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INSTALLATION PROCESS EXPERIMENT OF HEPS STORAGE RING EQUIPMENT

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Abstract

HEPS is a new generation synchrotron radiation source under construction in China. In order to complete high-precision installation of the 1.4 km storage ring within a limited construction period, it is necessary to identify and solve potential issues in various aspects, including operation space, installation process, alignment scheme, and unit transportation, prior to the regular batch installation. Therefore, a full-process installation experiment was performed and the feasibility of relevant schemes are verified. Batch installation is currently in progress based on the experimental experience.

INTRODUCTION

The High Energy Photon Source (HEPS) is the fourth-generation synchrotron radiation source currently under construction in China, characterized by high energy and extremely low emittance. The circumference of the storage ring is approximately 1.4 km, and compact 7BA achromats is adopted [1], which brings lots of challenges to the installation. In order to complete high-precision installation within a very limited construction period, it is necessary to identify and solve potential issues in various aspects, including installation operation space, alignment installation process, pre-alignment precision, and transportation reliability, before the regular installation in batches.

The experiment object is a standard 7BA cell, as shown in Fig. 1, which includes 6 pre-alignment units, 5 BLG magnets, 1 ID beamline, and 1 BM beamline.

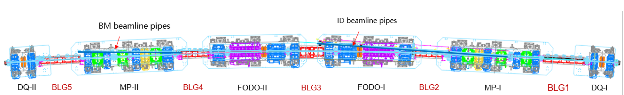

Figure 1: A standard 7BA cell.

The experiment was performed in a laboratory adjacent to HEPS. The pre-alignment was carried out in a thermostatic room, while other processes were conducted in the hall. The experiment lasted for approximately 4 months.

PRE-ALIGNMENT SCHEME

The magnet pre-alignment errors are required to be less than 30 μm, which accumulate from several processes such as measuring, magnet positioning, magnet opening/closing, and transportation. The magnet positioning deviation between magnets within a girder is required to be less than 10 μm, and much higher measuring accuracy and precise alignment mechanism of micron level are needed.

Measuring Accuracy

The laser tracker, which is the most popular instrument in accelerator alignment, cannot meet such high precision requirements directly. Therefore, a laser tracking interferometer system is developed and the measuring accuracy can be improved to 6 μm [2].

Based on multi-lateration measurement principle, four laser trackers are arranged in a specific layout, as shown in Fig. 2, to measure one target point simultaneously. Only distances are extracted from the measuring parameters, which is more accurate than the angles in the laser tracker measurement, for calculating the coordinates of the targets. Meanwhile, the target coordinate is displayed on the screen in real-time, and the magnet position can be adjusted precisely by operating the alignment mechanism.

Figure 2: Laser tracking interferometer system.

Pre-alignment Process

Before installation, wipe the mounting surface to ensure there are no debris, stickers, or other foreign objects. Ensure that the six support points of the girder body bear force evenly, and then assemble a group of magnets on this girder into a pre-alignment unit.

Basic pre-alignment procedure includes following steps:

1. Transport the unit into the thermostatic room for temperature stabilization. At least 4 hours are needed before measurements to eliminate the influence of environmental temperature on the equipment.
2. Level and tighten the girder on the plinth, and establish a coordinate system based on the girder as the alignment reference.
3. Measure the position of each magnet and fit it with the theoretical values to determine the adjustment amount for each magnet.
4. Select a magnet as the alignment reference, usually is the magnet located in the middle of the girder and with

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a larger size, and adjust it firstly. Then the other magnets are properly aligned one by one. This method is helpful to reduce alignment errors.

5. Do an overall measurement to verify and evaluate the accuracy of the alignment and save the data if the requirements are met.

Magnets Position Adjusting

As shown in Fig. 3, wedge jack is used for the magnet adjustment in the vertical direction and the adjustment range is ±1 mm. Fine screw push-pull mechanism is used in the horizontal direction and the adjustment range is ±4 mm [3]. Both mechanisms are designed with high stiffness to guarantee the resolution of micron level. The magnet position deviation is reduced gradually through adjustment until to 0.01 mm.

