DESIGN AND EXPERIMENT ON AUTO-ALIGNMENT CONTROL SYSTEM OF TAIWAN PHOTON SOURCE

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Abstract

TPS (Taiwan Photon Source) is a new 3-GeV synchrotron ring to be constructed at the NSRRC (National Synchrotron Radiation Research Center), Taiwan. There were hundreds of magnets that must be aligned on the absolute position to keep the electronic beam in the desire path while orbiting. Due to the problems of manpower, set up time, accuracy of adjustment, deformation of the floor, limited workspace and frequent earthquakes in Taiwan, an auto-alignment girder control system was designed to meet this requirement. The design and experiment of the auto-alignment system were tested successfully in the laboratory at NSRRC. The experiment of the auto-alignment control system would be implemented with half of the ring girders in the TPS. The detailed alignment design and status will be discussed in this paper.

INTRODUCTION

Taiwan Photon Source (TPS) is a new 3-GeV ring under construction at the NSRRC site in Taiwan with circumference 518.4 m and 24 double-bend cells. Based on the consideration of stability, the entire building is being constructed half underground at depth 12 m [1] [2]. The measured area is wide, and survey network is hard to be connected in the ring. Besides, the structure and environment of storage ring in TPS is unstable in the initial constructing stage. Therefore, the auto-alignment control system is proposed to improve the precision of survey in TPS construction.

TPS auto-alignment control system is designed for aligning the magnet girder system with little manpower and time and improving the accuracy of girder system in the whole storage ring simultaneously. The construction of system, calibration process, auto-alignment process, and discussion were included in the paper. Hardware includes pedestals, girders, cam movers, precision inclination sensors, laser PSD, a laser tracker and absolute length gauges. The process of auto-alignment is described as follow. Coordinates and angular deviation could be measured by absolute length gauges and laser PSD. Pitch and roll angle of girders were measured by precision inclination sensors, following by the calculation of auto-alignment process with above measured data to update the positions of girders. Finally, girders were aligned to updated positions by cam movers accordingly. In the planned schedule, there will be thirty-six girders equipped in TPS for the experiment initially; besides, a laser tracker is employed to acquire the data as the feedback one in auto-alignment process to form a closed loop.

CONSTRUCTION OF SYSTEM

The construction of TPS auto-alignment system in our experiment is shown in Figure 1. There were 6 double-bend cells SR1 (storage ring 1), SR2 (storage ring 2) to SR12 (storage ring 12) in the experimental construction. Each girder is located on six cam movers. Angular deviation between two double-bend cells is measured with a laser PSD system. Relation of positions between adjacent girders could be obtained from absolute length gauges. The laser tracker is employed to acquire the data as the feedback loop in auto-alignment process. In Figure 1, laser tracker was used to measure positions of point B and C automatically and the position of point A could be derived from point B and C.

The data of point B and C could be used to locate positions of girders and to form a closed-loop feedback.

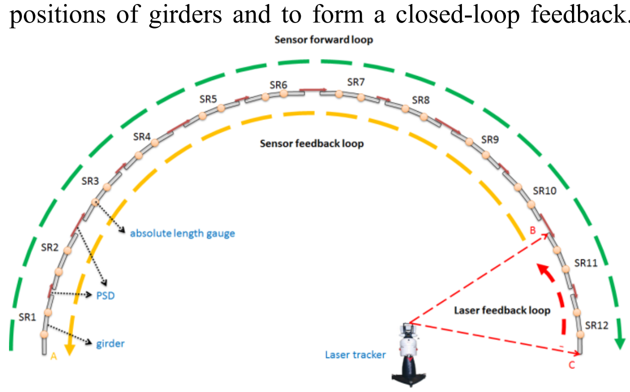

Figure 1: Illustration of closed-loop architecture for auto-alignment.

CALIBRATION PROCESS

In order to improve the accuracy and eliminate systematic error between different sensor modules of measurement, the calibration must be done in the initial auto-alignment process.

Measurement Matrix of Absolute Length Gauges

There were multi absolute length gauges installed between adjacent girders to improve the measurement accuracy shown in Figure 2. There were four fiducial points (P1, P2, P3, P4) between 2 adjacent girders. The position of P1 was (Z1, X1). The computation of P1 was shown as equation (1). The lengths (LX1, LX2, LZ1, LZ2,

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LS) in the equation were measured by linear encoders. The measurement matrix M of absolute length gauge was also obtained and could be used in the auto-alignment algorithm. In the equation (1), Sz1, Sz2, Sx1 represents measured value of absolute length gauges in the z axis and x axis separately. C1, C2 were the constants.

