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

Installation And Implementation Of An Auto-Alignment Girder System For TPS Storage Ring

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NSRRC, Taiwan
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Outline

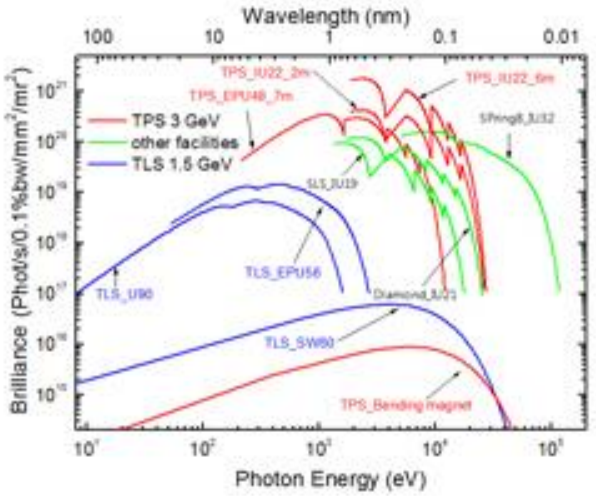
- Girder system design briefing
- Preparations at a rental plant
- Girders Installation at TPS tunnel
- Survey alignment works
- Auto alignment preparation and implementation
- Summary

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 relative to the girder)
- High nature frequency above 30 Hz
- Alignment accuracy within 0.1mm(relative)

Traditional alignment network simulation reveals an accuracy of 0.15mm typically. It needs to be iterated several times to reduce to 0.1mm and is also time consuming

- Precise resolution (um)

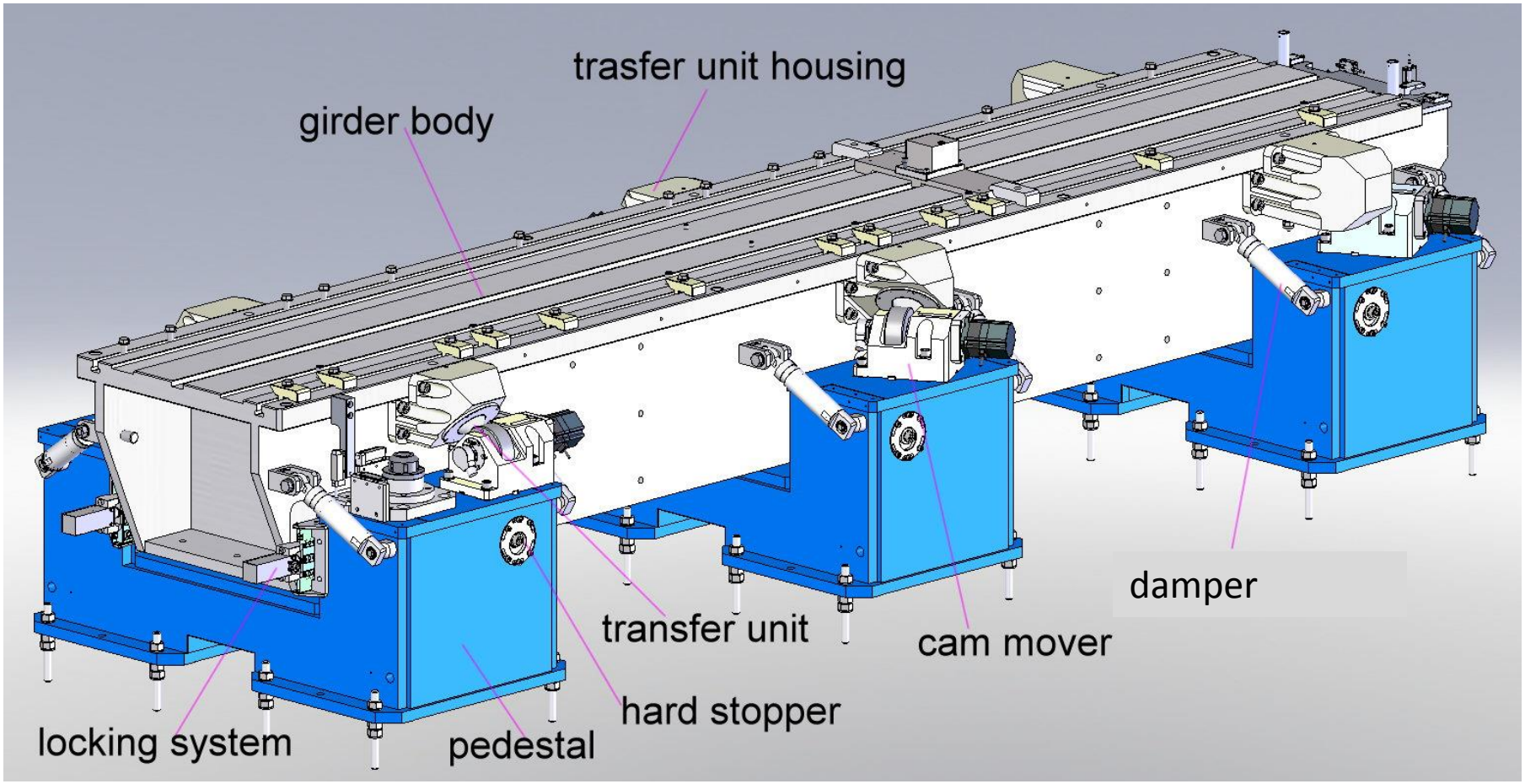
Manual adjustment mechanism is of poor resolution and time consuming

- 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 .

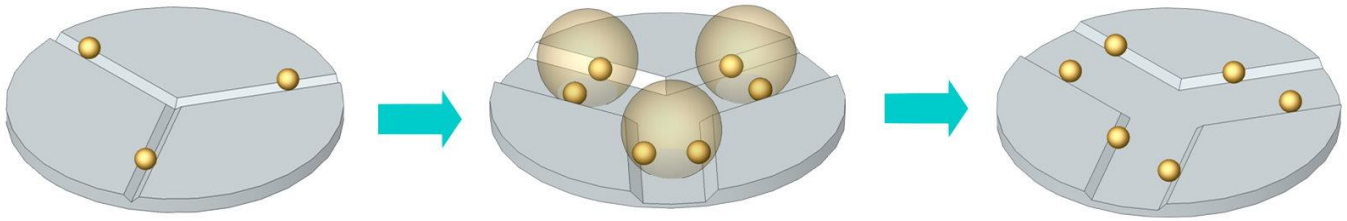
A 6-axis motorized adjusting mechanism is proposed!

One girder system configuration



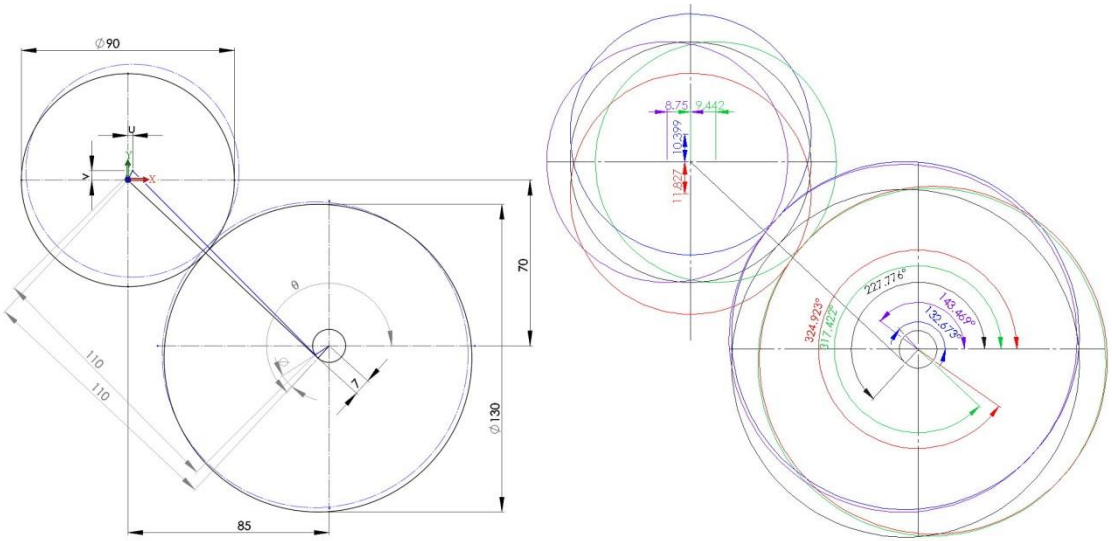
- More contact points with locking system to raise natural frequency and reduce deflection.
- All contact points persist rolling contact condition when adjusting to reduce friction and remain high mobility .
- Contact stress less than elastic limitation to reduce friction wear and keep high reliability

Cam mover type mechanism modification and adjusting algorithm

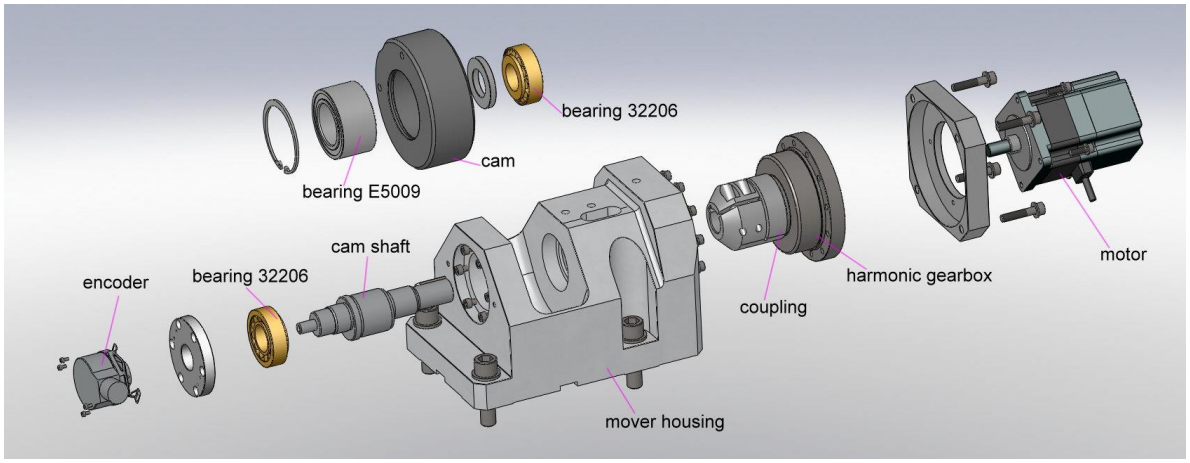


A 3 grooves type kinematic mounting modification to 6 stands girder design

- 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 transverse(X) direction (4.5mm) and √3/2 in longitudinal(Z) direction (7mm)

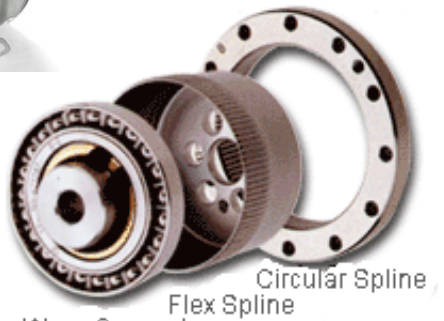


Modification of point contact type cam to line contact to reduce stress



- 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 beyond the elastic limitation of the cam.

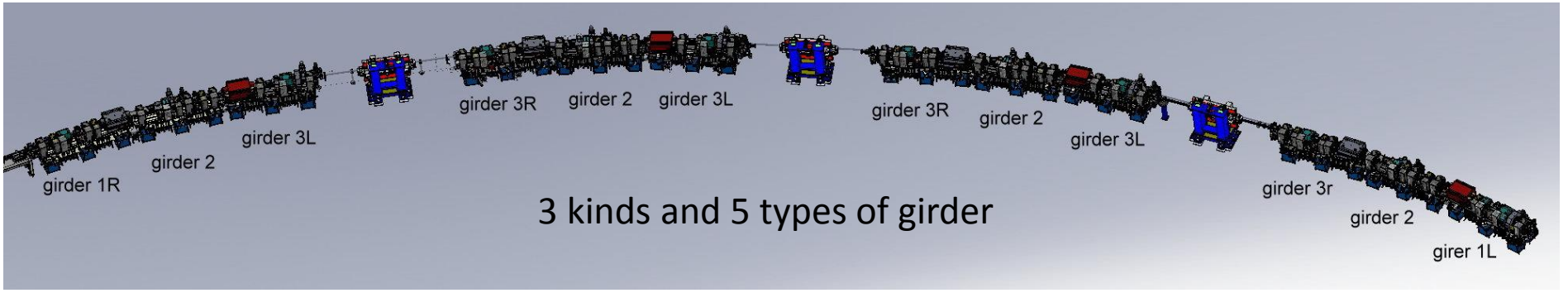
Heidenhain ECN425 rotary encoder



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

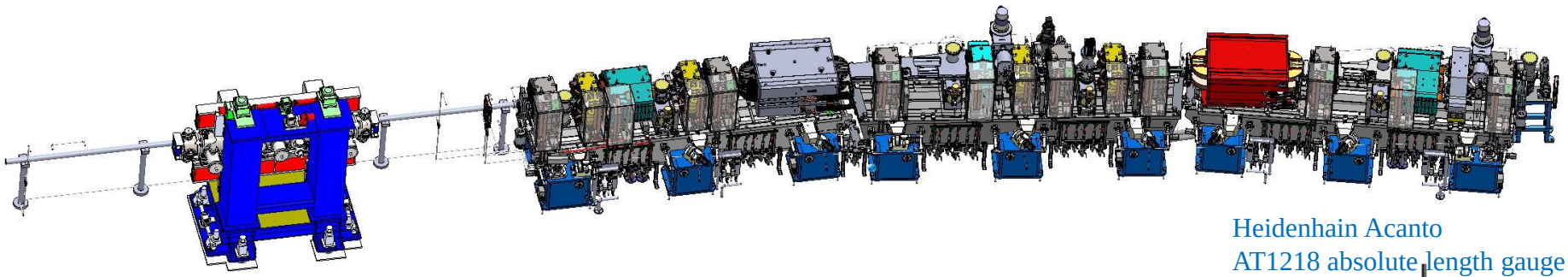
Steps of the stepping motor is 5000 and plus with the gearbox ratio of 160, it comes with a resolution of 80000 per turn and also refers to a step resolution of at least 0.03um in girder coordinate system

