

A Method to Establish Height Datum Online Based on Absolute Hydrostatic Leveling System

Na Ma ^{a,b}, Tong Wang ^{*a,b}, Lan Dong ^{*a,b}, Bo Li, Jing Liang ^{a,b}, Zhiyong Ke ^{a,b}, Zhengqiang He ^{a,b}

(a. China Spallation Neutron Source (CSNS), Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS), Dongguan 523803, China ; b. Spallation Neutron Source Science Center, Dongguan)

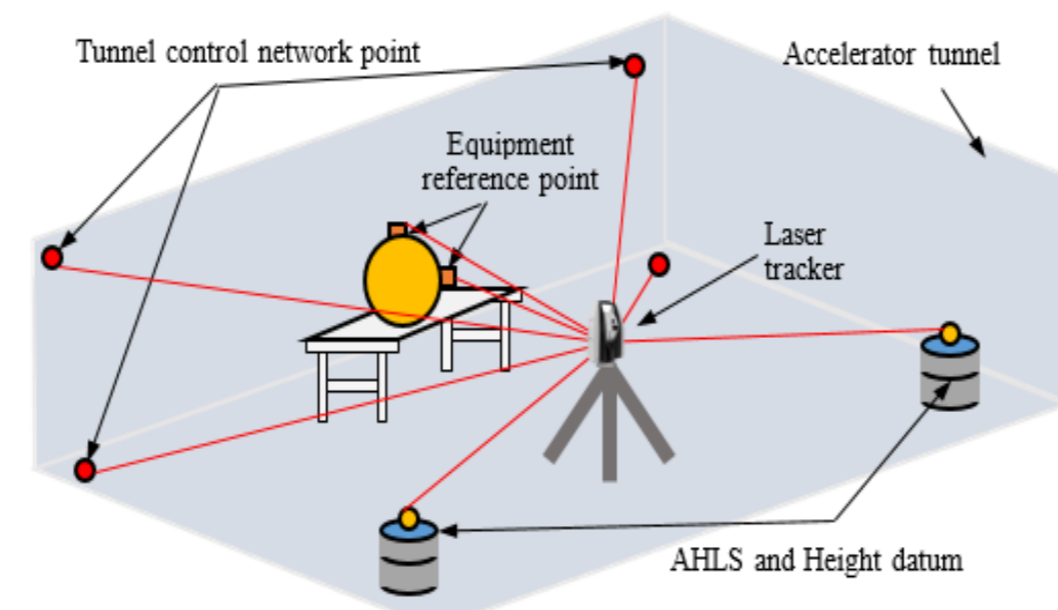
Introduction

With the increase of the scale and energy of the accelerator, more requirements are put forward for alignment. This paper proposes Absolute Hydrostatic Leveling System (AHLS), for establishing height datum. The principle of AHLS is described in detail, and it is emphasized that absolute calibration of the level is crucial for implementing this plan. A set of absolute calibration methods for non-contact absolute hydrostatic level is proposed, including measuring key dimensions of the level and liquid depth. The absolute calibration accuracy reaches 0.031mm. The height accuracy of validating an AHLS between two points within 10 meters using a laser tracker is more than 0.05mm. The results demonstrate the feasibility of using AHLS to establish absolute height datum with high precision. With this method, the absolute height of each point can be obtained independently without any accumulated errors, allowing the establishment of height datum with high precision on a large scale. This approach can be used in the next generation of accelerator devices and also represents a novel method for achieving high-precision vertical monitoring.

New Method

Absolute Hydrostatic Level System(AHLS)

