OVERALL DESIGN OF MAGNET GIRDER SYSTEM FOR HEPS-TF

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Abstract

HEPS-TF is the test facility of HEPS (High Energy Photon Source) of China. The magnet girders are used for supporting and positioning of the magnets. As the beam emittance is very low, the girder must has high adjusting precision and high stability. Besides, the girder should also be beam-based aligned. For these issues, two girder systems are designed. Both of them use cam mover mechanisms for precision adjustment. One has six cam mover mechanisms and another has eight. The design aim of the alignment accuracy between girders is within 50 μm, and the adjusting resolution is within 3μm. The design aim of the natural frequency is above 30 Hz. This paper will discuss the scheme selection and structural design of the girder systems.

INTRODUCTION

HEPS is one proposed high performance photon source with electron energy of 6 GeV and emittance of 0.05~0.1 nm.rad. It will has the highest spectral luminance after built up. HEPS-TF is the test facility of HEPS. The extremely low emittance and beam size make exact requirements on the mechanical and alignment system, especially for the straight multiplet and FODO section. According to the physical requirements, the accuracy between magnets mounted on one girder should be less than 30μm, and the accuracy between girders should be less than 50μm (relative).

Table 1 lists the girder system comparison of some photon sources [1-5]. The automatic adjustment is the tendency due to the accuracy, time and manpower save. The cam mover mechanism was first applied by SLS, and vigorously developed by TPS. They designed the 6-axes girder system using the theories of Kelvin Clamp and Boyes Clamp, and the designed relative alignment accuracy between girders was within 0.1 mm.

HEPS-TF will also use the cam mover mechanisms as the basic design, in order to improve the accuracy and save manpower and time. There are two types of girders need to be developed, for the straight multiplet and FODO section respectively, which are shown in Fig. 1. Flexible structure can leads to low natural frequency, so the dynamic stability should also be considered.

The length of straight multiplet is about 3300 mm, while 4300 mm for the FODO section. For the straight multiplet, a 6-axes girder system is designed, similar to the TPS design. For the FODO section, an 8-axes girder system is designed. Each girder system includes girder body, pedestals, cam mover mechanisms, sensor system and locking system. The overall 3D models are shown in Fig. 2 and Fig. 3.

Table 1: Girder System Comparison of Some Photon Sources

Facility		Adjustment method	Natural frequency (Hz)
Spring-8	Non-automatic adjustment	6-points support	19
SOLEIL		4-points support, 3 alignment Airloc jacks	46
SSRF		3 wedge jacks, 3 assistant supports	23
NSLS II		8-points support	30
APS U		3-points support, 3-points adjustment	~50
SLS	Automatic adjustment	5 cam mover mechanisms	15.5
Diamond		5 cam mover mechanisms	16.3
TPS		6 cam mover mechanisms	30
ESRF II		4 motorized wedges, 3 manual wedges	35

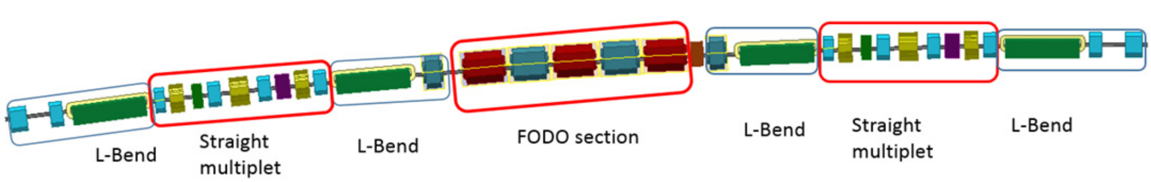

Figure 1: Magnet distribution in one cell.

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ISBN 978-3-95450-147-2

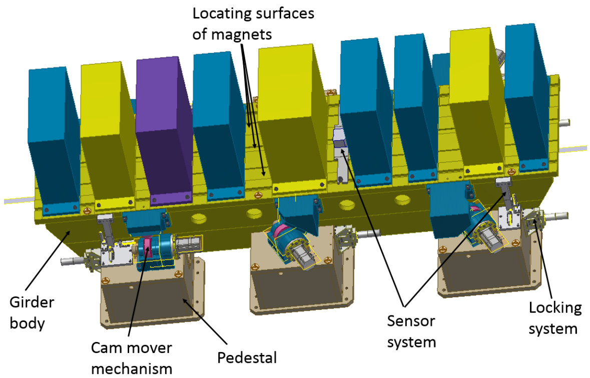

Figure 2: 6-axes girder system.

