MULTIPLE QUADRUPOLE MAGNETIC CENTER ALIGNMENT ON THE GIRDER

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Abstract

Taiwan Photon Source (TPS) project has been proposed 3 years ago to create a 3GeV synchrotron light source. The designated ultra-low emittance of this new light source requires high precision positioning of storage ring magnets. Among all the magnets, the alignment of quadrupole magnets is of most importance since it directly affects the closed orbit of electron beams. Conventional on-site alignment of quadrupole magnets was mainly relying on the theodolite performance. The cumulated errors could be in the order of 0.1mm. In this report, a new alignment scheme is proposed to enhance the on-site alignment of quadrupole magnets for TPS project. To achieve the high precision requirements, a device possessing the advantages of both Vibrating Wire Method (VWM) and Position Sensing Detector (PSD) is proposed. The development of this alignment device is anticipated to provide a better mechanism to properly align the quadrupole magnetic centres on girder with less than 20μm positioning errors.

INTRODUCTION

Taiwan Photon Source has been planned for several years in NSRRC and is in its final designing phase. Currently this 3GeV, ultra-low emittance synchrotron light source has a 486m storage ring with 24 periods and hundreds of magnets. The requirement for high accuracy magnetic field and magnets alignment are essential aspects for the machine performance [5]. Many methods have been attempted to exam the magnetic field of magnets, which include Hall probe measurement, pulsed wire technique, vibrating wire field measuring technique, moving wire technique, moving probe technique, and rotating coil technique, etc. These techniques were able to identify individual magnetic field with high accuracy [1]. However, when positioning magnets on girders, these methods were usually inapplicable. Technicians have to rely on theodolite to check the alignment of magnets based on mechanical targets. The cumulative alignment errors between magnetic centres and girder could be larger than 100μm.

To improve the alignment accuracy of quadrupole magnets, a reliable magnetic field measurement system has been proposed in NSRRC. This proposed method utilizes the advantages from both Vibrating Wire Method (VWM) and laser-PSD (position sensing detector) method. The fiducialization concept is to perform on-site magnetic field measurement using VWM then exam the misalignment between magnets using the laser-PSD system.

VIBRATING WIRE METHOD (VWM)

The vibrating wire method has been known for its high accuracy in locating quadrupole magnetic centres [1, 3, 4]. It is composed of a stretched wire in a magnetic field, as shown in Figure 1. By sending a sinusoidal current through the wire, the vibration of the wire induced by the Lorentz Force could be observed. When the vibration frequency is close to the natural frequency of the wire, the vibration amplitude would increase greatly hence enhance the sensitivity. The vibrating amplitude of the wire is directly proportional to the magnitude of the surrounding magnetic field. When the wire is positioned closer to a quadrupole magnetic center, the measured wire vibration amplitude would decrease accordingly, Figure 1 (b). A great advantage of VWM is that it could be operated in a relatively smaller space and is easier to set up on girder. Combined with laser-PSD system, the alignment of quadrupole magnetic centres on girder is much more accurate.

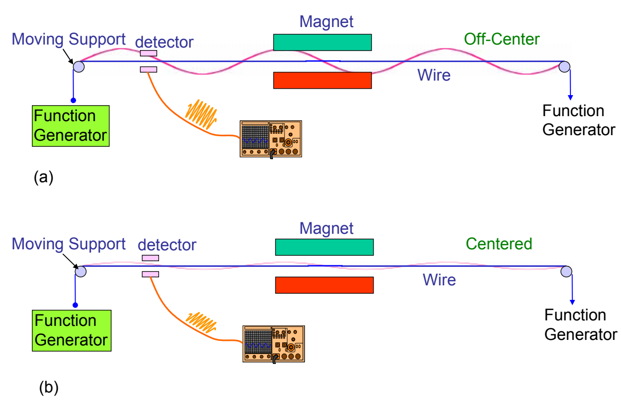

Figure 1: Vibrating Wire Method (courtesy of T. C. Fan).

PSD ALIGNMENT SCHEME

The position sensitive detector (PSD) has been widely used in many engineering areas to precisely align multiple targets. It is composed of large area photodiodes to detect and record the position of an incident light beam. The PSD system can measure position movement with high resolution (to the sub-micron level depending on the active area of PSD). Figure 2 shows the configuration of the VWM and PSD system. Two PSDs were mounted close to the ends of the stretched wire. Front PSD was mounted on a slider in order to provide a laser light path for Back PSD. The tilt of PSDs was monitored and adjusted using precision level and adjustable base, respectively. PSD tilt was controlled to within 0.1mrad. The natural frequency of the wire is adjusted by changing the applied tensile force using XYZ stage. The optical detector (phototransistor-LED assemblies H21A1) measured the vibrating amplitude of the stretched wire in both transverse and vertical directions.

