Design and Diagnostics of a Precise 1-Axis Goniometer Stage for a Kicker Magnet in the Injection Section of the TPS Storage Ring

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Theme: Precision Controls and Mechanical Systems

Abstract:

To eliminate the magnitude of horizontal magnetic stray field due to misalignment of kicker magnet, four precise 1-axis goniometer stages for a kicker magnet have been designed and manufactured in the injection section of the storage ring in Taiwan Photon Source (TPS). In this paper, we present the design and diagnostic process of the goniometer stage, and propose a verification of specification for the stage through the measurement of diagnostic results, including the dimensions, rotary center and resolution. Furthermore, we also construct the relation among a stepping motor, touch sensor and precise inclination sensor obtained through the technique of curve fitting.

1-Introduction

Taiwan Photon Source (TPS), a 3-GeV synchrotron facility, is under construction at National Synchrotron Radiation Research Center (NSRRC) until 2013. The electron beam is injected from the end of a transfer line to the injection section of the storage ring. AC/DC septum magnets, four kicker magnets (K1~K4), vacuum chambers and their corresponding adjustable stage are mounted on three girders in the injection section which is a straight section of length 12 m [1] as shown in Fig. 1. To eliminate the magnitude of horizontal magnetic stray field due to misalignment of kicker magnet [2], four precise 1-

axis goniometer stages for the kicker magnet were designed, as shown in Fig. 2, and manufactured in the injection section of the TPS storage ring.

The 1-axis goniometer stage is designed to position the kicker magnet and the support of the ceramic chamber, respectively. The stage is driven with a stepping motor through a ball screw to tilt the kicker magnet precisely in the roll direction. An arcuate crossed-roller guide is adopted to decrease the frictional force between the movable and fixed parts.

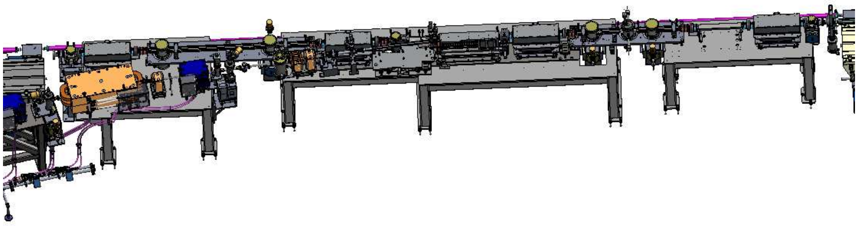

Fig. 1 Injection section of the storage ring in TPS

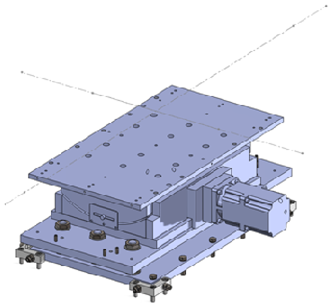

Fig. 2 1-axis goniometer stage for the kicker magnet in TPS

2-Design parameters of a precise 1-axis goniometer stage for the kicker magnet

The design parameters and criterion of a precise 1-axis goniometer stage for the kicker magnet are listed in Table 1.

Table 1 Design parameters and criteriion of the goniometer stage

tilt direction	Roll
tilt range	±3 mrad
resolution	<0.2 μrad
travel guide	crossed roller V-groove
feeding mechanism	ball screw type
stepping motor	Oriental PK599
gauge to set origin	Heidenhain AT 1218
capacity	>200 kg
limit switch	Omron D4N-2125
the height of rotation center	89.5±0.1 mm
ball screw lead	2 mm
radius of travel guide	187 mm

As one full-step angle of the stepping motor (Oriental PK599) is 0.72^{o} and the micro-steps of one full-step number 250, the theoretical resolution of the goniometer stage for the kicker magnet is calculated according to these relations:

0.72^{o} / 250 steps = 0.00288^{o} / micro-step

360^{o} / 0.0288 = 125000 micro-steps

Linear resolution: 2/125000 = 0.000016 mm / micro-step

Angular resolution: 0.000016/187 ≒ 0.0856 μrad

By verifying the theoretical resolution of the goniometer stage with design specification from Table 1, we can clearly see the good agreement.

Five, fine, M20 screws serve to adjust the height and pitch of the goniometer stage. Fig. 3 shows that three of these five screws are primary and the others are in auxiliary use to support the stage. Twenty fine nuts are thinned to fit the screws

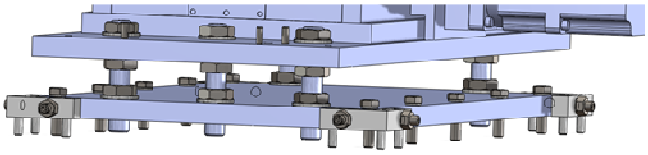

Fig. 3 Five fine M20 screws serve to adjust the height and pitch of the stage

Four L-type blocks in the four corners of the stage serve to adjust the surge, sway and yaw of the stage. An L-type block is fixed on top of a desk with three M8 screws. Two fine M10 screws per block are used to push the bottom plate of the goniometer stage. The goniometer stage is therefore pushed roughly into the correct position.

