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RESEARCH DEVELOPMENT OF HIGN PRECISION INSTALLATION AND ALIGNMENT SYSTEM FOR HEPS*

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Abstract

High Energy Photon Source (HEPS) is a proposed 6 GeV third generation light source with high brightness and ultra-low emittance. Because the measurement error of the traditional optical survey method in the girder and magnet installation can't meet the tight alignment tolerance, the installation and alignment will not only rely on laser tracker and some other optical survey instruments. So HEPS is developing the research of high precision installation and alignment system which is consists of the design of auto-tuning girder based on beam alignment and research of vibrating wire alignment system based on magnetic measurement. This paper introduces the research development of installation and alignment system in storage ring of HEPS.

INTRODUCTION

HEPS will be a 5 GeV, 1296 meters circumference third generation synchrotron radiation facility with ultra emittance and extremely high brightness. The emittance will be better than 0.1nm·rad. The storage ring is a 48 cell 7BA lattice. Fig.1 is one of 48 typical cells. In order to install the magnets easily, the adjacent quadrupole magnets, sextupole magnets and the corrector will use a common multipole support girder. Blue block represents quadrupole magnets and green block represents sextupole magnets. The multipole support girder is designed 3.8 meters [1]

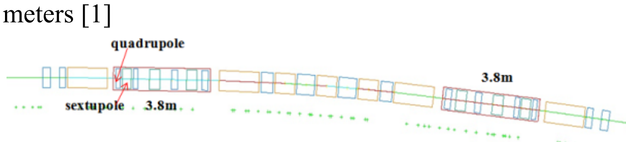

Figure 1: One of 48 typical cells.

Table 1: HEPS Alignment Tolerance

Tolerances	Magnet to Magnet	Girder to Girder
Horizontal	±0.03mm	±0.05mm
Vertical	±0.03mm	±0.05mm
Beam direction	±0.5mm	±0.5mm
Roll angle	±0.2mrad	±0.2mrad

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Table 1 shows the alignment tolerance in HEPS. It is difficult to achieve the required accuracy using the traditional optical survey. So vibrating wire alignment technique is considered to meet the tolerance ±0.03mm between magnet to magnet on a multipole girder. And auto-tuning girder can help to achieve the tolerance ±0.05mm between girder to girder.

AUTO-TUNING GIRDER

All girders in the storage ring will automatically adjust when the accelerator is running by monitoring the beams. The natural frequency of the auto-tuning girder should better than 30Hz. And the dynamic state of the auto-tuning girder must be stable. The high precision auto-tuning girder is based on the cam mover mechanism. The similar scheme has been used in Swiss Light Source [2], Taiwan Photon Source [3] and in some other facilities. The eccentric circle cam mover had demonstrated good resolution and good performance in the facilities which have used motorized adjusting mechanism. The design parameters of the auto-tuning girder for HEPS are in Table 2.

Table 2: Design Parameter of Auto-tuning Girder

Design parameter	Design value
Girder size(L×W)	3.8m×0.8m
Cam load	2.5t
Cam eccentric offset	7mm
Cam adjust range	X (-8.7mm~9.4mm) Y (-11.8mm~10.4mm)

Fig.2 is the schematic distribution of the girder supports and the location of the cam mover mechanisms. This eight girder supports distribute along the girder and form four groups of groove mounted mutually perpendicular. This can make full use of the adjust range of this 8 cam mover mechanisms.

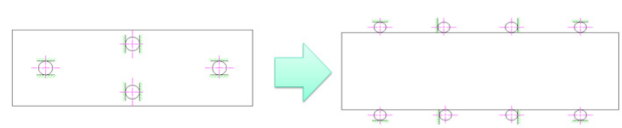

Figure 2: Distribution of girder supports and cam mover mechanisms.

