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TEST OF MAGNET GIRDER PROTOTYPES FOR HEPS-TF

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Abstract

Auto-tuning magnet girder is one of the key technologies to be solved for HEPS-TF (Test Facility of High Energy Photon Source). The girder should have high adjusting accuracy, high stability and can be beam-based aligned, to obtain the stability requirements of beam orbit. There are two girders developed, and the tests have been done. The accuracy of girder motion is within 10 microns while the adjusting range is 1 mm and the resolution is better than 1 microns, the natural frequency is higher than 24 Hz.

INTRODUCTION

HEPS (High Energy Photon Source) is a new generation photon source with extremely high spectral luminance proposed by China, of which test facility is called HEPS-TF. The Auto-tuning magnet girder is one of the key technologies should be solved in the TF stage. The design requirements is put forward by the strict beam characters: the alignment accuracy between girders is better than 50 μm; the adjusting resolution is better than 3 μm; the natural frequency is better than 30 Hz; and the girder is applicable for beam-based alignment.

Due to the requirements two auto-tuning girder prototypes have been designed and developed, which are shown in Fig. 1. Both of them use the cam movers as the kinematic mechanism, which has been proved to be a good choice for auto-tuning magnet girders [1-2]. Girder I is 3300 mm long with six supporting points, like the girder of TPS [2-3], which is designed for the straight multiplet magnets. Girder II is an improved scheme, 4300 mm long with eight supporting points, which is designed for the FODO magnets. The structure design has been described in previous work [3-4]. Now the two girder prototypes has been assembled, and the kinematic performance and stability performance tests are almost finished.

KINEMATIC PERFORMANCE

To detect the position of the girder, eight length gauges are used, shown as Fig. 2. The six DOFs can be obtained by simple calculation. In TPS, the rotation have an effect on the translation, so the rotation should be eliminated first [2]. For our cases, because the length gauge show the transposition and rotation relative to the pedestals, which we think are motionless, the six DOFs have no couplings with each other. The translation and rotation can be adjusted together. The algorithm is written in Matlab/Simulink and then imbedded into TwinCAT3.

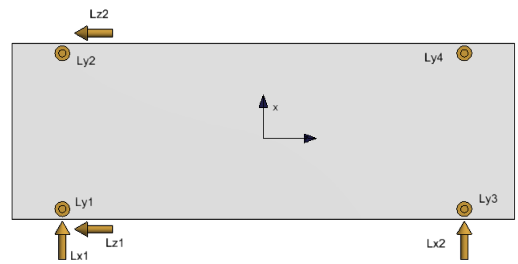

Figure 2: Distribution of length gauges.

Adjustable Range

Figure 3 shows the cross section of one cam mover mechanism. The adjustable range is relative to the eccentricity of the cam and the original relative locations between the cam and the ball. For the eccentricity of 7 mm, the original relative locations have been optimized to equivalent the ranges in both positive direction and negative direction, then the overall adjusting range can be enhanced. The theoretical adjusting ranges of the two girder prototypes are better than ± 10 mm in all the three directions.

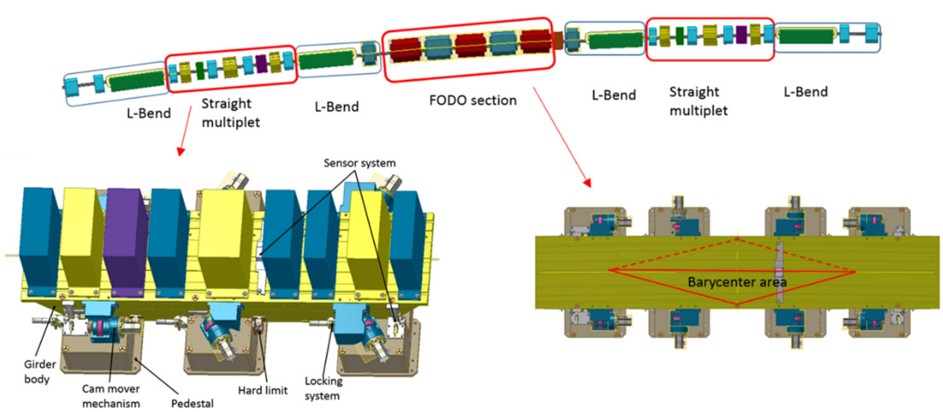

Figure 1: Overall designs of girder prototypes for HEPS-TF.

