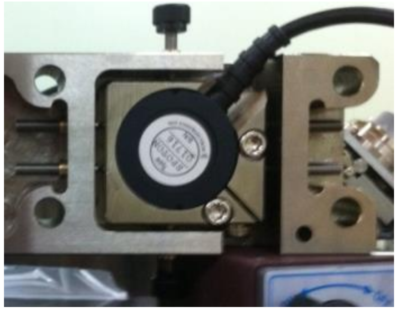
- With a levelling laser(harmmar laser) to level the adjacent girders, calibrating the electronic levelling (Nivel 220)to ±5urad and touch sensors to 5um

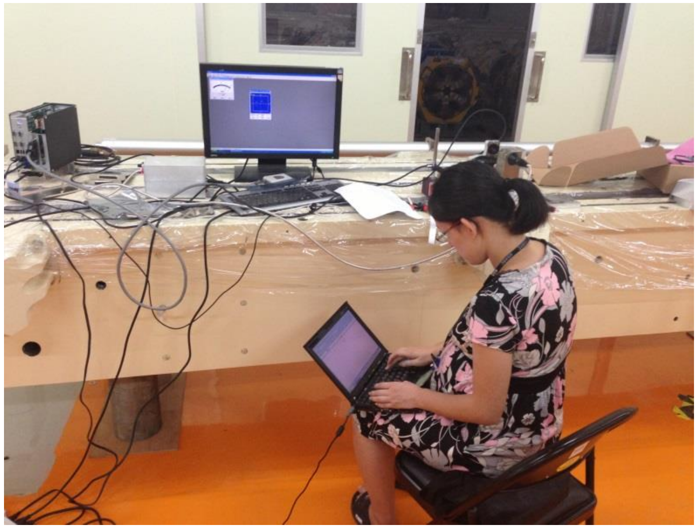
Laser positioning system part measurement

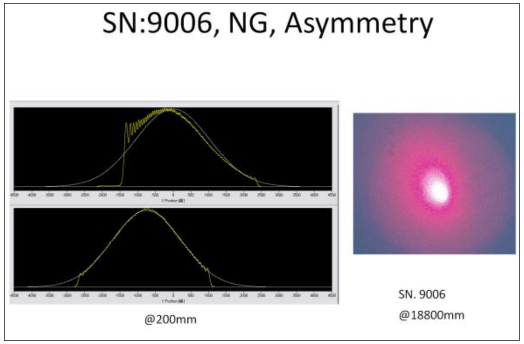


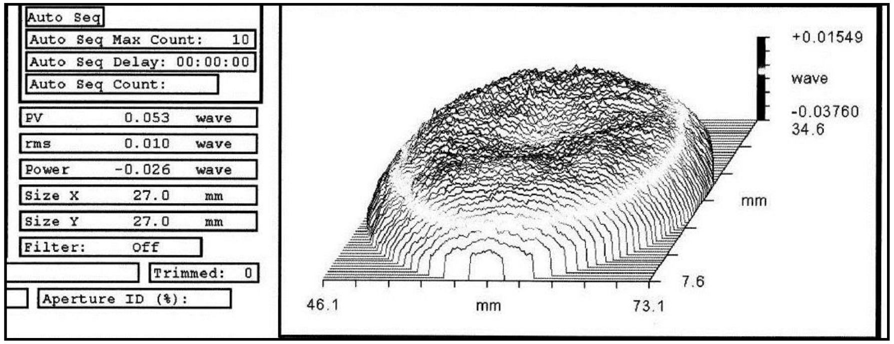
Laser Beam profile curve fitting





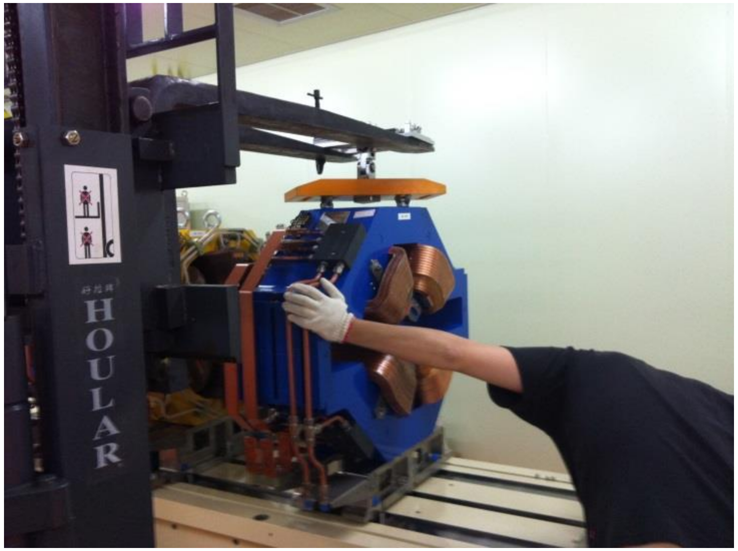






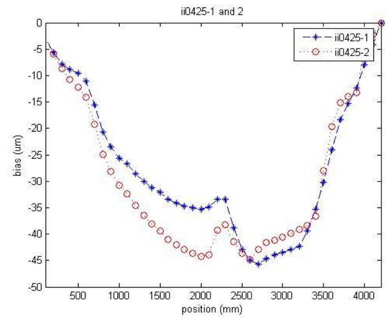
Magnets assembly

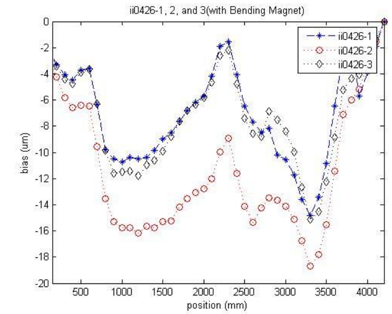


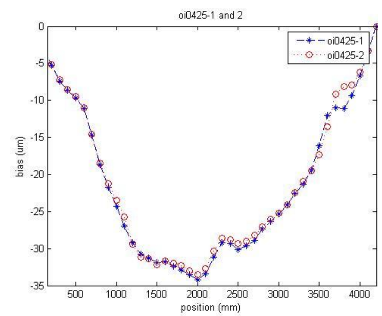


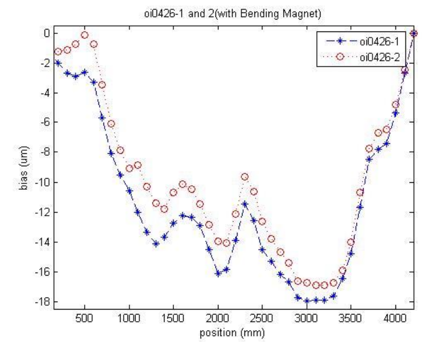
Transportation and assembling platform with aircushion was design and applied

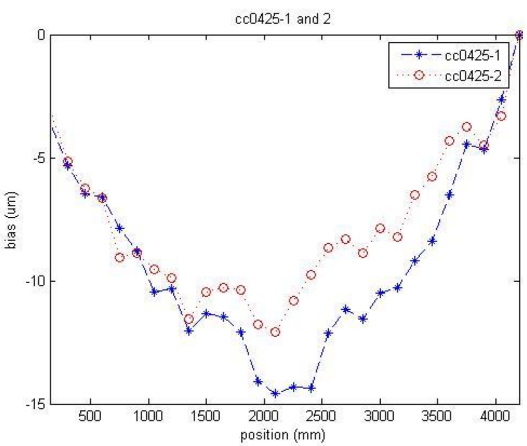
Girder flatness measurement after magnets assembled

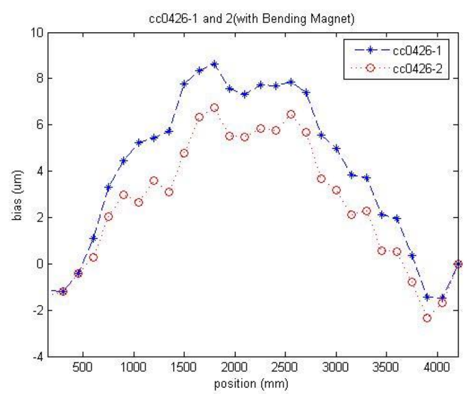










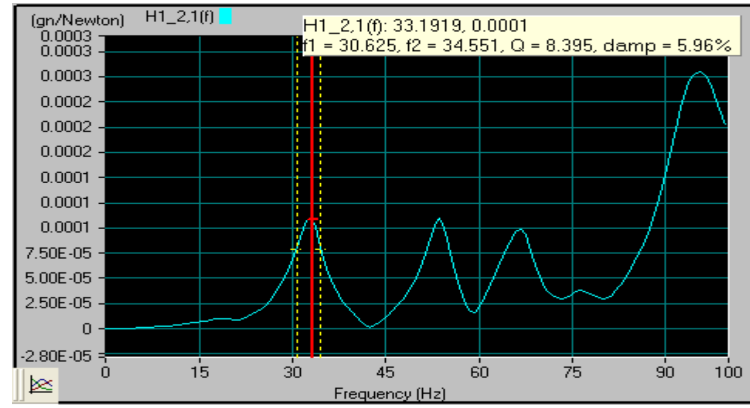


With dipole mag. Max.:18um

Without dipole mag. Max.:45um

Natural Frequency and damping testing of the mock-up system at the rental plant

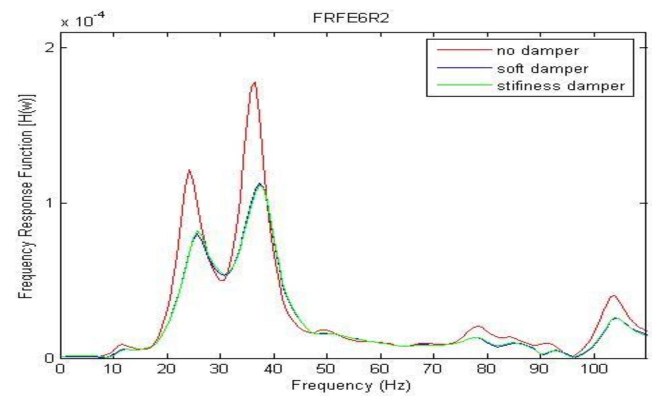
One girder section was installed with dampers and locking system for testing



The 1st NF can be raised from 24Hz to 33 Hz with locking mechanisms

	pedestal (x 10^{-5} mm)	ground (x 10-5 mm)	
	4~100Hz	4~100Hz	AMP
w/o damping X	5.85	5.52	1.060
Soft damping X	7.86	8.67	0.907
stiff damping X	6.78	6.78	1.000
w/o damping Y	6.71	6.68	1.004
stiff damping Y	6.95	7.64	0.910
Soft damping Y	8.23	8.26	0.996

