Studies on unifying method of multi-system displacement monitoring system to global coordinate system in particle accelerators

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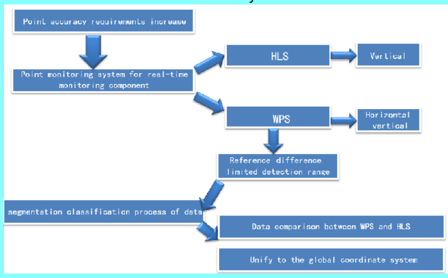
Abstract: The researching installation of multi-system position monitoring system(MPMS) has been designed and established to take position monitoring and obtain benchmarks in high accuracy, by which the monitoring data can be reviewed in the global coordinate system and relative position displacements can be transformed to absolute position displacements. The system consists of Hydrostatic Leveling System (HLS), Wire Position Sensor (WPS), SpotOn System and Inclination Sensors (IS). The transformation from the initial Sensor coordinate systems to the platform coordinate system is done by using target ball bases of laser tracker in the platform and by combining the measurement data of CMM and laser tracker. The transformation from the five platform coordinate systems to the MPMS coordinate system is completed by combining the measurement data of WPS and laser tracker. Finally the MPMS coordinate system is transformed to the Global system by the spatial measurement data from laser tracker.

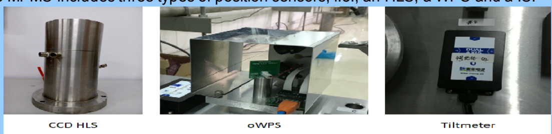
Introduction

Combining the previous research results of National Synchrotron Radiation Laboratory (NSRL), we designed and constructed an MPMS. An HLS, a WPS and a Inclination Sensor are fixed to a stainless steel plate. A coordinate-measurement machine (CMM) calibrated the plate to establish the coordinate system. Five of these plates constitute the MPMS, and the sag of the stretched wires in WPS is compensated to create a straight line. The coordinate transformation from the sensor coordinate system to the MPMS coordinate system was deeply studied. An experimental MPMS has been setup in a 20-m tunnel at NSRL to test its feasibility.

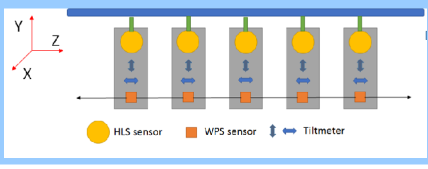


Design of the MPMS

The MPMS includes three types of position sensors, i.e., an HLS, a WPS and a IS.

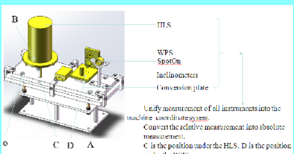


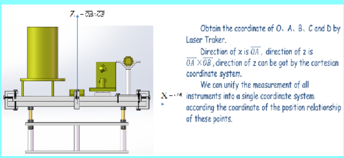
These sensors are fixed to a plate made of stainless steel, which has a coefficient of thermal expansion of 10.1ppm·K^{-1}. The plate is considered an nondeformable object, and the relative positions and orientations of the sensors are constant in the laboratory temperament. Several sensor plates are linked to be a MPMS by combining the HLSs and the WPSs. Five sensor plates are constructed the system which is installed in a 20-m tunnel at NSRL.



Construction of the MPMS

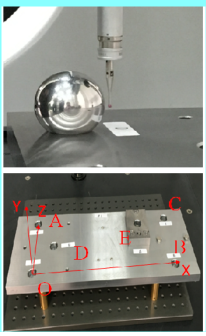
Calibration is necessary to ensure the measurement accuracy of these sensors before constructing the MPMS. A design of this plate and mechanical support equipment is developed and updated multiple times based on the shapes and weight of these sensors. The thickness of these plates and the diameter of the support pillars are 10 mm to keep the system stable when all the sensors are attached on them. Six holes that can support 1.5 inches diameter survey reflectors are distributed on these plates. These holes establish the plate coordinate system and to ensure the relationship between the sensors on that plate. Screws affix the sensors to the plate. The mechanical support equipment includes a load support, an adjusting mechanism and a plate fixed mechanism.





