Research on laser tracker measurement accuracy and data processing

Liang Jing

IHEP,CHINA

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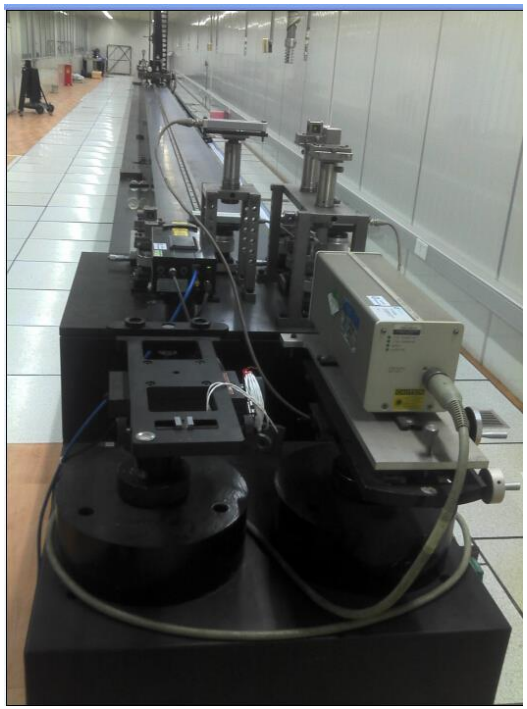
1. Accuracy test experiment for laser tracker

We used the instrument calibration device of Changcheng Institute of Metrology & Measurement to carry out the laser tracker accuracy test experiment . A laser interferometer in the device is as the standard and gives the reference lengths in horizontal and vertical direction . we tested the laser tracker accuracy in the transversal, longitudinal and vertical direction.