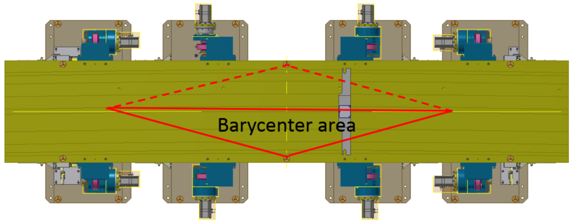

Figure 3: 8-axes girder system.

DESIGN OF 6-AXES GIRDER SYSTEM

Girder Body

The girder body is welded by several Q345 plates. There are two schemes to achieve the pre-alignment accuracy of 30 μm, one is using the vibrating wire alignment technique, which is studied for HEPS-TF too [6]. The other scheme is depending on the precision machining of the locating surfaces, taking the TPS design as reference. Furthermore, there has small angle offset between the FOFO magnets, which means only the latter scheme can be used for 8-axes girder system. The flatness or profile tolerance of the locating surface is 15μm/girder length.

To improve the stability of the girder system, topological optimization is first used in girder design area. Both modal topological optimization and static topological optimization are analysed, which are the references of structure design (see Fig. 4). For comparison, the integral analyses are done, assuming all the contacts are rigid. The results are not realistic because the calculation assuming, but they we can get the tendency. The natural frequency can increase about 15% while the deformation of the top plate can decrease about 64%. The results are listed in Table 2, and detailed improvement and analyses considering contacts need to done in the future.

Table 2: Optimization Comparison of the 6-axes Girder System

	Girder system before optimization	Girder system after optimization
Deformation of top plate (μm)	42.1	15.2
Natural frequency (Hz)	47.1	54.1

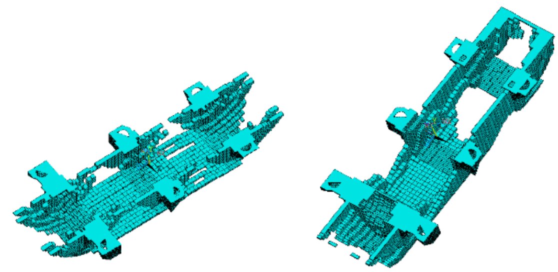

Figure 4: Topological optimization of 6-axes girder body. Left: structural, Right: modal.

Cam Mover Mechanisms

There are six cam mover mechanisms for the 6-axes girder system, which compose 3 grooves. While for the 8-axes girder system, there are eight cam mover mechanisms composing 4 grooves. Each cam mover mechanism contain one ball unit, one ball unit housing and one cam mover. According to the load, the ball unit are specially ordered with the capability of 5000kgs in the ball down position, and the diameter of the main ball is 88.9 mm. The cam is with 7 mm eccentricity. According the some mathematical calculation and optimization, the center distance between the ball and cam is 110 mm, and the initial location is shown in Fig. 5. The adjustment ranges are ±9.35 mm in X direction, and ±10.45 mm in Y direction. The calculated displacement per step is about 0.8μm, which is less than the designed adjusting resolution 3μm.

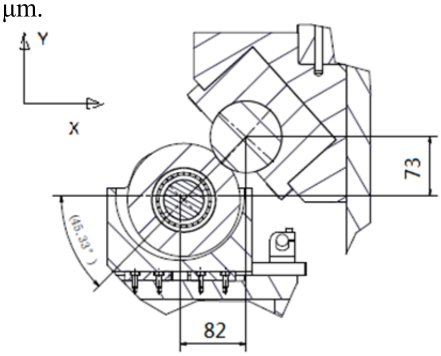

Figure 5: The initial location of the cam mover.

Pedestals

According to the distribution of cam movers, there are three pedestals for 6-axes girder system and four pedestals for 8-axes girder system. The cam movers are fixed on the top plate of pedestals by screws and keys. The pedestals are welded by several Q345 plates.

Sensor System

There are one inclination sensor and eight absolute length gauges. These sensors can detect the location of the girder body, and then the control system can judge if the girder body needs to be adjusted. If then the control system drive the motors of the cam mover systems, and the sensor system reads the location of the girder body again, and so on, to realize the adjustment of the girder body (see Fig. 6).