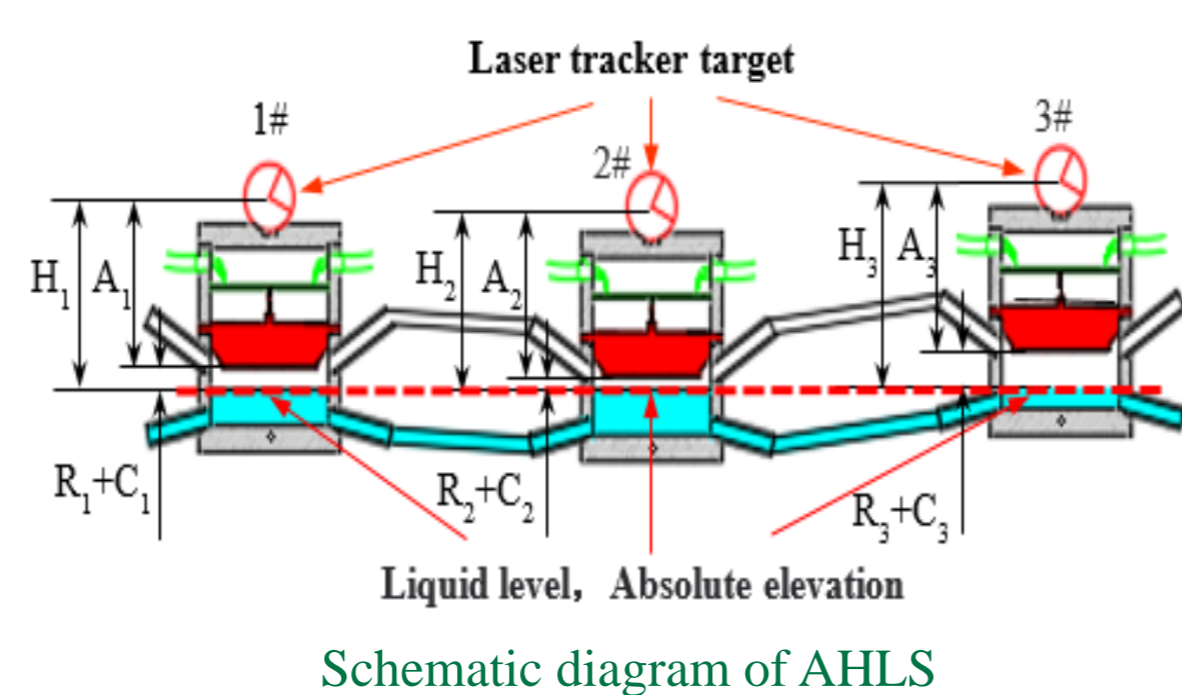
AHLS uses the actual level surface within the HLS as a datum, with no accumulation of errors in the system, allow for obtaining high-precision absolute height of leveling points, online and in real-time. The height can be used not only to establish a high-precision



height datum for the overall device in combination with leveling, but also as a high-precision height datum point in the tunnel to align critical devices. This is a new method for creating high-precision absolute height datum.

The top centre of all the levels in the figure are set with a datum base for a tracker's target ball. Using the liquid level in the system as the height datum, the absolute height ($H_{i,k}$) of the level is the distance from the centre of the ball to the liquid surface, and can be calculated as:

$$H_{i,k} = A_k + (R_{i,k} + C_k), k = 1, 2, \dots, K$$

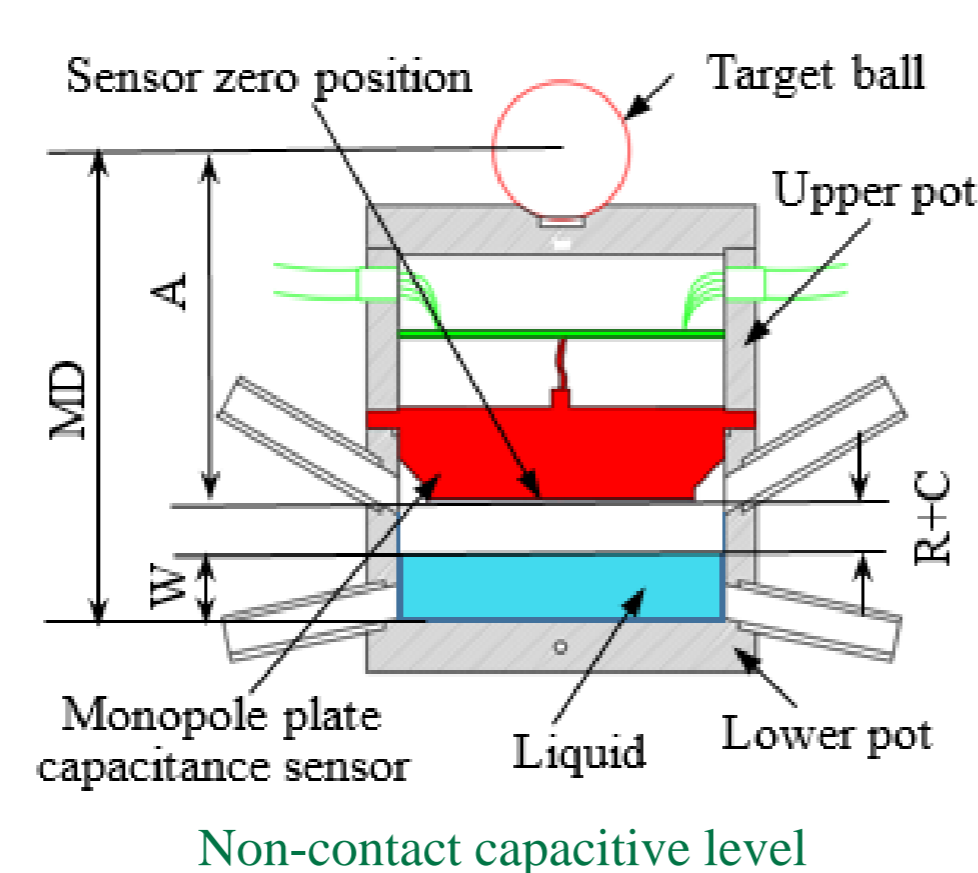


If the values of A_k and C_k are obtained, $H_{i,k}$ transmitted by the kth level without error at time i can be determined.

New Method

Structure of the Absolute Hydrostatic Level (AHL)

AHL is no-contact type and uses a capacitive sensor with monopole plate to monitor changes in liquid level, with a relative monitoring accuracy of 5μm. The structure and components are shown in Figure. This level is designed with a 1.5-inch datum base for tracker's target ball at the top centre, allowing for absolute calibration of liquid level extraction. This level can not only use the absolute height obtained by monitoring the ground settlement as height datum for height adjustment, improving the absolute accuracy of the overall device's height, but also serve as a datum point for high-precision adjustment of the nearby device's height, achieving high-precision alignment of critical devices.



New Method

Absolute Calibration of the Level(1)

The absolute calibration of the level is crucial for implement AHLS, the accuracy of the height obtained by AHLS depends on the precise determination of the constant C_k and absolute calibration value A_k of each level.

$$A_k = MD_k - W_k - (R_k + C_k)$$

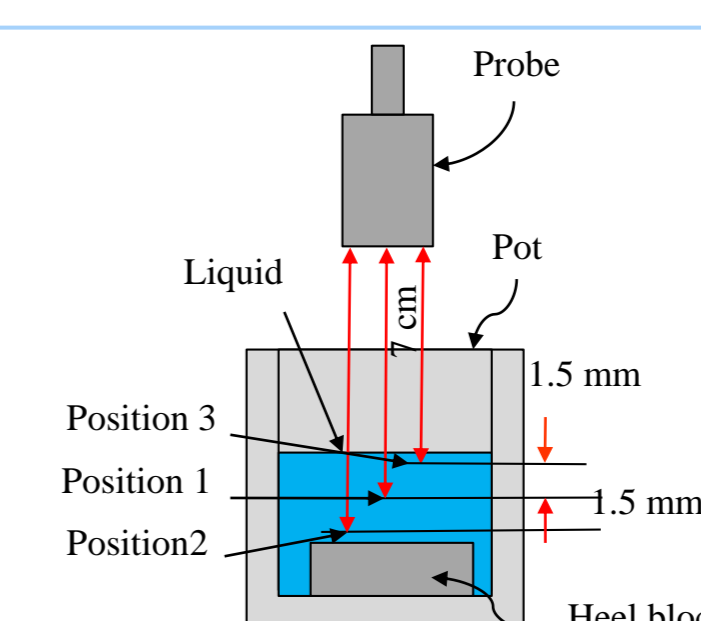
The three key parameters of absolute calibration for AHL, include the distance MD_k from the bottom of the lower bowl to the centre of the target ball, the liquid depth W_k , and the absolute distance $R_k + C_k$ from the zero position of the sensor to the liquid surface.

- MD of the bowl was measured by the three-coordinate measuring machine (CMM),
- the reading R_k of the level was recorded directly and repeated several times.
- Absolute measurement of the liquid depth W_k based on the coaxial displacement meter

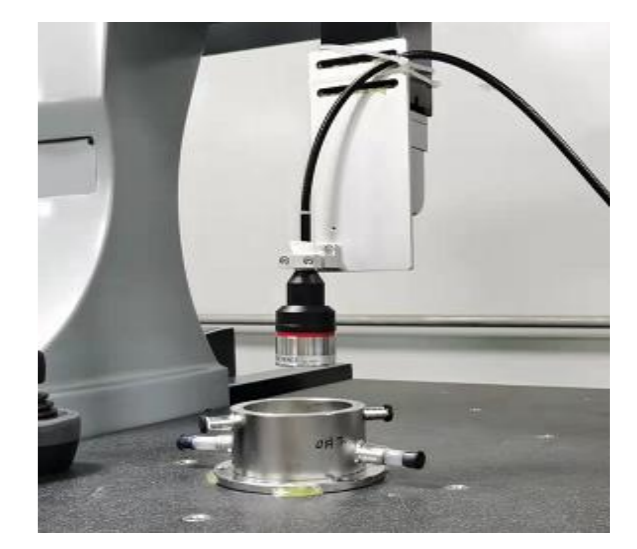
Absolute Calibration of the Level(2)