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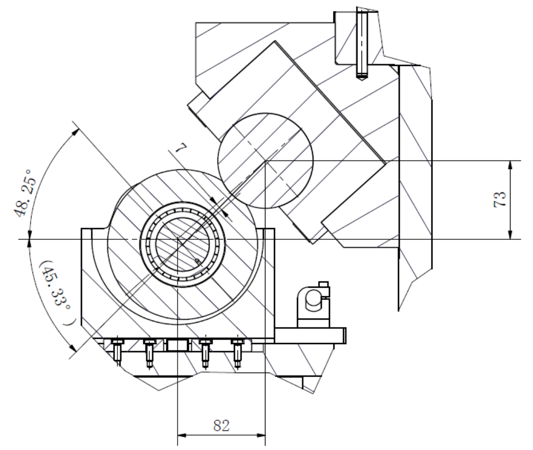

Figure 3: The cross section of cam mover mechanism.

Adjusting Accuracy and Resolution

The measurement of the length gauges is 12 mm, so the kinematic performance are tested within the range of ±5 mm.

For the test of kinematic accuracy, the girder is arranged to get the different positions. It shows that the kinematic error gets larger if the adjusting range increases. Basically, the kinematic errors and the coupling errors can be controlled within 10 microns when the adjusting range is within1 mm and 0.5 mrad. Detailed accuracy of Girder I is shown in Table 1 and Figure 4.

Table 1: Test Results of Kinematic Accuracy from Home Position of Girder I

Adjusting range and direction		**Kinematic error**	**Coupling error**
≤±1mm	X	≤3 μm	≤2 μm, 4 μrad
	Y	≤5 μm	≤4 μm, 5 μrad
	Z	≤11 μm	≤6 μm, 5 μrad
≤0.5 mrad	Pitch	≤1 μrad	≤2 μm, 1 μrad
	Yaw	≤3 μrad	≤3 μm, 2 μrad
	Roll	≤3 μrad	≤4 μm, 2 μrad
≤±5mm	X	≤13 μm	≤15 μm, 27 μrad
	Y	≤20 μm	≤30 μm, 58 μrad
	Z	≤17 μm	≤13 μm, 39 μrad
≤3 mrad	Pitch	≤13 μm	≤33 μm, 4 μrad
	Yaw	≤11 μm	≤14 μm, 11 μrad
≤10 mrad	Roll	≤106 μm	≤41 μm, 36 μrad

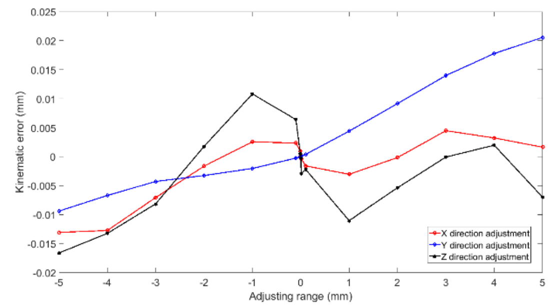

Figure 4: Kinematic error of three translation directions from home position of Girder I.

The large-range adjustment is used for the rough alignment after the girders are assembled in the tunnel. The pedestals will be surveyed by laser tracker, which accuracy is designed 33 micros. The kinematic error and coupling error of the girder with a 5 mm and 3mrad adjusting range is within 30 micros. Then the total error of the rough alignment will be better than 45 microns.

For the accuracy at different positions, it shows that there has no obvious difference with that at home position. Figure 5 shows the kinematic error when the adjusting range is within 100 μm in Y direction and the girder prototype is at different positions. The other DOFs and the kinematic performance of Girder II are similar. This means if the girder is arranged to move a little owing to beam-based alignment or other instruction, the accuracy is at micron-level.

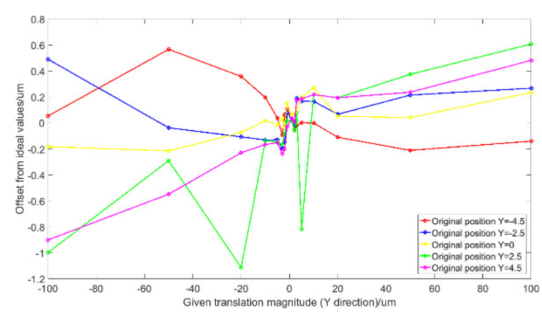

Figure 5: Kinematic error when the adjusting range is within 100 μm in Y direction at different positions of Girder I.

All the above test is under the open-loop control. The accuracy can be enhanced ever higher when added the feedback.

For the resolution, the calculated value is about 0.8 μm if the stepping motor have no subdivision. It is not a constant value because of the mechanism. The tested Y-direction resolution is shown in Table 2. The X and Z directions has similar results, as well as those of Girder II. The resolution is better than 1μm.

