PRECISE POSITIONING OF MAGNETIC FIELD CENTERS OF QUADRUPOLE MAGNETS ON THE GIRDER

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Abstract

Conventional alignment of quadrupole magnets on one girder was mainly based on the measurement from theodolite and fiducial. Most of the measurement errors came from human-eye resolution and fiducial precision. The resultant cumulative error could be in the order of 100μm. In this paper, vibrating wire method is proposed to align a group of quadrupole magnets concentrically on one girder to precision about 30μm. A short wire was adopted to reduce the sag. A laser PSD system was used to identify the position of the wire. Descriptions of the setup and test results are presented.

INTRODUCTION

The alignment of quadrupole magnets directly affects the closed orbit of electron beams in synchrotron light source. In past years, many efforts have been performed to accurately locate the magnetic center of quadrupole 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 [1]. Through these techniques, individual quadrupole magnetic center could be identified with less than 50μm error. However, when aligning two or three quadrupole magnets on girder, the error generated from using fiducial and theodolite could be cumulative. Rotating coil can exam quadrupoles in detail, nevertheless it is extremely difficult to be used on nominal girders. Pulsed wire method has good resolution in narrow areas [2]; however it does not provide the information of quadrupole pitch and yaw. Moving wire method would be more effective in measuring high magnetic fields like superconducting quadrupoles [3]. In order to precisely align quadrupoles on girder, a new alignment system is developed in National Synchrotron Radiation Research Center, Taiwan. This technique adopted the advantages from both vibrating wire method and position sensitive detectors (PSD).

Vibrating Wire Method (VWM)

The vibrating wire method (VWM) is composed of a stretched wire in a magnetic field. By sending a sinusoidal current through the wire, the vibration of the wire induced by the Lorentz Force is observed [4] and the magnitude and orientation of this magnetic field can be determined. To precisely align quadrupoles on a girder, VWM has some clear advantages over other methods: (a) It can be fairly easily operated on a girder; (b) It requires no more than 10cm operating space beside a quadrupole; (c) It requires less operation time, however is as accurate as other techniques.

PSD Alignment System

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. In this research, two PSDs were attached to the ends of the vibrating wire, as shown in Figure 1. When the laser position is fixed, one can literally "extend" the magnetic center of quadrupole Q1 to quadrupole Q2 by precisely reposition the wire using PSDs. Experiment setup and operation procedures were detailed in next section.

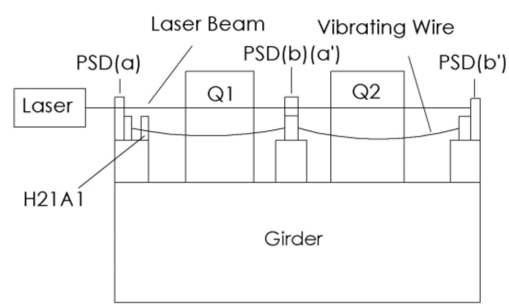

Figure 1: Experiment setup for vibrating wire method plus PSD system.

EXPERIMENT SETUP

Figure 1 shows the experiment setup of the vibrating wire and PSD systems. Two quadrupole magnets were pre-aligned on the girder using the traditional fiducial and theodolite method. The experiments took place in the following orders:

(1) The vibrating wire was tensioned around the ideal centerline of the first quadrupole magnet (Q1). The wire used in the experiment was 650mm length and 125μm diameter Be-Cu wire from GoodFellow™. In order to increase the repeatability of VWM, 100A constant current was applied to the testing quadrupole magnets while supplying the magnet coils with cooling water to keep their temperature at 20±0.5℃.

(2) HP 33120A function generator was connected to the wire to provide AC sine current. The frequency of the input current was carefully adjusted to match the fundamental mode frequency of the Be-Cu wire in order to maximize the vibration amplitude.

(3) The vibration amplitude was recorded by a pair of photo coupler H21A1, as shown in Figure 1. The magnetic center of the quadrupole was found by moving the vibrating wire along the horizontal and vertical directions to find the location with lowest vibration amplitude.

(4) The driving current was then tuned to the second harmonic frequency of the wire to find the magnetic center along pitch and yaw directions [4].

(5) A fixed laser, as shown in Figure 1, was utilized to match the position of the wire through the two PSDs mounted with the wire at PSD(a) and PSD(b). The PSDs in the experiments were ON-TRAK PSM 2-10. This 10mm x 10mm PSD module has typical resolution 250 nm. HP laser head 5517C was utilized as the light source. The distances between PSD center points and the two wire ends were measured using a microscope with 50 times magnification.

(6) The Be-Cu wire and PSDs were moved to PSD(a') and PSD(b') beside quadrupole Q2. The position of wire was carefully adjusted using PSDs and the fixed laser.

(7) The wire positioned at Q2 was taken as the extension of the magnetic center of Q1. By repeating step (1) through (4), the misalignment of magnetic centers between Q1 and Q2 can be determined and adjusted.

RESULTS AND DISCUSSION

Figure 2 shows the relationship between vibration amplitude and transverse location of the wire in a span of 550μm with 50μm increment. This experiment result showed good linearity between the vibrating amplitude (ordinate) and the transverse location (abscissa). When the wire moved from left hand side along horizontal axis towards the magnetic center, the vibrating amplitude decreased linearly and then increased linearly after the wire passed through the magnetic center. The approximated magnetic center in this measurement has location error 7.18μm (RMS). Figure 3 shows the relationship between vibration amplitude (ordinate) and yaw (abscissa) in an experiment. The approximated yaw measurement error is 0.012mrad.