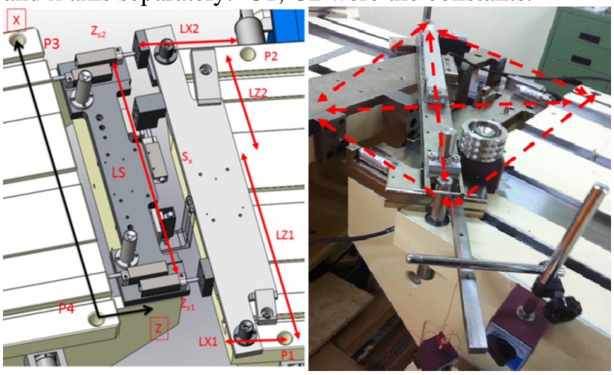


Figure 2: The local coordinate model and linear encoder.

$$Z_1 = -[(S_{z1} - S_{z1i}) + (S_{z2} - S_{z2i})]/2 + [(S_{z2} - S_{z2i}) - (S_{z1} - S_{z1i})]/LS \cdot [LZ_1 + (S_x - S_{xi})] + c_1$$

$$X_1 = -[(S_{z2} - S_{z2i}) + (S_{z1} - S_{z1i})]/LS \cdot [LX_1 - [(S_{z1} - S_{z1i}) + (S_{z2} - S_{z2i})]/2] - (S_x - S_{xi})] + c_2$$

$$[P1] = [M] \cdot [S_{z1}, S_{z2}, S_x] + [C] = \begin{bmatrix} M_1 & M_2 & M_3 & C_1 \\ M_4 & M_5 & M_6 & C_2 \end{bmatrix} \cdot \begin{bmatrix} S_{z1} \\ S_{z2} \\ S_x \\ 1 \end{bmatrix} \quad (1)$$

According to the above equation, the more precise position of P1 could be obtained. Because the precision of absolute length gauges were less than 2 µm and the calibration module precision was less than 10 µm. It was better than initial data from laser tracker.

PSD Calibration

The PSD adjusting mechanism was shown in Figure 3. It will be installed on the girder for calibration. The PSD laser spot which was grabbed by software was show in Figure 4. The calibration flow was to move girder as shown in Figure 5. Figure 5(a) was the illustration of horizontal calibration. The spot moved from origin along the horizontal way at the same Y. During moving process, the absolute length gauge value was also recorded for horizontal calibration. In this coordinate, X means horizontal direction and Y means the vertical direction. Figure 5(b) was the illustration of vertical calibration. The spot moved from origin along the vertical way at the same X. During moving process, the absolute length gauge value was also recorded for vertical calibration.

The laser spot on PSD and the absolute length gauge deviation would be updated simultaneously. Position data and power of PSD will be record. The recording data of PSD was compared with absolute length gauges, positive ratio between PSD and absolute length gauge was observed. The fitting curve of SR1 and SR2 was shown in Figure 6. The traveling process of girder was set within ±2000 µm from the origin which was shown in Figure 5. After traveling process, the coefficient equation between absolute length gauge and PSD was computed with curve fitting.

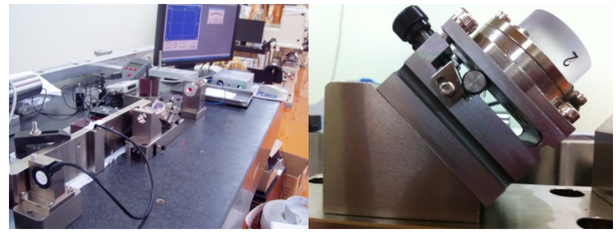


Figure 3: Illustration of PSD adjusting mechanism.

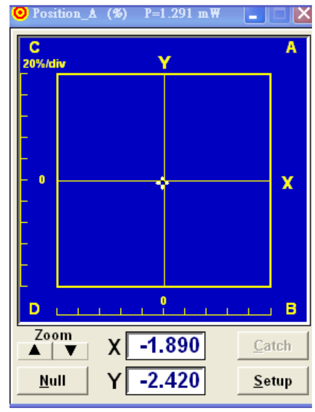
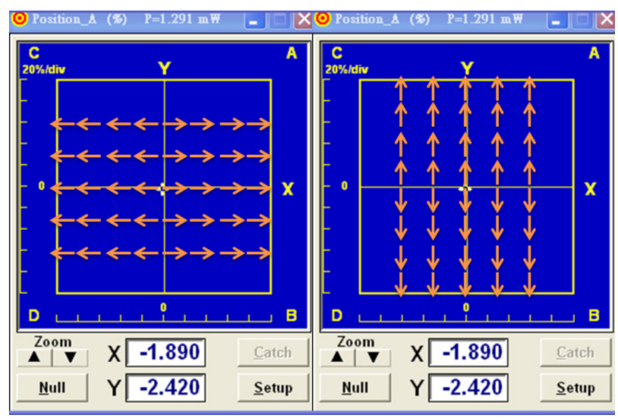


Figure 4: Illustration of laser spot on PSD displayed by software.



(a) (b)

Figure 5: Illustration of horizontal and vertical traveling process during calibration.