In the storage ring, adjust the position of the girder is by adjusting the origin position of coordinate system. The adjustment process is divided into two steps. Firstly,

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adjust the rotation of the girder in pitch, yaw and roll. Then, adjust the girder's position in horizontal direction, vertical direction and beam direction. The equation 1 is the rotation matrix and equation 2 is the translation of every support. Angle χ, η and σ are pitch, yaw and roll. u, v, w is the translation in x, y, z direction [4].

$$R = \begin{pmatrix} 1 & -\sigma & \eta \\ \delta & 1 & -\chi \\ -\eta & \chi & 1 \end{pmatrix}. \quad (1)$$

$$\begin{bmatrix} x_{n0} \\ y_{n0} \\ z_{n0} \end{bmatrix} = \begin{bmatrix} x_n \\ y_n \\ z_n \end{bmatrix} + \begin{bmatrix} \delta y_{n0} - \eta z_{n0} \\ \chi z_{n0} - \delta x_{n0} \\ \eta x_{n0} - \chi y_{n0} \end{bmatrix} - \begin{bmatrix} \mu \\ \nu \\ w \end{bmatrix}. \quad (2)$$

Fig.3 is the mechanical design of auto-tuning girder assembly. Each 2 cam movers will be put on opposite side of the girder on a pedestal.

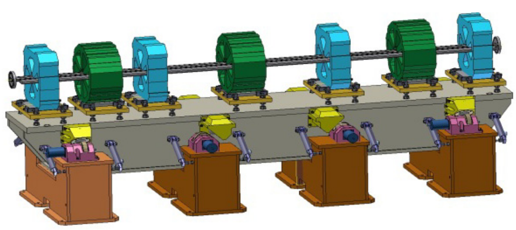

Figure 3: Auto-tuning girder assembly.

VIBRATING WIRE ALIGNMENT SYSTEM

Vibrating wire technique has been used in some different projects in many labs. It has demonstrated the potential to measure the magnetic center to the required accuracy. These applications of vibrating wire are based on the same fundamental principle, but the specific purposes are distinct. In BNL, this technique is used to align the quadrupoles and sextupoles on a multipole girder for NSLS-II [5]. The magnet alignment requirements in HEPS are similar to the requirements in NSLS-II. So the vibrating wire alignment in BNL has been used as our reference.

Vibrating wire is based on measurement of the magnetic axis to align the magnets. The principle is based on period Lorentz Force when the wire is driven by AC current.

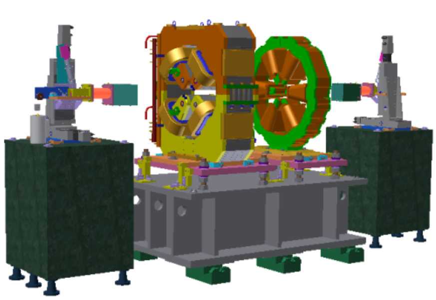

Figure 4: Vibrating wire alignment system model.

In the pre-research period, a test bench model with 3 meters vibrating wire has already been designed. The test bench is now in the process of manufacturing.

Vibrating wire alignment system is composed of multipole magnets girder, fixed end bench, free end bench, sensor circuit and motion control and data acquisition system. Fig.4 is the vibrating wire alignment system model. Vibrating wire is 0.125mm diameter made with alloy of copper-beryllium. The magnet support girder is designed 1.56 meters which can only support a quadrupole and a sextupole. The quadrupole and sextupole will be borrowed from BEPCII for lack of magnets made for HEPS. They are 105Q and 130S.

The fig.5 is the scheme of the motion control and data acquisition system. There are four input signal ranges in DAQ card. Its function is to sample 2 sensors and 1 driving current signals simultaneously. Datum will be transported to the IPC. IPC also controls the movement of 2 x-y stages. We use LabVIEW software to do motion control, data acquisition and data process.

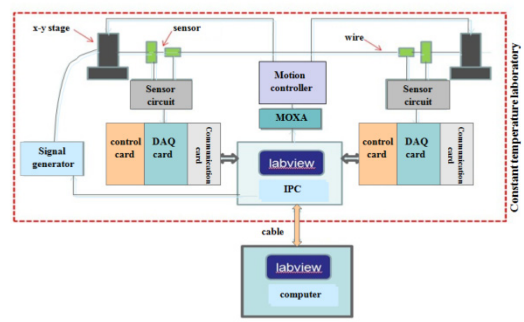

Figure 5: Scheme of motion control and data acquisition system.