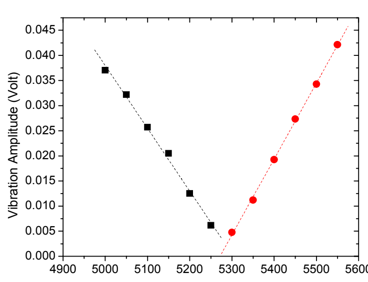

Figure 2: Vibration amplitude vs. transverse location in experiment 111006T.

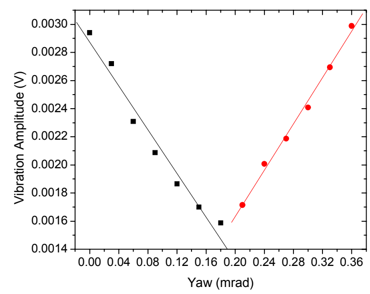

Figure 3: Vibration amplitude vs. yaw in experiment 012407T.

Error estimation

All wire methods suffer from the sag of wire and the temperature induced vibration frequency fluctuations. The sag-generated vertical position offsets were in the range of 25~100μm depending on its tension force. To estimate the sag of a vibrating wire, a simple relation between sag and the vibration fundamental mode frequency has been proposed by Temnykh [2]:

$$S = \frac{g}{32}\left(\frac{w_1}{2\pi}\right)^{-2} \quad (1)$$

In which S represents the sag of the stretched wire, g = 9.80665 m/s^2, and w_1 represents the fundamental mode frequency of the wire. In this project, the fundamental mode frequency of the vibrating wire was precisely controlled by means of carefully adjusting the tension force in the wire. The sag difference of the wire between location Q1 and Q2 was about 5μm.

Another error source is the drift of the laser which affects the PSD reading. Usual drift of the applied laser was 10μrad after warm up. To be certain about the amount of laser drift, the laser head was monitored and the results were displayed in Figure 4 and Figure 5.

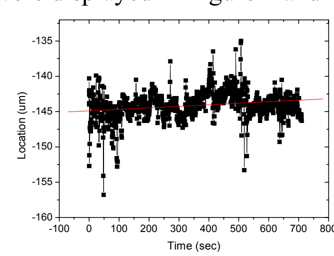

Figure 4: PSD reading along vertical axis with Standard Deviation = 1.77μm.

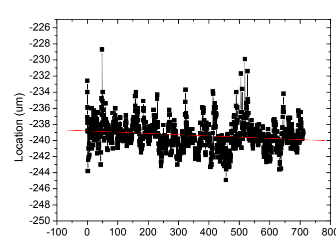

Figure 5: PSD reading along horizontal axis with Standard Deviation = 1.91μm.

Figure 4 and Figure 5 show the laser drift along vertical and horizontal axis, respectively. The abscissa represents the time from the beginning of the measurement, and the ordinate represents the position reading from PSD module. The data acquisition frequency was 1Hz and the durations of the experiments were 12 minutes. The laser drift induced positioning error was 1.91μm (RMS).

The sag of vibrating wire method is its main disadvantage because of the resultant dislocation of the whole wire to the magnetic centers. In this research, the sag problem was precisely controlled by adjusting the vibrating frequency of the wire. However, there were other error sources in this series of experiments. A summary of all the estimated errors is listed as following:

- VWM fitting: 7μm. The error came from the fitting process is about 7μm as discussed in the previous section.
- Wire parallelism: 15μm. In this research, PSD sensors were used as the coordinates of the wire, hence the parallelism between the PSD module and the wire is critical. To measure the parallelism between PSD and wire, a microscope with 50 times magnification was used. However, because of human eye resolution limit, error generated during this process is in the range of 15~20μm.
- PSD repeatability: 5μm. The drift of the laser was about 2μm plus the 3μm error from relocating the PSD module during the experiments.
- Sag difference: 5μm. Although the sag of the wire was carefully controlled by adjusting the tension in the wire, still, some error exists.

Table 1: Estimated Sources of RMS Error in VWM and PSD alignment method.

Error Sources	Current system error (μm)	Projected Future error (μm)
VWM fitting	7	5
Wire parallelism	15	5
PSD repeatability	5	5
Sag difference	5	5
Total error	32	20

Another VWM setting, which utilizes a stretched long wire through both quadrupole magnets, has also been planned to verify the accuracy of this proposed technique. The difference between using one long wire to this two-short-wire-segments technique is the sag issue. In the process of aligning both quadrupole magnetic centers, the sag of the short wire could be controlled by using the same wire with similar tension forces. When using a long wire, the sag of the wire become larger and requires precise inspections to determine its value. However, the precise transition of the short wire from one quadrupole magnet to another could be troublesome. The error sources were too many and could cause huge cumulative errors.

SUMMARY

This method can be used as a check method to align the magnetic center of multiple quadrupole magnets on a girder before installation of vacuum chambers. Although it has only been verified that the accuracy of this proposed method is better than the theodolite resolution, this novel method has the potential to align magnetic centers of multiple quadrupole magnets on one girder to 30μm.

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