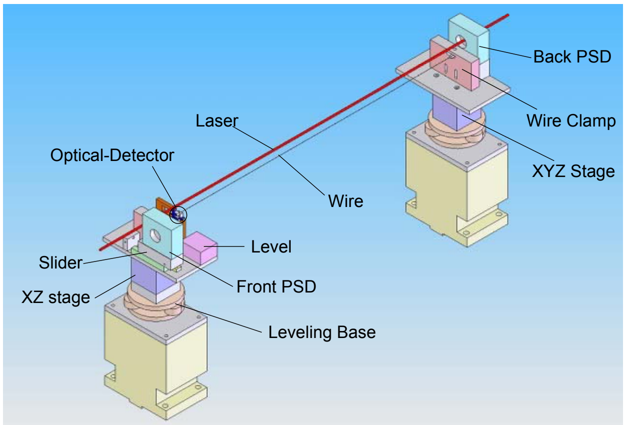

Figure 2: VWM and PSD system setup.

EXPERIMENT RESULTS

Two quadrupole magnets were pre-aligned on a girder using theodolite and precision level. The magnetic centres of the quadrupole magnets were located and their misalignments were checked through following procedures:

(1) The vibrating wire was tensioned around the ideal centerline of the quadrupole magnet Q1.
(2) HP 33120A function generator was connected to the wire to provide sine current. The frequency of the AC current was carefully adjusted to match the fundamental mode frequency of the Be-Cu wire.
(3) The vibration amplitude was recorded by a pair of optical detector H21A1, as shown in Figure 2. The magnetic center of the quadrupole was found by moving the vibrating wire along the transverse and vertical directions. Figure 3 shows the experiment result along transverse direction. The intersection of the two linear fit lines implies the magnetic center of the quadrupole magnet.
(4) The driving current was then tuned to match the second harmonic frequency of the wire in order to find the magnetic center along pitch and yaw directions [4]. Figure 4 shows the wire vibrating amplitude measurement along yaw direction. The approximated yaw measurement error is 0.015mrad.
(5) A fixed laser was pointing to the two PSDs to identify the position of the wire.
(6) The Be-Cu wire and PSDs were then moved to quadrupole Q2.
(7) By repeating step (1) through (4), the magnetic center of Q2 was identified. The misalignment of magnetic centres between Q1 and Q2 can be determined by the laser and PSD system.

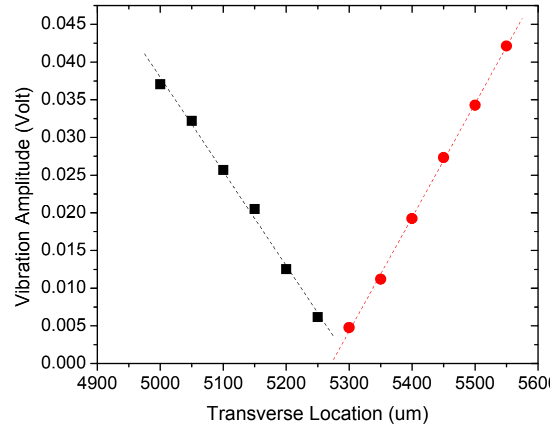

Figure 3: Vibration amplitude vs. Transverse location.

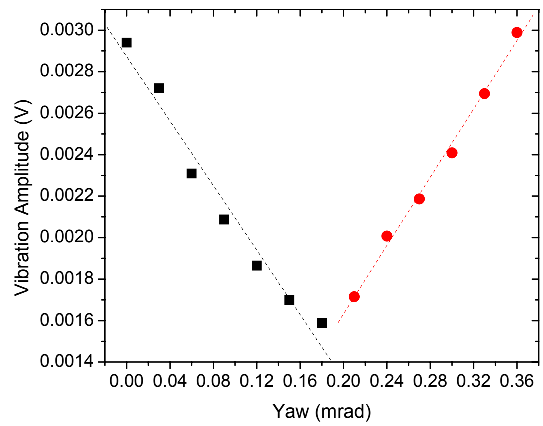

Figure 4: Vibration amplitude vs. yaw angles.