- **Establishment of the plate coordinate system**

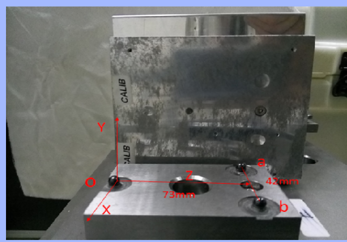
The plates are measured via a CMM with a 6μm uncertainty (2σ). The CMM provides the plate coordinates of the 1.5 inch diameter survey reflectors. A plate is fitted with the points A, B, C, D and O. OB is used as the X-axis and OA as the Z-axis. The line from O point, parallel with the external normal of the plane, is considered to be the Y-axis. Meanwhile, the CMM obtains the relative positions of these holes and the screw holes



- **Establishment and transformation of the sensors coordinate system**

The establishment of the HLS coordinate system is based on point D (x_D, y_D, z_D) of the plate. The first record h_0 of the HLS is considered to be the datum reference, and the following data are recorded as h. The difference $\Delta h=h-h_0$ is the displacement of the point in the vertical direction, and therefore, the coordinate value of the HLS is $(x_D, y_D, z_D+\Delta h)$.

Three 6.35 mm diameter of ceramic balls are used to establish the WPS coordinate system. The centers of the ball *O* are considered to be the coordinate origin of the WPS. The normal of the plane that is constructed by the three balls is considered to be the y-axis. The line from ball *O* to the midpoint between ball *a* and ball *b* is considered to be the z-axis. The ball *O* gives the position of the sensor. Because it is free along an axis, ball *a* determines the pitch and yaw. As *b* is in contact with a surface, it determines the last degree of freedom of the sensor, i.e., the roll. The interface coordinate system is built with respect to the kinematic effects of each point

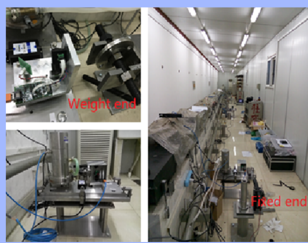


The tiltmeter monitors the rotation of the plate, and it is not necessary to construct a coordinate system for them.

The coordinate systems of the HLS and of the WPS can be transformed into the plate coordinate system by the SA software based on the results of the CMM.

- **Construction of the MPMS and its coordinate system**

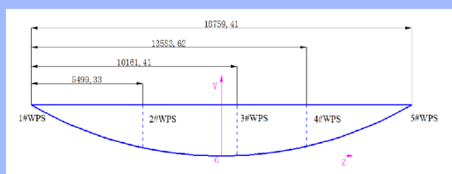
We set up an experimental MPMS in the NSRL tunnel which is 22 m long and 2 m wide. The supports are distributed along the existing HLS system, and expansion bolts are used to fix them. An N3 level and a DL10 spirit level ensure that these plates are level and their heights are equal.



The transformation parameters from the plate coordinate systems to the MPMS coordinate system include the shift of the plates (T_X, T_Y, T_Z), a rotation α about the X-axis, a rotation β about the Y-axis, and a rotation γ about the Z-axis. The transformation matrix can be expressed as follows:

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + \begin{bmatrix} \cos\beta\cos\gamma & \cos\beta\sin\gamma & -\sin\beta \\ -\cos\alpha\sin\gamma+\sin\alpha\sin\beta\cos\gamma & \cos\alpha\cos\gamma+\sin\alpha\sin\beta\sin\gamma & \sin\alpha\cos\beta \\ \sin\alpha\sin\gamma+\cos\alpha\sin\beta\cos\gamma & -\sin\alpha\cos\gamma+\cos\alpha\sin\beta\sin\gamma & \cos\alpha\cos\beta \end{bmatrix} \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}$$

The transformation parameters T_X, T_Y, T_Z, α, β, γ can be obtained from the measuring data of these sensors. The HLS and the WPS simultaneously obtain T_Y. The WPS sensors can obtain T_X. As mentioned below, a straight line is created to be a reference by compensating for the sag, and the relative movements of the other plates to the first plate are measured directly. T_Z is a constant value measured by the laser tracker because the longitudinal alignment specifications are less critical, as mentioned above. The double-axis tiltmeters provide the angles α and γ. The yaw, β, can be neglected because its effect is very small.



$$y(z) = \frac{T}{gq}\left(\cosh\frac{gqz}{T} - 1\right) \approx \frac{gqz^2}{2T}$$

Conclusion

The design and construction process of an MPMS have been completed. In particular, the establishment and transformation process of the coordinate system from these sensors to the MPMS coordinate system is described in detail. An experimental MPMS, which included five sensors plates, was constructed in an NSRL 20-m tunnel. Some verification tests, which prove the feasibility of the MPMS, have been performed.

However, there still are some valuable issues to be researched for improving the MPMS. Comparing the effect of the temperature and humidity on the wire sag, we note that the sag is closely related to the humidity. High precision humidity sensors have been purchased to study in depth the relationship between the wire sag and humidity. Meanwhile, the transformation method and transformation error from the MPMS coordinate system to the synchrotron source coordinate system will be studied in the next step. Overlapping stretched wires is also worth researching for expanding the MPMS measurement range.