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THE AUTO-ALIGNMENT GIRDER SYSTEM OF TPS STORAGE RING

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Abstract

To meet the stringent beam dynamic specs of TPS with high brilliance and low emittance characteristics, also to align the girders precisely and quickly with less manpower, the girder system for TPS (Taiwan Photon Source) storage ring is of an auto-tuning design. Each girder can be fine adjusted in 6 axes with 6 motorized cam movers of kinematic mounting design on 3 pedestals. With sensors between each girder, there are 72 girders to make up a whole ring auto-alignment girder system. All the sub-systems were carefully assembled and calibrated in a rented factory outside NSRRC during the civil construction period. Mock-up systems were set up and the auto–alignment processes were examined to modify interferences or mistakes between sub-systems. After the TPS building was nearly completed, the laser tracker alignment network was set up first and then the installation took place. When all the girders and sensors were installed into the tunnel, the auto-alignment procedures were carried out to fine tune all the girders. This paper describes the design, preparation, installation and implementation of this auto-alignment girder system for TPS storage ring.

INTRODUCTION

The TPS (Taiwan Photon Source) construction project started formally from 2006 while a feasibility study was initiated in 2004. It aimed to build a high brilliant and the very low emittance 3Gev ring with 518m circumference [1]. To meet the stringent beam dynamic specs, all the magnets should be located at precise positions and also firmly supported. However, considering the deformation of the floor and limited space in the tunnel also frequent earthquake in Taiwan, to align the girders precisely and quickly with less manpower is essential and an automatic-tuning girder system is thus proposed.

The design goal of the girders system for TPS is:

- To firm support and precise positioning of magnets
- Whole ring automatic alignment
- Precise resolution (μm)
- Beam based girder alignment (proposed)

In order to fulfill these challenging ambitions, a 6-axis motorized adjusting mechanism thus demanded. This girder system design is a modification from the girder system used in SLS (Swiss Light Source) by extending a 3 grooves type kinematic mounting from 3 balls to 6 balls and with a few major considerations:

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

In 2005, a preliminary study prototype bending section with 3 girders had been established for a test. This prototype proved the 6 axes adjustability with less than 1 μm resolution but the contact stress is exceed the elastic limitation due to point contact and wear occurred after a lifetime test [2-6].

In 2009, after the design stage of TPS is almost finished, a nearly real size testing mock-up system was set up in NSRRC fab for a system test and final examination [7-9]. After a few modifications, all hardware systems went into mass production processes.

From 2010, during the civil construction period, all the sub-systems were carefully assembled and calibrated in a rented factory outside NSRRC. A third mock-up system was set up again to modify interferences or mistakes [8-11].

After the tunnel completed, starting in January 2013, the pedestals were to be set out, anchor bolts drilling and installed with the accuracy around ±1mm. Upon completion of installation, the pedestals were grouted to the ground. There were 2 bending sections installed at July as an on-site mock-up testing system and the entire system installation began from October at a rate of 2 sections per week.

The whole storage ring girders were completed craned at March 2014 and finished control system installation test at May. In August, a whole ring girder automatic alignment was really performed the first time and it takes only 1900 seconds (32 minutes). In October, a second automatic alignment was performed to further minimize the deviations. Then, after the problem of high permeability booster vacuum chambers was discovered and solved, the commissioning of both rings were quick and accumulated beam took place at the end of 2014.

GIRDER SYSTEM DESIGN

According to the six-fold symmetric configuration DBA lattice design, 3 consecutive girders were used to accommodate one bending section magnets with the 2 dipole magnets assembled on side girders. With 4 bending sections to form a superperiod as in Fig. 1, there are 3 girder types and 72 girders total for the storage ring. With an electric levelling sensor (Leica Nevil 220) on each girder and touch sensors (Heidenhain Acanto AT1218 absolute length gauge) between consecutive girders in addition with a laser PSD (Position Sensitive Detector) system between straight section girders, a feedback controlled full ring automatic tuning girder system is established as in Fig. 2.