Storage Ring Girder System Design



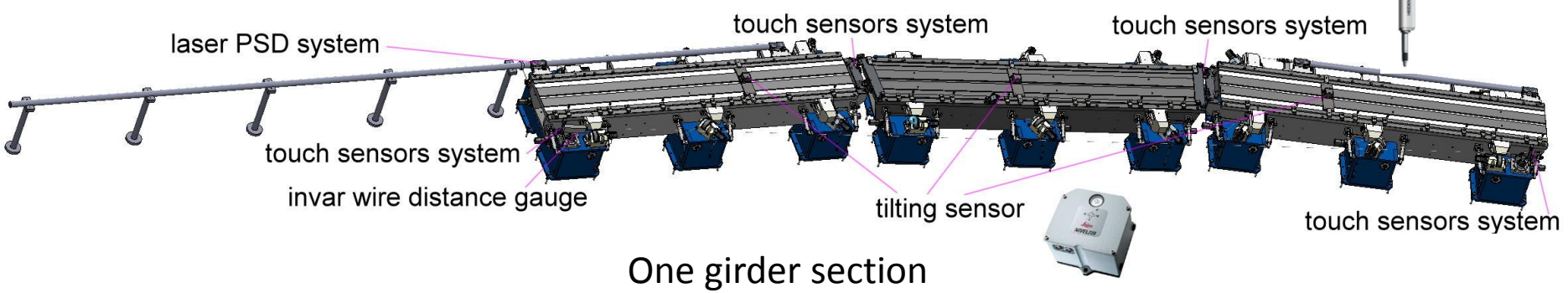
3 kinds and 5 types of girder

1/6 ring symmetry super-period configuration



Heidenhain Acanto
AT1218 absolute length gauge

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



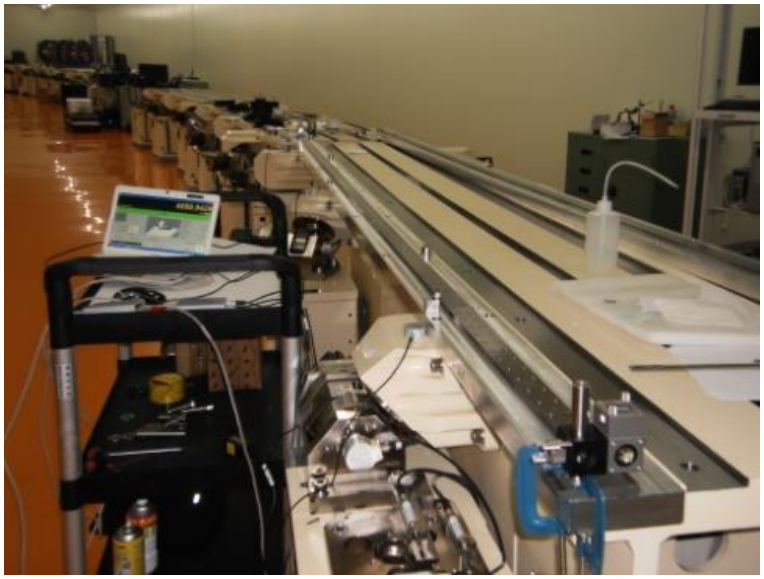
One girder section

Leica Nevil220 tilting sensors

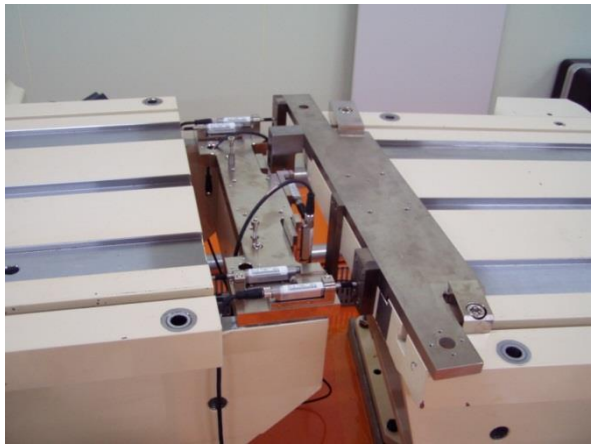
Girder System Assembling Processes

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

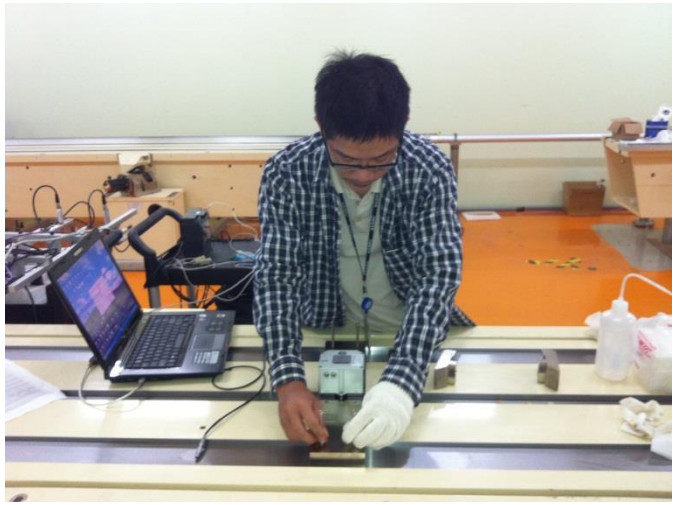
1. Measure distances between reference holes on one girder with a laser interferometer
2. Measure distances between reference holes on adjacent girders with a encoder rule
3. Touch sensor module assembling
4. PSD module assembling, partially auto-alignment processing and sensor's data acquisition

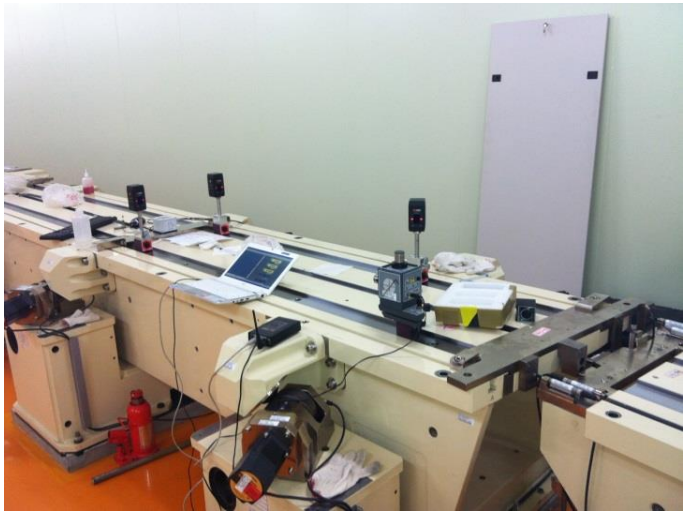


Inflatable mandrel



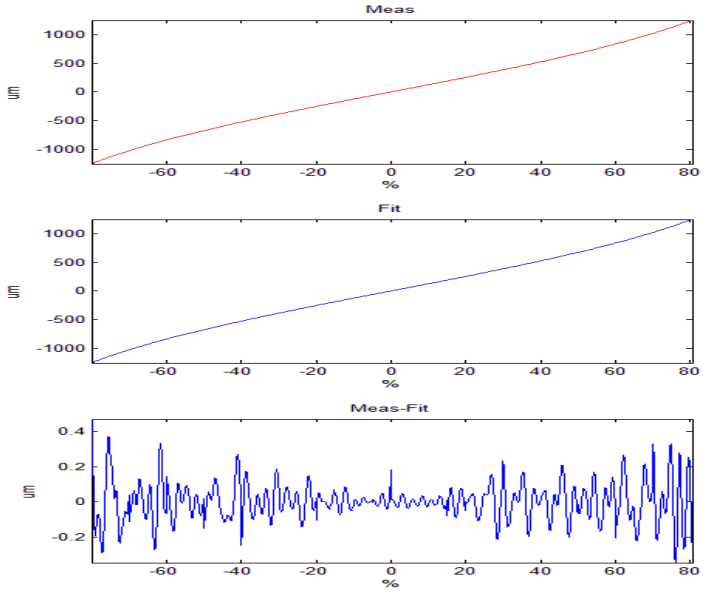
Sensors calibration at Chu-Dung plant



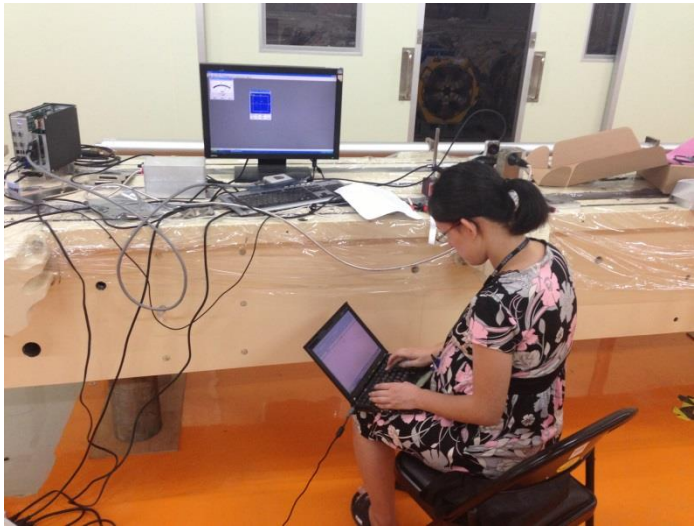


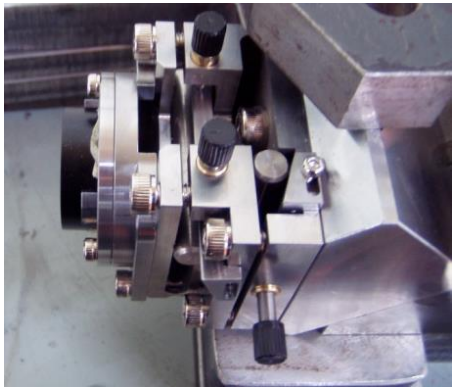
- With a levelling laser(harmmar laser) to level the adjacent girders, calibrating the electronic levelling (Nivel 220)to ±5urad and touch sensors to 5um

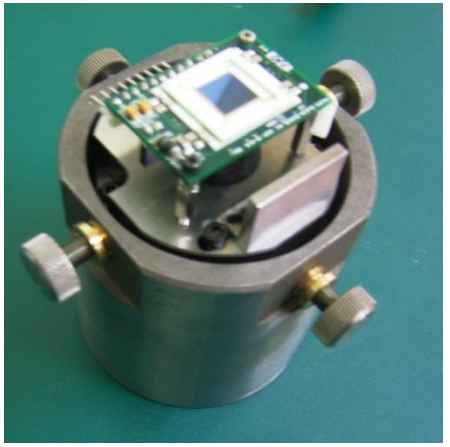
Laser positioning system part measurement

