DESIGN AND PROGRESS ON MECHANICAL & ALIGNMENT SYSTEM FOR HEPS-TF

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Abstract

HEPS is a new generation synchrotron facility with a stringent requirement of very low emittance. The key technology difficulties are supposed to be overcome during the stage of HEPS-TF. There are two projects in progress for mechanical and alignment system. One is the development of precision auto-tuning magnet girder, to meet the requirement of beam based alignment in tunnel, the other is the study on vibrating-wire alignment technique to improve alignment accuracy of magnets on a girder. This paper will describe the design and progress of both projects.

INTRODUCTION

HEPS storage ring consists of 48 7BA achromats, with the circumference of 1296m. Each arc section is about 27m. Girders provide firm support and precise positioning for magnets. There are 7 Magnet-Girder modules with 4 different sizes in an arc section, as shown in Fig.1. Each module will be pre-assembled, with components aligned, prior to installation in tunnel.

Figure 1: One arc section (1/48).

In order to achieve a very low emittance, magnetic centers should coincide with the theoretical orbit as much as possible. On the other hand, to close beam orbit may be rather difficult because of the large diameter of the storage ring and the small size of the beam. Therefor the physicists put forward stringent requirements to mechanical and alignment system, as shown in Table 1. The alignment error between magnets on a girder should be less than ±30μm in both horizontal and vertical direction. And that between girders in tunnel should be less than ±50μm after the first-time installation. Besides, the girder should be capable of doing beam-based alignment remotely to minimize the magnets position error during the runtime.

Table 1: Alignment Tolerance

Tolerances	Magnet to Magnet	Girder to Girder
Horizontal	±30μm	±50μm
Vertical	±30μm	±50μm

The regular alignment method mostly rely on laser tracker and traditional girder design is more applying to be manipulated by hand in tunnel, and that would accumulate lots of errors in several steps and the final error usually more than 0.1mm, which could not meet the requirements of HEPS. So it is necessary to develop some new technology and the difficulties are supposed to be overcome during the stage of HEPS-TF.

Based on this, there are two R&D projects on study: One is the Development of precision auto-tuning magnet girder, which could be manipulated through control system with the position monitored by sensors, to fulfil the alignment in tunnel, with or without beam. The other is the Research on vibrating-wire alignment technique, based on the measurement of magnetic center, to pre-align multipole-magnets on a girder. These study will be critical for HEPS to realize the final goal of emittance.

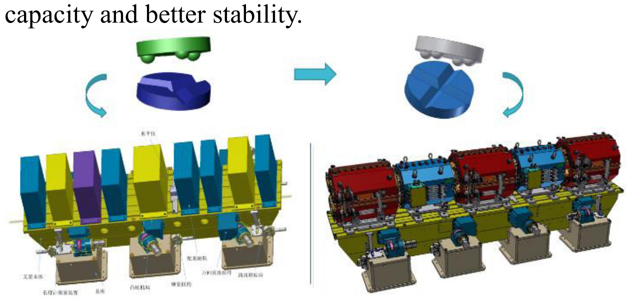
AUTO-TUNING GIRDER

Design Considerations

Girder should be of good performance on adjustability and stability. It is required that adjusting resolution should be better than 3μm, and the Eigen frequency should be higher than 30 Hz. Besides, auto-tuning mechanism and remote control system are required. So the girder was designed with features as follows:

- Cam movers driven by motors serve as adjusting mechanism.
- Sensors are used to monitor the girder position to fulfil closed loop control.
- Multi-point supporting and auto-locking mechanism are adopted to increase body stiffness.
- Pedestals will be grouted on the ground to raise stability.

Figure 2 is the supporting scheme of girders. There will be 2 prototypes. One is girder type I, which is for the supporting of straight multiplet section, with the length of 3.3m and 6 points supported. This design is mainly referred to TPS [1]. Girder type II is a modified design, for the supporting of FODO section. With the length of 4.3m, there are 8 points supported, to provide a heavier load capacity and better stability.



L: Girder Type I; R:Girder Type II

Figure 2: Supporting scheme of girders.

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The girder supporting scheme is based on the Boyes Clamp theory [2], which is of 3 grooves with angles of 120°, providing totally constrained mounting. Each couple of cam mover can be seen as a V-groove, 3 grooves have 6 contact points to provide a kinematic mounting. The 8 point supporting can be seen as a 4-groove mounting, each groove is perpendicular to the next. So there are 2 points served as auxiliary. Girder body was designed as welded structure with high stiffness to provide tough support for magnets. The top surface is compatible with two kinds of interface which have been shown in Fig.3: One is fit for the installation of adjustable wedges, through which the magnets can be aligned by the way of vibrating wire. The other is fine-machining plane to position magnets and do alignment. Both alignment methods will be tested to help determine the final alignment scheme of HEPS.