The alignment procedure is like that: (1) Install magnets on the girder and carry out pre-alignment using a laser tracker. (2) Stretch the Berylium-copper wire through the magnets' geometric center and fix it to the end benches. Use a signal generator to drive AC current through the wire and power the measured magnet. (3) By changing the position of the wire on horizontal direction and vertical direction and measuring the vibration of the wire, measure the magnetic induction intensity at different location of the magnet and find the magnetic center offset.(4) Measure another magnets' magnetic center and get the magnetic center offsets of every magnet.(5) According to the datum of the magnetic center offset, adjust the position of every magnet under the observation of displacement sensors and lock the magnets' position. (6) Comprehensively measure the position of the magnets, girder and vibrating wire using laser tracker.

The model of the sensor that used to detect the vibration amplitude change over time in HEPS is also GP1S094HCZ0F. It is a photo-interrupter with opposing emitter and detector in a molding that provides non-contact sensing. There are two linear output parts about the sensor. In each part, the wire displacement is about 0.1~0.12mm. One part will be chosen as the workspace. The vibration amplitude must be in the linear area. The

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sensitivity of the sensor is approximately 30mV/mm. In one test position, the measurements of variation of 500 data samples reduced from 20mV to 6mV after filtering. Fig.6 is the results of the datum before filtering and after filtering. The error caused by voltage measurement is smaller than 1μm.The stability has improved significantly.

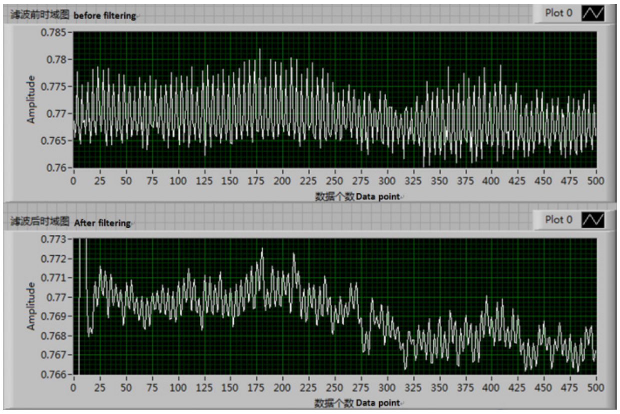

Figure 6: 500 Data samples in one test position before filtering and after filtering.

Vibration amplitudes should be controlled within the voltage linear output part. And it also should be make full use of this region. According to the measurement, the linear region width is about 0.1~0.12mm. We designed the wire vibration amplitudes 0.045mm. The equation of measurement of quadrupole magnetic center is deduced:

$$y_{\max}(z) = [\frac{I_0 2Gl_0}{\mu\omega_n \alpha l} \sin\left(\frac{n\pi}{j}\right) \sin\left(\frac{n\pi z}{l}\right) |\Delta y|. \tag{3}$$

And we do measurement of sextupole magnetic center using the equation 4.

$$y_{\max}(z) = [\frac{I_0 B''l_0}{\mu\omega_n \alpha l} \sin\left(\frac{n\pi}{j}\right) \sin\left(\frac{n\pi z}{l}\right) (\Delta x^2 + \Delta y^2). \tag{4}$$

I_0 is the wire current amplitude. Gl_Q is the quadrupole integrated gradient. $l_Q$is the quadrupole length. n is the resonance order. ω_n is the harmonic frequency. α is the damping constant. j equals l/z_{magnet}. l is the length of the wire and z_{magnet} is the location of the magnet along the wire. B”$l_Q$is the sextupole integrated gradient. y is the distance between magnetic center relative to the wire in y direction and Δx and Δy is the distance between magnetic center relative to the wire in x and y direction.

CONCLUSION

In order to meet the requirement of high precision alignment of magnets, HEPS is developing a high precision installation and alignment system which includes the research of auto-tuning girder and vibrating wire alignment technique. We have already finished the scheme design of auto-tuning girder and deduction of adjusting. Detailed structure design and adjustment program is underway. In the research of vibrating wire alignment system, the work about theoretical derivation, test bench design, the scheme design of motion control and data acquisition system have already finished. The sensor circuit has confirmed and the voltage output has been tested. The experiment of vibrating wire alignment technique will begin soon. All research about high precision installation and alignment system need to be finished at the end of 2016.

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