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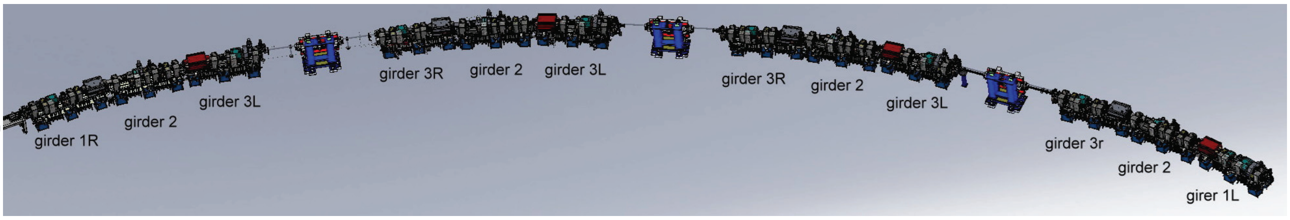

Figure 1: One superperiod girder configuration of the TPS storage Ring.

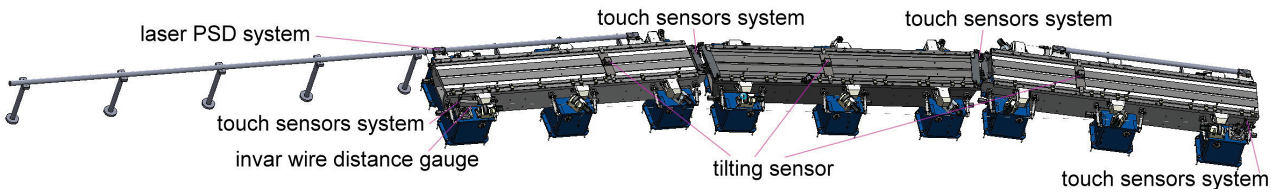

Figure 2: One superperiod girder configuration of the TPS storage Ring.

One Girder System Design

The girder adjusting system design is a modification of a 3 grooves type kinematic mounting by extending 3 balls to 6 balls as in Fig.3. Each 2 balls contact with one groove can be imaged as a part of a big ball that encloses and is tangent to the 2 balls. Replacing the balls with ball transfer units, expanding them further and equally spacing along the girder, replacing the contacting groove's surfaces with cam movers, putting each 2 cam movers on opposite side of the girder on a pedestal, then a girder system with 6 cam movers on 3 pedestals was established as shown in Fig.4.

A major design modification to the cam mover was made after the first prototype. The size of the cam is enlarged form diameter 130mm to 140mmm and a recess arc of radius (45.2mm) slightly larger than the SP90 transfer unit ball radius (45mm) is put on the contact position then the contact positions of the ball and the cam remain the same but the contact situation changes from point contact to line contact as shown in Fig 5. It not only reduce the contact stress but also preserve the advantage of kinematic mounting and will still resume the existing adjusting algorithm [2] of single girder. From the Herz contact stress calculation, the stress is reduced drastically and far beyond the elastic limitation of the cam.

In this design the ball will always contact with the cam at the recess arc area, so the cam could not be rigidly connected and rotate simultaneously with the shaft. An additional E5009 type bearing is placed between the cam and the shaft, then the cam will swing with the ball or the ball will rolls along the arc area in the axial direction at adjustment. Thus, the conditions of kinematic mounting are still met in this design only there will be slightly differential friction when the ball rolls along the arc area in the axial direction. The differential friction is only about 3% due to radius change and is met the spec of a normal bearing, besides, this is a slow speed adjusting mechanism and will not operate continuously. The friction wear due to this phenomenon is negligible.

The locking mechanism is a wedge type DC motor driving stage inserted between girder and pedestal in order to raise the natural frequency and reduce vibration magnification of the girder system.

There are 3 hard stop shafts across the pedestal and girder body that limit the girder adjusting range to ±0.5mm after all the components of the ring are installed. In Addition, these shafts also secure the girder from earthquake jumping.

