

The Application of Vibration Wire Measurement Technology in Pre-alignment Unit of HEPS Storage Ring



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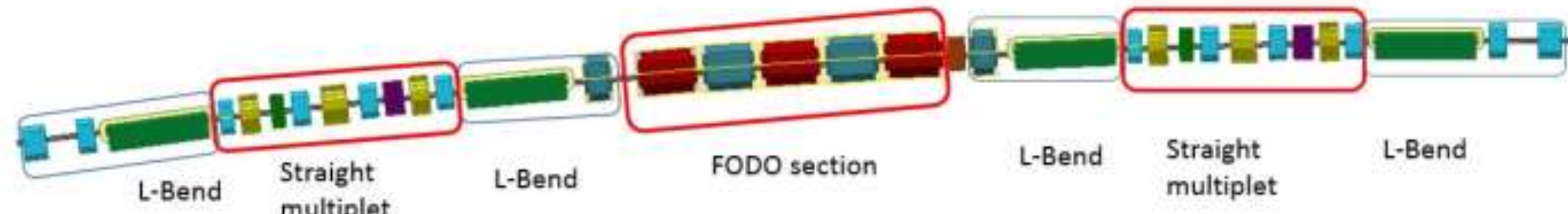
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Abstract

The High Energy Photon Source (HEPS), China's first fourth-generation synchrotron light source, requires a pre-alignment precision of 0.03 mm between unit magnets in the storage ring pre-alignment units. This poster presents the 3-magnet and 5-magnet unit structures of the HEPS storage ring, where the vibrating wire technique is employed for magnetic center measurement. A laser displacement system has been developed to enhance sag correction accuracy. Experimental results demonstrate that the fitting deviations of both standard unit types are better than 0.015 mm, meeting the pre-alignment precision requirements.

Introduction

The storage ring of HEPS has a circumference of approximately 1.3 km and consists of 288 pre-alignment standard units, including 96 three-magnet units, 96 five-magnet units and 96 eight-magnet units. the alignment accuracy between magnets in the pre-alignment units is a critical technical indicator for ensuring long-term stable and efficient operation of the storage ring. Currently, multi-laser systems are used for magnetic center pre-alignment in the HEPS storage ring pre-alignment units. To ensure the reliability and accuracy of this high-precision measurement system, it is essential to introduce vibration wire technology as an independent high-precision measurement system for verifying the alignment accuracy of the pre-alignment units.



Layout of a standard unit equipment

Principle

Vibration wire magnetic center measurement technology involves scanning vibration wire in both horizontal and vertical directions near the approximate magnetic center of a magnet to detect the magnetic field distribution and determine the magnetic center position. The relationship between the magnetic field components of a quadrupole magnet and their deviation from the magnetic center is given by:

$$B_y = G(x - x_0)$$

$$B_x = G(y - y_0)$$

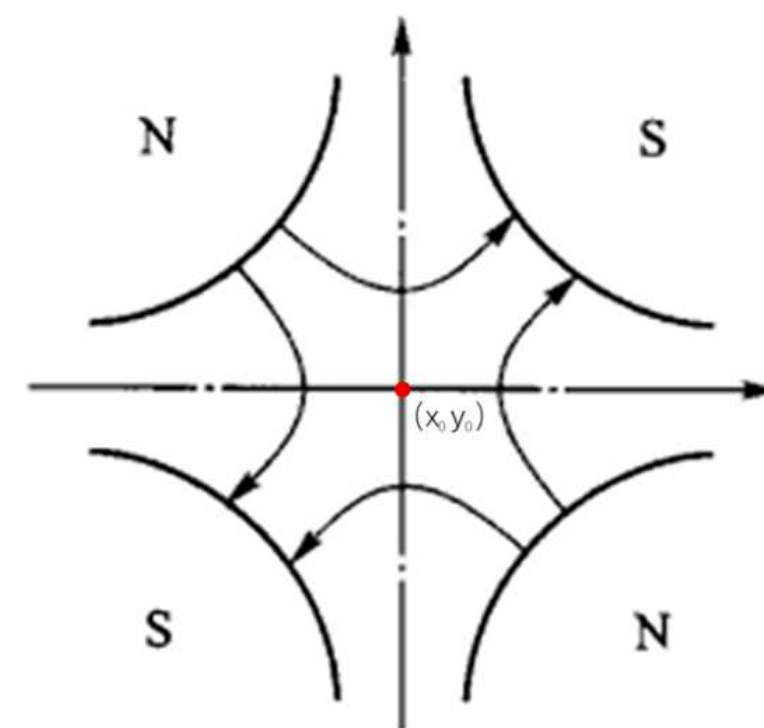
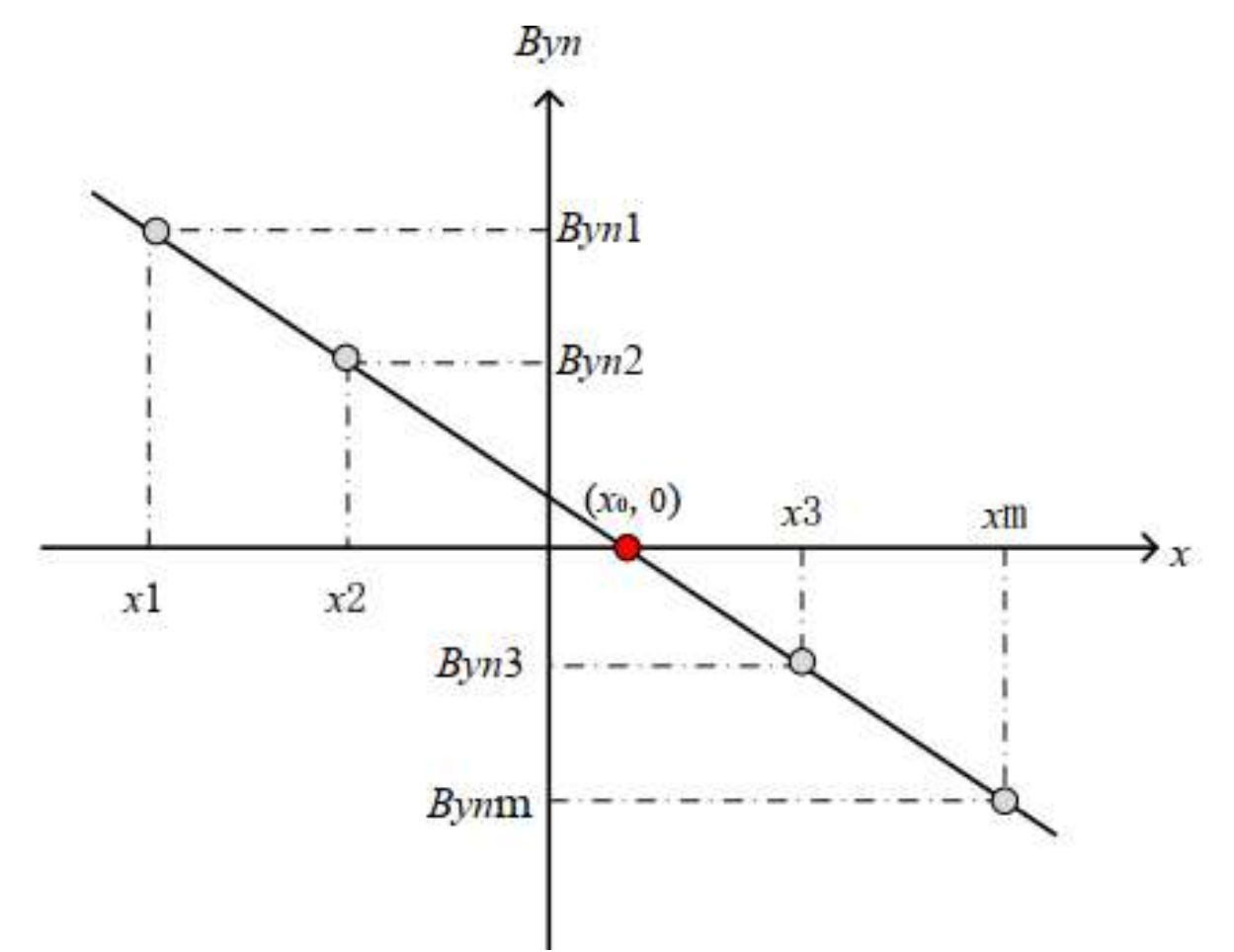


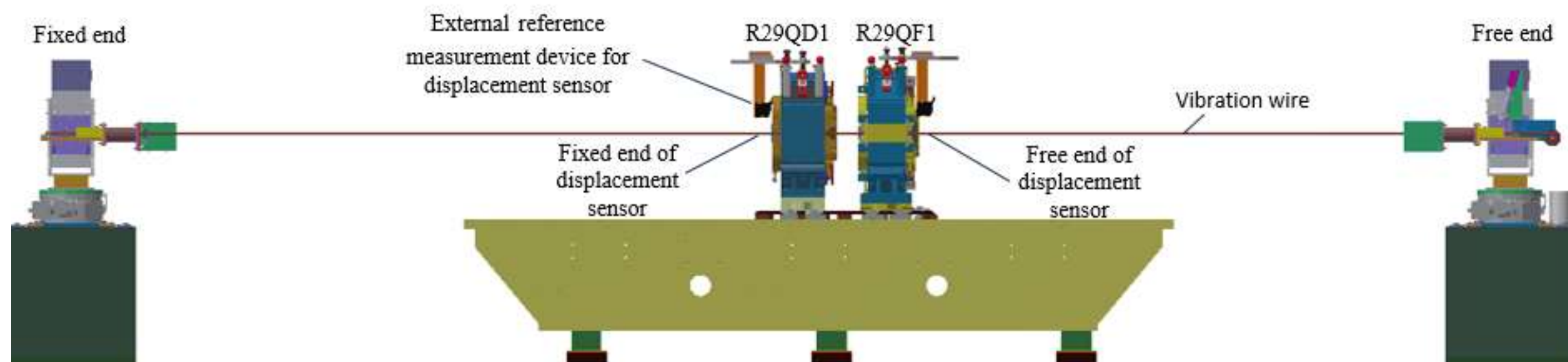
Diagram of vertical quadrupole magnetic field