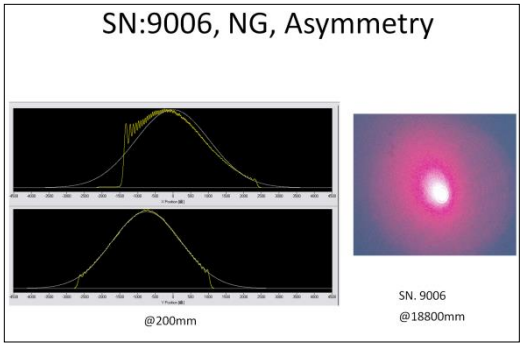


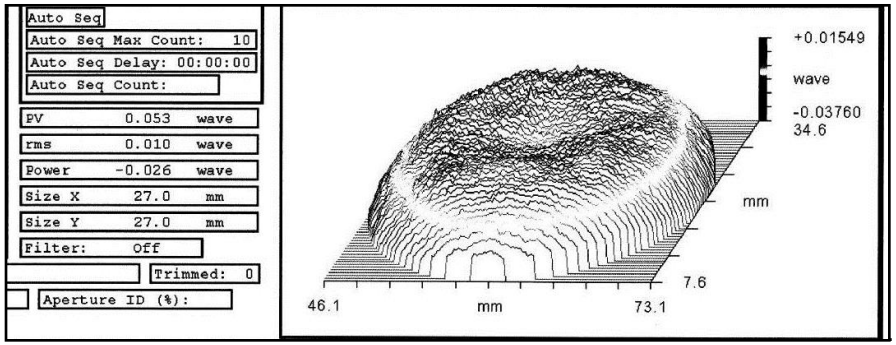
Laser Beam profile curve fitting



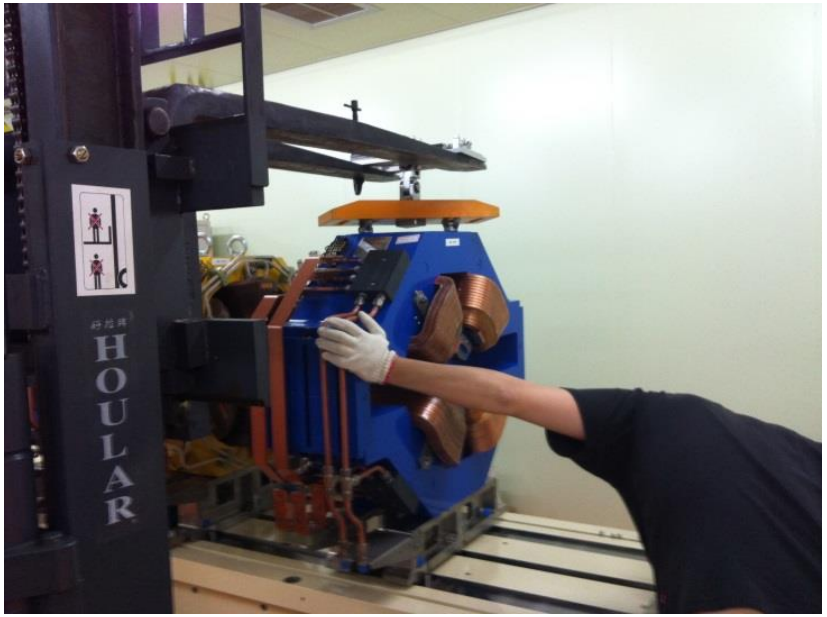




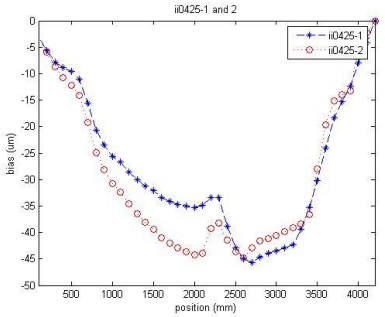


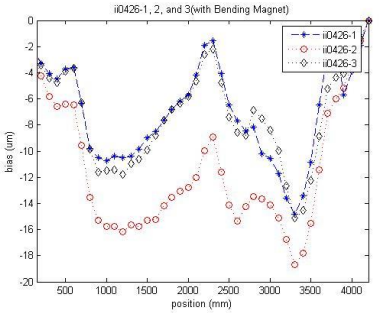


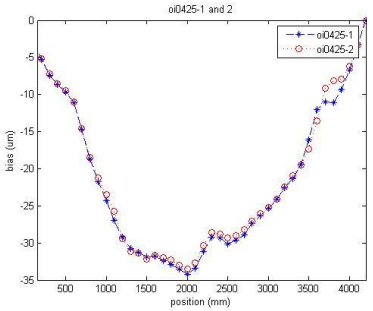
Magnets assembly

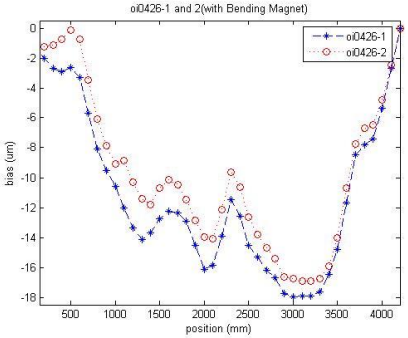


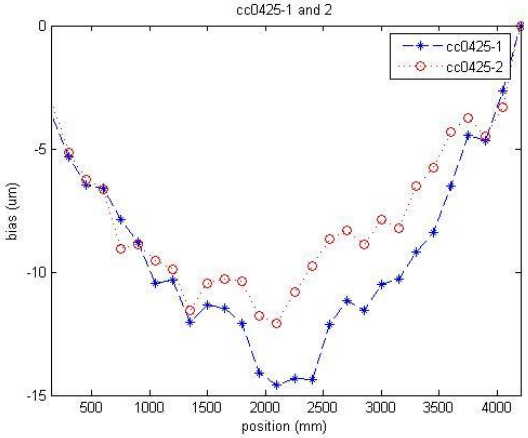
Girder flatness measurement after magnets assembled

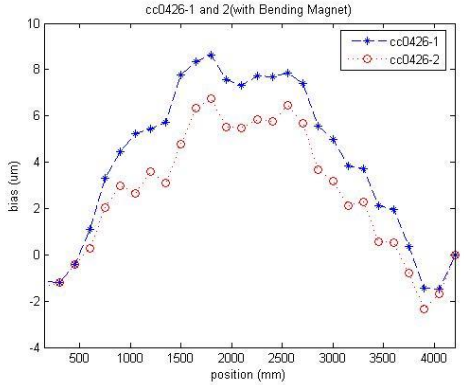






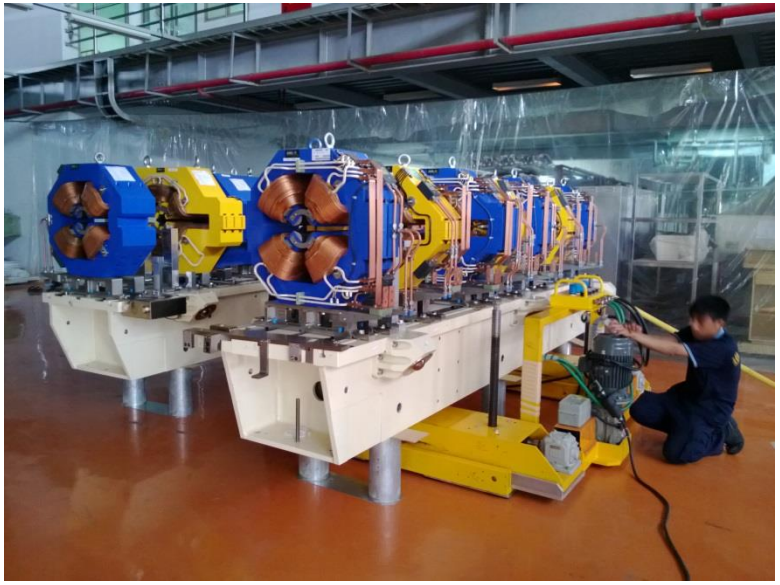




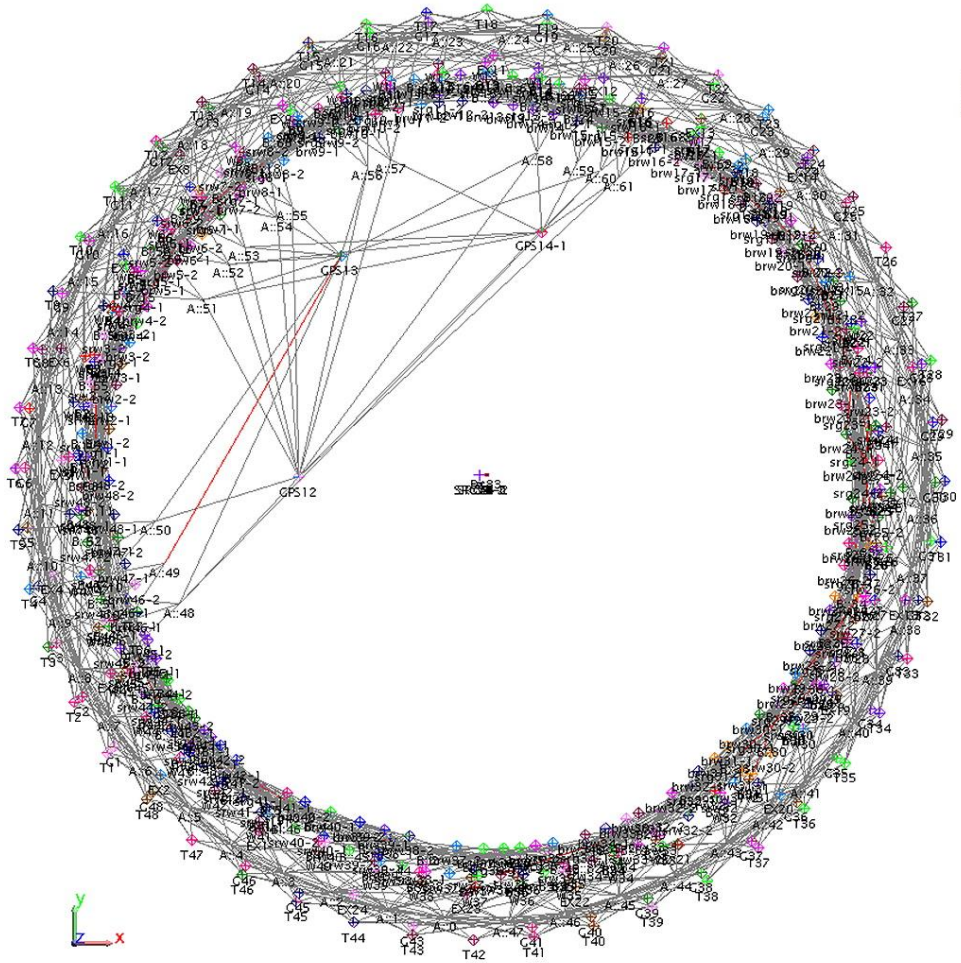


With dipole mag. Max.:18um
Without dipole mag. Max.:45um

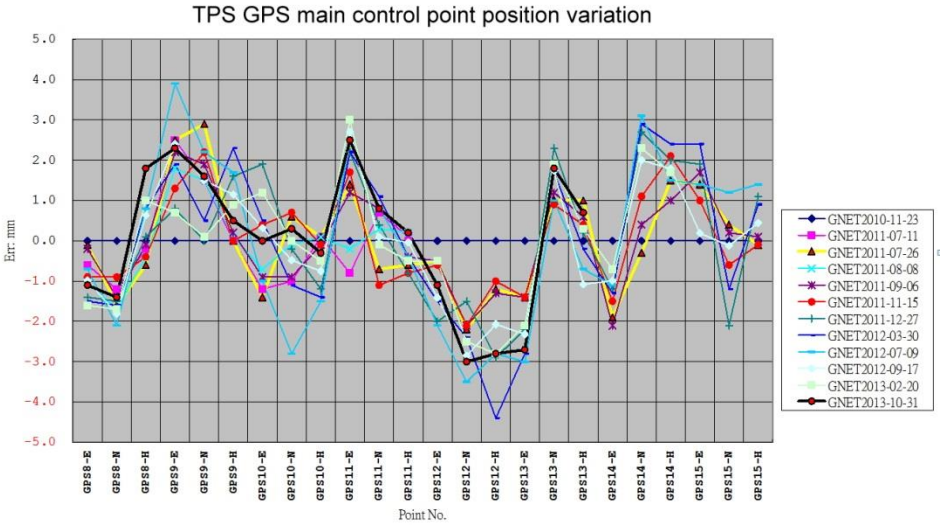
Girder with magnets package

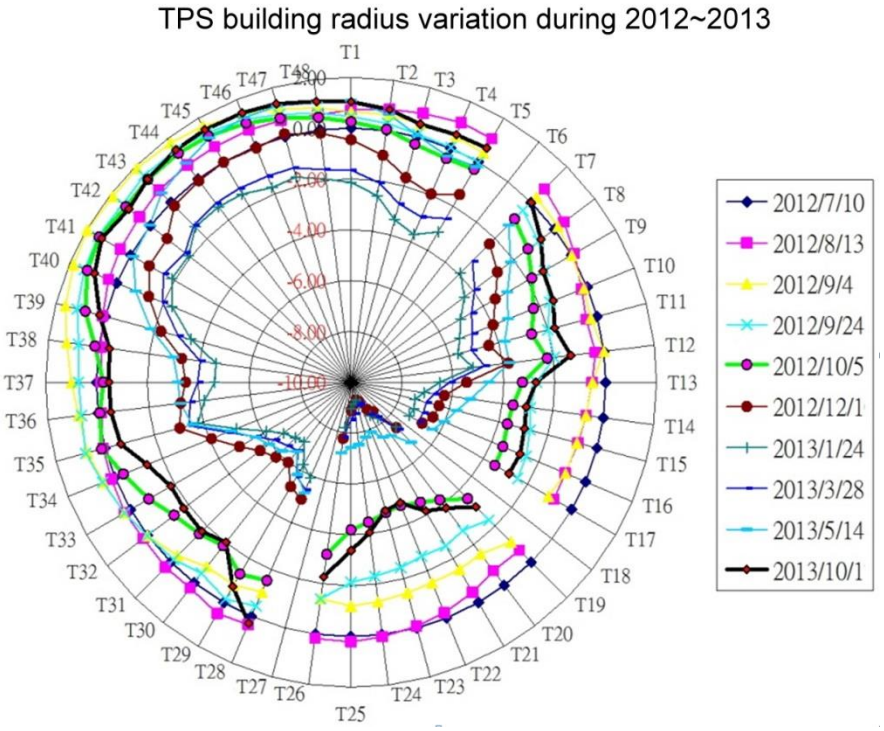


Survey data accumulation



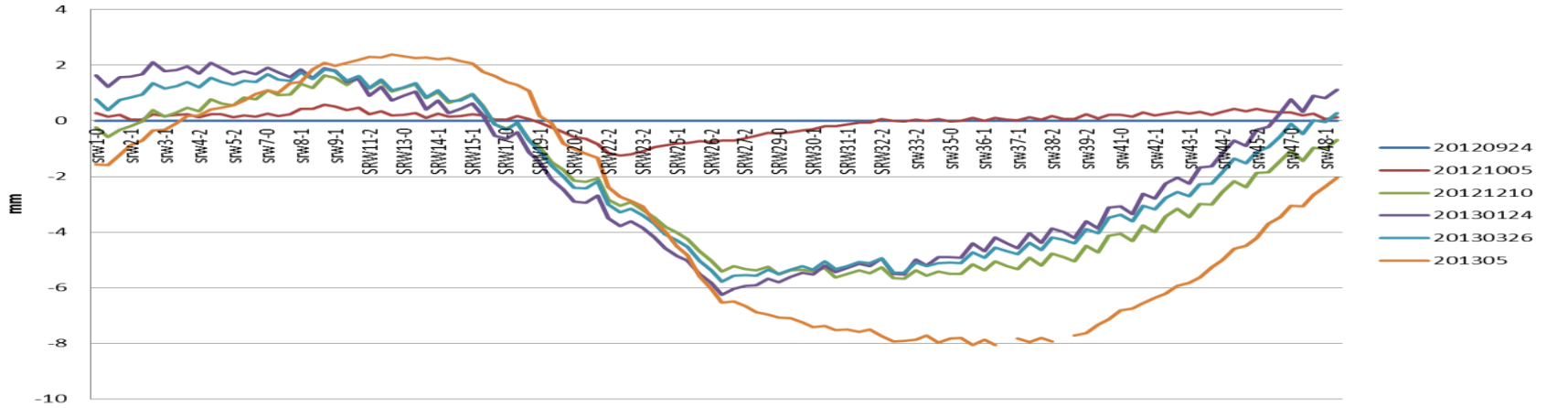
Survey network implementation



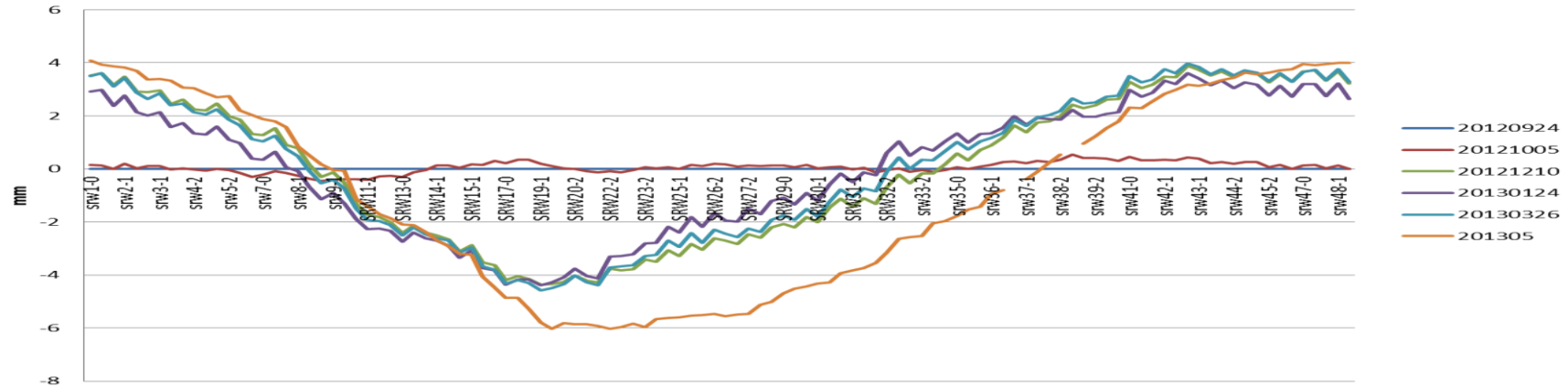


TPS tunnel variation during 2012~2013

Shielding wall (x dir.)

