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Automated quadrupole magnet positioning for enhanced harmonic coil measurement

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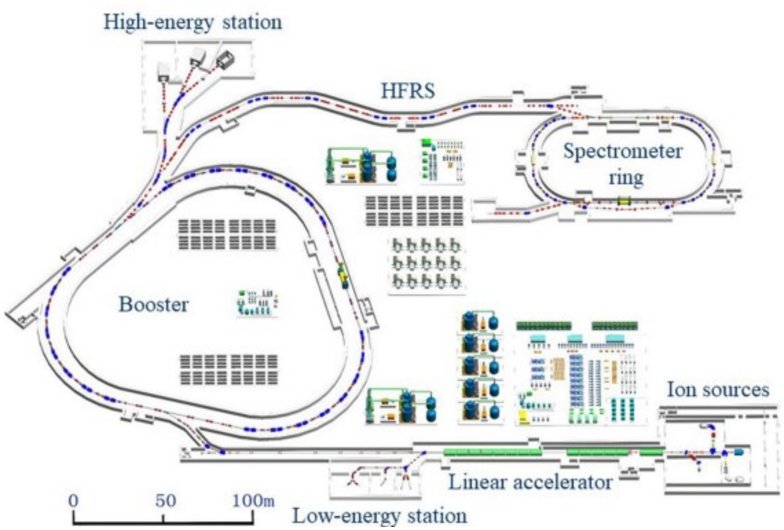
High-Intensity Heavy-Ion Accelerator Facility (HIAF) under construction in Guangdong, China, is a large machine