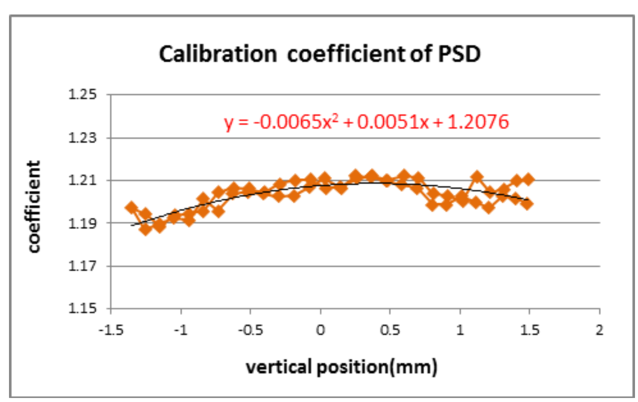


Figure 6: calibration coefficient between PSD and absolute length gauges.

PROCESS OF AUTO ALIGNMENT

The auto-alignment flowchart could be designed as shown in Figure 7. The algorithm was established under a condition that the sensor accuracy was within a few um, so the system could improve the initial position of laser tracker accuracy with data from precise sensors via iteration cycle.

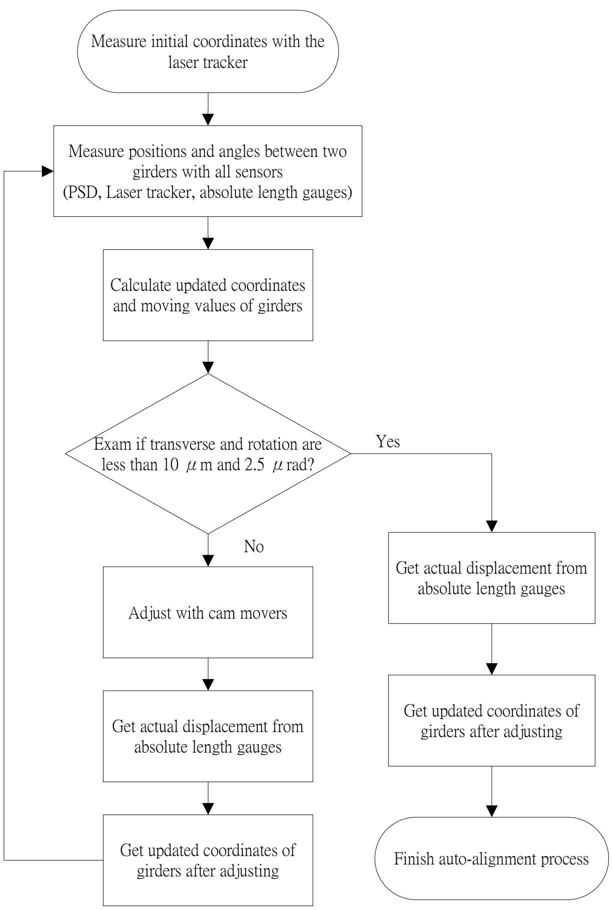


Figure 7: Auto-alignment flowchart.

The new position of each fiducial point was computed from the positions of two adjacent points and the data read from the sensor according to the equation (2).

$$
\begin{aligned}
G_{nL}(X,Y,Z)_{i+1} = \{ & [G_{(n-1)R}(X,Y,Z)_i + W(S_{(n-1)n}(X,Y,Z)) \\
& + (1-W)[G_{nL}(X,Y,Z)_i - G_{(n-1)R}(X,Y,Z)_i]] \\
& + [G_{nR}(X,Y,Z)_i - WS_n(X,Y,Z)_i \\
& - (1-W)[G_{nR}(X,Y,Z)_i - G_{nL}(X,Y,Z)_i]]\}/2
\end{aligned} \qquad (2)
$$

The symbols, $G_{(n)R}(X,Y,Z)_i$ and $G_{nL}(X,Y,Z)_i$ signify two end points of a girder as shown in Figure 8, and n denotes the number of a girder. L and R denote left and right points on the girder, and suffix i denotes the number of iteration sequence. Symbols $S_n(X,Y,Z)$ and $S_{(n-1)n}(X,Y,Z)$ was defined as the angle between girders and the sensors module. W denotes a weighting value.

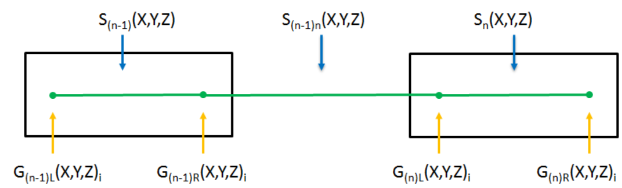


Figure 8: Illustration of symbols.

There was a mock-up section built in the TPS. It was shown in Figure 9. The drilling holes and bolts bonding had completed. The pedestal also positioned accurately. The following work was to position multi girders placed on the pedestal, and set up all the magnets and vacuum chamber. Except for hardware installation, the software and algorithm had been tested successfully in prior experiment [4]. Besides, the control software was also updated for half the ring of girders.

Figure 9: Mock-up section in TPS.

DISCUSSION

The laser tracker could form a closed loop to resolve the problem of current open-loop structure in the experiment. The summary of experiment from one double-bend cell was that the translation and rotation deviations of the system could be less than 10 μm and 2.5 μrad, respectively. The repeatability of the system is tested 10 times with only 10 μm of systematic error. The auto-alignment control system shows good repeatability and convergence. Moreover the system could be converged rapidly within 10 iteration cycles.

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