Amplification with damper

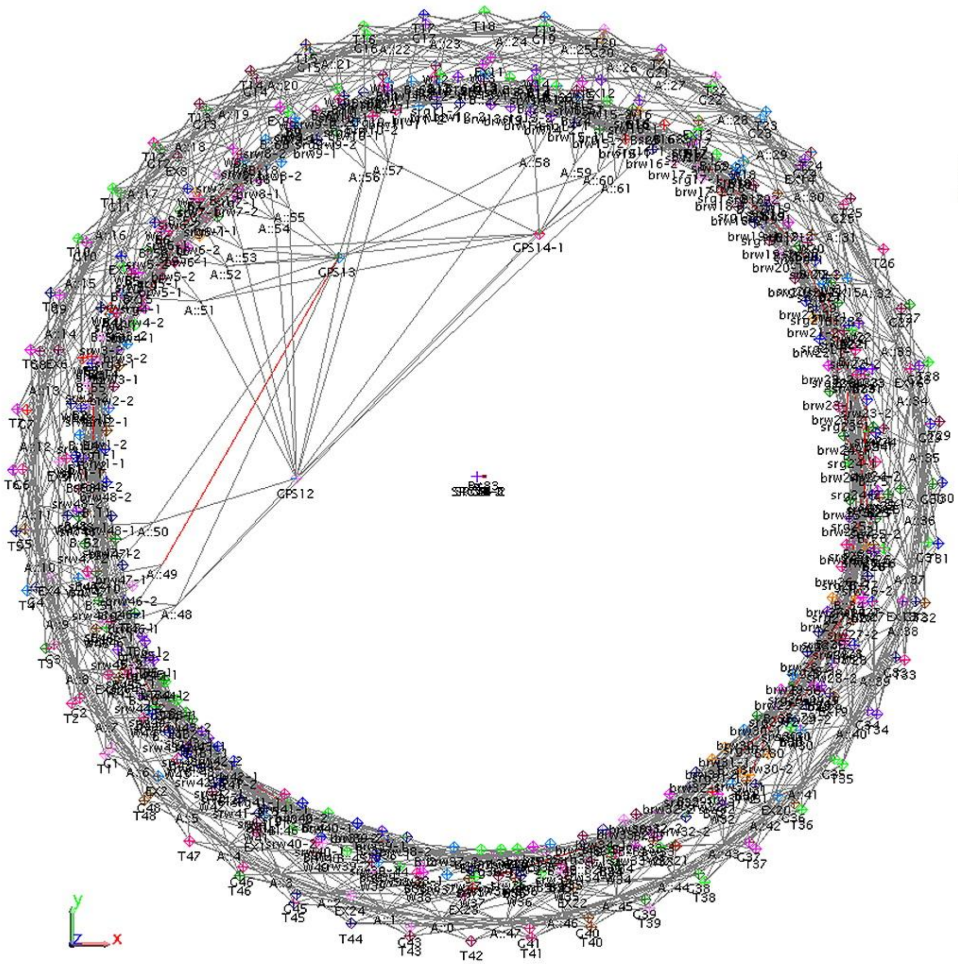


The Peak amplitude is reduced with dampers

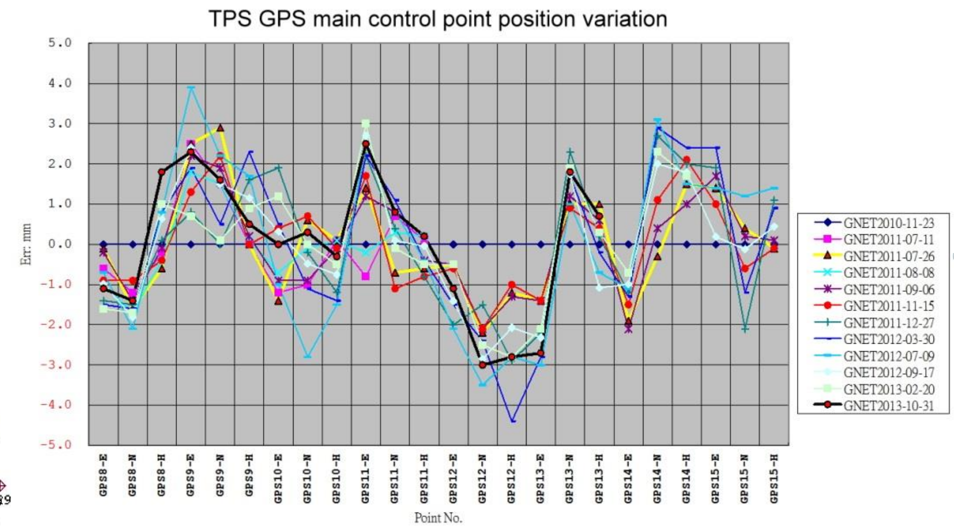
Girder with magnets package

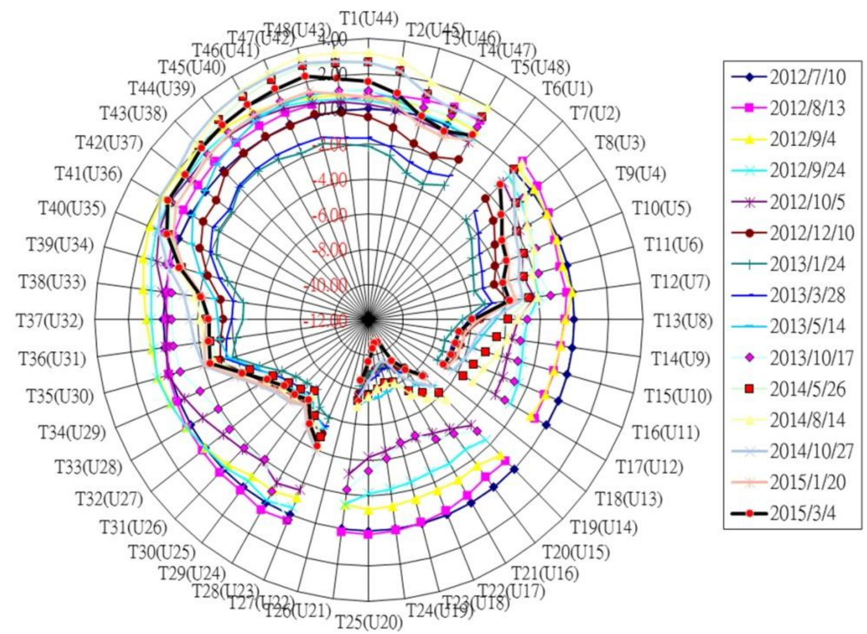
Another transportation platform with aircushion was design and applied

Survey data accumulation



Survey network implementation

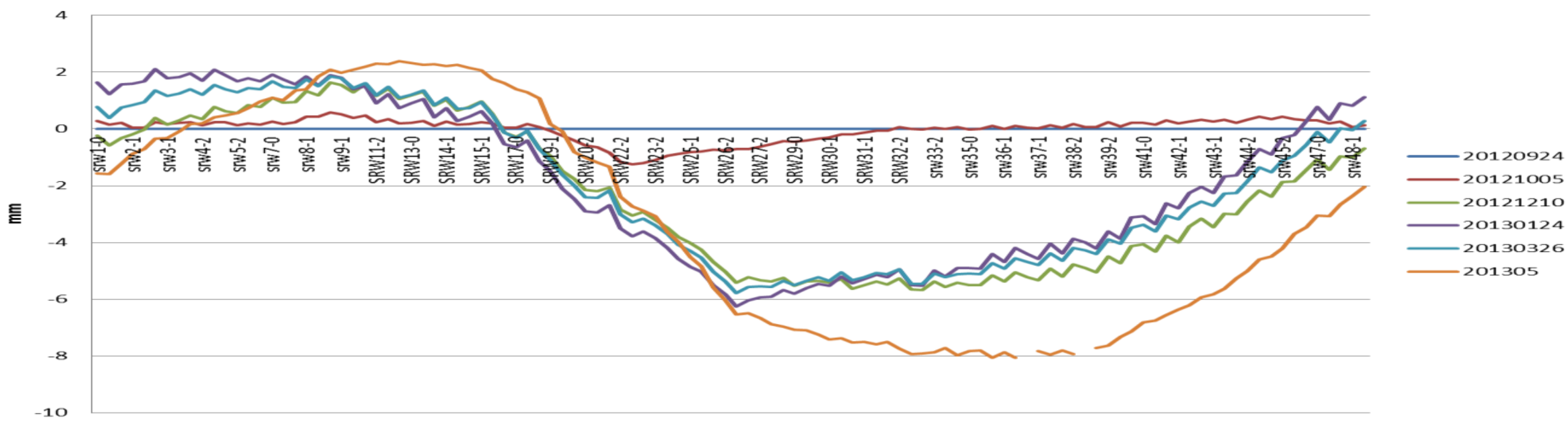




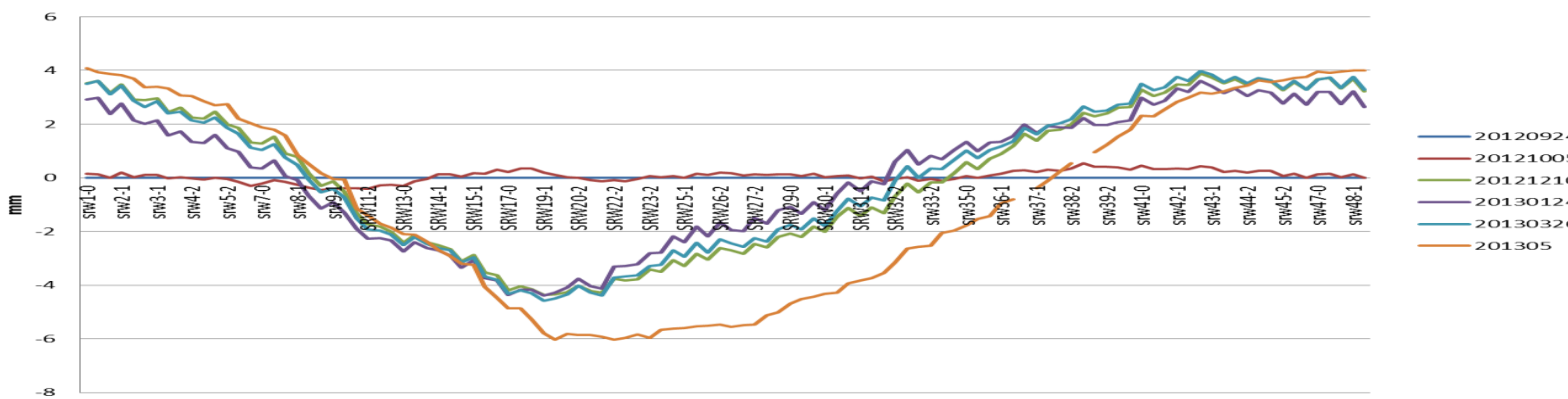
** WEPHA044, W.Y. Lai et al., "ALIGNMENT (SURVEY) DESIGN AND STATUS OF TAIWAN PHOTON SOURCE" IPAC'15*

TPS tunnel variation during 2012~2013

Shielding wall (x dir.)

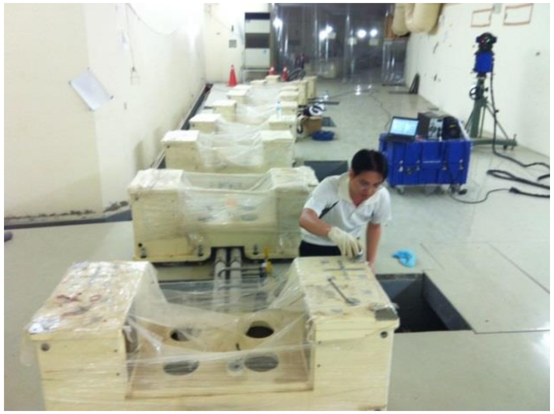


Shielding wall (y dir.)



With the survey data from the sockets at tunnel walls, a small displacement of (-3,-1) and rotation of 0.0021 degree (about 5mm at lattice position) clockwise of the virtual center were derived and a coordinate values adjustment of all components were decided accordingly.