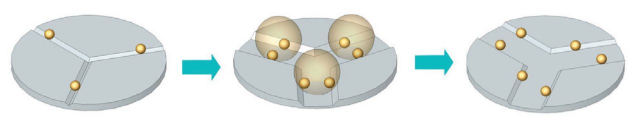

Figure 3: Expand 3-Groove type kinematic mounting from 3 balls to 6 balls.

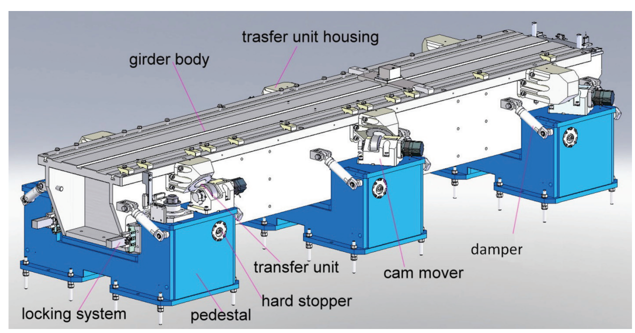

Figure 4: One girder configuration.

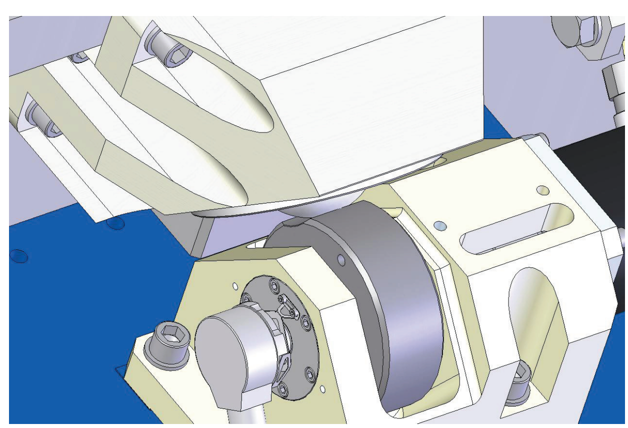

Figure 5: Cam mover design modification.

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Magnet Clamping Design

The girder is of a table type design basically and there are 3 magnet installation referencing channels precisely machined within 15μm tolerance to keep the magnets aligned precisely. The magnet was pre-assembled on a mounting base. The mounting base was also precisely machined within 15μm tolerance. When assembled on the girder, two side channels can keep the magnets on the same height with minimized rotation. Then 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 as show in Fig. 6.

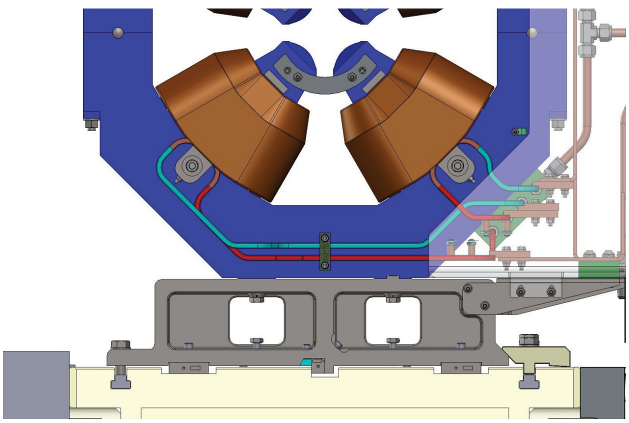

Figure 6: Magnet clamping design.

Control System

TPS girder control system consists of twenty four local girder control systems and a global girder-position computer. Each local control system controls 3 girders of a bending section. It consists of 5 sub-systems: cam mover control, rotational encoder with touch sensor reading, tilting sensor reading, PSD reading and locking control.

In order to automatic adjust the girders quickly and precisely, 2 major algorithms had been developed. An auto-alignment algorithm optimizes the girder adjustment quantities according to the deviation reading from sensors and a girder adjustment algorithm transfer the girder adjustment quantities to the mover motor's rotating degrees[8,9].