It is important to make sure there is as less internal stress as possible after the tightening of the magnets, to keep the position unchanged in a long time. Therefore, in-place tightening technique [4] is proposed and tested, and the positional deviation during tightening can be controlled less than 0.01 mm with a torque of 130 N·m.

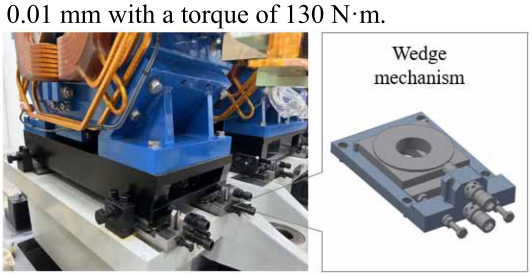

Figure 3: Magnet alignment mechanism.

Alignment of Sextupoles and Movers

In order to reduce the residual error of beam optics correction and improve the dynamic aperture, sextupole Mover is developed to do beam-based alignment online. Wedge mechanism is adopted in the Mover design, and two motors drive a couple of wedge plates by a certain algorithm to realize transverse and vertical motion. The moving accuracy is required to be less than 5 µm at the magnet center height, and the online moving range is ±0.3 mm [5]. Both the sextupole and the Mover should be aligned on the girder properly.

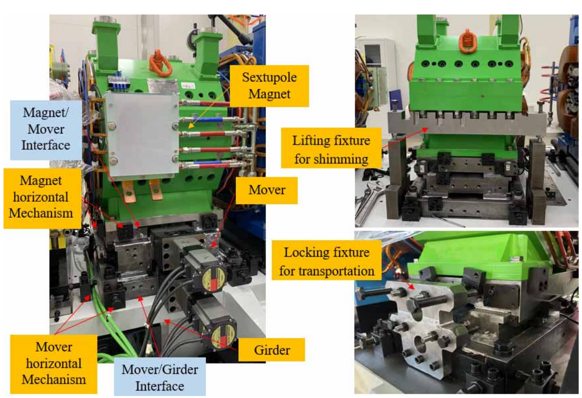

Figure 4: Installation of the sextupole and Mover.

Figure 4 shows the installation of the sextupole and the Mover. There are 3 Movers mounted on each MP girder, positioning errors and efficiency are both aspects of concern. According to the check results, the Mover can be fixed on the girder directly and shims are inserted in the interface of magnet and Mover using a special lifting fixture to compensate the flatness errors. Residual errors are eliminated by operating the Mover. A whole range motion of the Mover is tested to check the coupling errors in the non-motion directions.

The position stability of the Mover during the transportation is also tested [6], and the change of grating readings is about 10 µm. The solution is to lock the Mover slide using a fixture, record the grating readings before transportation and restore them after transportation

REPEATABILITY OF MAGNET OPENING AND CLOSING

The magnets will be opened to install the vacuum chambers after pre-alignment, and the magnet position error after reclosing should meet the alignment requirements. The repeatability error is required to be less than 0.01 mm, and the deviation from the theoretical value should be less than 0.021 mm. The magnets of two typical large units are tested, and one is the MP unit with 8 magnets and the other is FD unit with 5 magnets. All the magnets are designed with pins to obtain repeatability after the core opening/closing.

Table 1: Test Result of Magnet Opening/Closing

Unit Type	Test Times	Deviation/mm			Comparison Item
		DX	DY	DZ	
MP	1st	0.006	0.008	0.005	Before opening
		0.006	0.008	0.016	Theoretical value
FD	1st	0.017	0.009	0.017	Before opening
		0.018	0.012	0.019	Theoretical value
	2nd	0.006	0.003	0.004	1st opening
	3rd	0.006	0.003	0.004	2nd opening

Table 1 presents the result of the test, with DX and DY data being of utmost concern. For the MP unit, the magnet position repeatability and the deviation from the theoretical value are both less than 0.01 mm. As for the FD unit, the deviation from the theoretical value is less than 0.02 mm while the repeatability exceeds 0.01 mm at the first time. Therefore, two more tests are performed, and the position variation reduced a lot to 0.006 mm in the second time and keep stable in the third time, which meeting the error requirements of this stage.