SYSTEM ERROR ESTIMATION

A summary of all the estimated errors is listed as following:

- Vibrating Wire Method: 7µm. The averaged magnetic center location error from linear fitting is about 7µm.
- Wire parallelism: Coordinate Measuring Machine (Brown & Sharpe) was used to measure the location of PSD and wire. The standard error of this CMM setting is in the range of 3~5µm. Also, 5µm error is generated when the wire is demounted and remounted between different magnets.
- PSD repeatability: 5µm. The drift of the laser was about 2µrad plus 3µm repeatability from repositioning the front PSD during the experiments.
- Sag difference: less than 3µm. When the variation of wire fundamental frequency is controlled to be within 0.1Hz, the sag difference is less than 3µm.

Table 1: Estimated Errors of the VWM and PSD system

Error Source	VWM	Parallel	PSD	Sag	Total
Error (µm)	7	10	5	3	15

AUTOMATION

To improve the experiment resolution, increase the operation efficiency, and enhance the repeatability, motorized stages were installed to replace the micrometer head positioning stages. Using the vibrating wire amplitude as input, a feedback loop was implanted to automatically locate the magnetic center of Quadrupole magnets. The control process is as following:

(1) The vibrating wire was moved along the transverse direction to identify the position with lowest vibrating amplitude.
(2) Move the wire to scan along the vertical axis to find the lowest vibration amplitude position.
(3) Adjust the pitch angle of the wire.
(4) Adjust yaw angle of the wire.
(5) Repeat steps (1) ~ (4) until the position of the wire is within 5 micron difference from previous round.

Preliminary experiments have been taken using the new automated system. Figure 5 shows the experiment result of VWM compared with Hall probe measurements for a quadrupole magnet. The wire vibrating amplitude and Hall probe data along transverse axis was measured with 1µm increment. The repeatability of Hall probe was less than 1µm. Based on the Hall probe measurement results, the repeatability of VWM was about 2µm. Sextupole magnetic field has also been measured using the automated VWM system. Figure 6 shows the vibrating amplitude of a Sextupole magnet along its vertical axis. The increment between each measurement was 100µm. The black dots indicates the relationship between B_Y and transverse position. For a normal Sextupole, $B_Y \propto x^2$, by using a 2nd order polynomial fit, the magnetic center of a Sextupole magnet could be found. The red squares indicated the red squares indicate the relationship between B_X and transverse position, $B_X \propto x$ when $y \neq 0$.

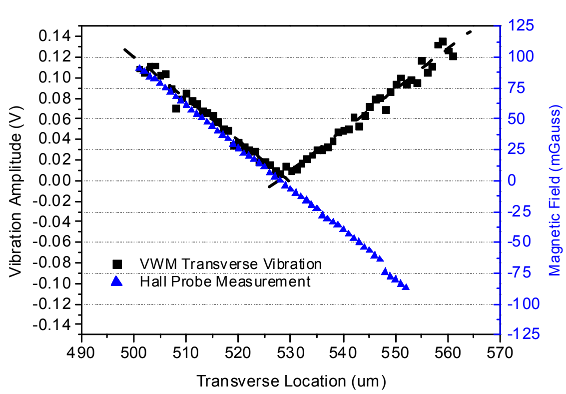

Figure 5: Comparison between VWM and Hall probe measurement for a Quadrupole Magnet.

CONCLUSIONS

The proposed VWM and PSD system is proved to have great potential in improving the alignment of Quadrupole magnets on girder. The repeatability of VWM was compared with Hall probe measurement, and the VWM was proven to be very consistent. The accuracy of VWM and PSD system provide a new method to align Quadrupole magnetic centres on girder to within 20µm transverse positioning errors. Motorized stages have recently been installed to upgrade the accuracy and resolution of this presented measuring system. The future goal of this new system is to improve the accuracy and repeatability for Sextupole Magnetic center measurement to within 30µm, so that the alignment of Quadrupole and Sextupole magnets could all be verified on girder using the proposed system.

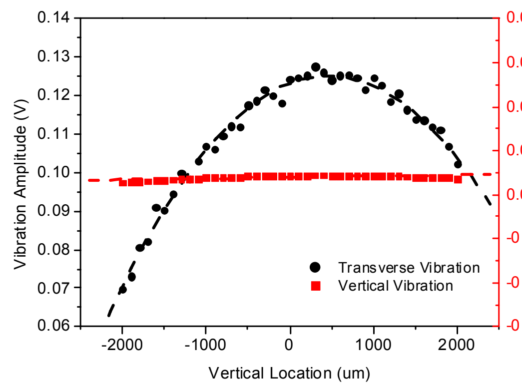

Figure 6: Vibration Amplitude vs. Vertical Location in measuring a Sextupole Magnet.

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