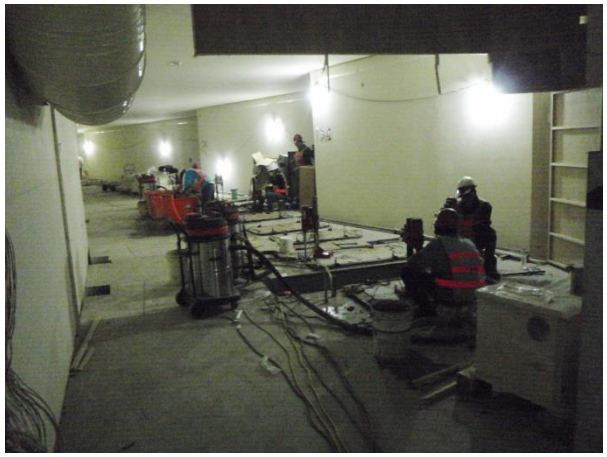


Shielding wall (y dir.)



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



Transportation of Girders with magnets form rental plant to TPS







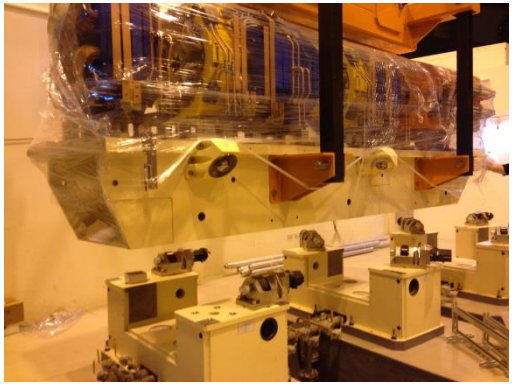


Lifting and Installation Girders of TPS



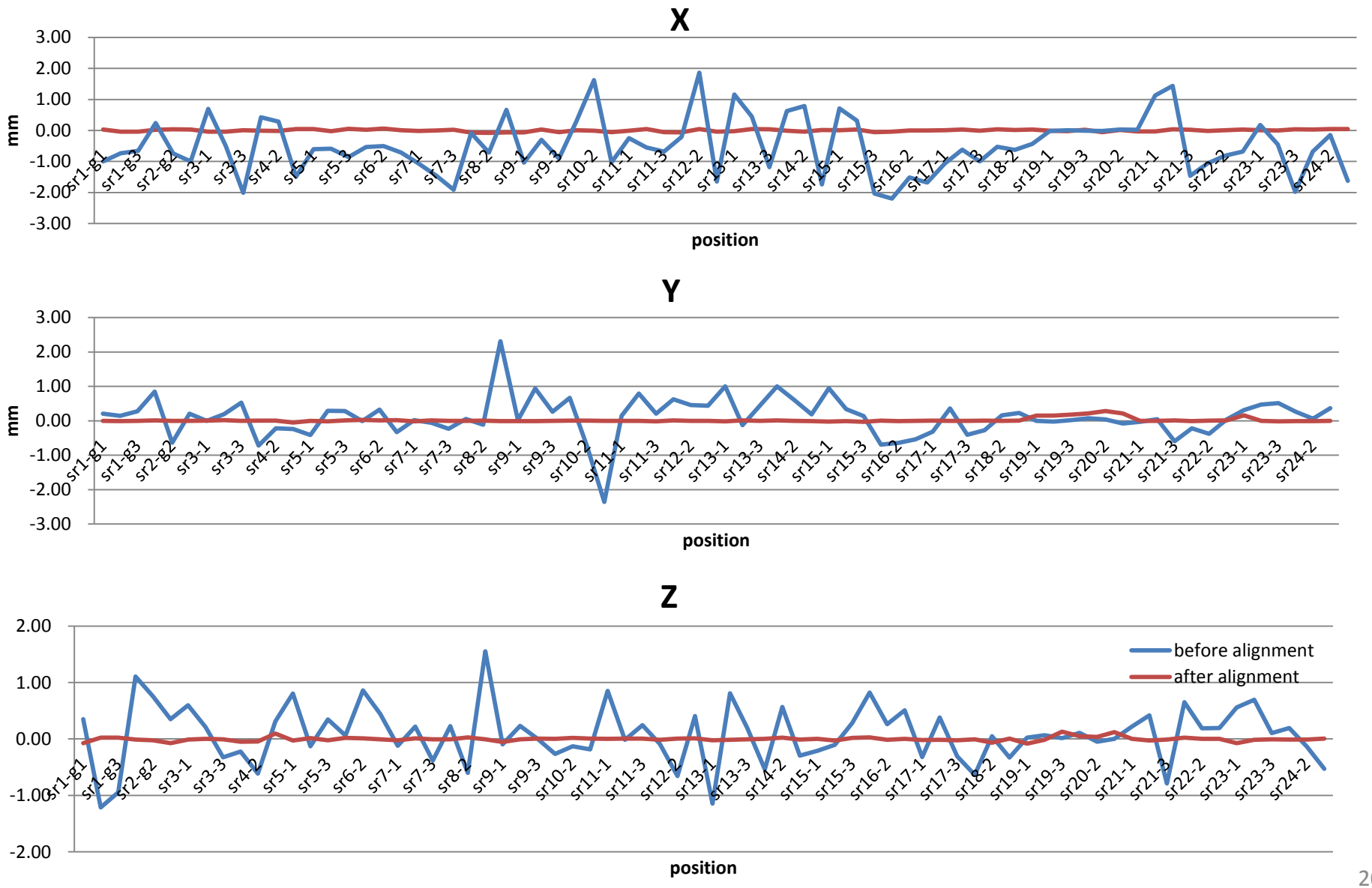




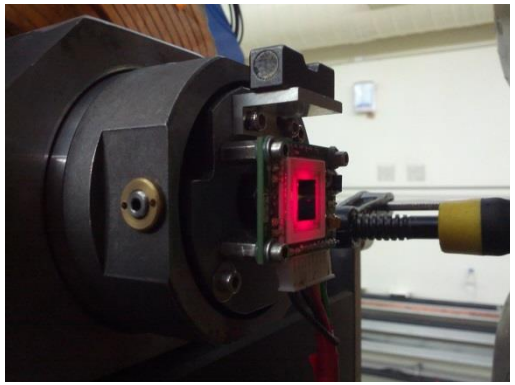
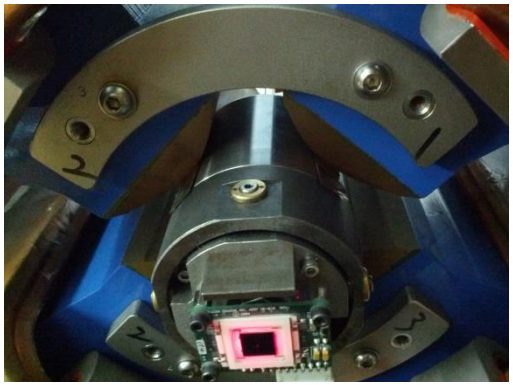


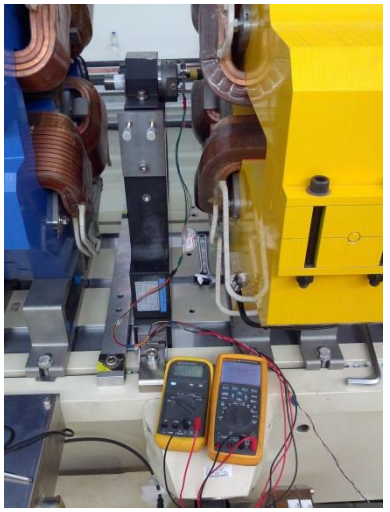
It spends about 40 min to an hour to install a girder

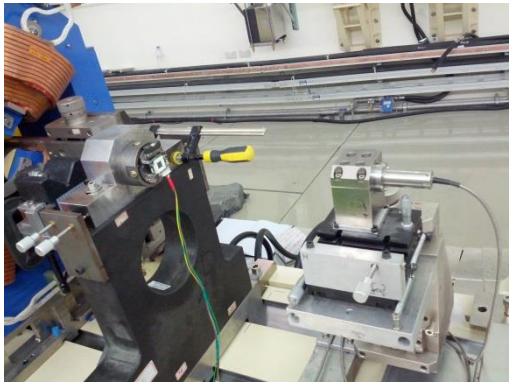
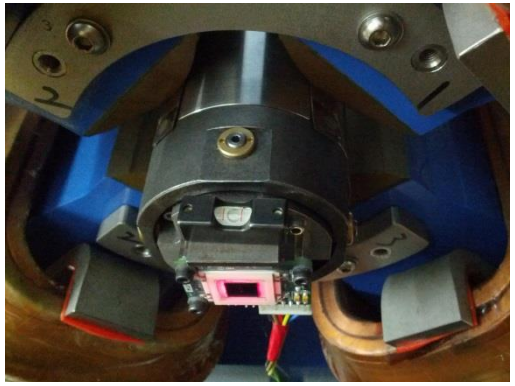
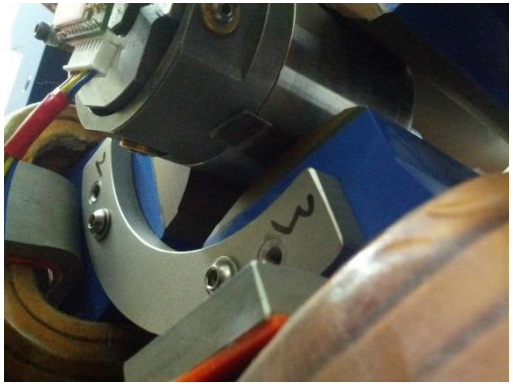
Girder installation deviations



Magnet Centralizing

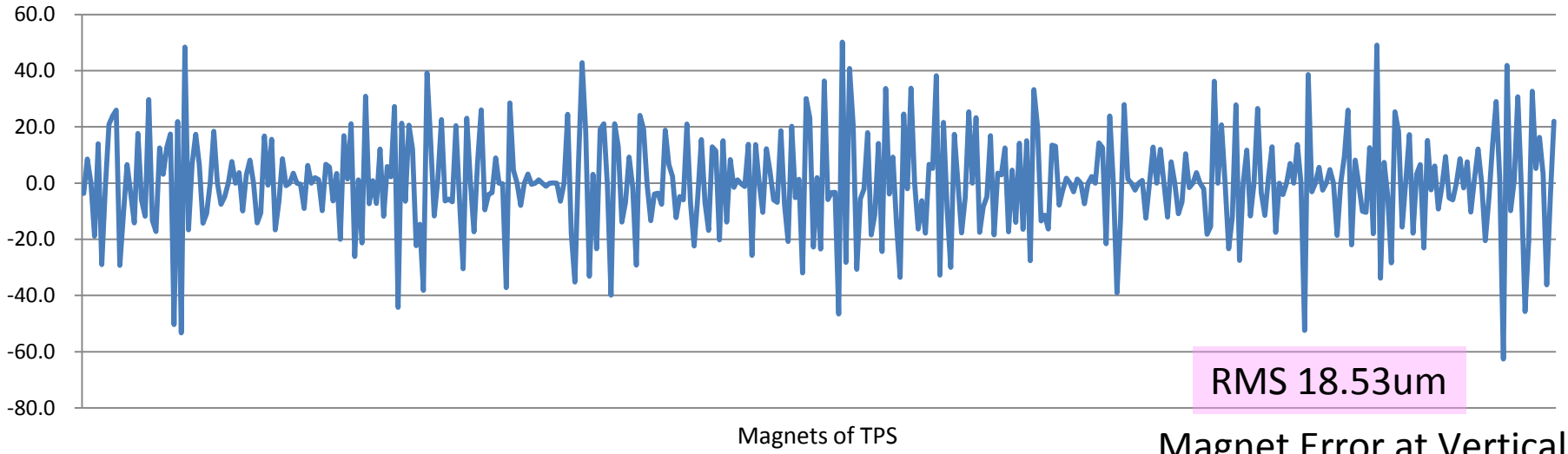





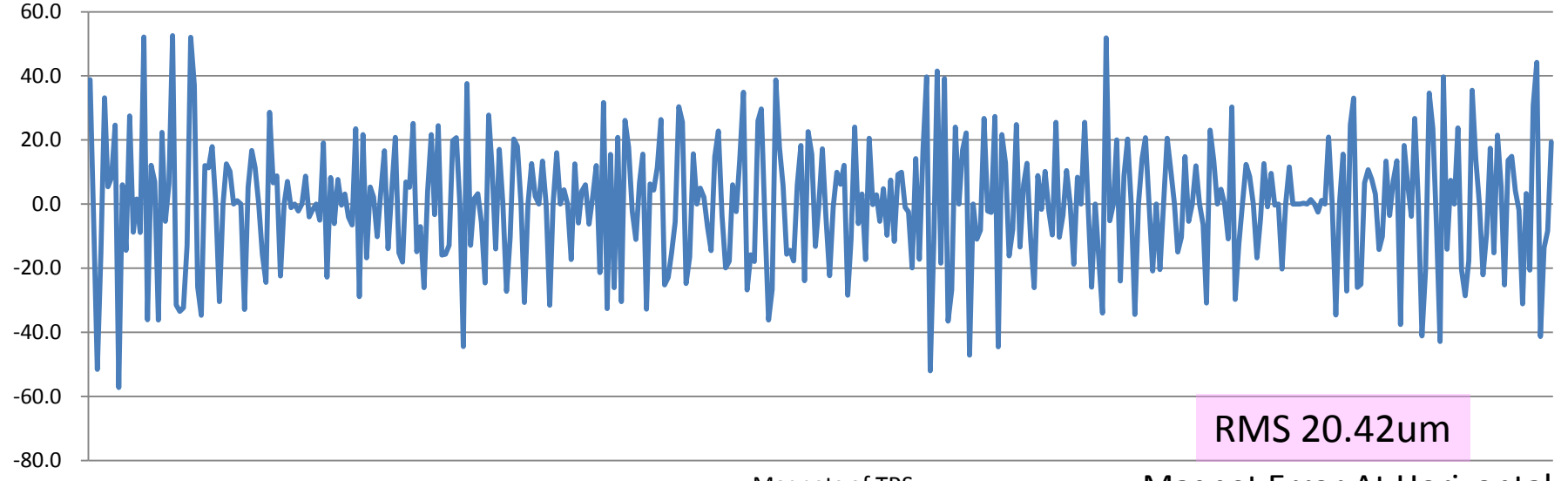




- Adjust Position Jig and Circular PSD jig
- Install two position jigs with PSD on girder
- Adjust laser to parallel and have equidistance to girder datum plane
- Replace the Position jig with the quadrupole and sextupole magnets
- Insert Circular PSD jig on the center of quadrupole and sextupole magnets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