MD measured by CMM



Liquid depth W_k based on the coaxial displacement meter



The accuracy of absolute calibration value A_k can be calculated as:

$$m_A = \sqrt{m_{MD}^2 + m_W^2 + m_R^2}$$

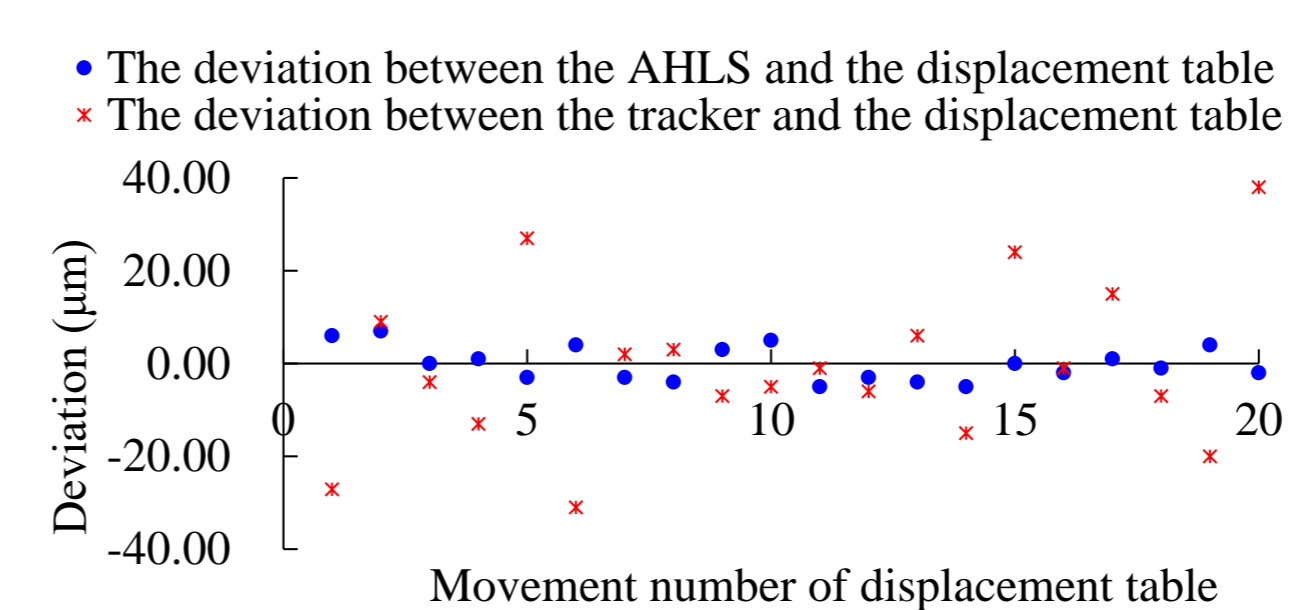
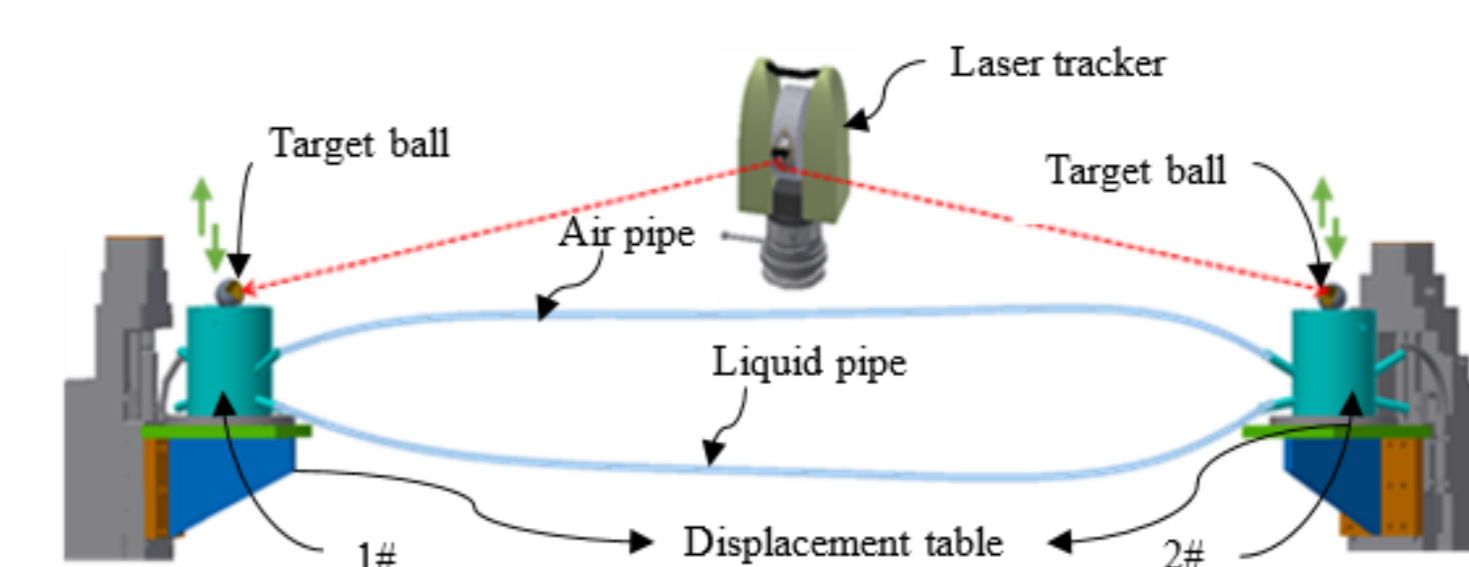
The measurement accuracy m_{MD} of the bowl structure was 5μm, the measurement accuracy m_W of the liquid depth was 0.03mm, and the reading accuracy m_R of AHL was 5μm. The absolute calibration accuracy m_A of the level was within 0.031mm.