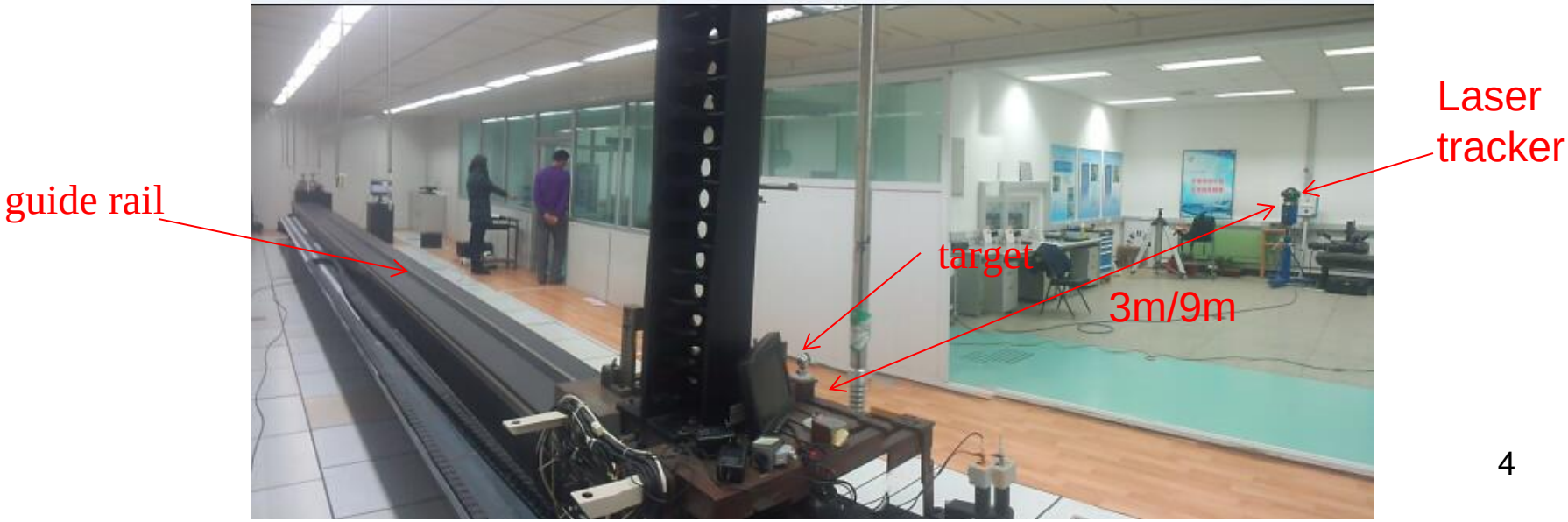


Horizontal calibration device:30m

vertical calibration device:3m

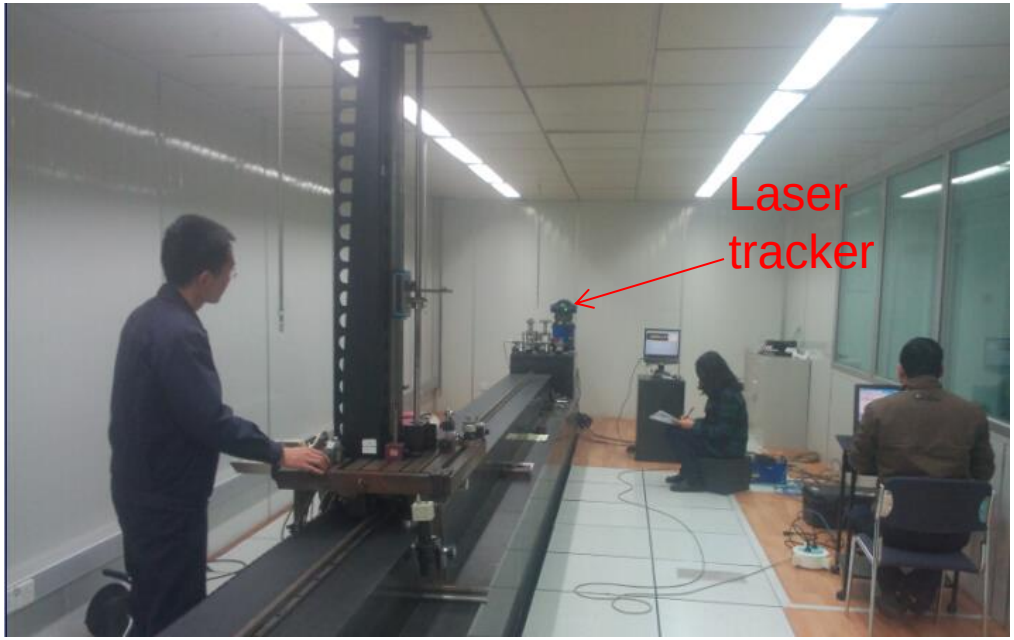
1. Accuracy test experiment for laser tracker ----in the transversal direction

The laser tracker stationed away from the horizontal device 9m and 3m separately. The target moves along the guide rail ,from the difference between the laser tracker measuring distance and the standard distance given by laser interferometer, we can calculate the laser tracker accuracy in the transversal direction.



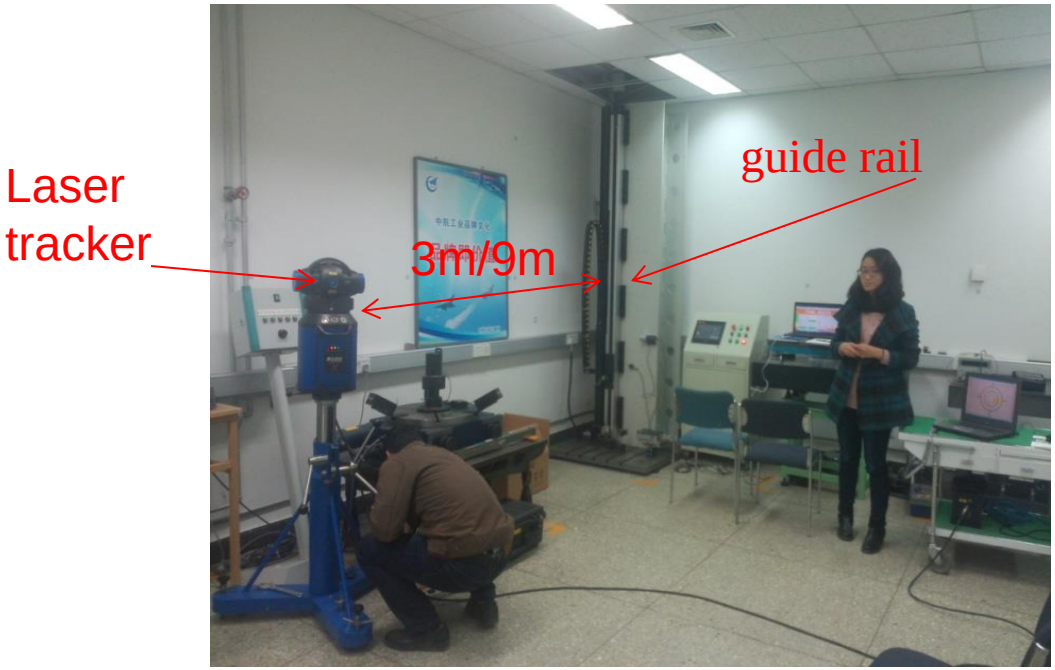
1. Accuracy test experiment for laser tracker ----in the longitudinal direction

The laser tracker stationed on one side of the guide rail. The target moves along the guide rail ,from the difference between the laser tracker measuring distance and the standard distance given by laser interferometer, we can calculate the laser tracker accuracy in the longitudinal direction.



1. Accuracy test experiment for laser tracker ----in the vertical direction

The laser tracker stationed away from the vertical device 9m and 3m separately. The target moves along the guide rail in the vertical direction, from the difference between the measuring distance and the standard distance, we can calculate the laser tracker accuracy in the vertical direction.



1. Accuracy test experiment for laser tracker ----the result of test experiment

We measured 270 distances using Faro Xi laser tracker, the RMS of difference is shown as follow.