Magnet Centralizing Results



Magnet Error at Vertical

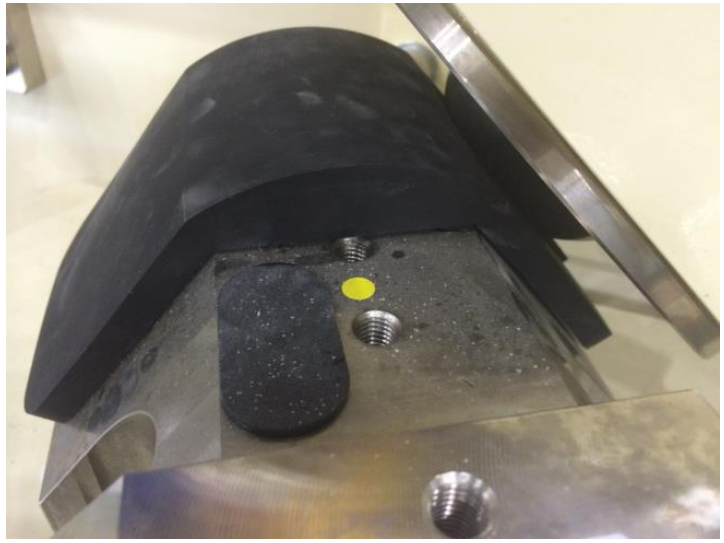


Magnet Error At Horizontal

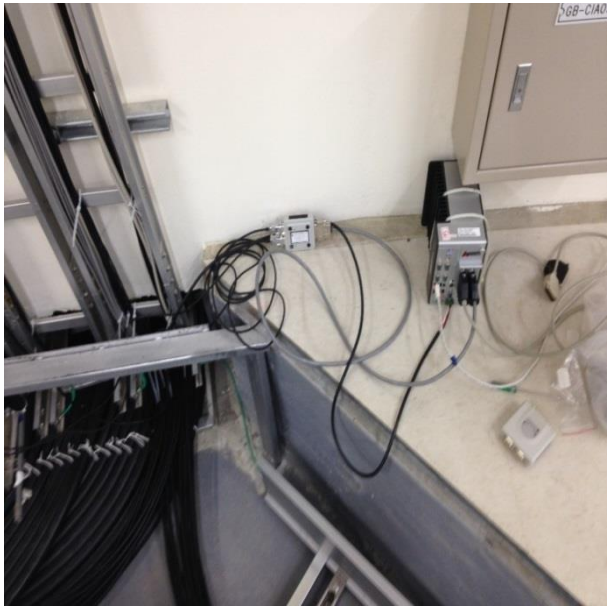
Girder system completed installation

- 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 assemblage

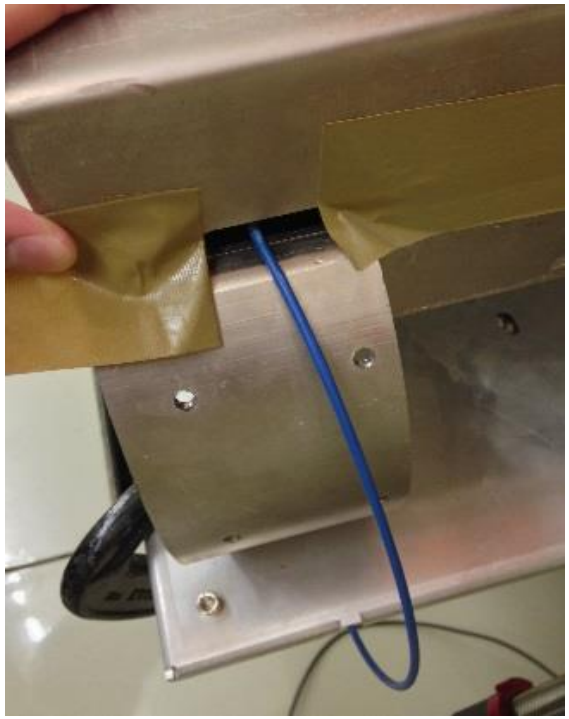


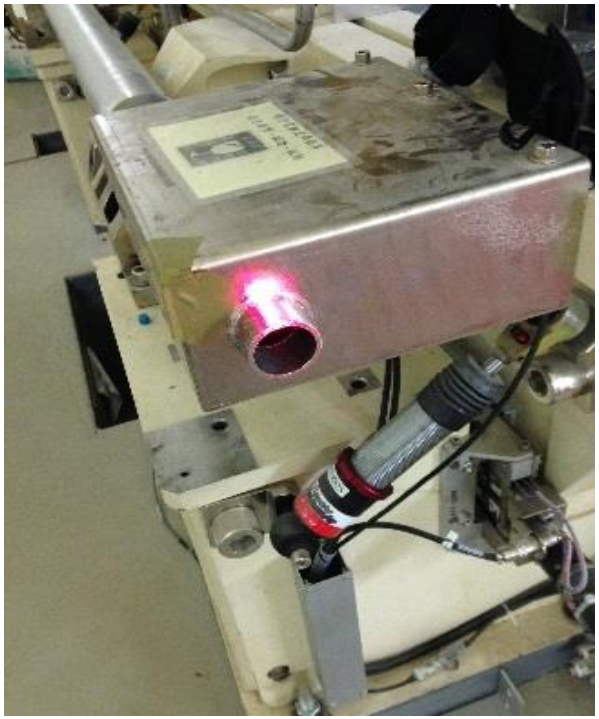
Control rack installation and wiring



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)