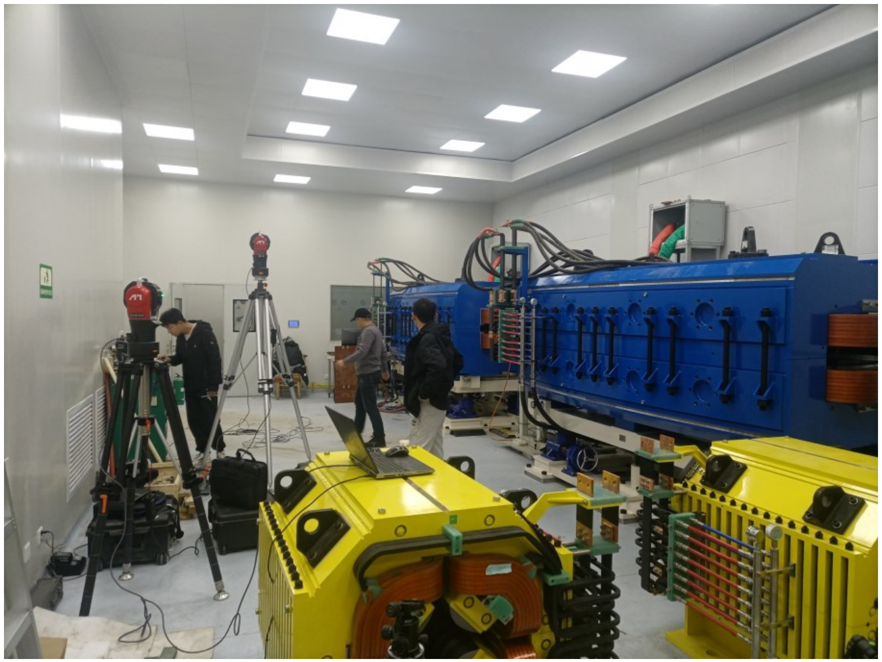


Layout of HIAF

aerial image

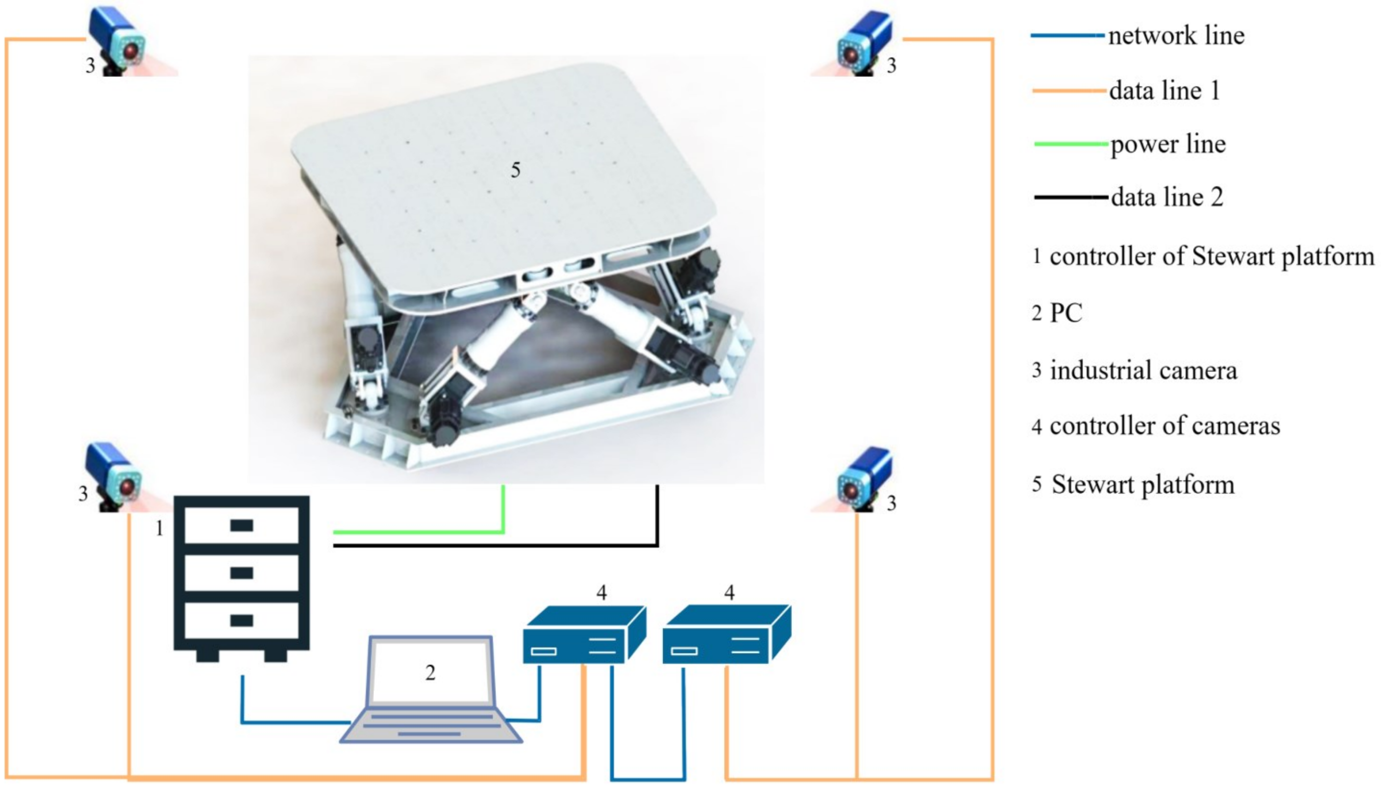
The major sub-systems are sketched, including the ion sources, the superconducting ion linear accelerator, the high-energy synchrotron booster, the high-energy fragment separator, and the experimental spectrometer ring. The low-energy and high-energy experimental stations are also indicated

There are many heavy magnets needed to be positioned in the process of magnetic field measurement