Pedestal set out, anchor bolts implanting, alignment ,grouting and cam movers installation



Started from Jan. 2013

Transportation of girders with magnets to TPS





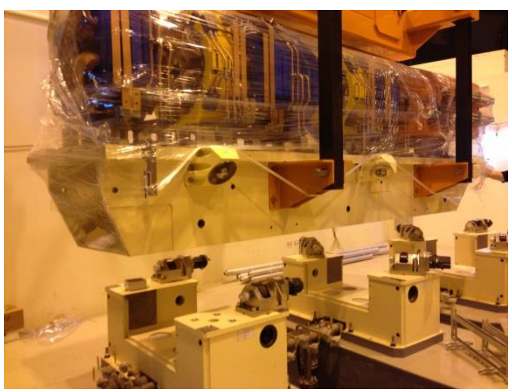



Lifting and installation girders



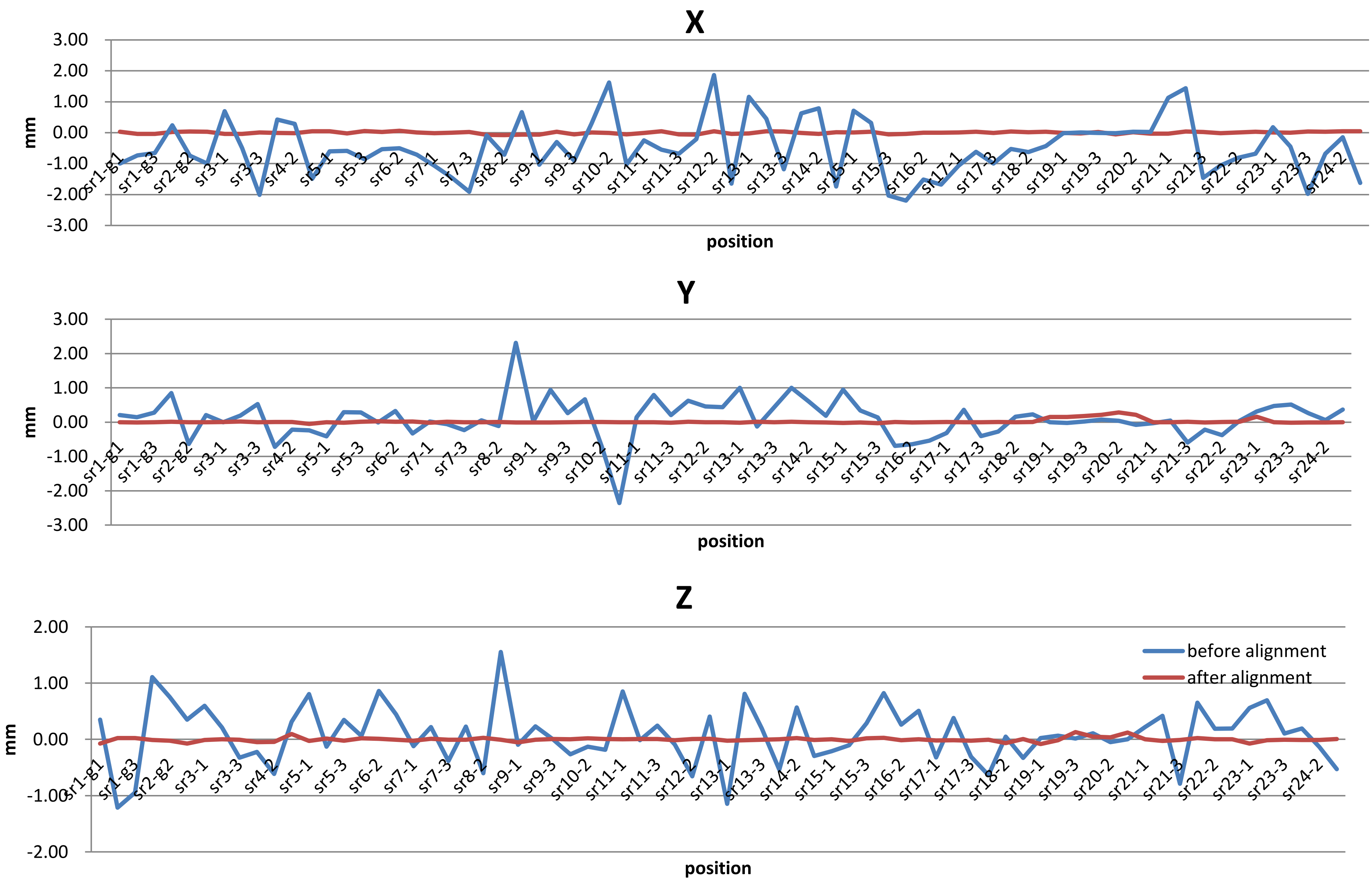




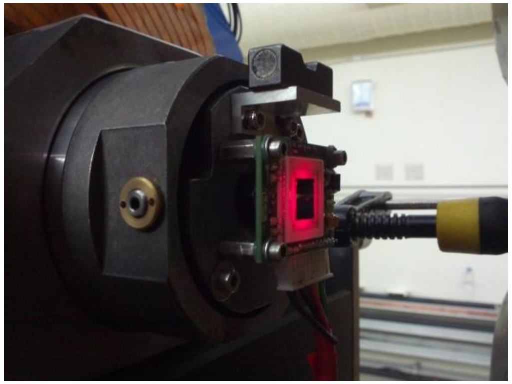
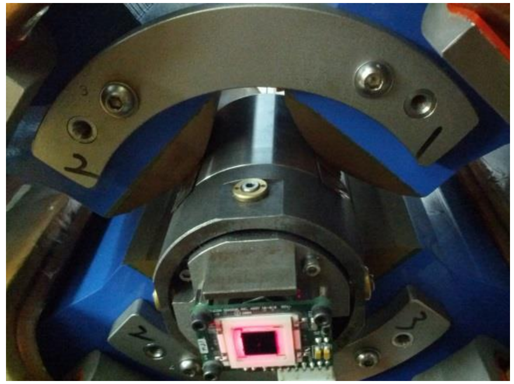


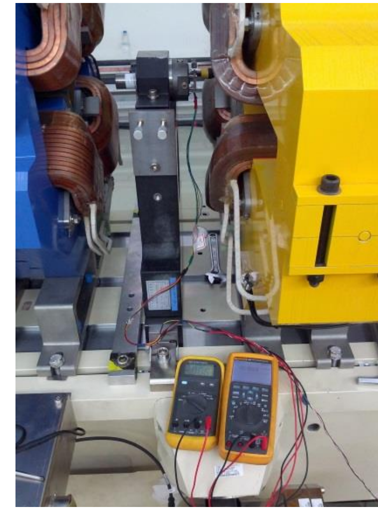
It spends about 40 min to an hour to install a girder

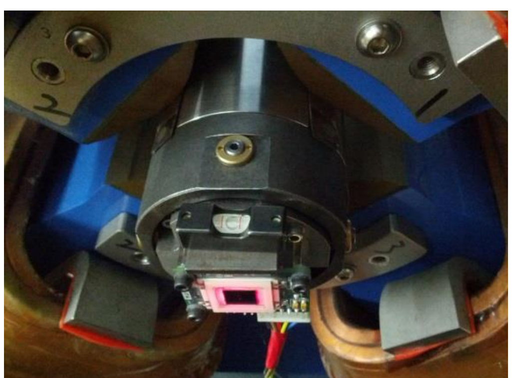
Girder installation deviations



Magnet centralizing

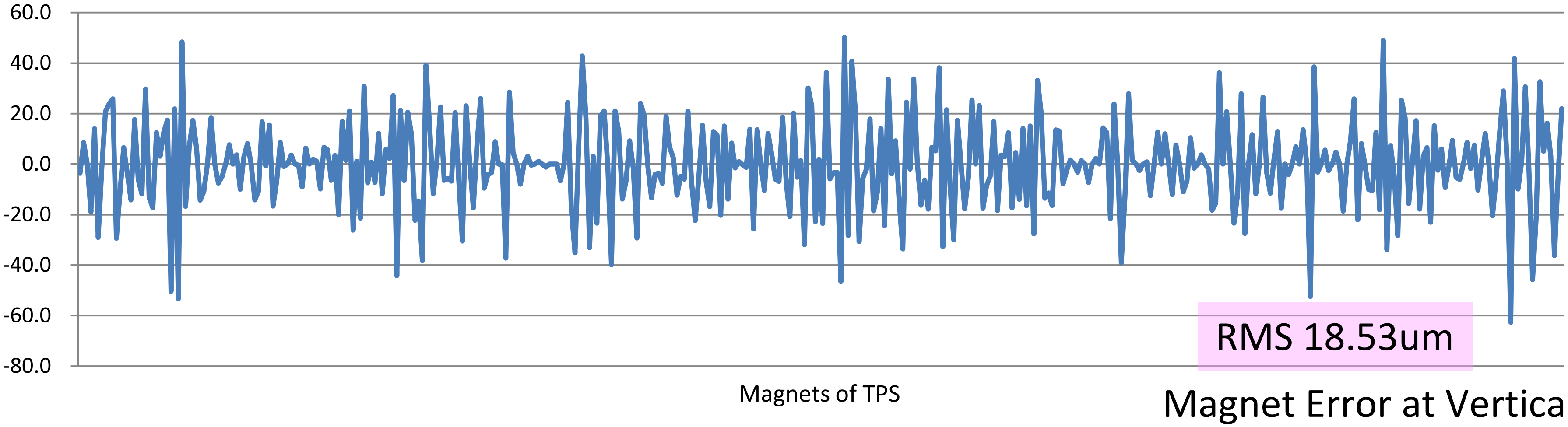



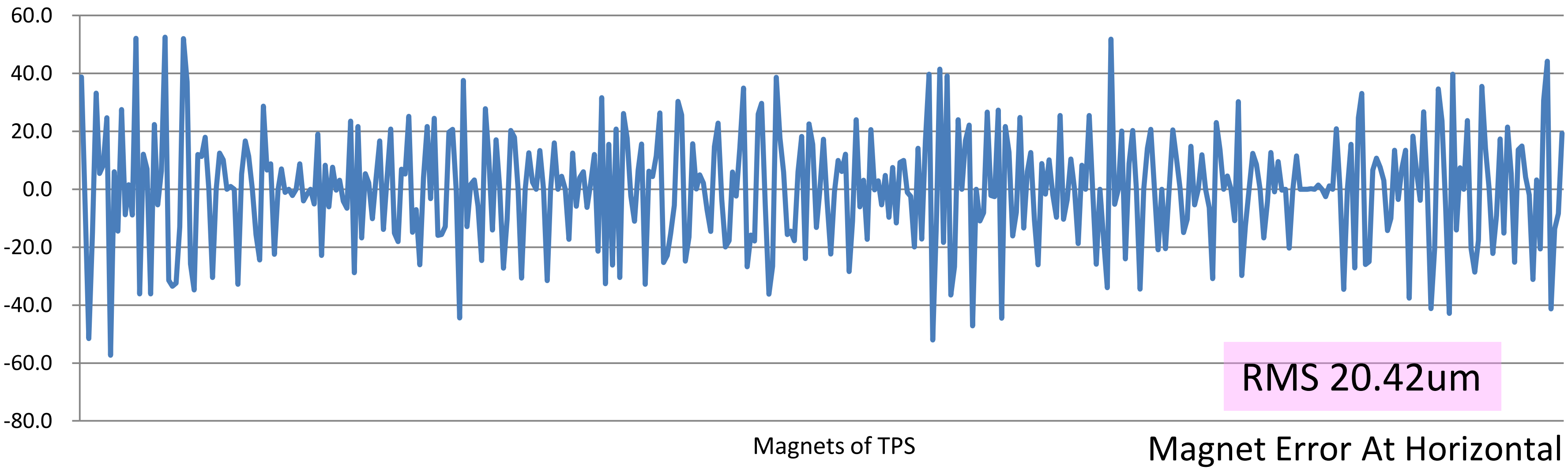



- Adjust Position Jig and Circular PSD jig
- Install two position jigs with PSD on girder
- Adjust laser to parallel and have equidistance to girder datum plane
- Replace the Position jig with the quadrupole and sextupole magnets
- Insert Circular PSD jig on the center of quadrupole and sextupole magnets
- The offset of beam position can be detected by PSD
- Insert the steel shims between magnet and girder for error compensation

Magnet Centralizing Results





Most magnets were acceptable but a few were still shimmed after double checked

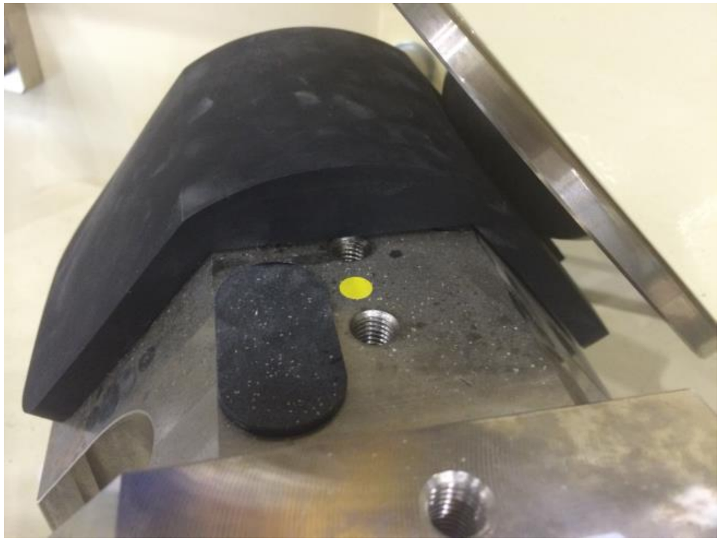
Girder system completed installation

- In May 2013, 2 mockup sections (R19 and R20) were installed at storage ring.
- The full ring installation processes began from Oct. 2013 and the last girder was finished installation at March 2014.

