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

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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

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

Brightness of Synchrotron Light Sources

![Brightness of Synchrotron Light Sources Graph]
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!
• 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 $\sqrt{3}/2$ 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.

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.

Heidenhain ECN425 rotary encoder
Storage Ring Girder System Design

3 kinds and 5 types of girder

1/6 ring symmetry super-period configuration

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

laser PSD system

touch sensors system

invar wire distance gauge

tilting sensor

One girder section

Heidenhain Acanto AT1218 absolute length gauge

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 an encoder rule
3. Touch sensor module assembling
4. PSD module assembling, partially auto-alignment processing and sensor’s data acquisition
Sensors calibration at Chu-Dung plant

• With a levelling laser (hammer 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
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

**X**

Position

**Y**

Position

**Z**

Position

before alignment

after alignment
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
RMS 18.53um

Magnet Error at Horizontal
RMS 20.42um
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.
Auto-alignment system calibration

PSD beam profile curve fitting

PSD to linear encoder curve fitting

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
Girder sensor reading variations with respect to temperature change

1°C in temperature change induces 0.1mm deviation between girders
The deviation of girders in transverse direction reveals a shrinkage might be due to temperature.
Laser tracker measurement data

TPS SR girder position deviations (2014.05)

-0.80 -0.60 -0.40 -0.20 0.00 0.20 0.40 0.60 0.80 1.00

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

TPS SR girder position deviations (2014.06)

-0.80 -0.60 -0.40 -0.20 0.00 0.20 0.40 0.60 0.80 1.00

Girder auto-alignment in 1/3 ring each (1mm drop protection)
Laser tracker measurement data

TPS SR girder position deviations (2016,7)

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

TPS SR girder position deviations (2014,8)

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) \( \leftarrow \) (dXs, dYs) of each girder
   - Calculate new position by average with the laser tracker data
     - \( P_2(X_{\text{new}}, Y_{\text{new}}) = \frac{1}{2} * [ P_1(XL, YL) + \frac{1}{2}(dXs1, dYs1) + \frac{1}{2}(P2(XL, YL)-P1(XL, YL)) + P3(XL, YL) - \frac{1}{2}(dXs2, dYs2) - \frac{1}{2}(P3(XL, YL) - P2(XL, YL))] \)
   - Calculate all \( P_1(X_{\text{new}}, Y_{\text{new}}) \sim P72(X_{\text{new}}, Y_{\text{new}}) \)
   - Compare with (P1_theory~P72_theory) to calculate adjusting values
     - Adjust girder 1 of each section and record touch sensor 1\(^{st}\) readings
     - Adjust girder 2 of each section and record touch sensor 2\(^{nd}\) readings
     - Adjust girder 3 of each section and record touch sensor 3\(^{rd}\) readings
     - Accord to the 3 touch sensor readings to calculate the real movement of each girder
     - Renew each girder postions \( P(X', Y') = P(X_{\text{new}}, Y_{\text{new}}) + \text{movement} P(dX, dY) \)
   - Iteration till converge
Auto alignment calculated values

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

SR girder auto alignment first adjustment values

Second adjustment values

longitudinal (mm)

transverse (mm)

yaw (urad)

To be check

Mistakes
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
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 $\pm 0.5\text{mm}$ 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!