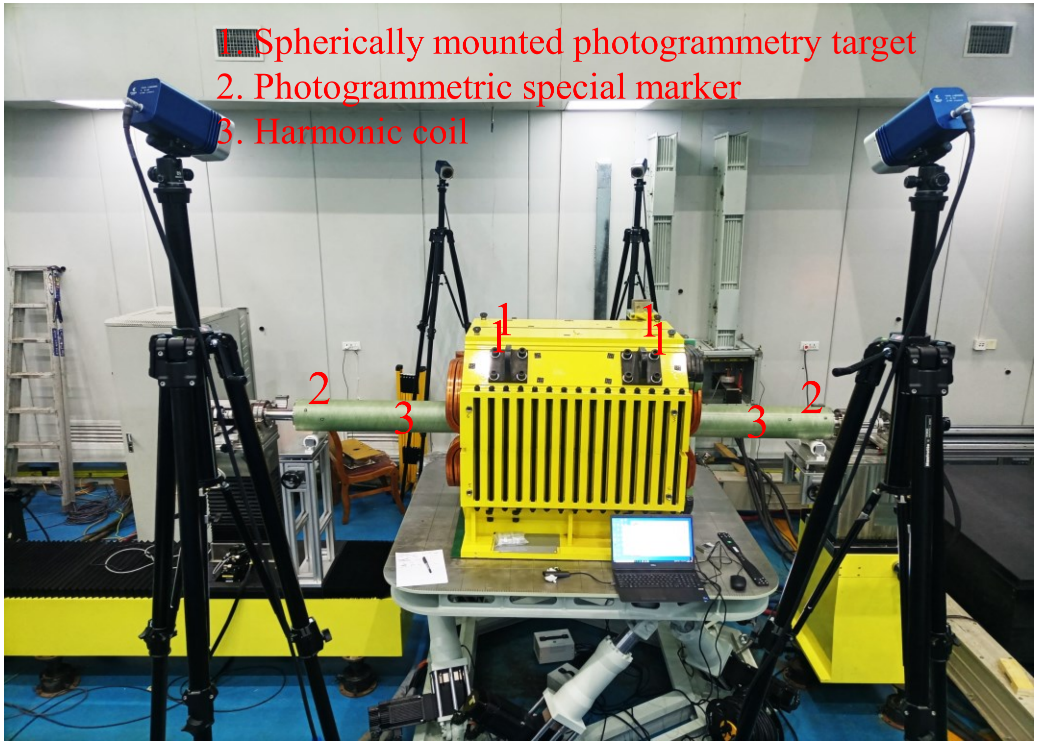


The harmonic coil measurement system is suitable for the multipole field because of its unique advantages.
The current positioning technique employed for harmonic coil measurement is inefficient due to its labor-intensive and time-consuming nature.

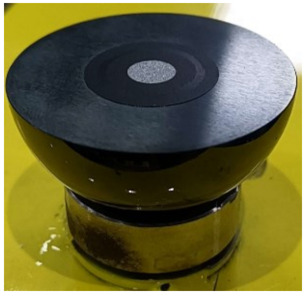
In order to improve the positioning efficiency of the quadrupole magnet for the harmonic coil measurement system, a close-range photogrammetry system and a Stewart platform are used



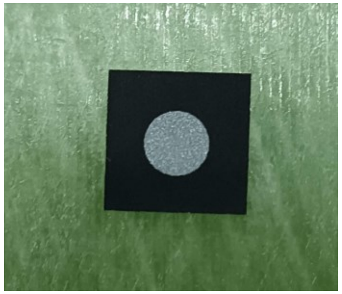
The close-range photogrammetry system is used to monitor the position of the quadrupole due to its non-contact feature, and an electrically driven Stewart platform is utilized to move the magnet



Layout of automated quadrupole magnet positioning system



1. spherically mounted photogrammetry target



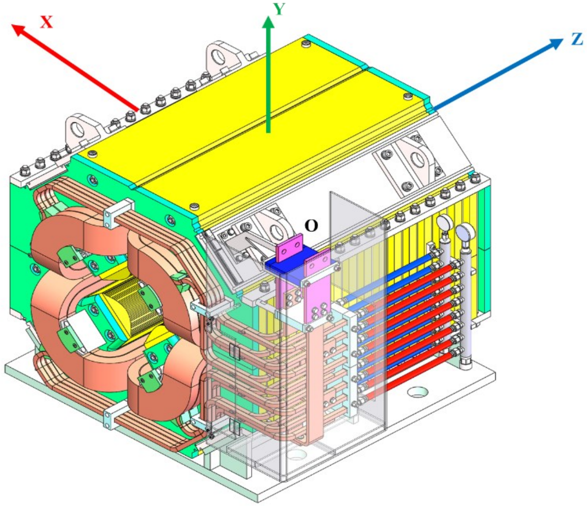
2. photogrammetric special marker

Calculation of rotation angles and translations

Assuming that the rotation centers of the specialized markers located at the two ends of the harmonic coil are denoted as points A and B, with their coordinates in the mechanical coordinate system of the magnet being (X_A, Y_A, Z_A) and (X_B, Y_B, Z_B) respectively. When considering the distance between points A and B as S, and the distance between point A and the origin of the magnet mechanical coordinate system as L, and Eq. (1) and (2) are expressed as follows:

$$S = \sqrt{(X_B - X_A)^2 + (Y_B - Y_A)^2 + (Z_B - Z_A)^2} \quad (1)$$

$$L = \sqrt{(X_A - 0)^2 + (Y_A - 0)^2 + (Z_A - 0)^2} \quad (2)$$



The spherically mounted photogrammetry targets were used to position the cameras in the mechanical coordinate system

Calculation of rotation angles and translations

If the yaw and pitch between the coil rotation axis and the magnet mechanical coordinate system are set, then Eq. (3) and (4) are expressed as follows:

$$yaw = arctan\left(\frac{X_B - X_A}{Z_B - Z_A}\right) \tag{3}$$

$$pitch = arctan\left(\frac{Y_B - Y_A}{Z_B - Z_A}\right) \tag{4}$$

The displacements of the magnet center relative to the coil rotation axis, denoted as (ΔX, ΔY), can be calculated through Eq. (5) and (6) due to the tiny gap between the magnet aperture and the harmonic coil, as shown below:

$$\Delta X = \frac{S - L}{S} X_A + \frac{L}{S} X_B \tag{5}$$

$$\Delta Y = \frac{S - L}{S} Y_A + \frac{L}{S} Y_B \tag{6}$$

Therefore, the motion vector of the magnet to attain the target position is represented as (pitch, yaw, 0, ΔX, ΔY, 0). Stewart platform aligns the magnet in accordance with this vector

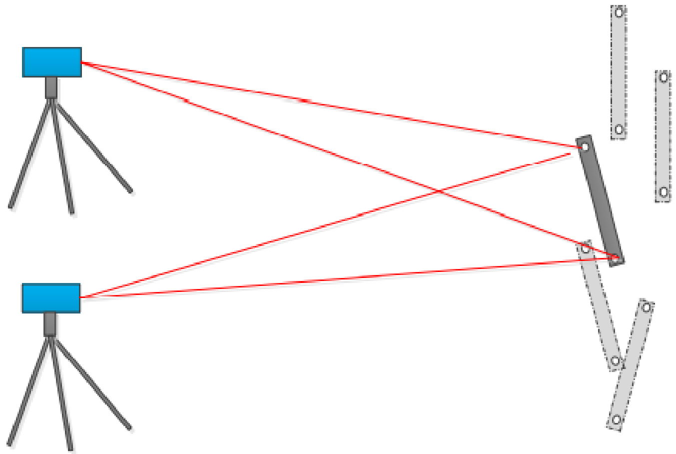
Control system

A control system has been programmed to regulate the automatic positioning

The system can receive measurements from the close-range photogrammetry system in order to compute the displacements of the magnet from its current position to the target. Meanwhile, it can send commands to Stewart platform to regulate its movement.