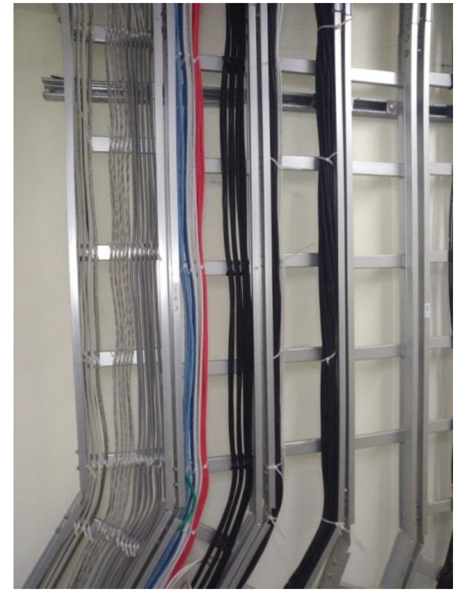
Hard stop, Locking system and damper assembling





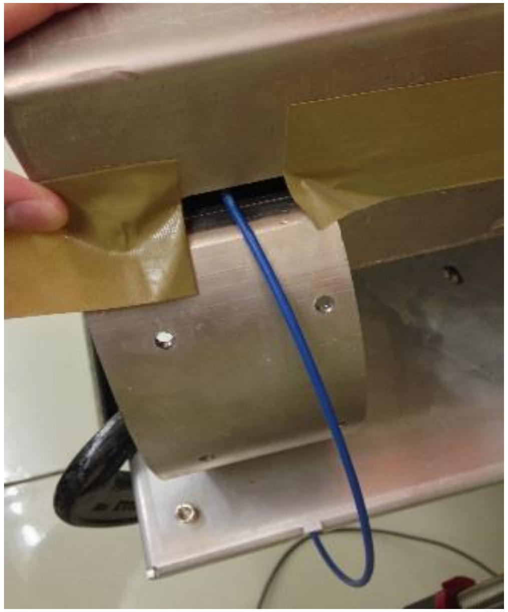



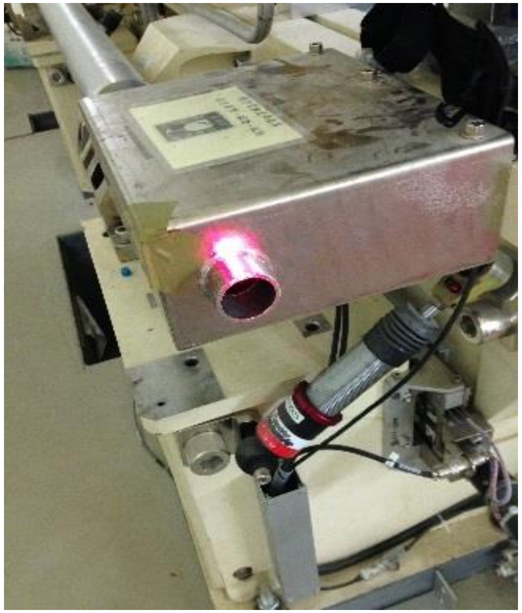
Control rack installation and wiring



Control system problems encountered

- Motor malfunction → check and changed
- Touch sensor or connector damaged → check and changed
- Touch sensor signal direction inversed → check and adjusted
- Laser optical fiber damaged → check and changed
- Laser holder being moved → check and adjusted
- PSD module holder replaced (conflicted with frontend)



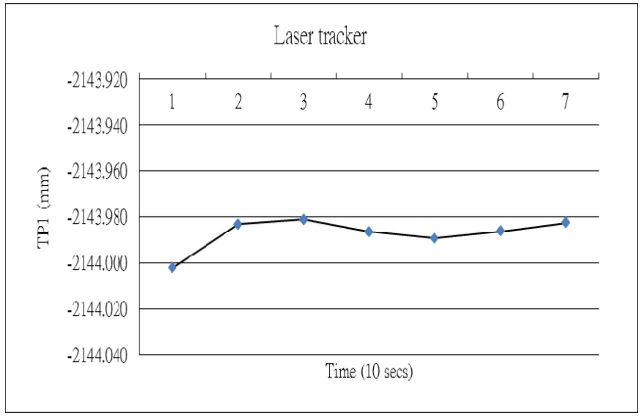


＊ *MOPTY079, M.L. Chen, et al., "THE INSTALLATION AND OPERATION OF TPS LASER PSD SYSTEM IN TPS STORAGE RING", IPAC'15*.

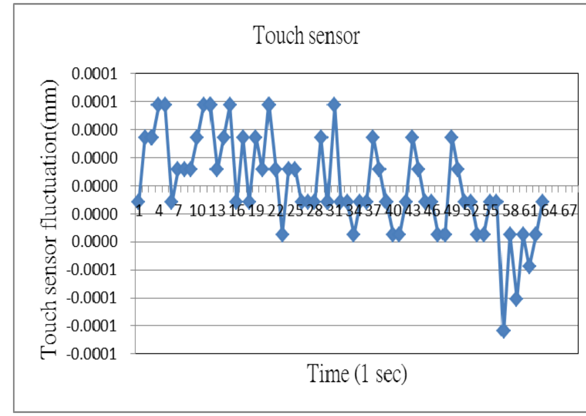
Sensor stability check in 1 minute

All the sensor reading will be accumulated within 1 minute in each iteration

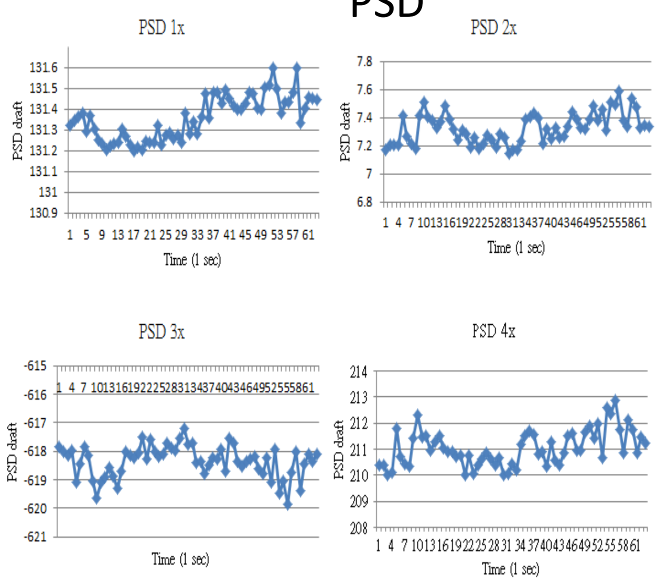
Laser Tracker



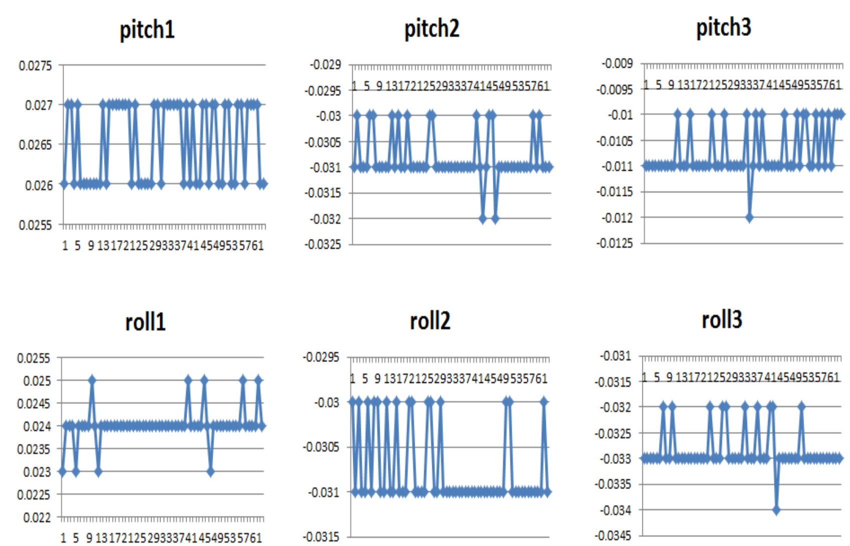
Touch Sensor



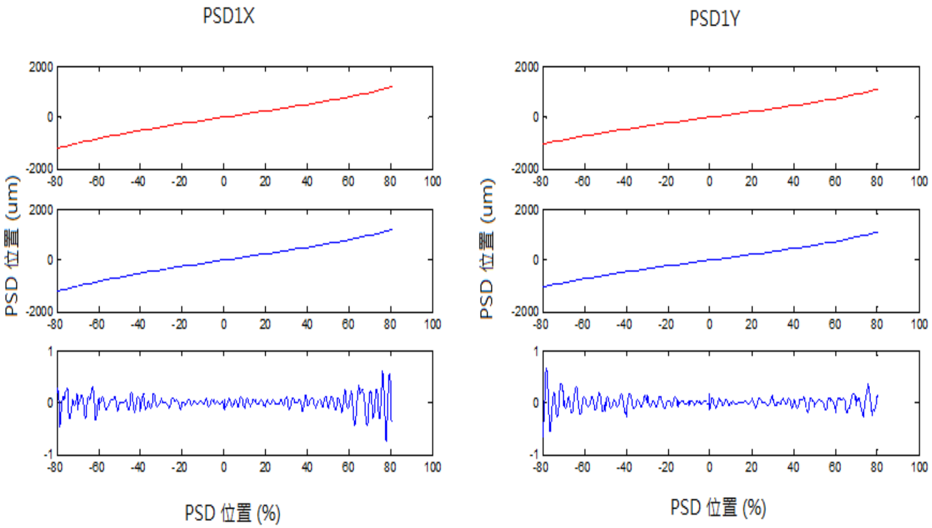
PSD



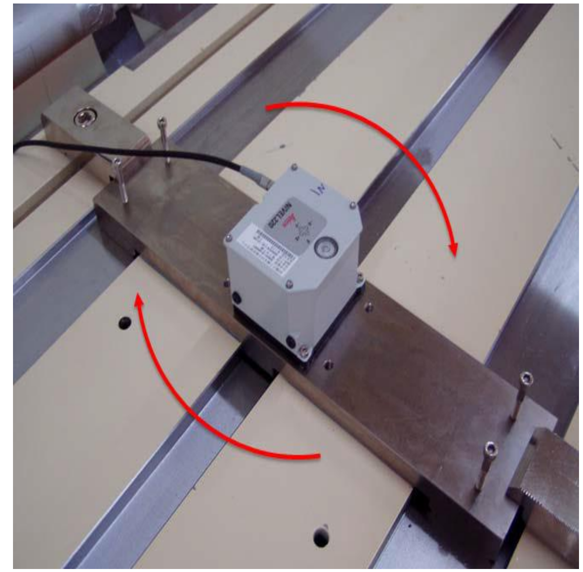
Nivel

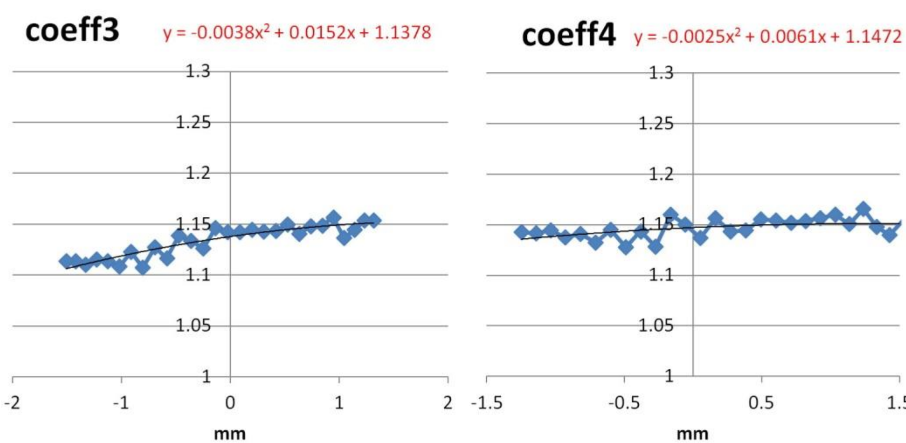


Auto-alignment system calibration



PSD beam profile curve fitting





PSD to linear encoder curve fitting

$$p\_offset = \frac{p1 + p2}{2}$$

$$r\_offset = \frac{r1 + r2}{2}$$

Nivel 220 calibration

The data base for auto-alignment

- Linear encoder distance measurement data between 2 adjacent girders
- Girder reference point distance measurement data with a laser interferometer
- Laser interferometer distance measurement data compensation chart
- Linear encoder distance measurement data compensation chart
- PSD beam profile curve fitting
- PSD1 / PSD2 coefficient calibration
- PSD to linear encoder calibration