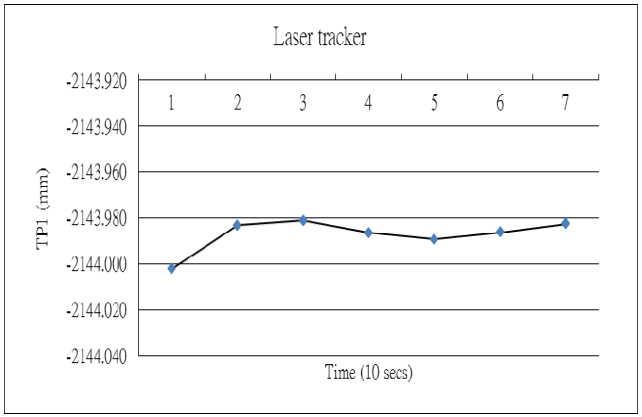




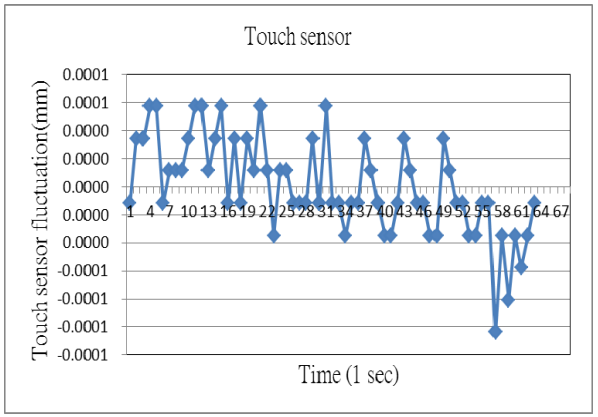
Sensor stability check in 1 minute

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

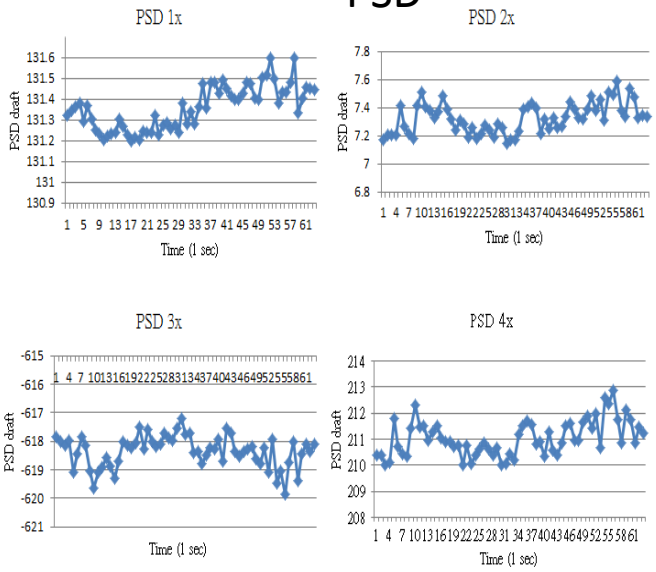
Laser Tracker



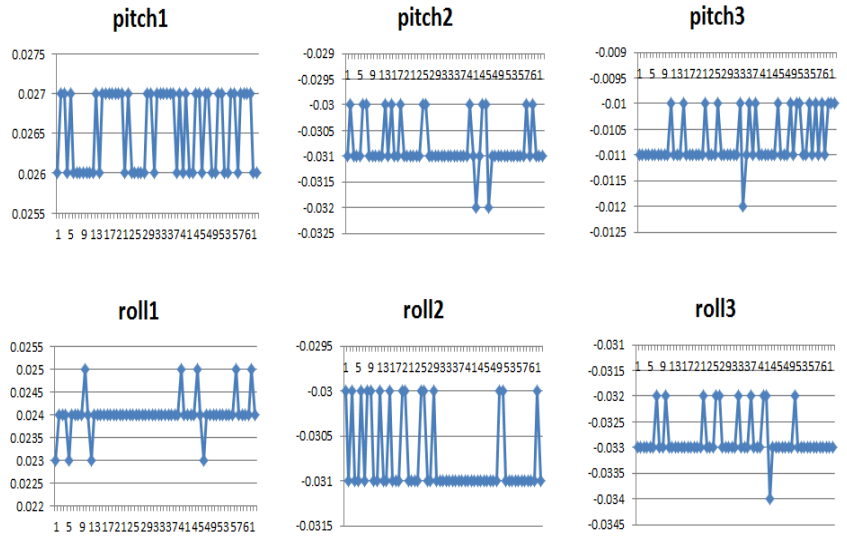
Touch Sensor



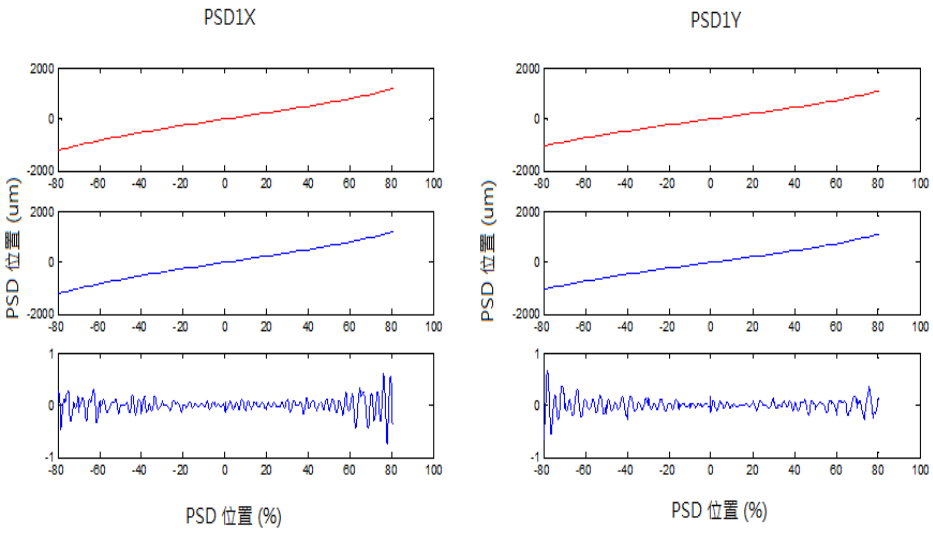
PSD



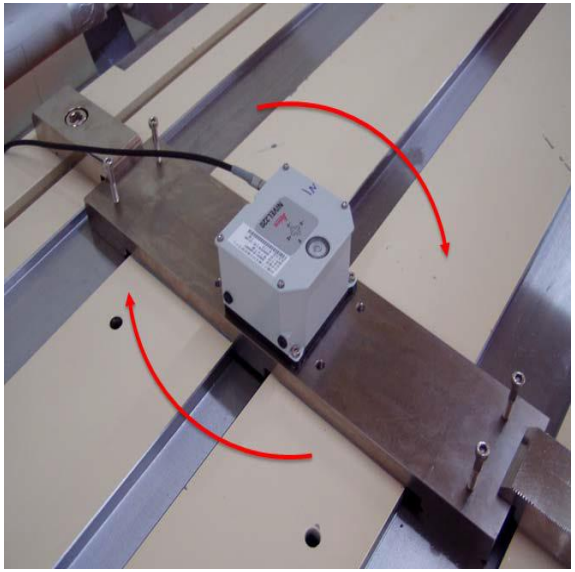
Nivel

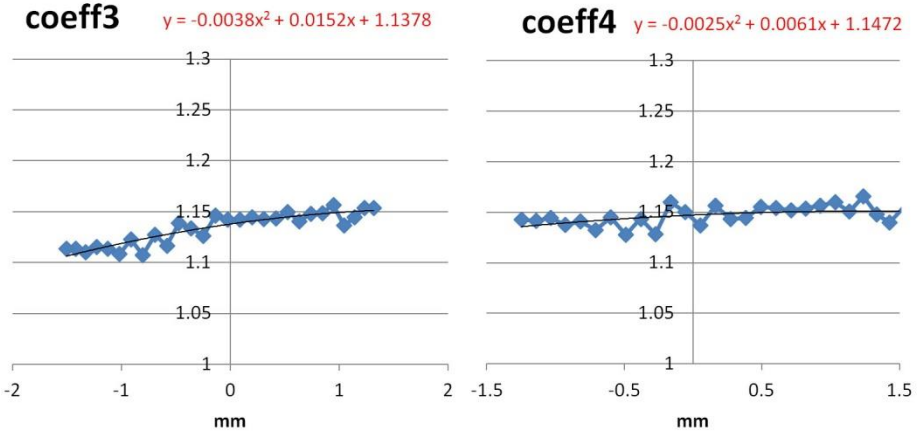


Auto-alignment system calibration



PSD beam profile curve fitting





PSD to linear encoder curve fitting

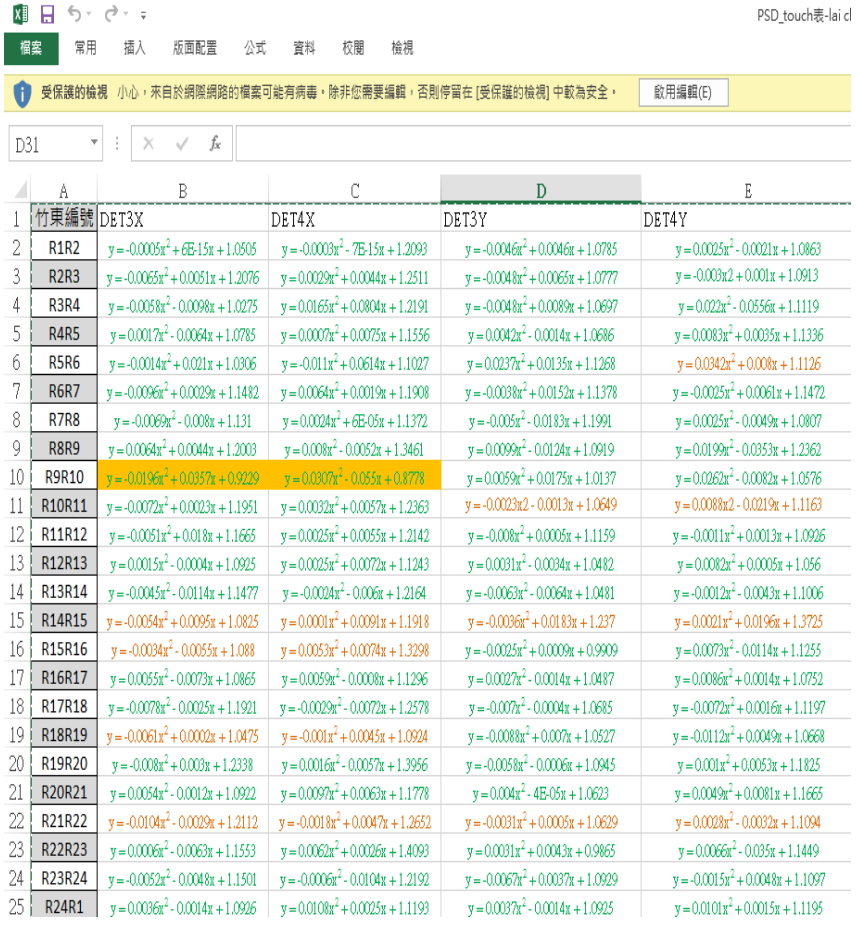
$$p\_offset = \frac{p1 + p2}{2}$$

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

Nivel 220 calibration

The data base for TPS 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

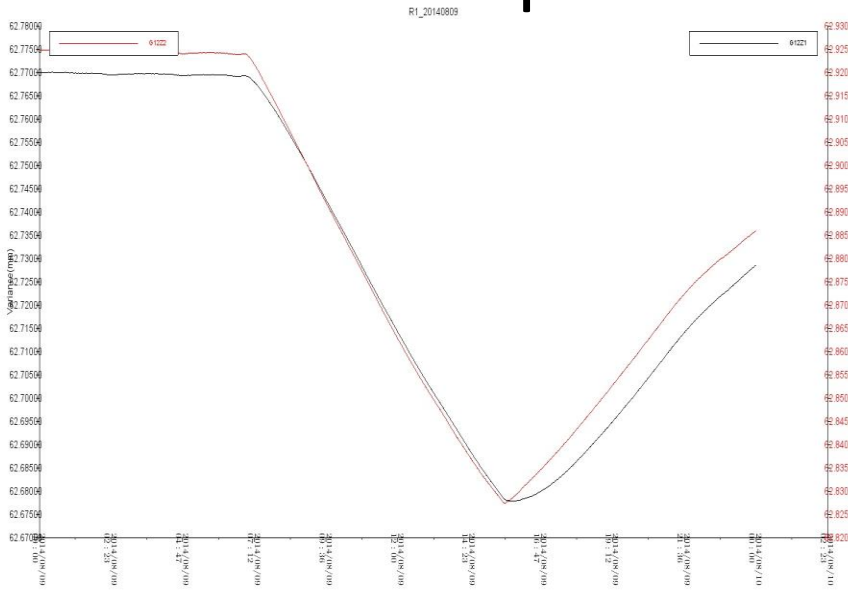
檔案 常用 插入 版面配置 公式 資料 校閱 檢視

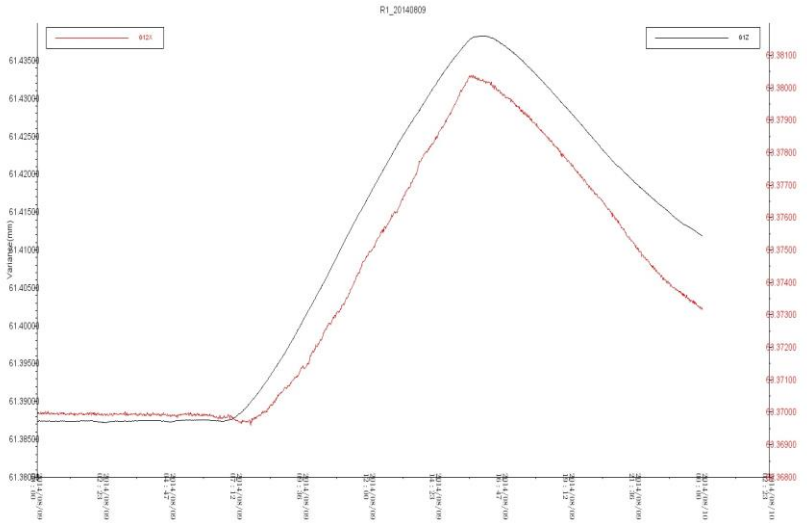
受保護的檢視 小心，來自於網際網路的檔案可能有病毒。除非您需要編輯，否則停留在 [受保護的檢視] 中較為安全。 啟用編輯(E)

D31

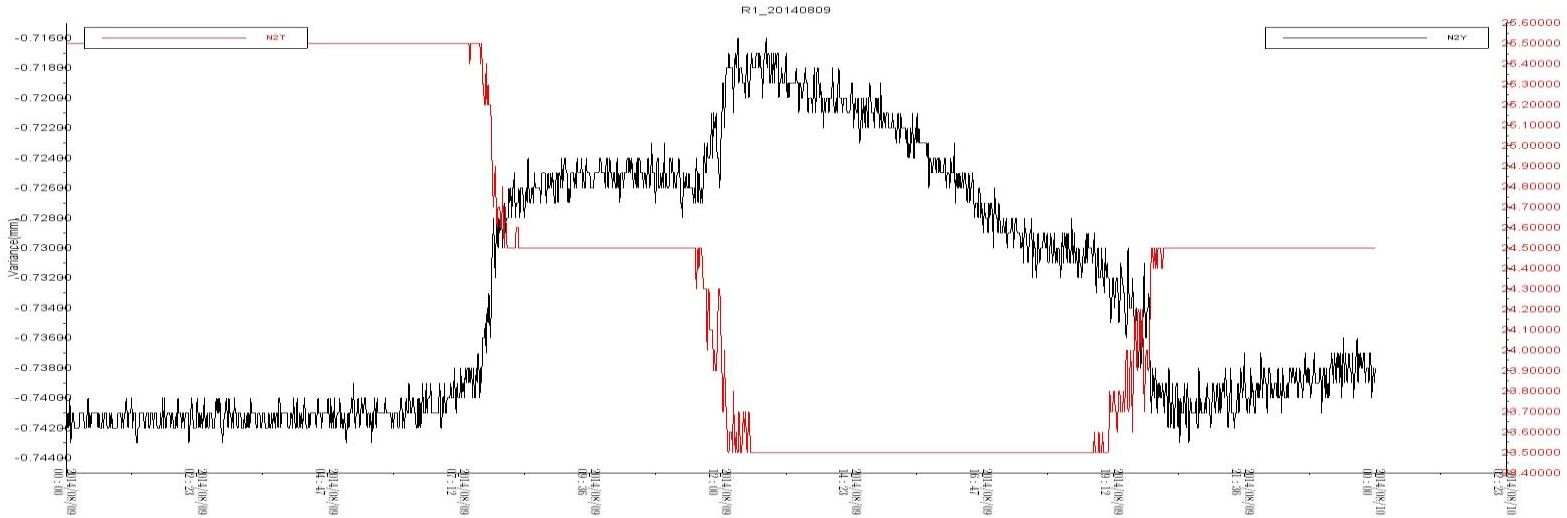
	A	B	C	D	E
1	竹東編號	DET3X	DET4X	DET3Y	DET4Y
2	R1R2	$y=-0.0005x^2+6E\text{-}15x+1.0505$	$y=-0.0003x^2-7E\text{-}15x+1.2093$	$y=-0.0046x^2+0.0046x+1.0785$	$y=0.0025x^2-0.0021x+1.0863$
3	R2R3	$y=-0.0065x^2+0.0051x+1.2076$	$y=0.0029x^2+0.0044x+1.2511$	$y=-0.0048x^2+0.0065x+1.0777$	$y=-0.003x2+0.001x+1.0913$
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	$y=-0.0069x^2-0.008x+1.131$	$y=0.0024x^2+6E\text{-}05x+1.1372$	$y=-0.005x^2-0.0183x+1.1991$	$y=0.0025x^2-0.0049x+1.0807$
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	$y=-0.0196x^2+0.0357x+0.9239$	$y=0.0307x^2-0.055x+0.8778$	$y=0.0059x^2+0.0175x+1.0137$	$y=0.0262x^2-0.0082x+1.0576$
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	$y=0.0054x^2-0.0012x+1.0922$	$y=0.0097x^2+0.0063x+1.1778$	$y=0.004x^2-4E\text{-}05x+1.0623$	$y=0.0049x^2+0.0081x+1.1665$
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

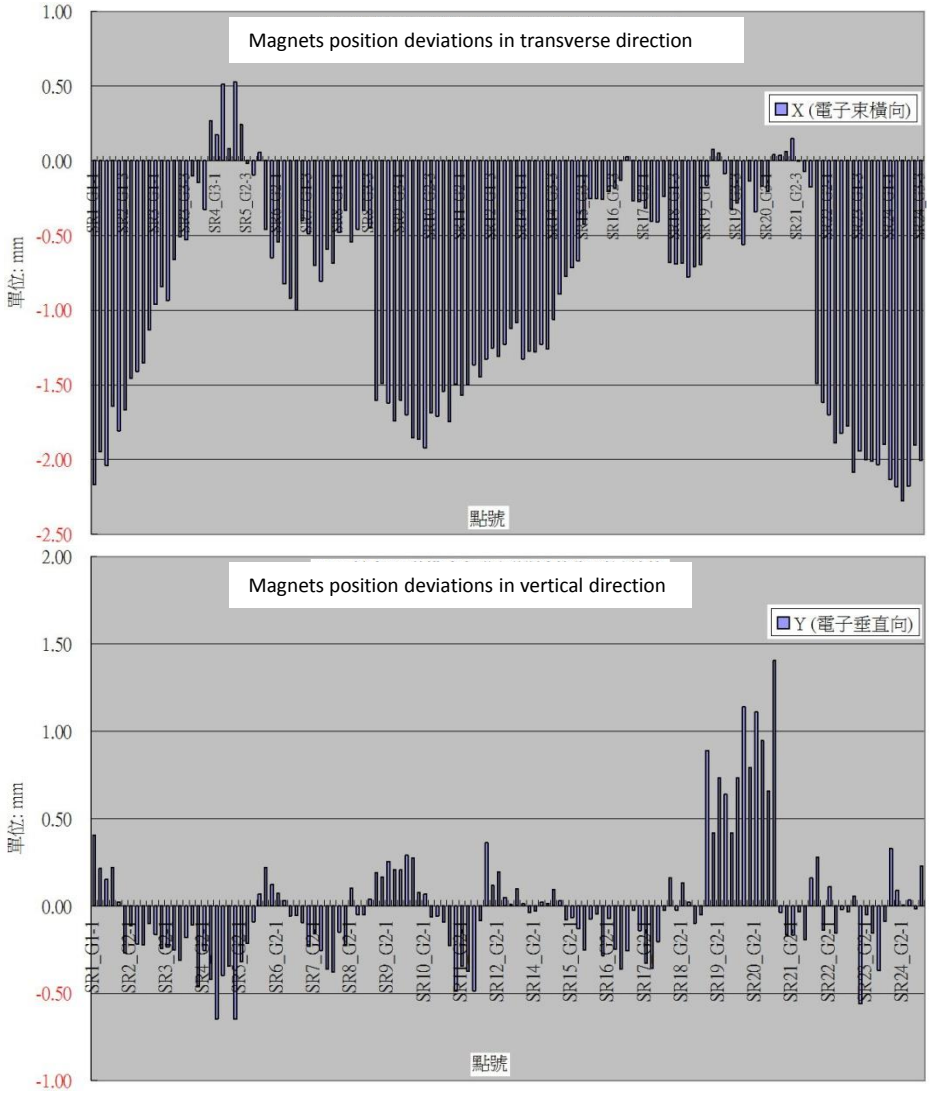




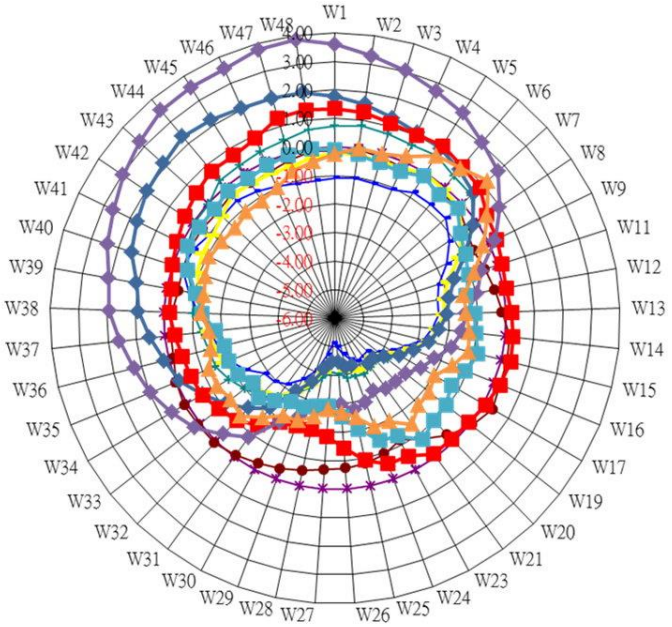
1℃ in temperature change induces 0.1mm deviation between girders