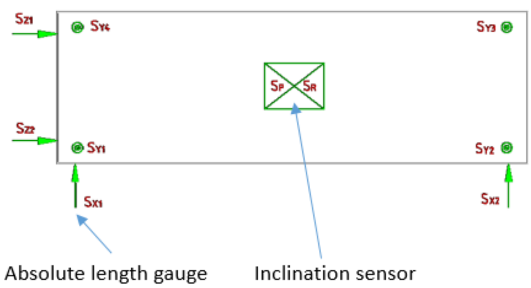

Figure 6: Distribution of sensors.

Locking System

Locking systems are between the girder body and pedestals, they are used for increasing the natural frequency and stability. A locking system is a motor driven wedge. After alignment, the wedge is driven to lock the girder body by extrusion force. But the extrusion can also leads to translation of the girder body, so if the locking systems can be used needs to be further considered or tested.

DESIGN OF 8-AXES GIRDER SYSTEM

The components of the 8-axes girder system are almost the same as the 6-axes girder system's, which are described above. Since there are eight axes to control six DOFs, the harmonization of these axes should be defined. As shown in Fig. 2, the girder has a slight barycentre offset from the geometry center because of structure. The servo motors of the driving cam mover work at location mode, but they can detect the moment. In case of moment accident, the control system do some commands to solve it.

ADJUSTING ALGORITHMS

The aim of the adjusting algorithms is to transfer the adjusting magnitude to the motor's steps. First, the coordinate of the girder should be built at the center of the girder on the beam path, as shown in Fig. 7 [3, 5].

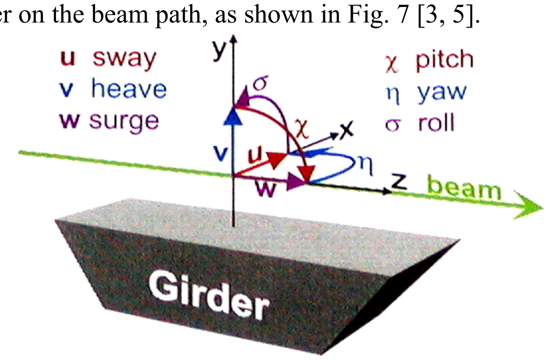

Figure 7: The definition of coordinates of the girder (This figure is borrowed from [3, 5]).

The correct location of the girder is called G_0. The wrong location is called G, which can be recognized a combination of the rotation and translation. Since the rotation will affect the translation and the rotation by the sensors, the rotation will be adjusted first [5].

$$G = RG_0 + T_T \tag{1}$$

When the rotation is adjusted,

$$G + T_R = RG_0 + T_T + T_R = G_0 + T_T \tag{2}$$

$$T_R = (1 - R)G_0 \tag{3}$$

The rotation matrix R can be approximately described as

$$R = \begin{bmatrix} 1 & -\sigma & \eta \\ \sigma & 1 & -\chi \\ -\eta & \chi & 1 \end{bmatrix} \tag{4}$$

The G and G0 is composed by six or eight columns. Suppose the ball N has a coordinate value of G_n, then

$$G_n = \begin{bmatrix} x_n \\ y_n \\ z_n \end{bmatrix} = RG_{n0} + T_T = \begin{bmatrix} x_{n0} - \sigma y_{n0} + \eta z_{n0} + u \\ y_{n0} - \chi z_{n0} + \sigma x_{n0} + v \\ z_{n0} - \eta x_{n0} + \chi y_{n0} + w \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} x_{n0} \\ y_{n0} \\ z_{n0} \end{bmatrix} = \begin{bmatrix} x_n \\ y_n \\ z_n \end{bmatrix} + \begin{bmatrix} \sigma y_{n0} - \eta z_{n0} \\ \chi z_{n0} - \sigma x_{n0} \\ \eta x_{n0} - \chi y_{n0} \end{bmatrix} - \begin{bmatrix} u \\ v \\ w \end{bmatrix} \tag{6}$$

The second matrix is the rotation adjusting magnitude, and the third is the translation adjusting magnitude.

CONCLUSION

The automatic girder systems are the key devices to realize the extremely low emittance and online alignment. This paper described the overall design of the girder systems. The further study will focus on the detailed design, including the structure and control system. The prototypes will be developed in this year.

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ISBN 978-3-95450-147-2