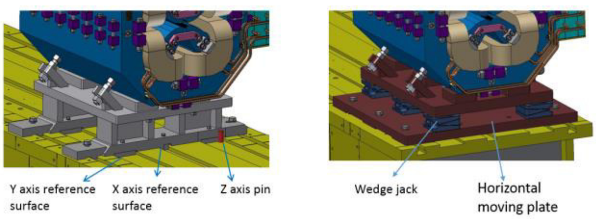

Figure 3: Supporting Interfaces.

Auto-control system is based on the Beckoff controller and EtherCAT, and adjusting algorithm of the girder location is developed in Matlab. Position errors feedback can be obtained through the reading of length gauges.

General Progress

After mechanical design was finished, tender for fabrication was completed on July 2016. Now girder type I is being tested in factory. All the parts are machined and checked, Cam movers have been assembled and installed in the pedestals, Control system was built up and program is on debugging. Fig.4 is the Cam movers and Fig.5 is the fiducialization of girders.

Figure 4: Cam Mover assembled.

Figure 5: Fiducialization of girder.

Girder type II will be optimized according to the experience learned from type I and fabrication will be started subsequently. Both girders will be finished in early 2018.

VIBRATING WIRE ALIGNMENT

Design Considerations

To achieve intra-girder accuracy of ±30μm in optical way is difficult. So Vibrating wire alignment technique is considered in HEPS-TF.

The detailed measurement principle and alignment method of vibrating wire technique has described in the ref.[3-6].

The vibration amplitude is of a functional relation with the magnetic intensity. Move the wire across the aperture in horizontal or vertical direction and measure amplitudes at each position, the transverse field distribution and magnetic axis can be derived.

Figure 6 is the magnetic field profile. In the case of quadrupole, a linear dependence of field with horizontal and vertical position is seen, the magnetic axis is the point where the field is zero. In the case of the sextupole magnets, the field profile is parabolic and the magnetic center is defined as the point where the field gradients are zero.

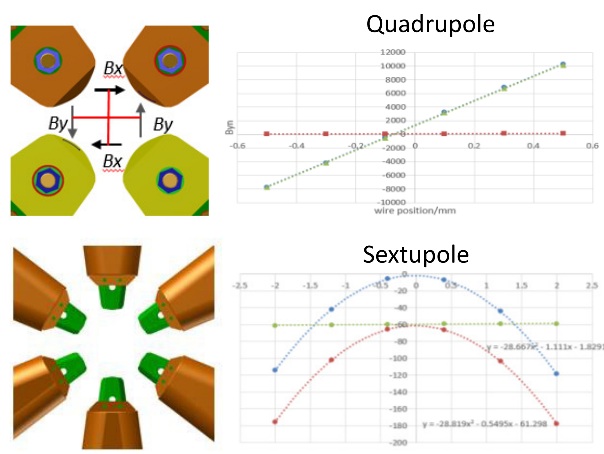

Figure 6: Magnetic field profile.

Due to the long length (~6 to 7m) of the wire, there is a significant sag (~600μm) which must be precisely measured and corrected [7]. It has been shown that the sag can be computed to sufficient accuracy from the measured fundamental resonant frequency. For confirmation, sag measuring scheme is under consideration and wire position sensors will be used.

Background fields, especially the remnant fields of other un-powered magnets on the girder could cause big errors and should be eliminated by measuring at two different exciting current and then do subtraction.

The wire for test is made of Beryllium copper, with the diameter of 0.125mm. One end of the wire is locked at the fixed end stand, and the other end is stretched by weights at the free end stand. On the granite platform, there is the wire mover assembly, as is shown in Fig. 7. The wire is positioned by a V-notch at each end, which is installed on the X/Y translation stages. During the measurement, the

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wire location will be changed with the movement of the stages, and the vibration can be measured by the sensors. To ensure the wire is seated properly in the notch, there is a camera for checking. The AC current, with amplitude and frequency adjustable, is provided by a signal generator. Auto-measuring program developed by LabVIEW is used to control the movement of wire, acquire vibrating relative information, analyse data and give magnetic center of each magnet.