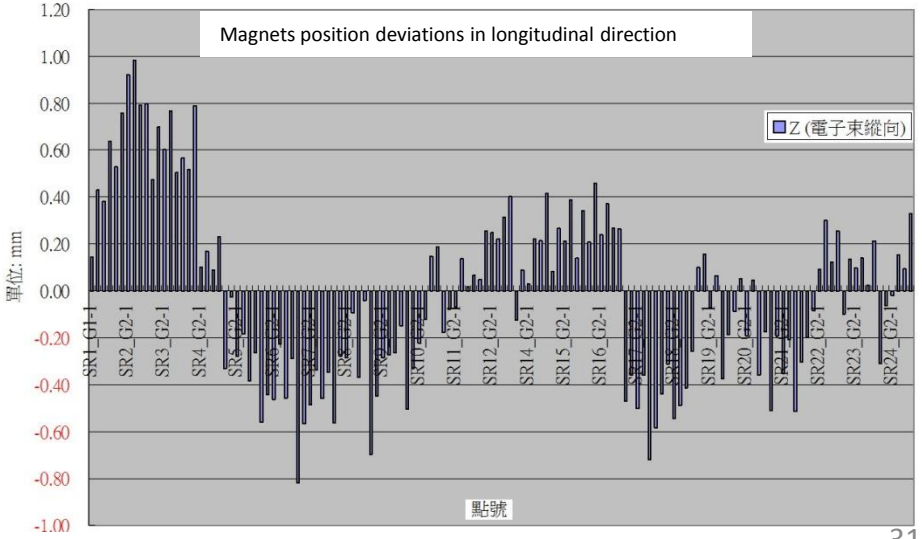


Girder position deviation survey at April 2014



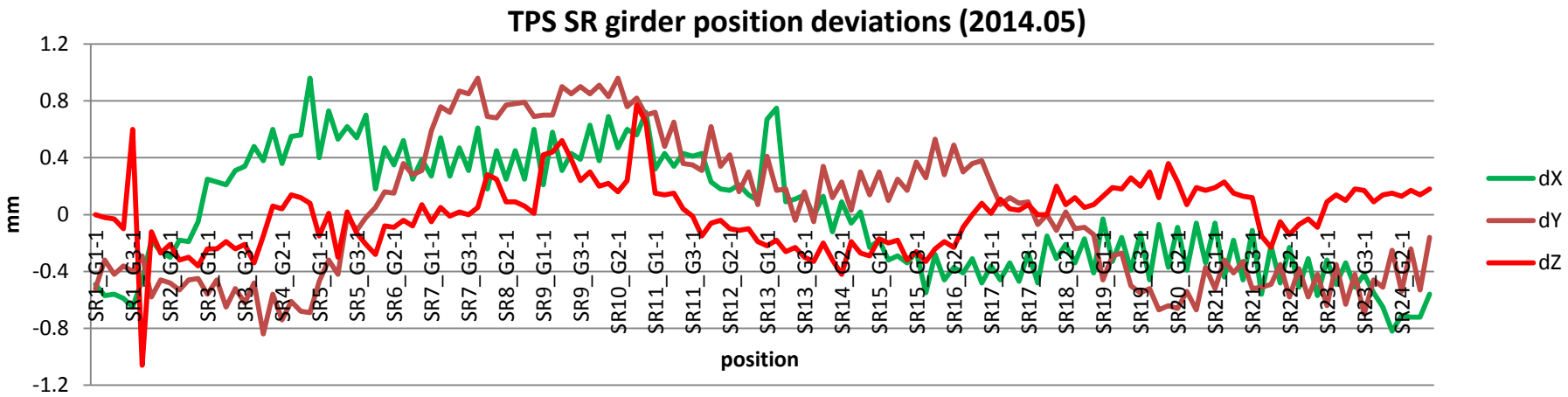
Shield wall position variations in radius direction



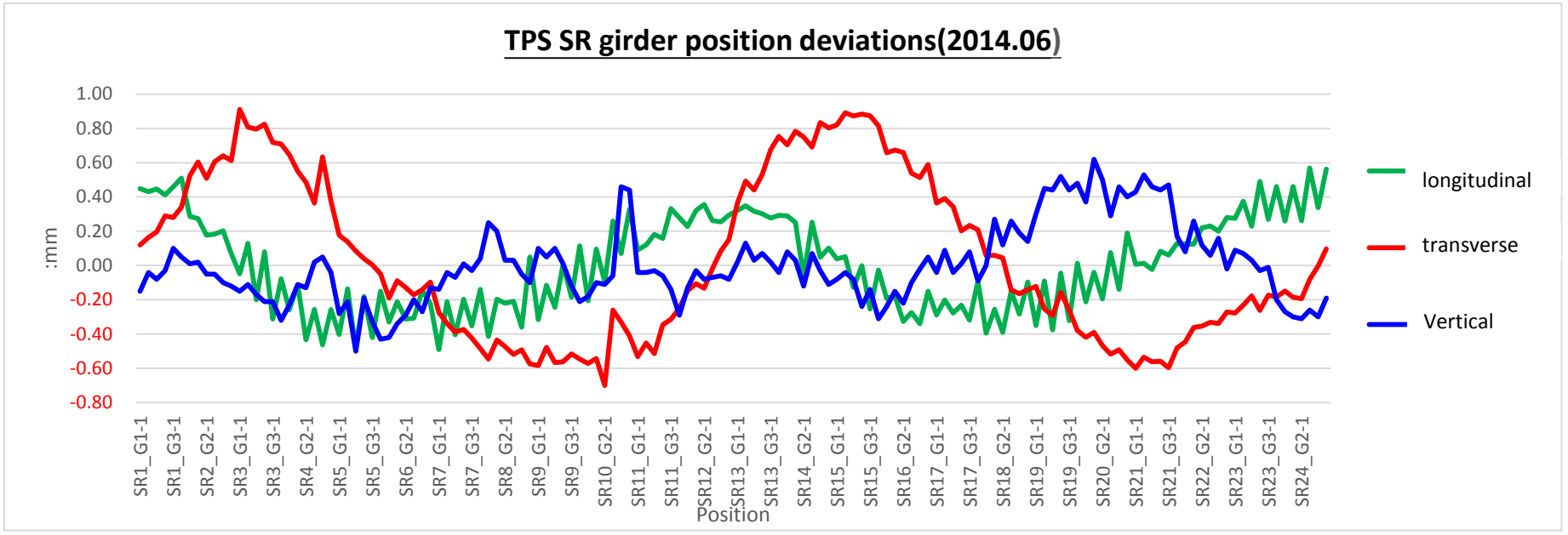


The deviation of girders in transverse direction reveals a shrinkage might be due to temperature.

Laser tracker measurement data

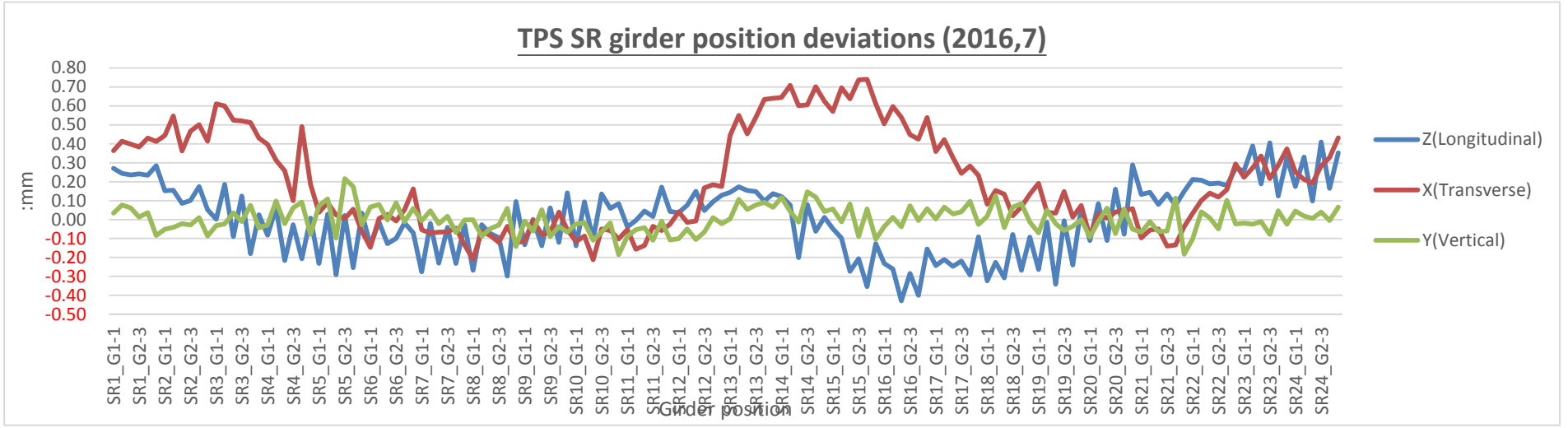


Girder adjusting individually with a laser tracker (a few motor failues encontered)

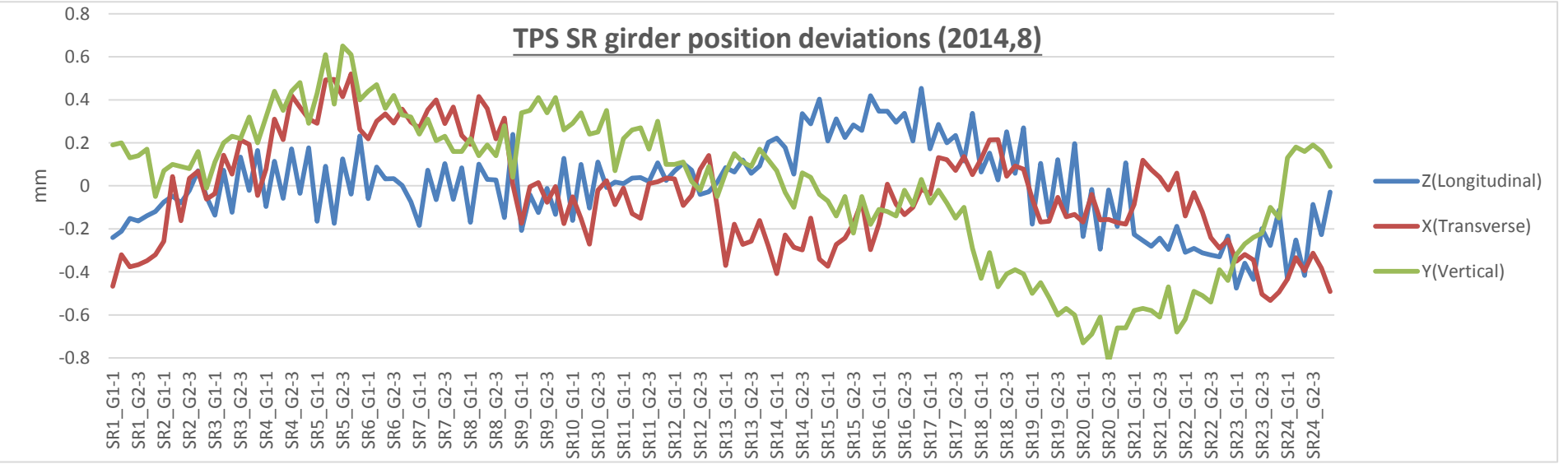


Girder auto-alignment in 1/3 ring each (1mm drop protection)

Laser tracker measurement data



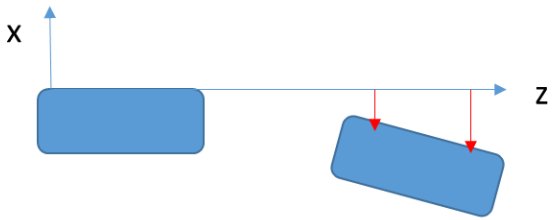
Girder auto-alignment in 1/3 ring each (vertical direction only)