Table 2: Y-direction Resolution of Girder I

Arranged value (μm)	-5	-3	-2	-1	1	2	3	5
Response (μm)	-5.014	-2.967	-2.035	-0.845	1.06	2.076	3.11	5.198

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Table 3: Test and FEA Results of Girder I without Locking System

Modal	Tested results	FEA results, steel plate fixed to ground by bolts	FEA results, pedestals fixed to ground
1	17.3 (X+Yaw)	17.6 （X+roll+yaw）	23.2 （Yaw+Roll）
2	19.7 (Z)	18.8 （Z+pitch）	24.6 （Z+Pitch）
3	21.3 (Yaw)	21.1 （Yaw+Roll）	32.2 （Yaw+Roll）
4	23.6 (Pitch)	25.3 （Z+pitch）	32.5 （Z+Pitch）
5	27.8 (Y)	32.1 （Y）	38.2 （Y）
6	42.6 (Roll)	36.8 （Roll+Yaw）	52.0 （Roll）

STABILITY PERFORMANCE

The two girder prototypes are designed with the natural frequencies above 30 Hz. This should be on the condition that the pedestals are fixed to the ground by cement grouting. By now, the girders haven't been grouted, so the vibration tests which have been done can't indicate the designed condition, but they can be used for the reference.

Figure 6 shows the vibration test site of Girder I. The pedestals are mounted to a big steel plate, which is fixed to the ground by several anchor bolts. This kind of fixing method don't as stable as grouting. The natural frequency of the pedestals are about 63 Hz. The natural frequency of the girder prototype is 17 Hz without locking system. The first modal is mainly manifesting as the wiggling along Y axis.

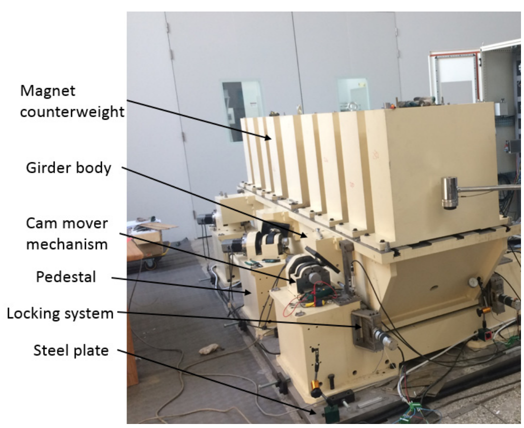

Figure 6: Vibration test site of Girder I.

To estimate the natural frequency when the pedestals are grouted to the ground, the FEA calculation are done using ANSYS. Two cases are simulated, one is the steel plates fixed to the ground by bolts and the other is the pedestals fixed to the ground, which are listed in Table 3. The constraints of the former case is similar to the installation of Fig.6, and the results is in accordance with the test results. For the latter case, the analysed results show the natural frequency can be enhanced by over 5 Hz from the former case, which indicates the tested natural frequency should be enhanced by grouting.

The natural frequency of Girder I with locking system is 24 Hz, which is shown in Fig. 7. This means the locking system can enhance the natural frequency obviously. If the pedestals are grouted to the ground, the natural frequency of the pedestal is estimated to be enhanced from 63 Hz to above 200 Hz [5]. Then the natural frequency of Girder I is estimated to be enhanced from 24 Hz to about 30 Hz.

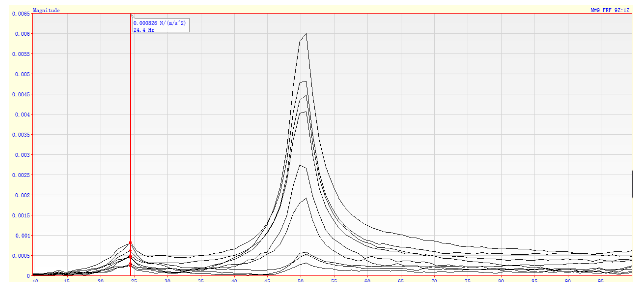

Figure 7: Transfer function of X-direction vibration of Girder I.

Girder II is also not grouted to the ground, so the test results again cannot indicate the designed condition. But it is estimated the natural frequency of Girder II is better than Girder I, which will above 30 Hz.

CONCLUSION

Two auto-tuning magnet girder prototypes have been developed for HEPS-TF, the kinematic performance have reached the design parameters, the accuracy is better than 10 microns and the resolution is better than 1 microns. The natural frequencies haven't reached the design parameters, but should be enhanced if the pedestal are grouted to the ground.

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