PSD_touch表-lai cl

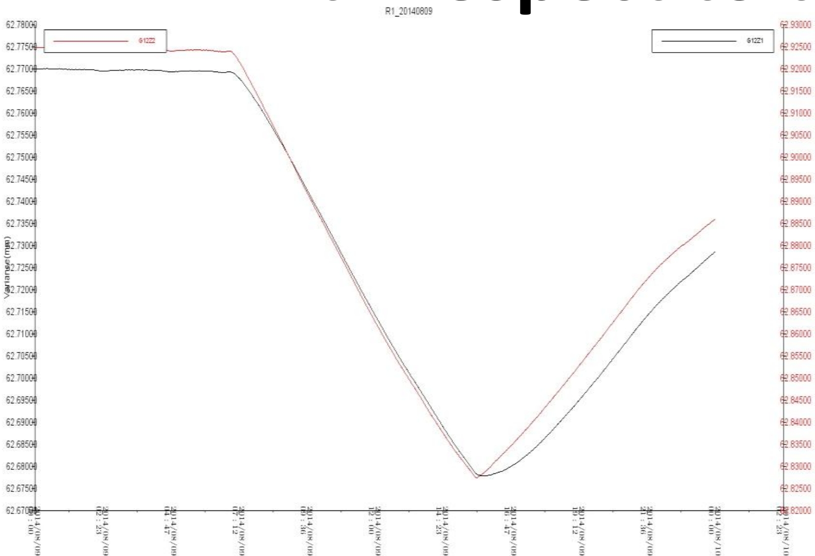
檔案 常用 插入 版面配置 公式 資料 校閱 檢視

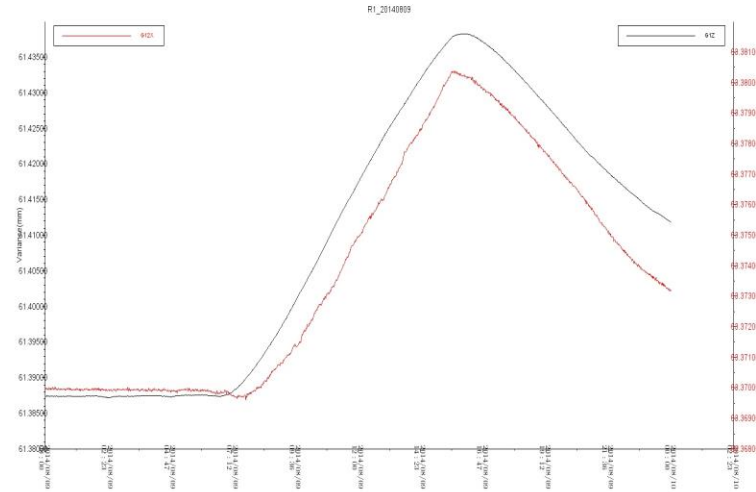
受保護的檢視 小心，來自於網際網路的檔案可能有病毒，除非您需要編輯，否則停留在 [受保護的檢視] 中較為安全。 啟用編輯(E)

D31

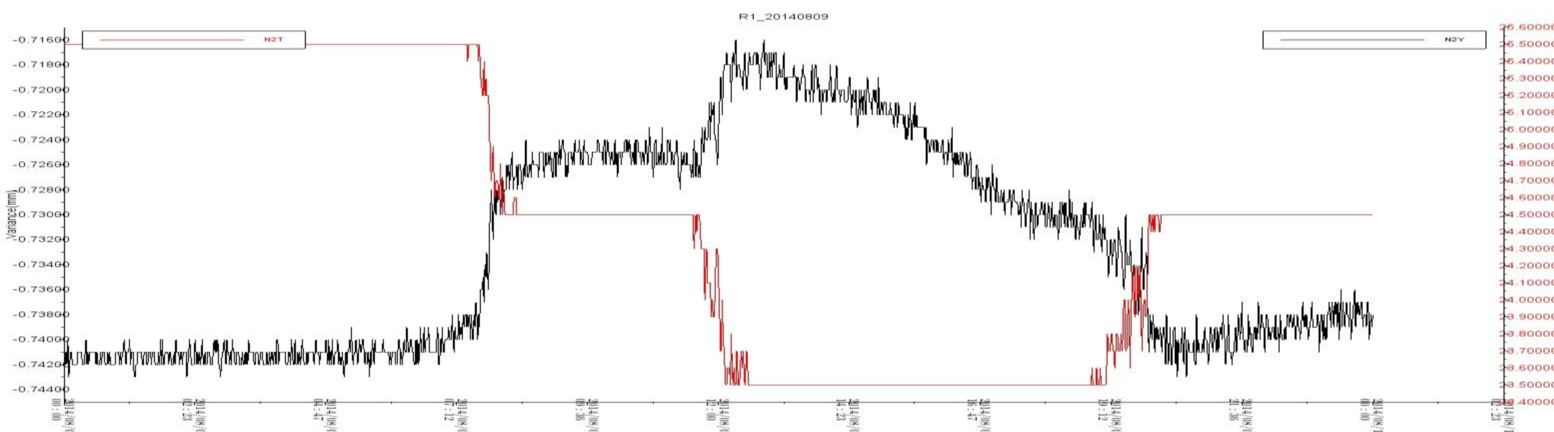
	A	B	C	D	E
1	竹東編號	DET3X	DET4X	DET3Y	DET4Y
2	R1R2	$y = -0.0005x^2 + 6E-15x + 1.0505$	$y = -0.0003x^2 - 7E-15x + 1.2093$	$y = -0.0046x^2 + 0.0046x + 1.0785$	$y = 0.0025x^2 - 0.0021x + 1.0863$
3	R2R3	$y = -0.0065x^2 + 0.0051x + 1.2076$	$y = 0.0029x^2 + 0.0044x + 1.2511$	$y = -0.0048x^2 + 0.0065x + 1.0777$	$y = -0.003x2 + 0.001x + 1.0913$
4	R3R4	$y = -0.0058x^2 - 0.0098x + 1.0275$	$y = 0.0165x^2 + 0.0804x + 1.2191$	$y = -0.0048x^2 + 0.0089x + 1.0697$	$y = 0.022x^2 - 0.0556x + 1.1119$
5	R4R5	$y = 0.0017x^2 - 0.0064x + 1.0785$	$y = 0.0007x^2 + 0.0075x + 1.1556$	$y = 0.0042x^2 - 0.0014x + 1.0686$	$y = 0.0083x^2 + 0.0035x + 1.1336$
6	R5R6	$y = -0.0014x^2 + 0.021x + 1.0306$	$y = -0.011x^2 + 0.0614x + 1.1027$	$y = 0.0237x^2 + 0.0135x + 1.1268$	$y = 0.0342x^2 + 0.008x + 1.1126$
7	R6R7	$y = -0.0096x^2 + 0.0029x + 1.1482$	$y = 0.0064x^2 + 0.0019x + 1.1908$	$y = -0.0038x^2 + 0.0152x + 1.1378$	$y = -0.0025x^2 + 0.0061x + 1.1472$
8	R7R8	$y = -0.0069x^2 - 0.008x + 1.131$	$y = 0.0024x^2 + 6E-05x + 1.1372$	$y = -0.005x^2 - 0.0183x + 1.1991$	$y = 0.0025x^2 - 0.0049x + 1.0807$
9	R8R9	$y = 0.0064x^2 + 0.0044x + 1.2003$	$y = 0.008x^2 - 0.0052x + 1.3461$	$y = 0.0099x^2 - 0.0124x + 1.0919$	$y = 0.0199x^2 - 0.0353x + 1.2362$
10	R9R10	$y = -0.0196x^2 + 0.0357x + 0.9229$	$y = 0.0307x^2 - 0.055x + 0.8778$	$y = 0.0059x^2 + 0.0175x + 1.0137$	$y = 0.0262x^2 - 0.0082x + 1.0576$
11	R10R11	$y = -0.0072x^2 + 0.0023x + 1.1951$	$y = 0.0032x^2 + 0.0057x + 1.2363$	$y = -0.0023x2 - 0.0013x + 1.0649$	$y = 0.0088x2 - 0.0219x + 1.1163$
12	R11R12	$y = -0.0051x^2 + 0.018x + 1.1665$	$y = 0.0025x^2 + 0.0055x + 1.2142$	$y = -0.008x^2 + 0.0005x + 1.1159$	$y = -0.0011x^2 + 0.0013x + 1.0926$
13	R12R13	$y = 0.0015x^2 - 0.0004x + 1.0925$	$y = 0.0025x^2 + 0.0072x + 1.1243$	$y = 0.0031x^2 - 0.0034x + 1.0482$	$y = 0.0082x^2 + 0.0005x + 1.056$
14	R13R14	$y = -0.0045x^2 - 0.0114x + 1.1477$	$y = -0.0024x^2 - 0.006x + 1.2164$	$y = -0.0063x^2 - 0.0064x + 1.0481$	$y = -0.0012x^2 - 0.0043x + 1.1006$
15	R14R15	$y = -0.0054x^2 + 0.0095x + 1.0825$	$y = 0.0001x^2 + 0.0091x + 1.1918$	$y = -0.0036x^2 + 0.0183x + 1.237$	$y = 0.0021x^2 + 0.0196x + 1.3725$
16	R15R16	$y = -0.0034x^2 - 0.0055x + 1.088$	$y = 0.0053x^2 + 0.0074x + 1.3298$	$y = -0.0025x^2 + 0.0009x + 0.9909$	$y = 0.0073x^2 - 0.0114x + 1.1255$
17	R16R17	$y = 0.0055x^2 - 0.0073x + 1.0865$	$y = 0.0059x^2 - 0.0008x + 1.1296$	$y = 0.0027x^2 - 0.0014x + 1.0487$	$y = 0.0086x^2 + 0.0014x + 1.0752$
18	R17R18	$y = -0.0078x^2 - 0.0025x + 1.1921$	$y = -0.0029x^2 - 0.0072x + 1.2578$	$y = -0.007x^2 - 0.0004x + 1.0685$	$y = -0.0072x^2 + 0.0016x + 1.1197$
19	R18R19	$y = -0.0061x^2 + 0.0002x + 1.0475$	$y = -0.001x^2 + 0.0045x + 1.0924$	$y = -0.0088x^2 + 0.007x + 1.0527$	$y = -0.0112x^2 + 0.0049x + 1.0668$
20	R19R20	$y = -0.008x^2 + 0.003x + 1.2338$	$y = 0.0016x^2 - 0.0057x + 1.3956$	$y = -0.0058x^2 - 0.0006x + 1.0945$	$y = 0.001x^2 + 0.0053x + 1.1825$
21	R20R21	$y = 0.0054x^2 - 0.0012x + 1.0922$	$y = 0.0097x^2 + 0.0063x + 1.1778$	$y = 0.004x^2 - 4E-05x + 1.0623$	$y = 0.0049x^2 + 0.0081x + 1.1665$
22	R21R22	$y = -0.0104x^2 - 0.0029x + 1.2112$	$y = -0.0018x^2 + 0.0047x + 1.2652$	$y = -0.0031x^2 + 0.0005x + 1.0629$	$y = 0.0028x^2 - 0.0032x + 1.1094$
23	R22R23	$y = 0.0006x^2 - 0.0063x + 1.1553$	$y = 0.0062x^2 + 0.0026x + 1.4093$	$y = 0.0031x^2 + 0.0043x + 0.9865$	$y = 0.0066x^2 - 0.035x + 1.1449$
24	R23R24	$y = -0.0052x^2 - 0.0048x + 1.1501$	$y = -0.0006x^2 - 0.0104x + 1.2192$	$y = -0.0067x^2 + 0.0037x + 1.0929$	$y = -0.0015x^2 + 0.0048x + 1.1097$
25	R24R1	$y = 0.0036x^2 - 0.0014x + 1.0926$	$y = 0.0108x^2 + 0.0025x + 1.1193$	$y = 0.0037x^2 - 0.0014x + 1.0925$	$y = 0.0101x^2 + 0.0015x + 1.1195$