The main contribution of the variation comes from the larger-sized magnets of ABF2/3 and BD1/2, and additional experiments are carried out on the two types of magnet. As shown in Fig. 5, dozens of targets are glued on the magnet

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for measuring, and the variation of the magnet shape before and after opening/closing can be monitored easily. According to the result, the shape of iron cores changes slightly and the coordinates of the target points changes accordingly. It is deduced that the internal stress generated during the assembly process have released during the magnet opening/closing process. This experience has been taken into account for reference in the batch installation, and relevant procedures have been developed accordingly.

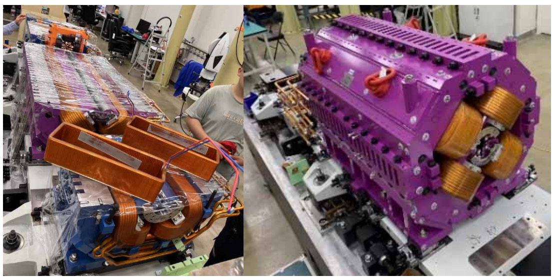

Figure 5: Opening/closing test on BD1/2.

TRANSPORTATION RELIABILITY

On the way to HEPS tunnel, the pre-alignment unit need to pass through a sinking channel. The magnet positions deviation after transportation is required to be less than 0.015 mm. Both MP unit and FD unit are tested. The transportation route is from alignment hall to the entrance of the HEPS tunnel. Figure 6 shows the transportation fixtures.

Several measures are taken to ensure minimal change in magnet positions in this process:

1. A self-levelling and vibration-reducing transport platform is designed specially to keep the magnet and girder level, which is particularly useful when the truck is going up or down slopes.
2. The 6 support points of the girder should maintain balanced force in the whole transportation process.
3. A constant speed of 10-20 km/h of the truck is secured.

According to the test result, as shown in Table 2, the magnet position variation after transportation is less than 0.01 mm, and the deviation from the theoretical value is less than 0.015 mm, better than the requirements of this stage.

Table 2: Test Result of Transportation

Unit Type	Deviation/mm			Comparison Item
	DX	DY	DZ	
MP	0.005	0.004	0.005	Before Transportation
	0.007	0.007	0.014	theoretical value
FD	0.006	0.006	0.011	Before Transportation
	0.01	0.009	0.007	Theoretical value

Self-levelling platform FD Unit lifted onto the truck

Figure 6: Transportation test.

MOCKUP EXPERIMENT

The alignment process in the tunnel has been simulated in the experiment hall on the 7BA mockup. The sequence is shown below:

1. 6 pre-alignment units and 5 Dipoles: Tightened on the plinth by non-stress method.
2. 12 BPMs: Aligned prio to the vacuum chambers, which request as less exposure time to the atmosphere as posssible, due to the NEG film.
3. 18 vacuum chambers: installation, alignment and vacuum seal proceed through a flow process. Same reason as above.

The operation space is checked in the whole process, including the magnet opening/closing, vacuum elements alignment, and vacuum connection, and special tools are used a lot in the critical places.

SUMMARY

A full-process installation experiment was performed and the feasibility of relevant schemes are verified:

1. The alignment accuracy meets the required specifications.
2. The repeatability of the magnet opening /closing better than 0.01 mm is achievable. The issues encountered during the process have been solved.
3. The magnet displacement during transportation is less than 0.015 mm, confirming the reliability of the transportation scheme.
4. The installation process in the tunnel has been tested and the operation space has been checked, with potential issues resolved.

Batch installation is currently in progress.

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