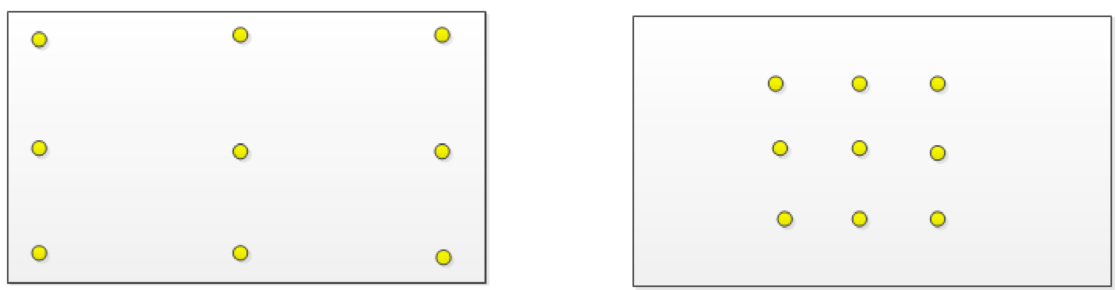
Results

calibration of the close-range photogrammetry system



Calibration

length reference ruler

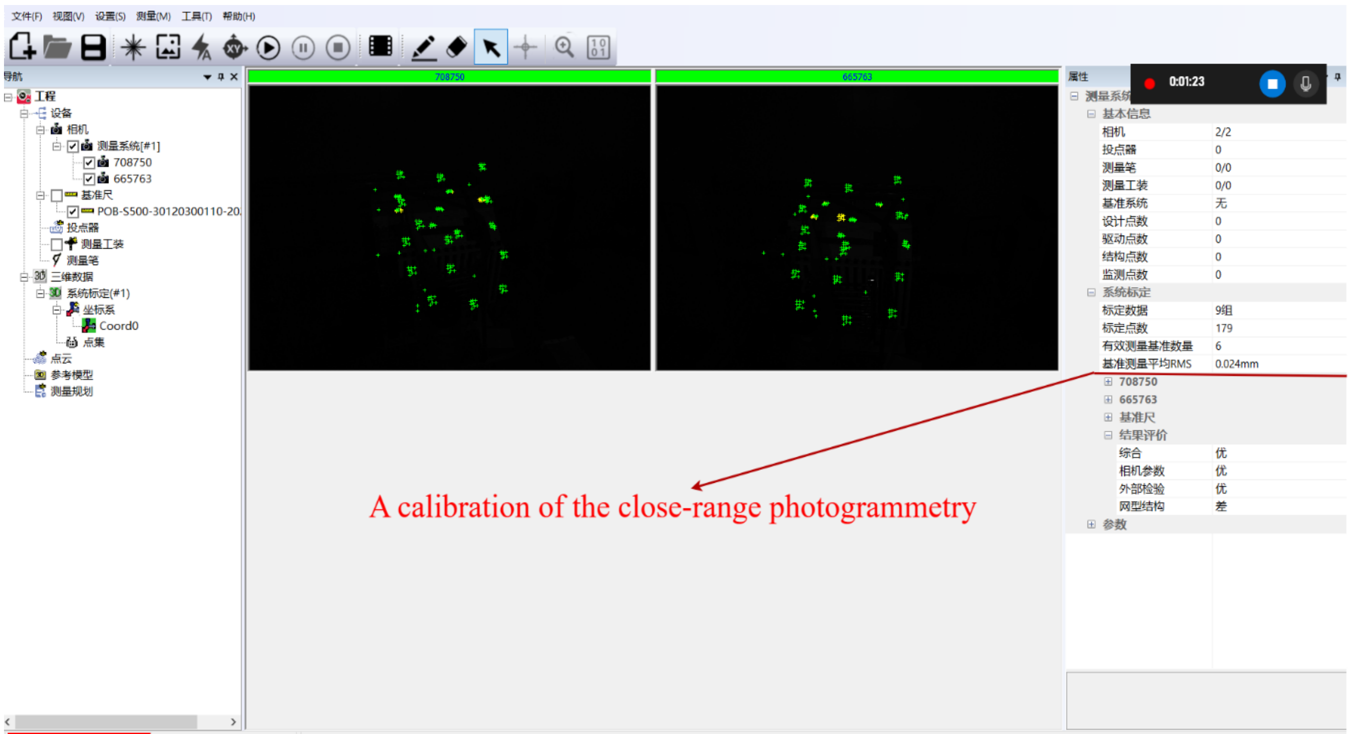


Distribution of length reference ruler

A length reference ruler is used to calibrate the close-range photogrammetry system. The ruler should be measured nine times, with the measurement overlap of the four cameras being evenly distributed.