Two pairs of limit switches and hard stoppers are installed in one side of the goniometer stage as shown in Fig. 4. Limit switches restrict the tilting angle of the stage within ±3 mrad, and interference between the vacuum chamber and magnet can thereby be avoided. If the limit switches fail, the hard stoppers can then be applied to get rid of collision between the vacuum chamber and magnet. A locking mechanism is also installed in the same side of the goniometer stage to fix the movable part when the stage is positioned within tolerance. The touch sensor (Heidenhain AT 1218) is installed in the other side of the goniometer stage to set the origin and to monitor the tilting angle of the stage. The resolution of the touch sensor can reach 23 nm.

Fig. 4 Two pairs of limit switches and hard stoppers are in one side of the stage and a touch sensor is in the other side

3- Diagnostics of a precise 1-axis goniometer stage for a kicker magnet

The dimensions of the goniometer stage are measured with a Brown&Sharp CMM. The dimensions include the flatness and parallelism of the top and bottom plates of the stage, the true position and the radius of the fiducial holes. We try to adjust the top plate of the stage parallel to the bottom plate. After the parallelism of the top and bottom plates of the stage is verified to be within tolerance, we set the touch sensor in the side of the stage as the origin. The dimensions of the stage are finally measured semi-automatically with a PC-DMIS program. Through measuring the dimensions of the stage, the results of the measurement of the stage are obtained and they are within tolerance.

The rotary center of the goniometer stage is obtained via measurement architecture, as shown in Fig. 5. A program compiled with Visual C++ is developed to acquire data automatically. The stage is commanded by the motor driver when receiving pulses sending from the controller. A laser tracker (Leica AT901) serves to measure the moving traces of six fiducial holes when tilting the stage. Each two of the six moving traces are fit into one circle. In total we obtain three rotary centers (RC) of the stage that are individually defined as the front, the middle and the rear circle in each stage. The error of the RC of stages 1, 2 and 4 (S1, S2 and S4) are almost within 0.1 mm as listed in Table 2, but the measured results of the RC of stage 3 are not satisfactory with accuracy and repeatability. The reasons for the latter condition are attributed to the limit of the tracing range and the accuracy of the laser tracker. In general, a circle fitted from the measurement points uniformly distributed reach superior accuracy, but the range of measurement points in this test is less than a quarter circle. The repeatability of the RC of S3 is unsatisfactory as shown in Table 3.

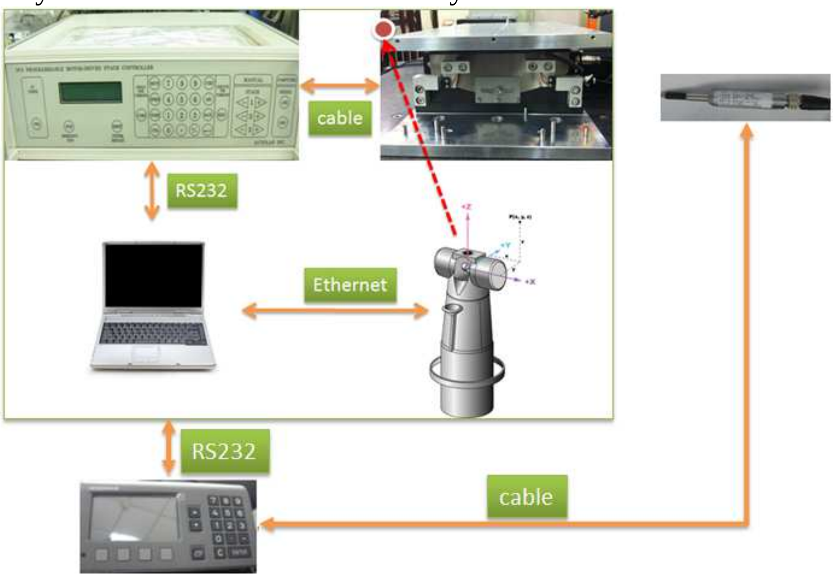

Fig. 5 Measurement architecture to acquire automatically rotary centers of the stage

Table 2 Results of the RC measurement of four stages

		stage 1	stage 2	stage 3	stage 4
Front	Height*	89.468	89.4075	-89.4756	89.538
	Error†	-0.032	-0.0925	0.0244	0.038
Middle	Height	89.5687	89.4539	-88.971	89.5144
	Error	0.0687	-0.0461	0.529	0.0144
Rear	Height	89.5803	89.6143	-89.7852	89.6011
	Error	0.0803	0.1143	-0.2852	0.1011

*: The "Height is obtained from measuring the distance from the top plane to the rotary center of the stage.