The global girder-position computer grabs each girder's deviation values in six degree of freedom from sensor's reading and calculates all girders best positions by minimizing global girder position errors according to the auto-alignment algorithm. Then the local girder control systems determines the rotating angles of the mover motors by the girder adjustment algorithm with the adjustment quantities from the global girder-position computer via intranet. Fig. 7 shows the network and system architectures of the girder control system.

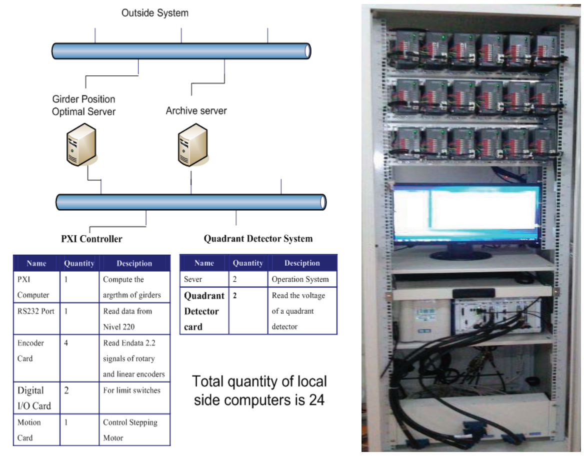

Figure 7: Network and system architectures of the girder control system.

PREPARATIONS AT THE RENTED PLANT

During the civil construction period of the main building, all components had been design modified completely and contracted out for manufacturing. Due to space limitation, a plant outside NSRRC was rented for assembling and testing of girder, magnets and vacuum system.

At a temperature controlled (±0.1^{o}C) lab, 2 bending sections of 6 girders with a straight section assembling area had been set out. The sensors system assembling and calibration were carried out at first as in Fig. 8 and the procedures include:

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

Afterward, the magnets assembling and centring processes followed and transported to the loading dock when installation procedure started as in Fig. 9.

Figure 8: Sensors system assembling and calibration.

Figure 9: Magnets assembling and transporting.

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SURVEY ALIGNMENT WORKS

Taiwan photon Source started to break ground at February 2010. Accompanying with construction of the main building, there are GPS pillars set up as civil construction control points. With the progress of construction, benchmark points were expanded to form the entire survey network for the accelerator installation as in Fig. 10 [12].

With the survey data from the sockets at tunnel walls and experimental hall columns, a seasonal expansion and shrinkage about 3 mm in radius direction according to the temperature change can be observed and 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. However, as the storage ring temperature control available from May 2014, the situation seems moderated as in Fig. 11 but still need to accumulate survey data monthly later on for future operation reference.

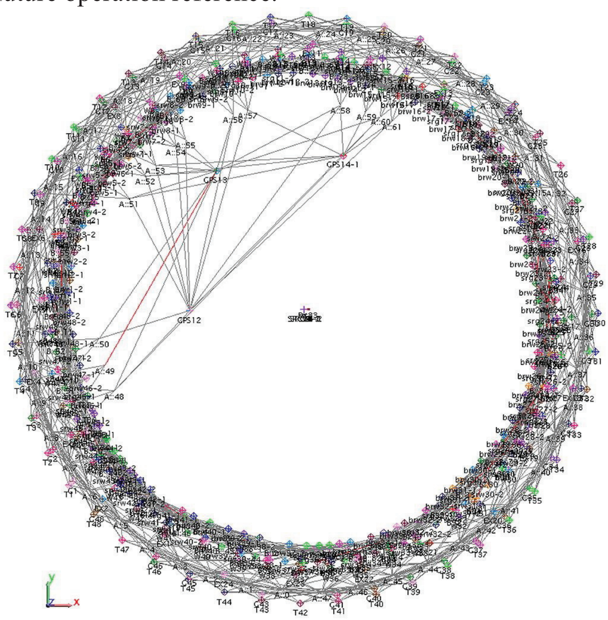

Figure 10: The survey network of TPS.

