

# High Precision Spatial Measurement Method of Accelerator Cell Pre-alignment Based on Multiple Total Station

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For stable operation of accelerators, high-precision alignment, positioning, and installation are crucial. Installing all equipment individually inside the tunnel poses safety risks as personnel may be exposed to enclosed and potentially radiative environments for extended periods. To address the challenges of long adjustment times and prolonged maintenance within the tunnel, most accelerator equipment under construction or in research consists of pre-aligned units. The magnets within each unit are pre-aligned with high precision in the laboratory before being transported to the tunnel. Aligning the entire magnet support frame can significantly improve installation efficiency within the tunnel. To meet the requirement of 10  $\mu\text{m}$  transverse and vertical pre-alignment accuracy for the magnet units in the HEPS storage ring, this study designed a high-precision pre-alignment measurement system for accelerator units using four total stations for angle observations. Only angle measurements are used. By employing different instrument layout configurations and incorporating reliable distance benchmarks, high-precision pre-alignment of the magnet units are achieved. Theoretical analysis and simulation calculations reveal that when three total stations are arranged in an equilateral triangle in the plane, the measurement accuracy of the circumcircle center point is the highest, with the highest elevation measurement accuracy observed during horizontal total station observations. By arranging ceramic balls and utilizing image recognition for automatic targeting, real-time point calculations during pre-alignment enhance efficiency. Subsequently, based on this system, pre-alignment simulation calculations and experimental verification of eight magnet units in the HEPS storage ring are conducted, achieving high-precision online adjustment of individual points and ultimately realizing the 10 $\mu\text{m}$  lateral and vertical pre-alignment accuracy target within the cells. This method, based on high-precision measurements in a small-scale space, reduces the time and activity required for personnel on-site, mitigates radiation exposure risks, and facilitates laboratory-scale batch pre-alignment unit adjustments. It also provides a reference for pre-alignment of multiple magnet units in large accelerators such as the CEPC.

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