Results

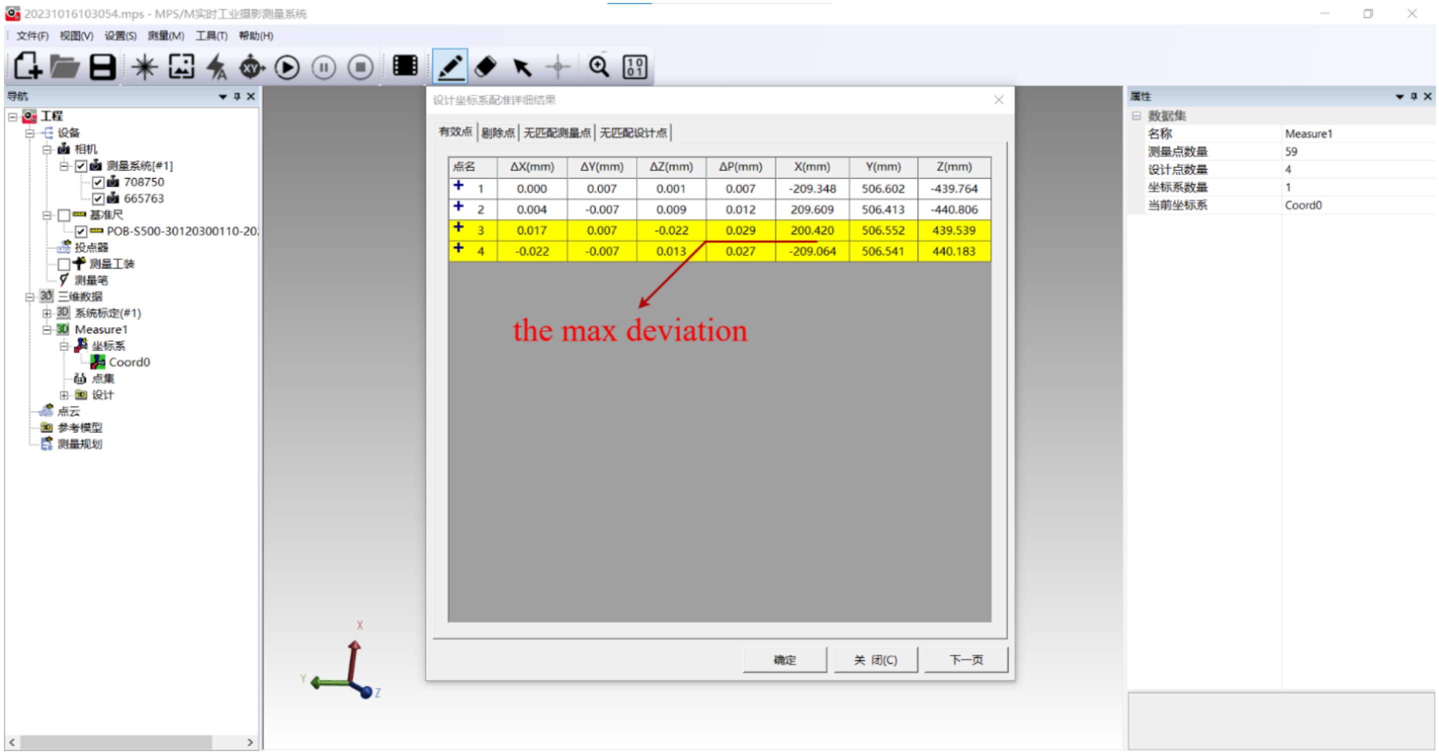
calibration of the close-range photogrammetry



The average Root Mean Square (RMS) of the reference measurement reflects the calibration of the cameras. During the calibration process, the average RMS of the reference measurement for the system is 0.024 mm. It is advisable for the value to be less than 0.03 mm.