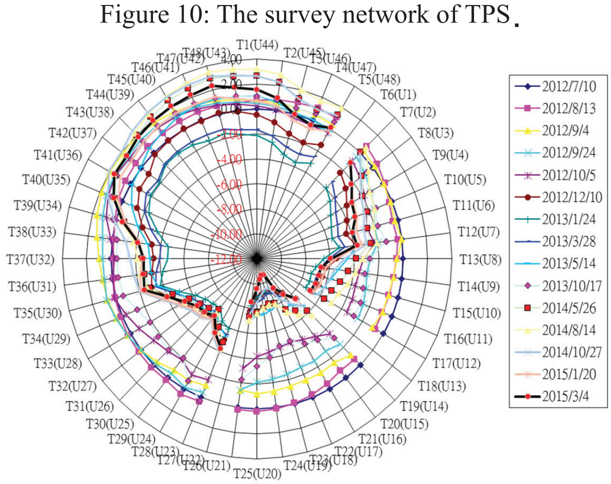

Figure 11: The TPS building variation in radius direction.

GIRDERS INSTALLATION AT TPS TUNNEL

After the tunnel completed, starting in January 2013, the pedestals were to be set out, anchor bolts drilling and installed at the accuracy around ± 1mm. Upon completion of installation, the pedestals were grouted to the ground. Two bending sections were installed at July as a mock-up testing system and the entire system installation began from October at a rate of 2 sections per week as in Fig. 12. The whole storage ring girders were completed craned at March 2014 and finished control system installation test at May as in Fig.13 [13].

As each 2 girder sections installed, the position deviation were examined with a laser tracker and mostly were around ±1mm within the adjusting range and were adjusted with local network to less than 0.1mm.

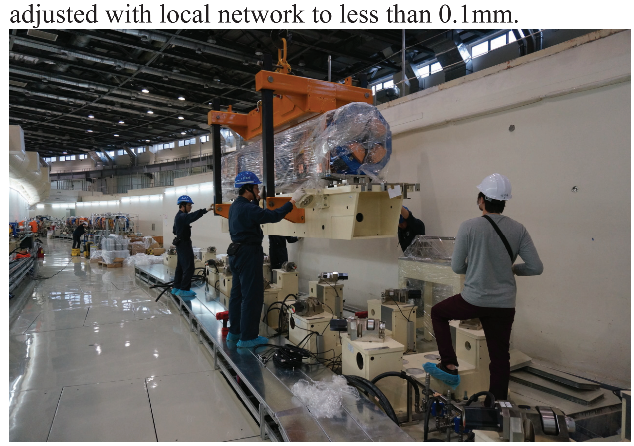

Figure 12: Girder installing with a cradle by a crane.

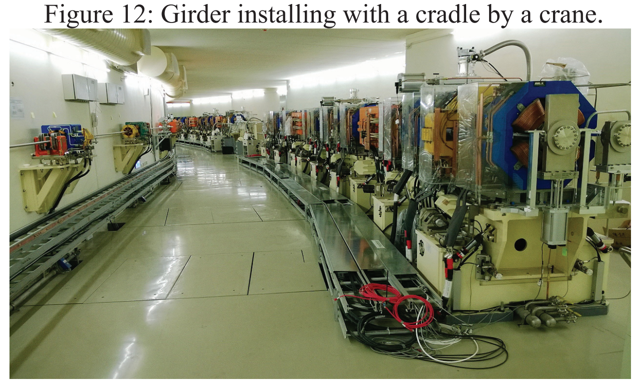

Figure 13: The whole ring girders installed at TPS tunnel.

AUTO ALIGNMENT PREPARATION AND IMPLEMENTATION

A laser PSD magnet centring measurement had been established to check the alignment deviations of each magnet machine center when installed at the girder. The work had been started at the rented plant at a repeatability of 2μm. Due to the tight schedule, 3/4 ring magnets were examined at tunnel at a repeatability of 10μm when the air conditioning and temperature control was still unavailable. However, the RMS errors of 18.5μm and 20.4μm in vertical and horizontal direction respectively still meet the spec of beam dynamic as in Fig.14.