Girder sensor reading variations with respect to temperature change

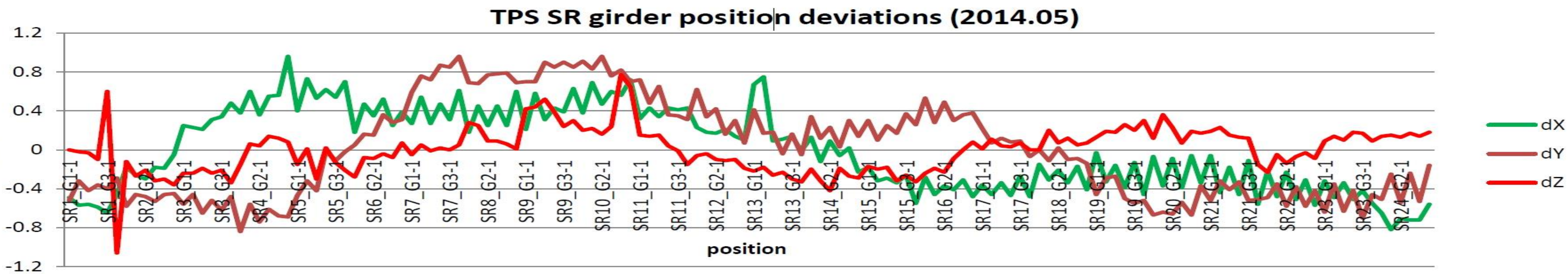




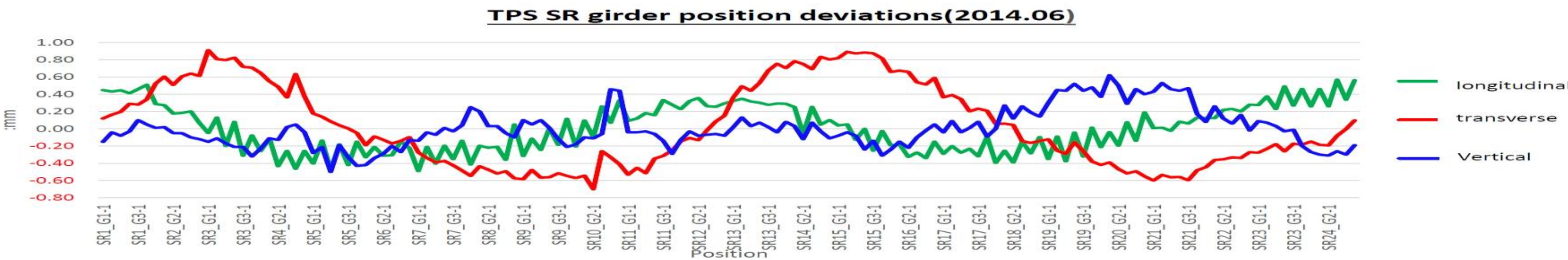
1℃ in temperature change induces 0.1mm deviation between girders



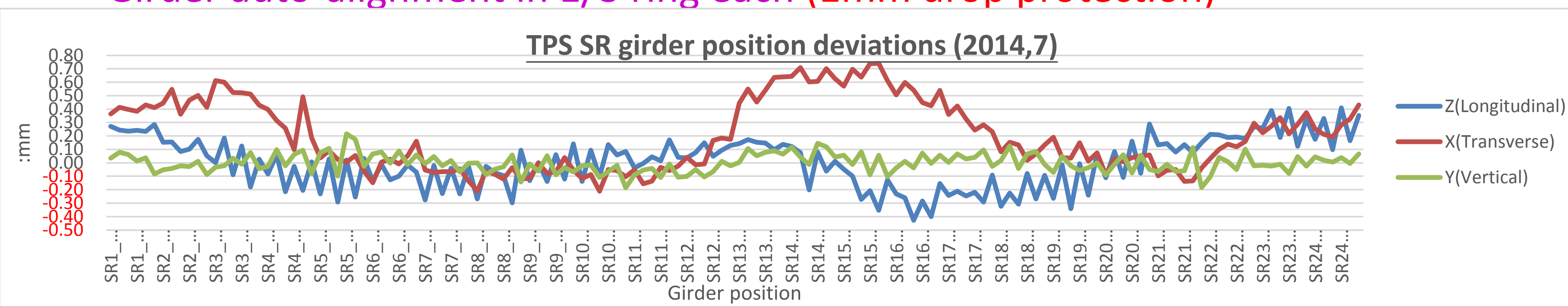
Laser tracker measurement data



Girder adjusting individually with a laser tracker (a few motor failures encontered)

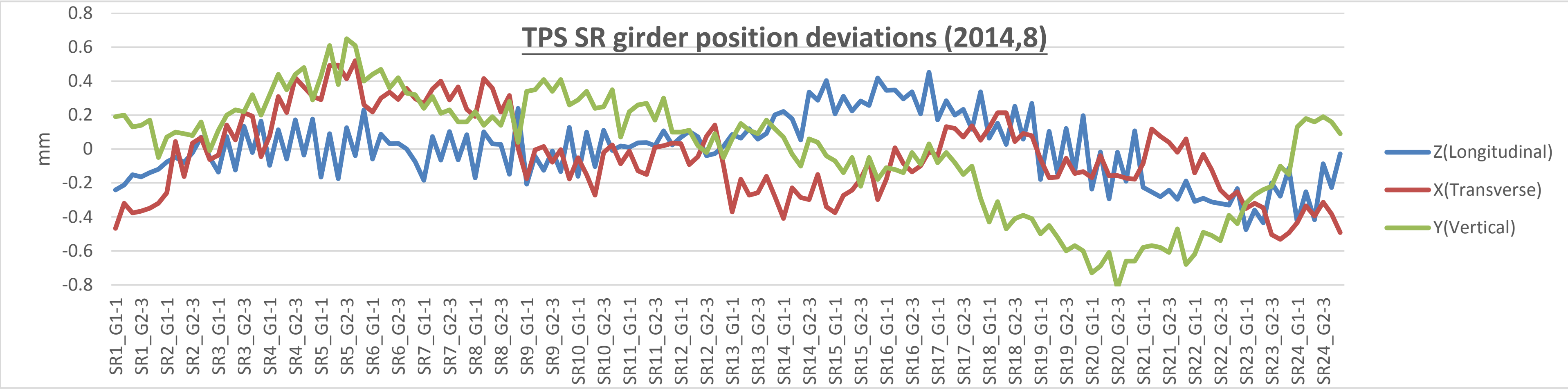


Girder auto-alignment in 1/3 ring each (1mm drop protection)

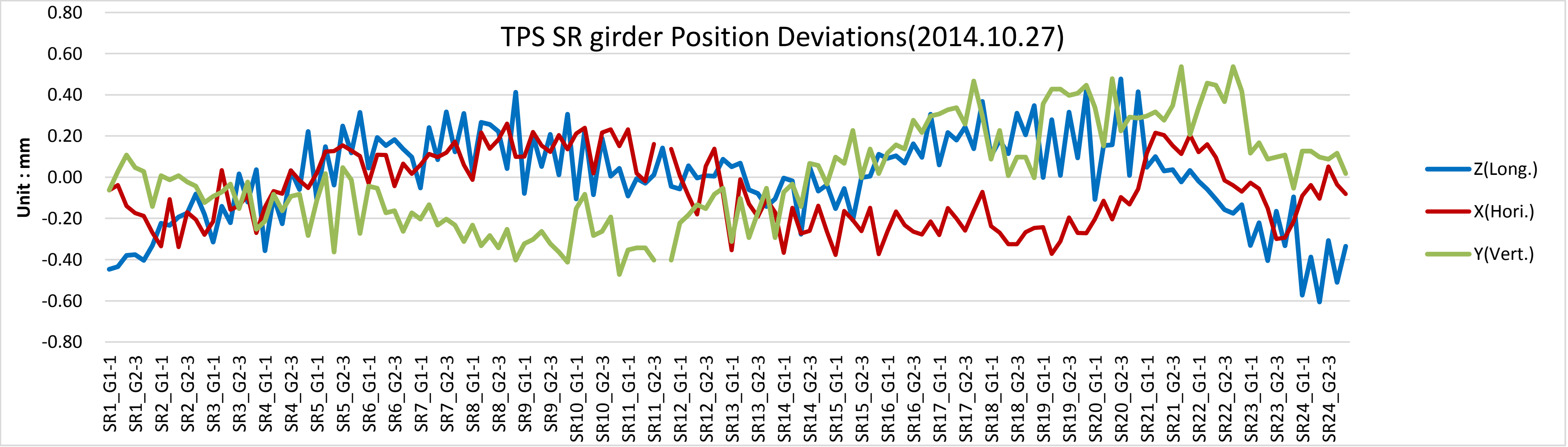


Girder auto-alignment in 1/3 ring each (vertical direction only)

Laser tracker measurement data



First girder auto-alignment in full ring

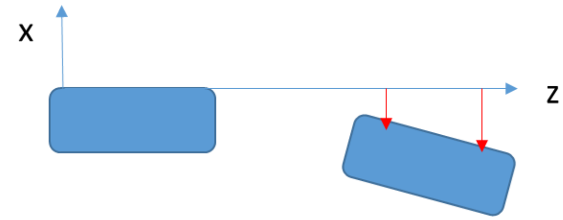


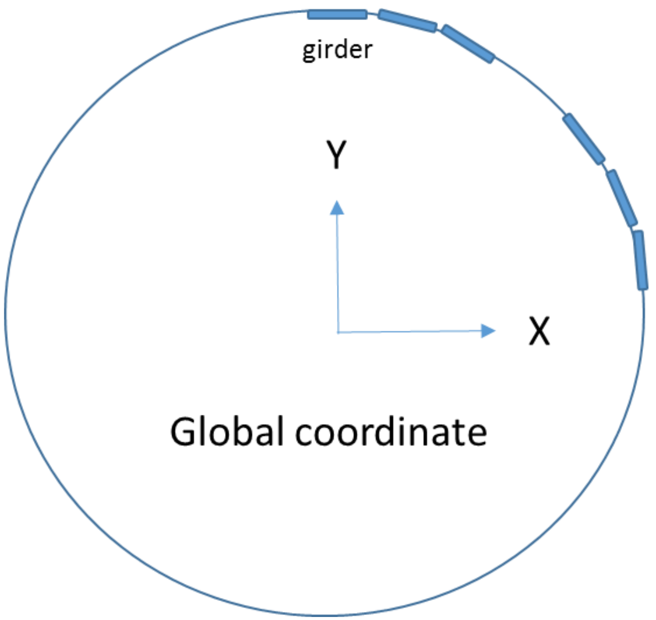
Second girder auto-alignment in full ring