Schematic of horizontal magnetic center measurement method for quadrupole magnets

Three-magnet unit

The selected pre-alignment three-magnet unit R29DQ1 consists of 2 quadrupole magnets and 1 corrector magnet. The corrector magnet is used to correct beam deviations from the orbit. Mechanical center calibration can meet alignment accuracy requirements, so it is not included in the scope of this vibration wire magnetic center verification measurement.



The pre-alignment three-magnet unit vibrating-wire scanning schematic diagram

Magnet types	Measurement times/times	Fixed end		Free end	
		x /mm	y/mm	x/mm	y/mm
R29QF1	1	-0.031	-0.326	-0.038	-0.329
	2	-0.038	-0.340	-0.038	-0.335
	Deviation/mm	0.007	0.015	0.000	0.006
R29QD1	1	-0.026	-0.339	-0.028	-0.342
	2	-0.032	-0.340	-0.032	-0.340
	Deviation/mm	0.006	0.001	0.004	0.002

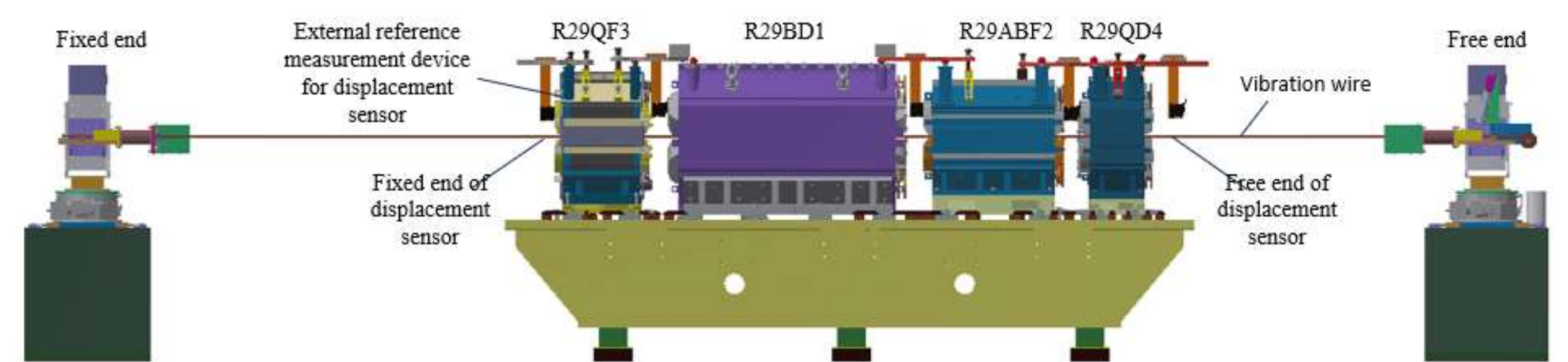
Repeatability result of vibrating-wire magnetic center scanning in pre-alignment three-magnet unit

Vibration wire fixation method	Magnet entrance and exit	Horizontal x/mm	Vertical y/mm	Longitudinal z/mm
Fixed end	R29QF1EN	0.000	0.000	0.0
Free end	R29QF1EX	0.000	0.000	246.0
Fixed end	R29QD1EN	0.005	-0.004	445.0
Free end	R29QD1EX	0.008	-0.006	639.0

Vibrating-wire scanning results of the pre-alignment three-magnet unit in the HEPS storage ring

Five-magnet unit

The selected pre-alignment five-magnet unit R29FD1 consists of 4 quadrupole magnets and 1 corrector magnet.