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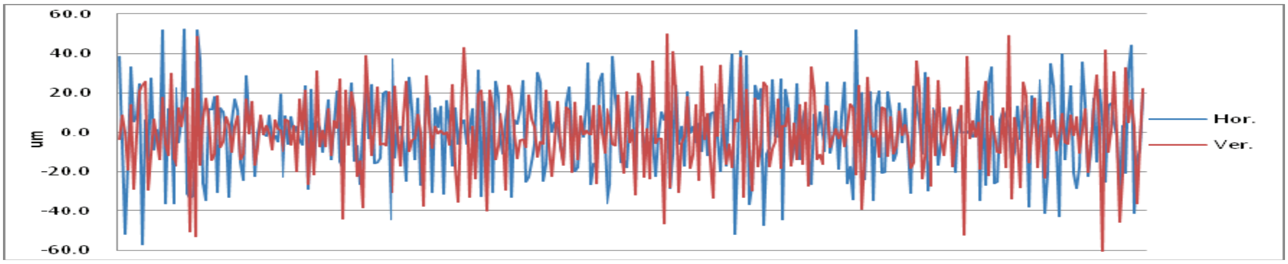

Figure 14: The position deviations of each magnet center when assembled on the girder.

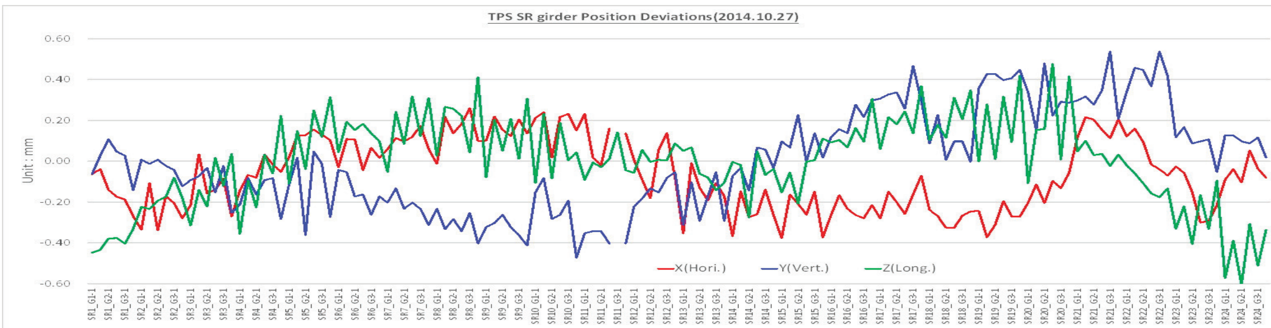

Figure 15: The laser tracker survey network errors of girders after second auto-alignment.

As the girders finished installation, the important works were the inspection of the connection of the sensors with the control system. After about 2 months examination and further calibration including some damage sensors replacing, in the middle August, the storage ring were preliminary automatically aligned and the booster ring were manual aligned according to the laser tracker survey network with the deviations within ± 0.5mm. The adjustment time for storage ring (72 girders) is about 1900 seconds once time. In October, a second automatic alignment was performed to further minimize the deviations as in Fig.15. From the commissioning results, the measured COD is quite closed to the simulated one from sub-system deviation data and even better [14].

CONCLUSION

TPS girder system including storage ring, booster ring and transport line were almost finished installation in August 2014. A basically full ring auto-alignment according to the laser tracker survey result had been performed and shows good conditions.

The laser tracker survey results show that the full ring real accuracy might be about ± 0.5mm. However, 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 girder alignment.

Though the TPS commissioning had been completed, the locking systems of girder were still not applied yet. The cabling was starting from April 2015. Further measurements and improvements on vibration issues are scheduled.

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