Results

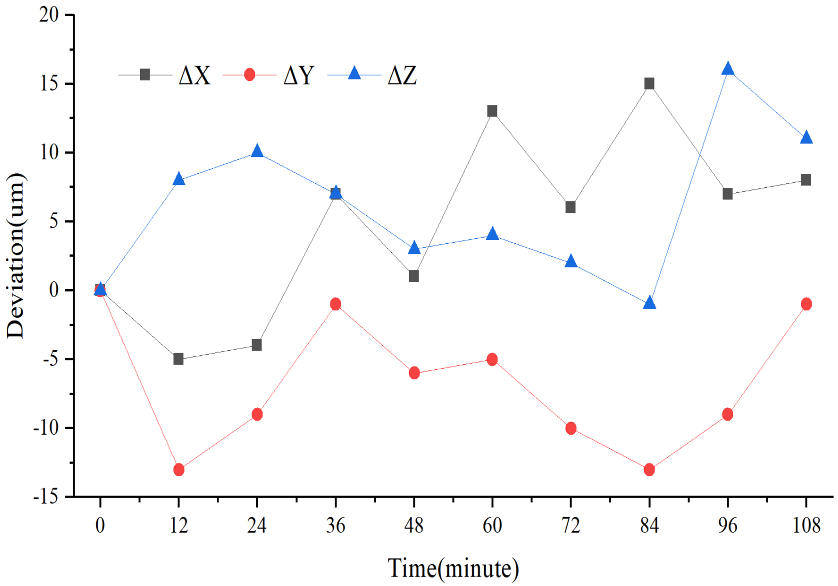
coordinate system transformation



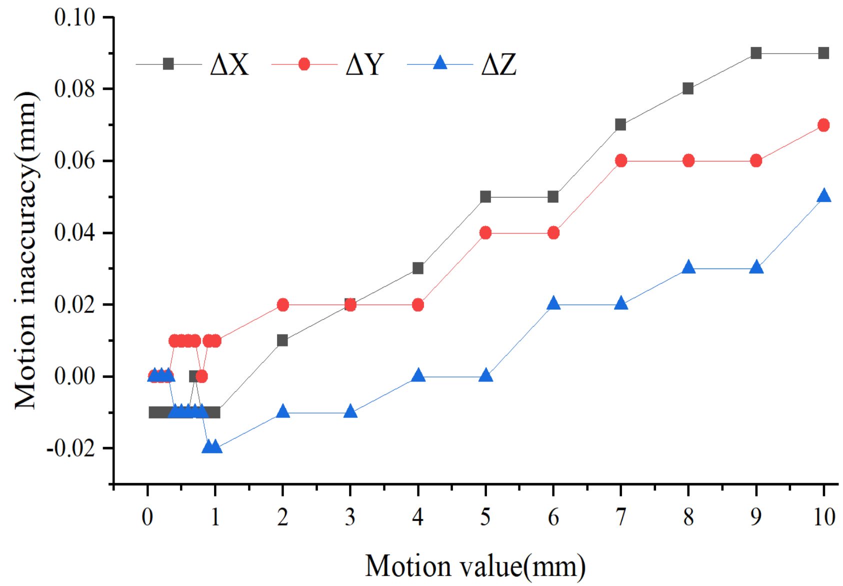
It is necessary to convert the close-range photogrammetry system from its current to the magnet mechanical coordinate system. The deviation of each point is observable above. The maximum deviation of 0.029 mm meets the requirement for magnet alignment.

Results

The stability and motion performance of Stewart platform



Stability performance of Stewart platform



Motion inaccuracy of Stewart platform

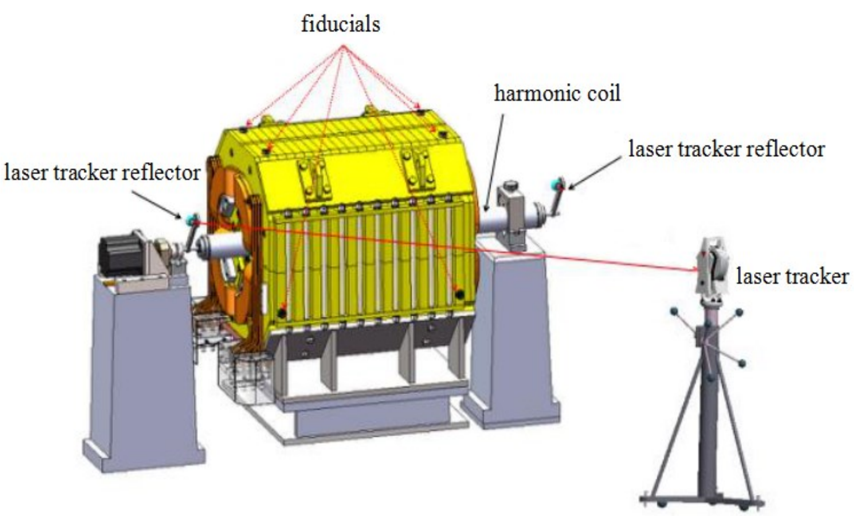
Stewart platform shows a variation of less than 0.017 mm over a 2-h period in the absence of electromagnetic interference, a level of precision consistent with that of the laser tracker.