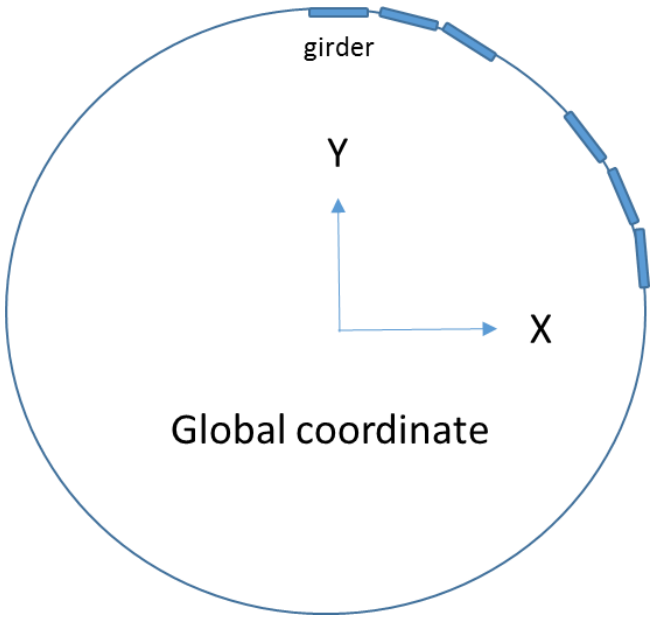
Girder auto-alignment in Full ring

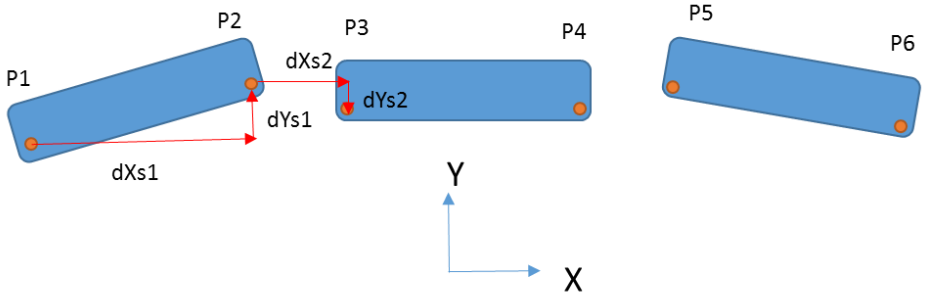
Auto Alignment Processes

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

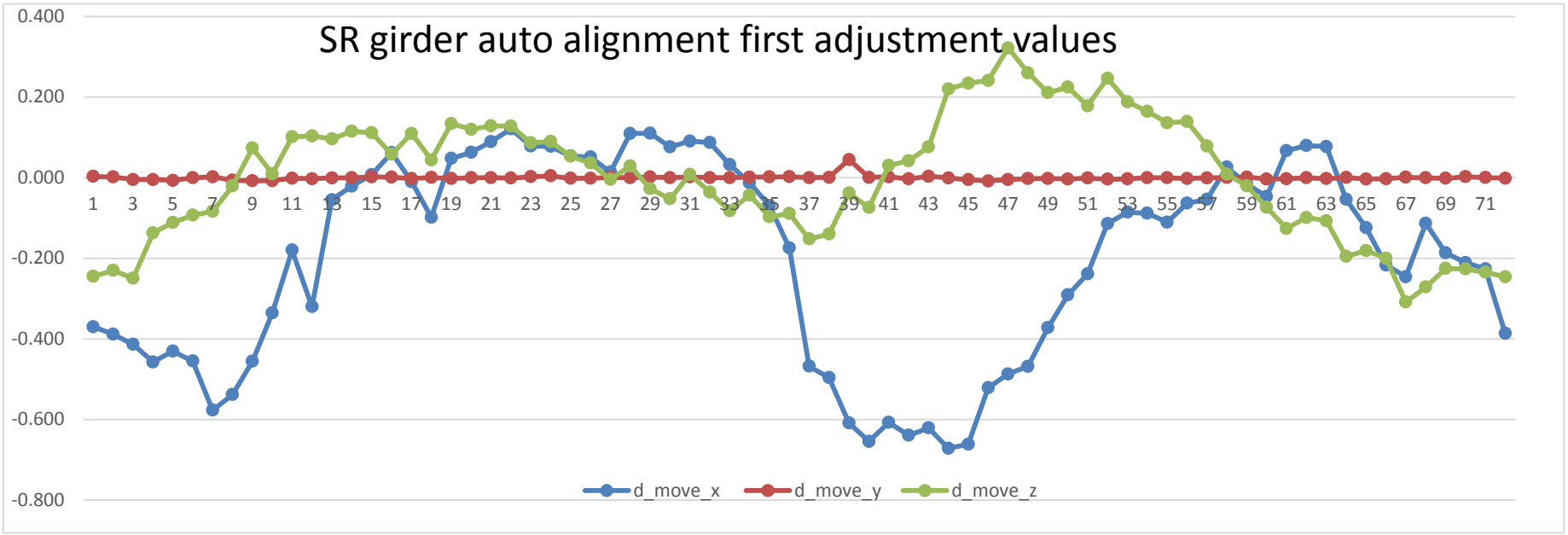


Local coordinate





Auto alignment calculated values



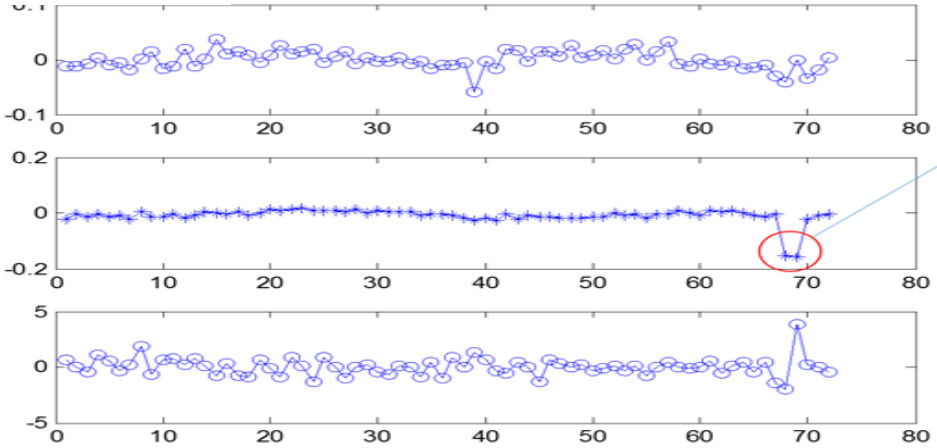
The first turn full ring adjustment takes about 1900 seconds (32min)

Second adjustment values

longitudinal(mm)

transverse(mm)

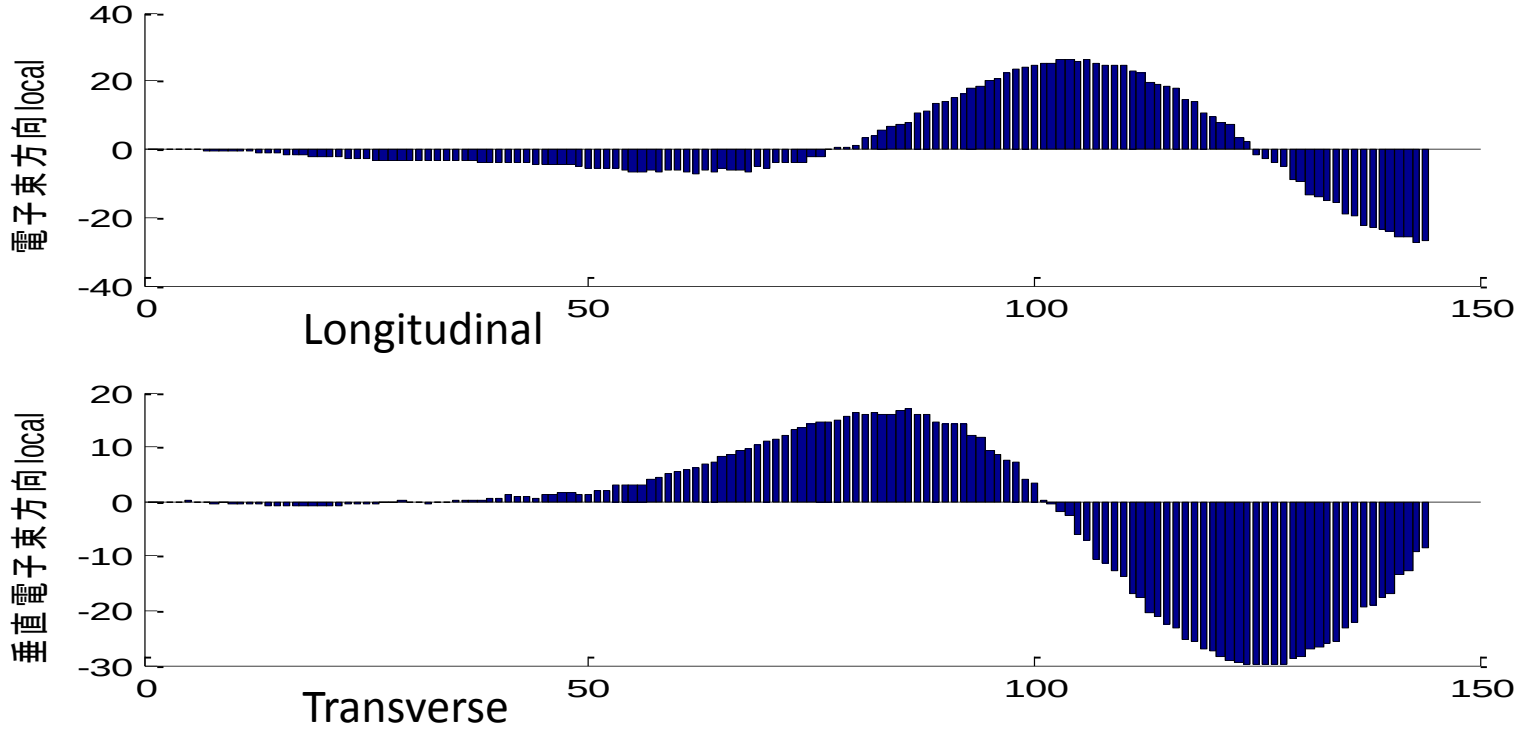
yaw(urad)



SR23g2,g3 Mistakes

To be check

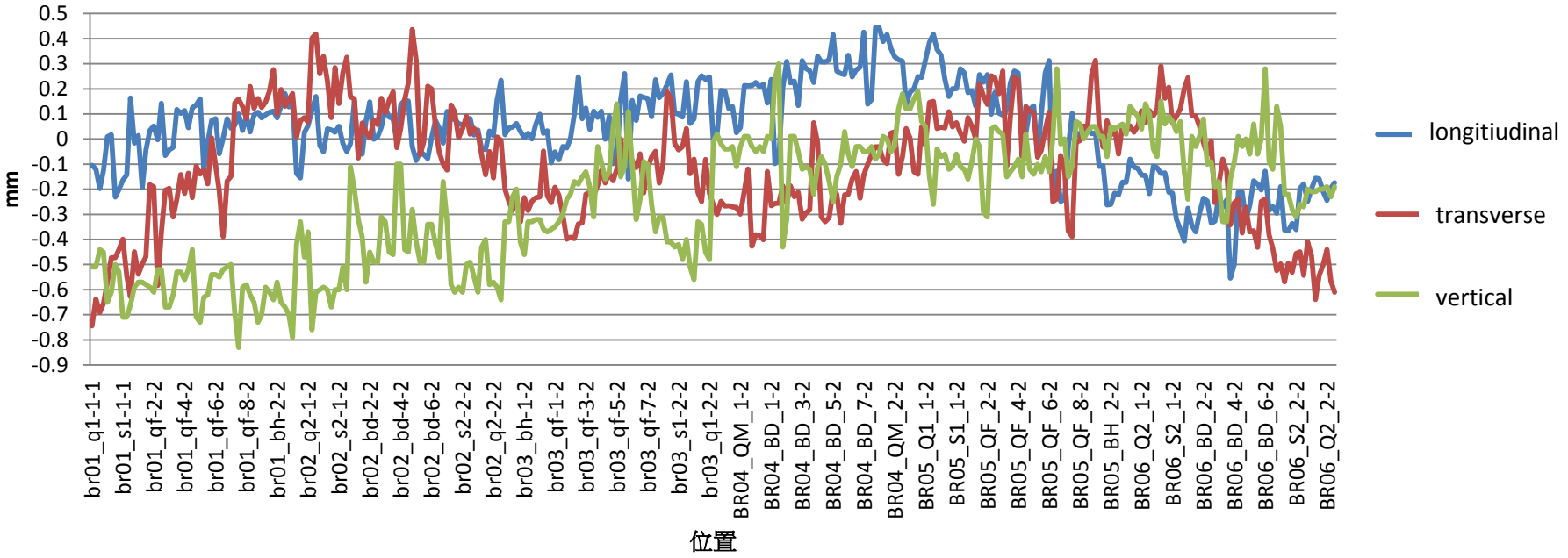
Girder positions comparison between from sensors and laser tracker

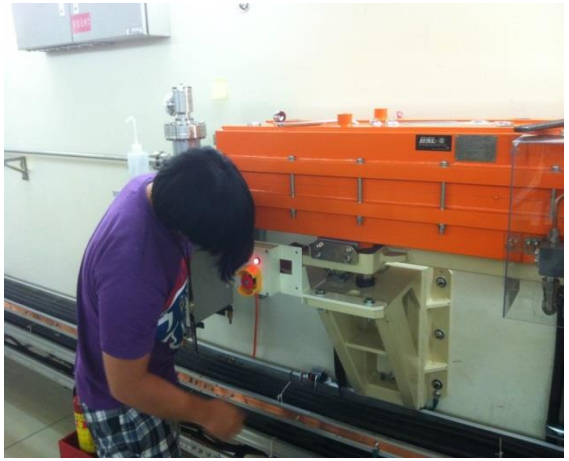


Due to sensor initial conditions are corrupted, two steps will be adopted

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

201408-BR-magnets survey





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

After 2 day's survey work then the booster commissioning started

Summary

1. TPS girder system including storage ring, booster ring and transport line were almost finished installation and the booster ring is now under commissioning.
2. A basically full ring auto-alignment according to the laser tracker survey result had been performed and shows good conditions.
3. The laser tracker survey results show that the full ring real accuracy might be about $\pm$ 0.5mm and the girder sensor's initial conditions should be further improved to optimized the girder alignment.
4. A new adjustment will performed next week to reduce the vertical deviation and a beam based girder alignment might be also adopted during storage ring commissioning.

Thank you for your attention!