The pre-alignment five-magnet unit vibrating-wire scanning schematic diagram

Magnet types	Measurement times/times	Fixed end		Free end	
		x/mm	y/mm	x/mm	y/mm
R29QF3	1	0.003	-0.019	0.006	-0.022
	2	0.003	-0.017	0.004	-0.017
	Deviation/mm	0.000	-0.002	0.002	-0.005
R29BD1	1	0.003	0.125	0.006	0.126
	2	0.003	0.128	0.004	0.127
	Deviation/mm	0.000	-0.003	0.002	-0.001
R29ABF2	1	0.005	0.099	0.006	0.099
	2	0.005	0.099	0.006	0.099
	Deviation/mm	0.000	0.000	0.000	0.000
R29QD4	1	0.004	-0.049	0.002	-0.047
	2	0.001	-0.051	0.001	-0.051
	Deviation/mm	0.003	0.002	0.001	0.004

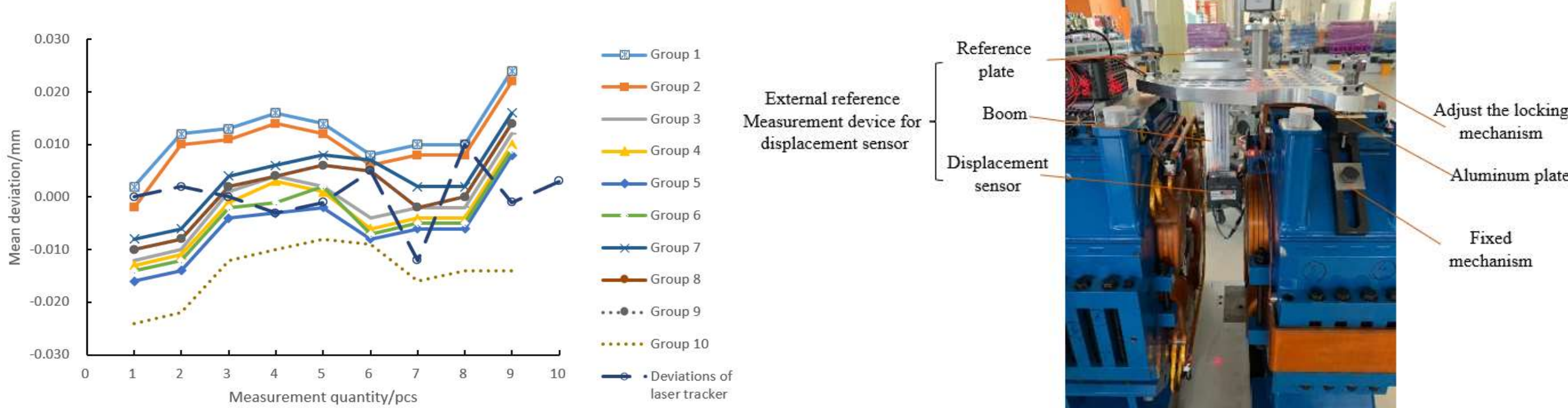
Repeatability result of vibrating-wire magnetic center scanning in pre-alignment three-magnet unit

Vibration wire fixation method	Magnet entrance and exit	Horizontal x/mm	Vertical y/mm	Longitudinal z/mm
Fixed end	R29QF3EN	0.004	-0.002	0.000
Free end	R29QF3EX	0.003	-0.002	375.000
Fixed end	R29BD1EN	-0.007	-0.001	633.920
Free end	R29BD1EX	-0.003	-0.002	1 674.920
Fixed end	R29ABF2EN	0.000	0.011	1 869.720
Free end	R29ABF2EX	0.002	0.009	2 460.720
Fixed end	R29QD4EN	0.002	-0.007	2 674.120
Free end	R29QD4EX	0.000	-0.007	2 935.120

Vibrating-wire scanning results of the pre-alignment five-magnet unit in the HEPS storage ring

Laser displacement system-Repeatability

The working principle of a laser displacement sensor involves emitting a laser beam onto the surface of the measured object and receiving the reflected light signal to calculate the distance.



Repeatability test results of external reference for laser displacement sensor

Laser displacement system-Compare

Magnet types	Longitudinal/mm	Sag/mm
R29QF1	229	-0.017
R29QD1	648	-0.014
Magnet types	Longitudinal/mm	Sag/mm
R29QF3	296.83	-0.055
R29BD1	1 138.69	-0.196
R29ABF2	2 298.93	-0.157
R29QD4	2 920.68	-0.025

Wire sag of three-magnet and five-magnet units

Wire position	Longitudinal z/mm	Sag of conductor obtained by two methods/mm		
		Fundamental frequency method	Displacement sensor fitting method	Deviation /mm
Fixed end	0.0	0.000	0.000	0.000
Mid of R29QF1	229.0	-0.010	-0.017	-0.007
Mid of unit	423.0	-0.012	-0.021	-0.009
Mid of R29QD1	648.0	-0.008	-0.014	-0.006
Free end	828.0	0.000	0.000	0.000

Comparison of Sag obtained by two methods