The motion inaccuracy of Stewart platform is directly proportional to the magnitude of motion. The motion error, being better than 1%, is sufficient for the alignment of quadrupole magnets.

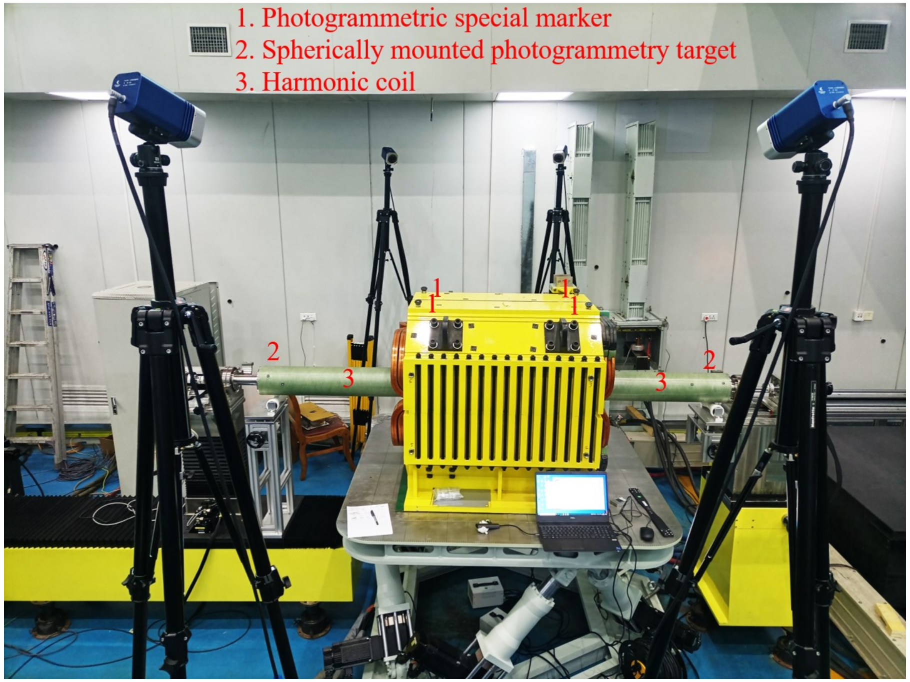
Results

high efficiency

The experiments indicate that the efficiency of the quadrupole magnet positioning has increased significantly by at least 5 times.



1 hour



8 – 12 minutes

According to the experiments, the entire process requires a duration of 8 min to 12 min, which is notably shorter than the standard alignment time of 1 h for the same object.

Results

Accuracy Verification

Table 1. Dimensions of HIAF fast pulse quadrupole magnet

Length (mm)	Width (mm)	Height (mm)	Weight (kg)
980	1000	955	5978

The dimensions of the quadrupole magnet used in the experiments are provided in Table 1.

Table 2. The final alignment results verified by the API Radian laser tracker

Yaw (°)	Pitch (°)	ΔX (mm)	ΔY (mm)
-0.002	0.001	-0.094	0.039

- **The final positioning accuracy was verified by the laser tracker.**
- **Table 2 indicates the final displacement and angular deviations. This positioning accuracy meets the requirements of the HIAF fast pulse quadrupole magnet.**
- **More experimentation is needed in practice**

Potential application

- **The study may have the potential application in high radiation environments that are otherwise inaccessible.**

THANKS