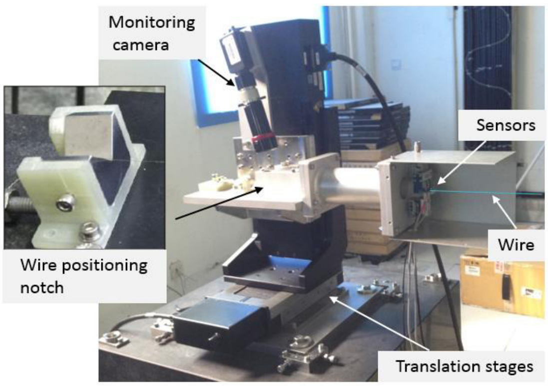

Figure 7: Wire mover assembly.

Progress of Testing

In order to acquire stable and reliable data, the temperature stability of testing environment should be controlled within±0.1°C. Considering the schedule requirement and construction duration of required environment, a test bench has been built in a temporary lab with temperature stability of about±1°C. A series of testing has been carried out for theory confirmation and measuring method exploration.

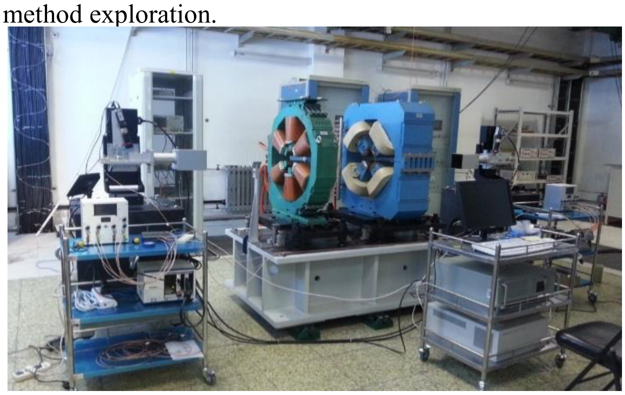

Figure 8: Vibrating wire testing bench.

Prior to the normal testing, a lot of preparation work has been done to ensure the measuring accuracy, including calibration of wire moving precision, checking of wire positioning repeatability and stability of the sensors output and so on. Test parameters should be optimized to reduce measuring error. For example, the amplitude of AC current should be proper so that the vibration amplitude is identified and also as small as possible. Field scan range of ±2mm is selected to improve data fitting accuracy and measuring efficiency; According to the longitudinal location of the testing magnet in the bench, resonance mode 4 of the wire is the first choice. The wire tension is about 1Kg which is adequate but not too much.

First stage measurement has been completed. Fig.8 is the vibrating wire test bench. Although the environment is less than ideal, the magnetic center measuring result shows high repeatability in a time scale of 3-5 days, for both quadrupole and sextupole magnet, as is shown in Table 2, Figs. 9 and 10.

Table 2: Measuring Repeatability

Repeatability	Quadrupole	Sextupole
Horizontal	±2μm	±3μm
Vertical	±3μm	±5μm

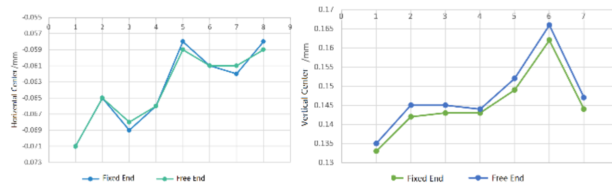

Figure 9: Quaupole center measuring repeatability.

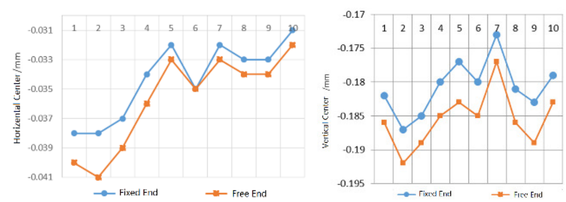

Figure 10: Sextupole center measuring repeatability.

Some phenomenon was also observed:

1. Measurement accuracy in vertical direction is lower than that in horizontal direction. It is understandable that vertical direction is apt to be disturbed because of the gravity effect.
2. Quadrupole, with the linear relation fitting, shows higher accuracy than Sextupole, which is of parabolic curve fitting.
3. Background field correction is very important for the presence of other magnets on the girder.
4. Magnetic center measured sometimes varied for some uncertain reasons, so well controlled environment is necessary for reliable result.

CONCLUSION

Ultra-low emittance of HEPS puts forward tough requirements to mechanical & alignment system, and two R&D projects are under study to overcome difficulties. For the auto-tuning girder, detail design has been finished and fabrication is ongoing. The prototype of girder Type I is now on assembling and is to be tested together with the control system. The first stage measurement of vibrating wire alignment has been finished. After a series of testing, theory confirmation and measuring method exploration were accomplished. Now the test bench has already been moved into the temperature controlled room, and further precision improvement test will be carried out. All research work should be finished in early 2018.

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