†: The "Error" is obtained from the value of the measurement minus that of the design.

Table 3 Repeatability test of the RC of S3

	stage 3	first	second	third	fourth
Front	Height	-89.4756	-89.4163	89.6845	89.4318
	Error	0.0244	0.0837	0.1845	-0.0682
Middle	Height	-88.971	-89.42	89.6145	89.5398
	Error	0.529	0.08	0.1145	0.0398
rear	Height	-89.7852	-89.9097	89.4759	89.7132
	Error	-0.2852	-0.4097	-0.0241	0.2132

The relation among the pulse, the touch sensor and the precise inclination sensor (Nivel 220) is constructed through the testing data obtained from the above mentioned measurement architecture in conjunction with Nivel 220. The relation between the touch sensor (*T*) and the precise inclination sensor (*N*) is shown in Fig. 6. Each traveling angle is about 3 μrad per step, and the traveling range is about 200 μrad.

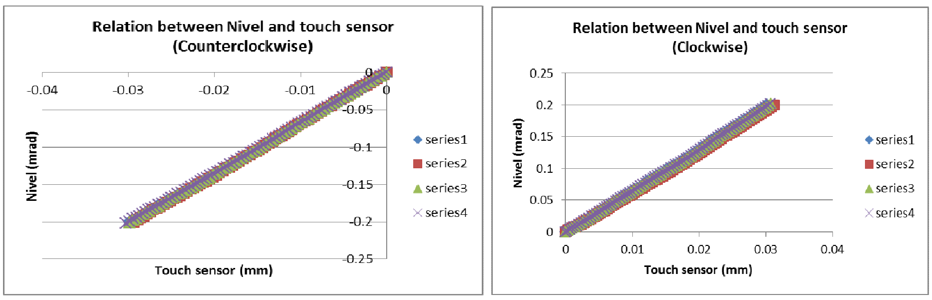

Fig. 6 Relation between the touch sensor and the precise inclination sensor

In Fig. 6, we use a curve-fitting technique to obtain equation L1 and L2 when the stage tilts clockwise and counterclockwise, respctively, as follows:

$$\text{L1:}\quad \Delta N = 6.5821 * \Delta T$$

$$\text{L2:}\quad \Delta N = 6.1285 * \Delta T$$

The curve relating the pulse (P) and the touch sensor (T) as shown in Fig. 7 is fitted with the following equation:

$$\Delta T = 0.0128*\Delta P$$

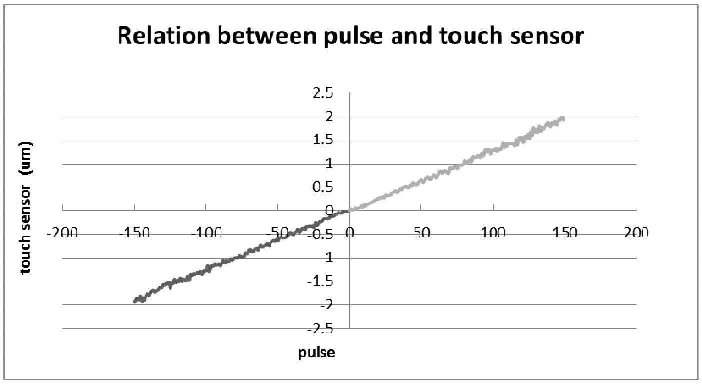

Fig. 7 Relation between the pulse and the touch sensor

Due to that limitation of the minimum resolution of the Nivel 220 is only 1 μrad, we calculate indirectly the relation between the pulse number of the motor and Nivel 220. The variation of the data obtained from the Nivel 220 per pulse, which is the so-called indirect resolution, is

$$\Delta N/\Delta P \fallingdotseq 0.084\ \mu\text{rad/pulse}$$

The comparison of the theoretical and the indirect resolution is as shown in Table 5, where good agreement are observed.

Table 5 Comparison of theoretical and indirect resolution

Theoretical resolution	0.0856
Indirect resolution	0.084

4-Conclusion

The design and diagnostic process of a precise 1-axis goniometer stage have been developed. We have also proposed a verification of specification for the stage through the measurement of diagnostic results, including the dimensions, rotary center and resolution. In addition, we further construct the relation among a stepping motor, touch sensor and precise inclination sensor obtained through the technique of curve fitting.

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