Verification and discussion

The absolute height of level K at time i is calculated as:

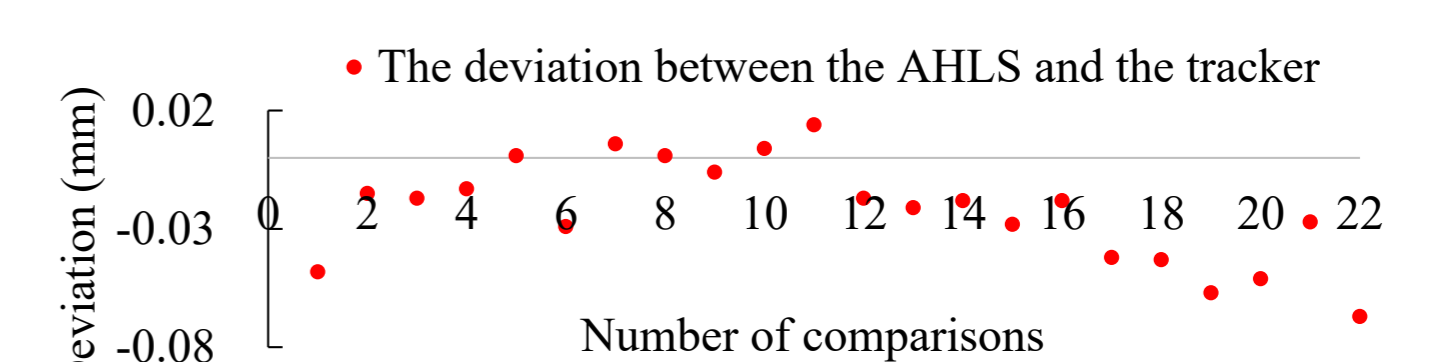
$$H_{i,k} = MD_k - W_k - (R_k + C_k) + (R_{i,k} + C_k) = MD_k - W_k - R_k + R_{i,k}$$

Two-point AHLS verification experiment was implemented. The accuracy was verified by comparing the absolute height difference between Level 1# and Level 2# measured by the laser tracker and two-point AHLS.



The difference between the level and displacement table ranged from -3 μm to 7 μm. After eliminating the instrumental error of the displacement table itself, the relative monitoring accuracy of the level was within 5 μm, which met the nominal accuracy of the level.

Based on the measurement results from 22 upward and downward points, the RMS of all deviations is 0.031. The experiment shows that AHLS can achieve absolute height with an accuracy of no less than 0.05mm within a 10m range, supporting the feasibility of the principle of absolute height acquisition of AHLS.



Conclusion

This paper proposes a method for establishing absolute height datum based on the accelerator settlement monitoring method HLS, called AHLS. AHLS not only provides relative monitoring, but can also provide absolute datum. The laboratory established an AHLS between two points within 10 meters and used a laser tracker with an electronic level and a micrometer displacement table to verify and calibrate the principle and absolute height accuracy of the AHLS. The results showed that the absolute height accuracy within 10 meters is not less than 0.05mm.