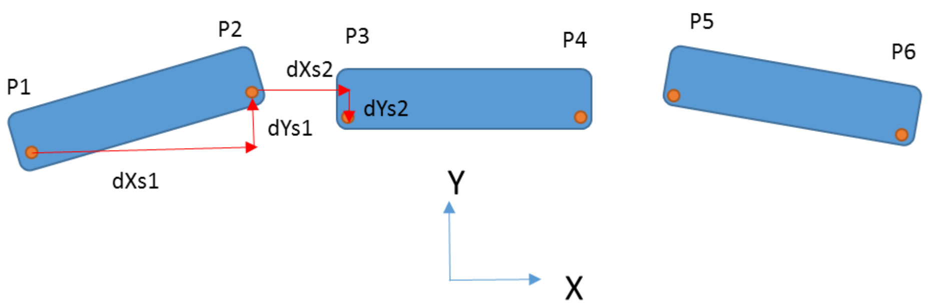
Auto alignment processes

1. Load laser tracker measurement data (XL,YL)
2. Load touch sensor matrix and calibration coeff. , calibration coeff. , girder length… initial data
3. Read touch sensor, PSD, Nivell, Encoder initial data
4. Calculate local dz(longitudinal deviation), dx(transverse deviation)

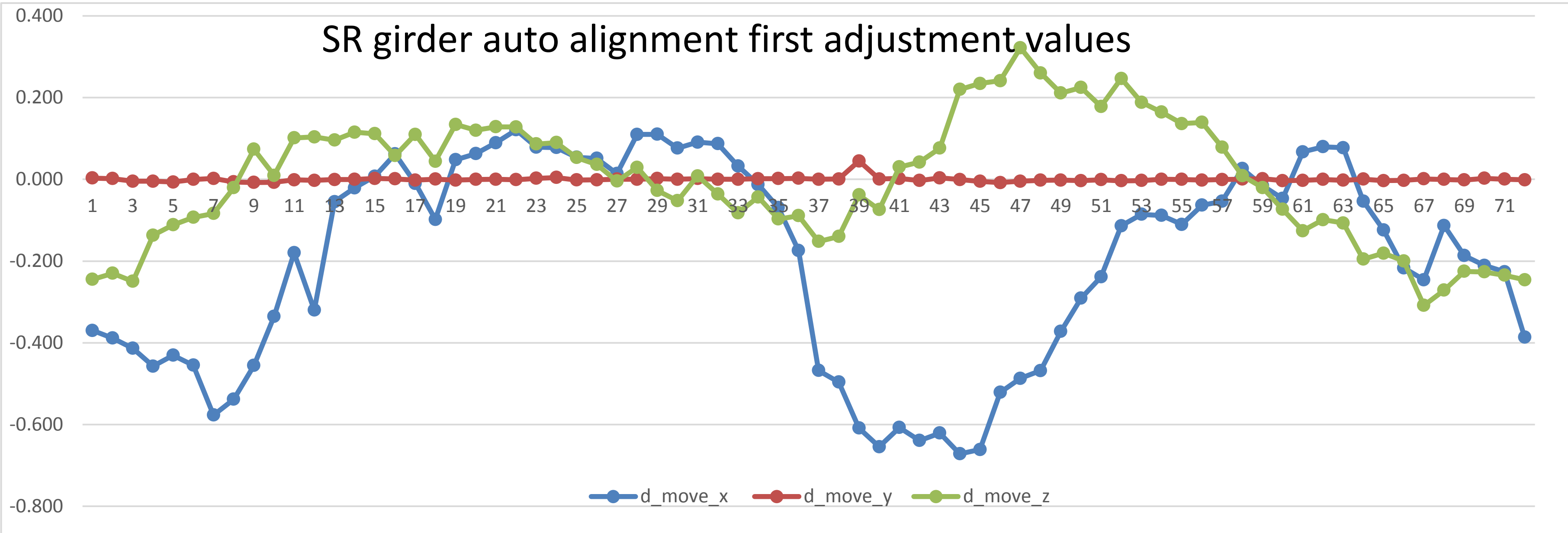
- Touch sensor matrix and PSD reading to calculate local (dzs , dxs)
- Local (dzs , dxs) transfer to global (dXs,dYs) ← (dXs,dYs) of each girder
- Calculate new position by average with the laser tracker data
  - P2(X_new,Y_new) = ½ *[P1(XL,YL) + ½*(dXs1,dYs1) +1/2*(P2(XL,YL)-P1(XL,YL))+ P3(XL,YL) – ½*(dXs2, dYs2) - 1/2*(P3(XL,YL) - P2(XL,YL))]
  - Calculate all P1(X_new, Y_new)~P72(X_new, Y_new)
  - Compare with (P1_theory~P72_theory) to calculate adjusting values
  - Adjust girder 1 of each section and record touch sensor 1st readings
  - Adjust girder 2 of each section and record touch sensor 2nd readings
  - Adjust girder 3 of each section and record touch sensor 3rd readings
  - Accord to the 3 touch sensor readings to calculate the real movement of each girder
  - Renew each girder postions P(X',Y') = P(X_new,Y_new)+movement P(dX,dY)
  - Iteration till converge







Auto alignment calculated values



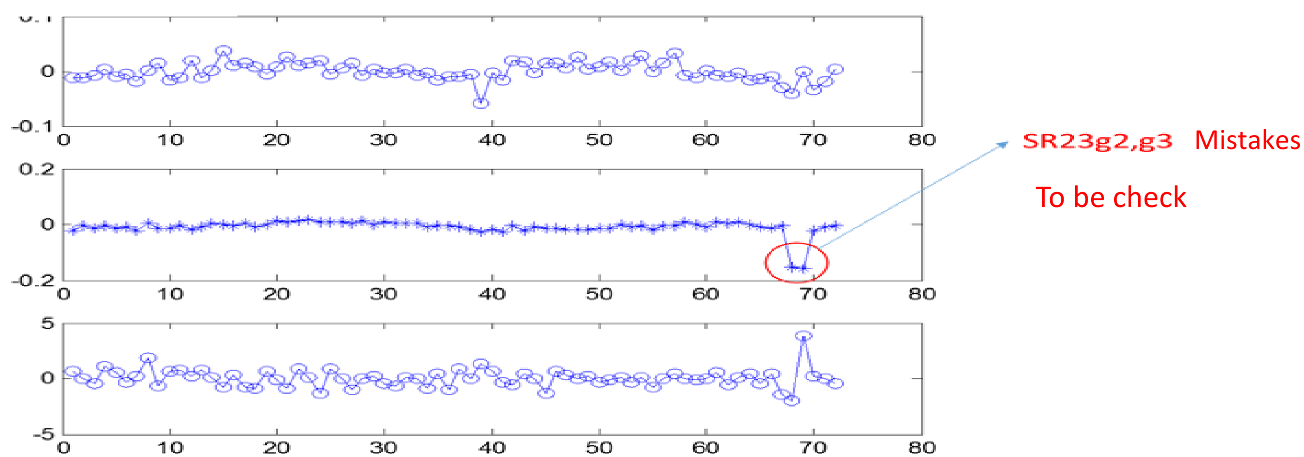
The full ring adjustment takes about 1900 seconds (32min) in 5 iteration

Second adjustment values

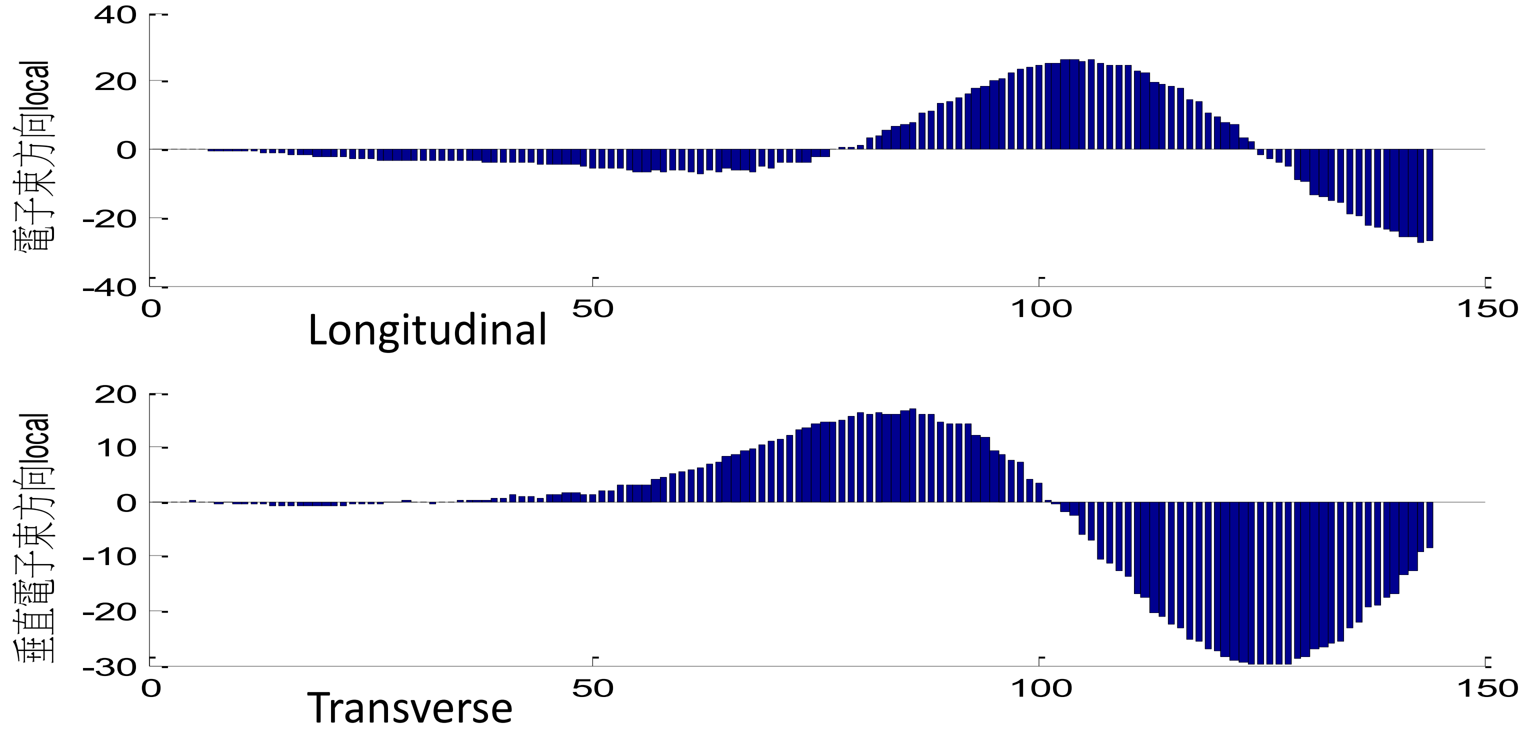
longitudinal(mm)

transverse(mm)

yaw(urad)



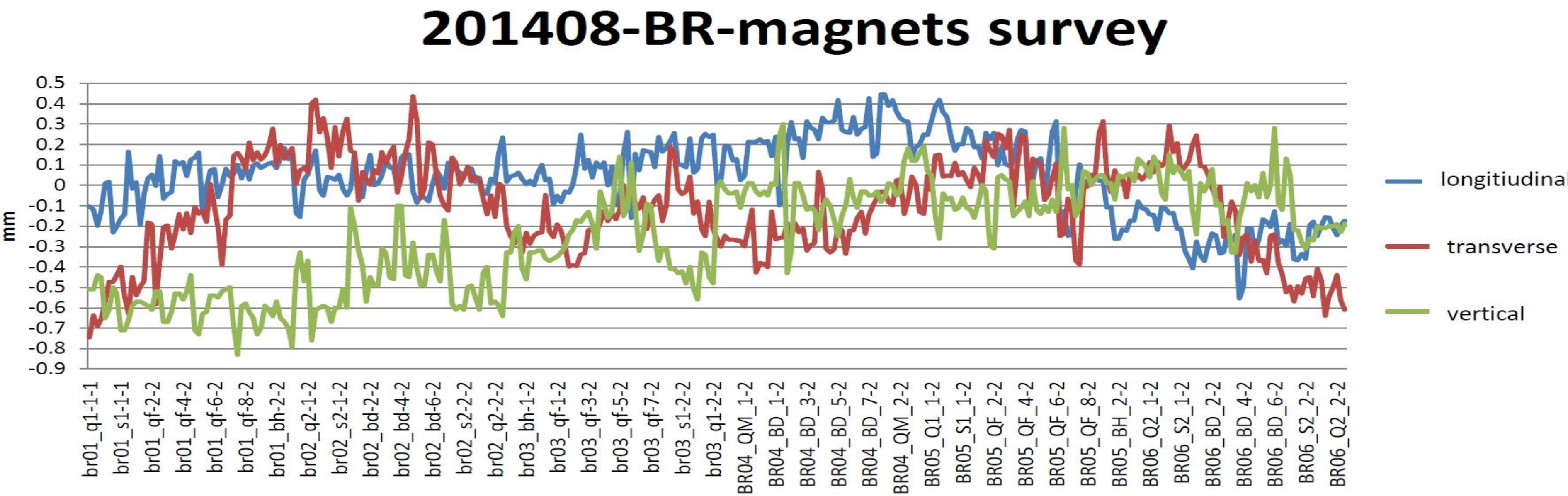
Girder positions comparison between from sensors and laser tracker



Due to sensor initial conditions are corrupted, two steps are to be adopted

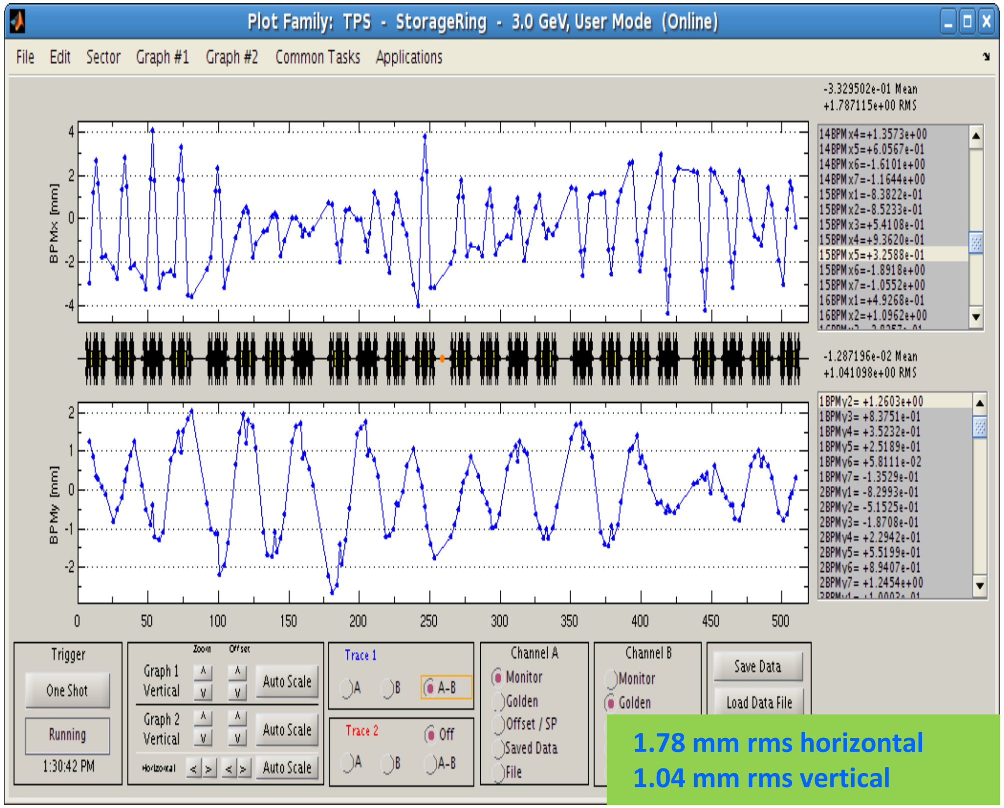
1. Applied optimizing method to calculate
2. Re-calibration

Booster ring alignment



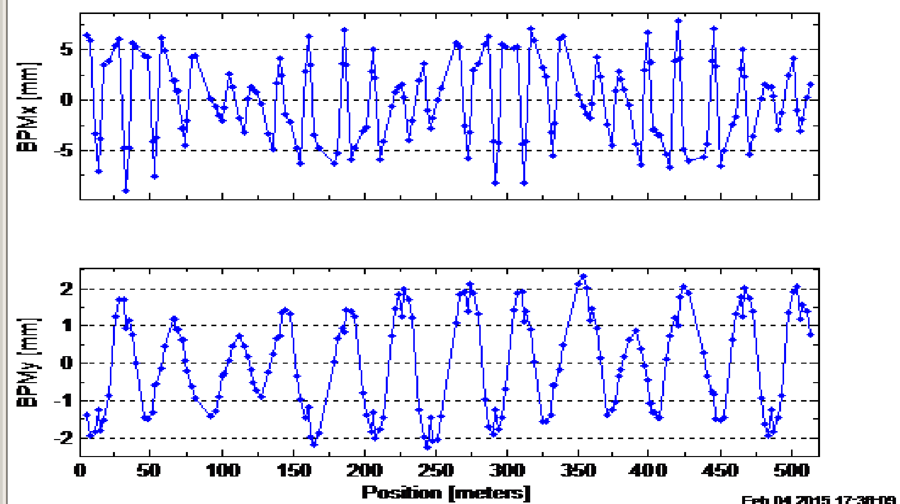
3 teams with 3 laser trackers and 4 weeks to align the booster ring manually

TPS COD before correction



1.78 mm rms horizontal
1.04 mm rms vertical

Measured COD with all correctors off
After LOCO and BBA

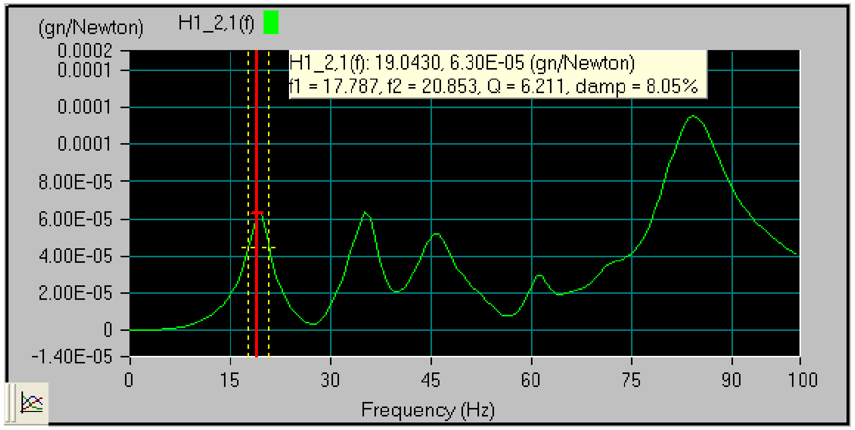


Simulated COD with all correctors off
from alignment errors, dipole field errors

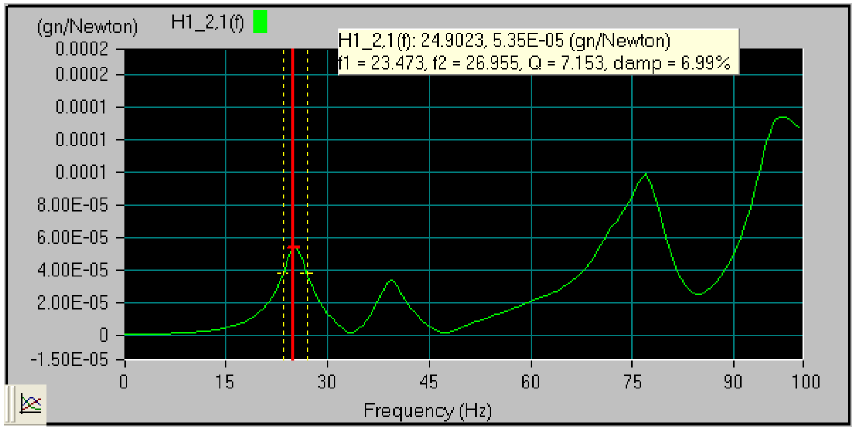
The measured data were even better shows good alignment conditions

⁎ *TUXC3, C. C. Kuo, et al., "Commissioning of the Taiwan Photon Source", IPAC'15* .

Vibration measurement recent (April 2015)



Natural Frequency without locking



Natural Frequency with locking

	wedge 0V													
	R1G1 X	R1G1 Y	R1G1 Z	R1G2 X	R1G2 Y	R1G2 Z	R1G3 X	R1G3 X-2	R1G3 X-3	R1G3 long-Q X	R1G3 long-Q X-2	R1G3 Y	R1G3 Z	R1G3 Z-2
ground	3.05	4.05	3.13	2.77	4.17	2.66	2.37	4.17	3.73	2.81	2.71	3.7	2.25	2.66
girder	2.85	3.9	2.63	2.81	4.32	2.7	2.87	3.07	3.23	3	3.16	4.09	2.65	3.08
MG	3.43	3.97	3.01	3.36	4.37	3.15	4.48	5.08	5.29	3.93	3.83	4.14	3.41	3.88
girder/ground	0.93	0.96	0.84	1.01	1.04	1.02	1.21	0.74	0.87	1.07	1.17	1.11	1.18	1.16
MG/ground	1.12	0.98	0.96	1.21	1.05	1.18	1.89	1.22	1.42	1.40	1.41	1.12	1.52	1.46
	wedge 1A clamp													
ground	3.57	4.05	2.65	3.63	5.32	2.57	2.91					3.73	2.45	
girder	2.51	4.06	2.55	3.01	5.15	2.53	2.92					3.72	2.79	
MG	2.7	4.12	2.63	3.4	5.16	3.25	3.47					3.59	3	
girder/ground	0.70	1.00	0.96	0.83	0.97	0.98	1.00					1.00	1.14	
MG/ground	0.76	1.02	0.99	0.94	0.97	1.26	1.19					0.96	1.22	
	wedge 2A clamp													
ground	2.63	3.75	3.04											
girder	2.98	3.88	3.04											
MG	3.23	3.81	2.66											
girder/ground	1.13308	1.034667	1											
MG/ground	1.228137	1.016	0.875											

Amplification factors with respect to the ground

Conclusions

- **TPS girder system including storage ring, booster ring and transport line were finished installation in August 2014.**
- **A laser tracker survey data based full ring auto-alignment had been performed and shows good conditions for commissioning.**
- **The laser tracker survey results show that the full ring accuracy is about ±0.5mm.**
- **From the sensor's data only, the accumulated error is still quite large and the sensor's initial conditions should be further improved to optimize the sensor based girder auto-alignment.**
- **Though the TPS commissioning had been completed, the locking systems of girder were still not applied yet and the vibration measurement showed some problems. Further measurements and improvements on vibration issues are scheduled.**

Hard-working group members

- **Part design, checking and assembling (including booster ring and inject section) :**

  Shen-Yaw Perng, Wei-Yang Lai, Keng-Hao Hsu, Pei-Lun Sung

- **Laser PSD system :**

  Mei-Ling Chen, His-Chou Ho, Hsueh-Cheng Lin , (C.W. Tsai)

- **Control system and auto-alignment :**

  Jeremy Wang, Thomas Wu, (Wei-Yang Lai)

- **Survey and alignment :**

  Chia-Jui Lin, Hung-Ming Luo, His-Chou Ho, (Wei-Yang Lai)

- **Vibration measurement and elimination :**

  Chang-Sheng Lin, Keng-Hao Hsu, Jeremy Wang

- **Drawing management and assistant :**

  Din-Goa Huang, (Pei-Lun Sung)

- **Photon Beam Monitor :**

  Chien-Kuang Kuan , C.W. Tsai, (Mei-Ling Chen)

Thank you for your attention!