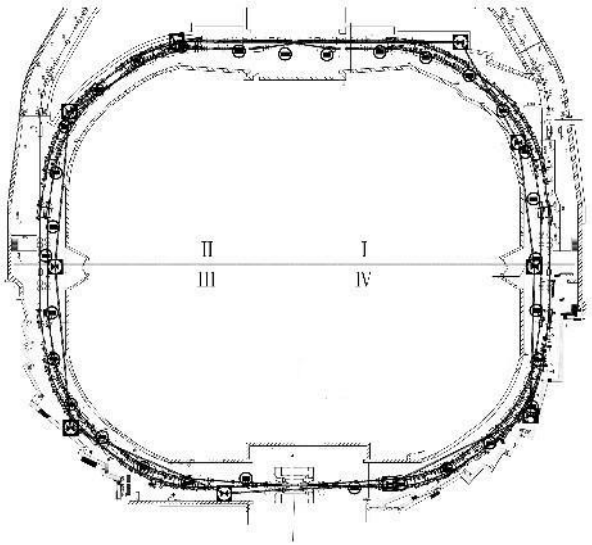
It is more accurate in the longitudinal direction, the RMS of difference is 4.3 μm. It is mostly influenced by distance measurement error in the longitudinal direction, and in the two other direction mostly influenced by angle measurement error.

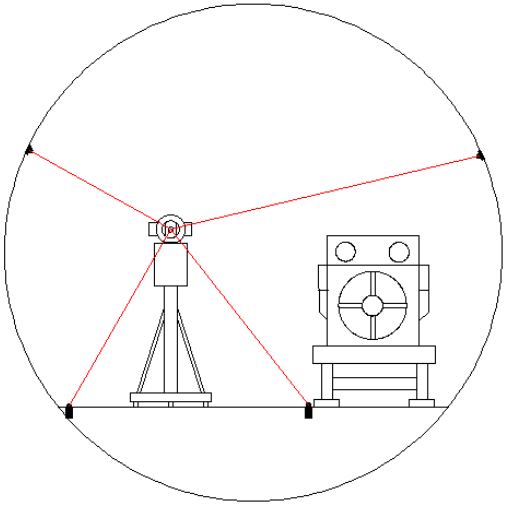
Laser tracker : Faro Xi			
Direction	**Distance of laser tracker to guide rail**	**Measurement range**	**RMS of difference**
transversal	9m	4m	22.1μm
	3m	8m	17.9μm
longitudinal	0.3m	32m	4.3μm
vertical	9m	2m	11.1μm
	3m	2m	17.3μm

2. Repeatability stastistics in BEPCII storage ring ----layout of tunel control network

BEPCII storage ring tunnel is about 240 m in circumference. Control point sections are set with the interval of 6 m along the tunnel. In each section, there are four control points, two on the floor, one on the inner wall and one on the outer wall.

There are 67 control point sections along tunnel, totally 268 control points.

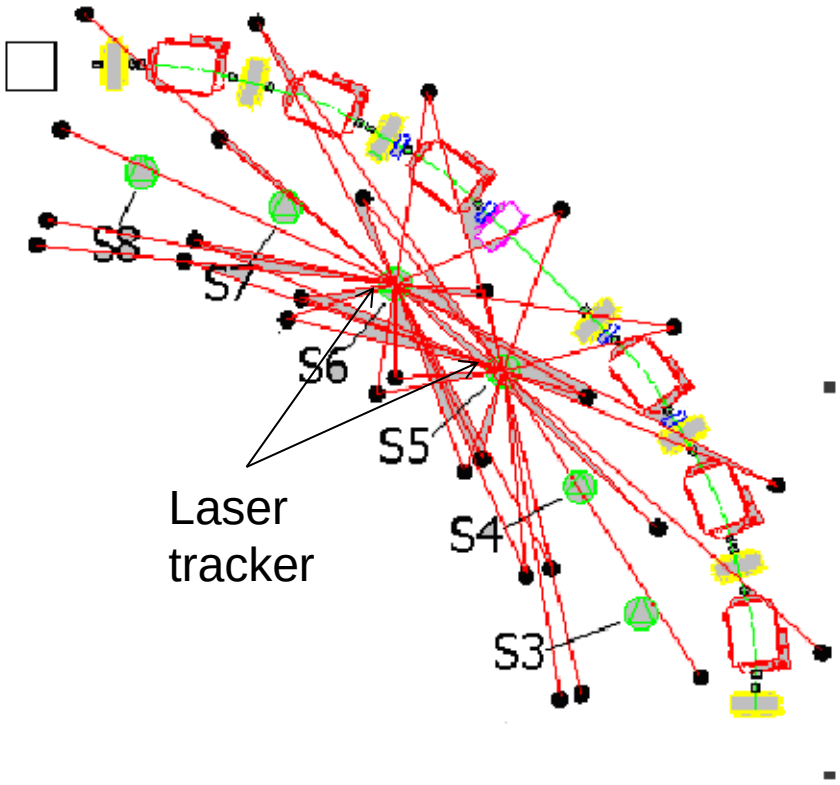




2. Repeatability stastistics in BEPCII storage ring ----measurement scheme

We used laser tracker to carry out control network survey by free station method. The measuring station is set between every two neighboring sections.

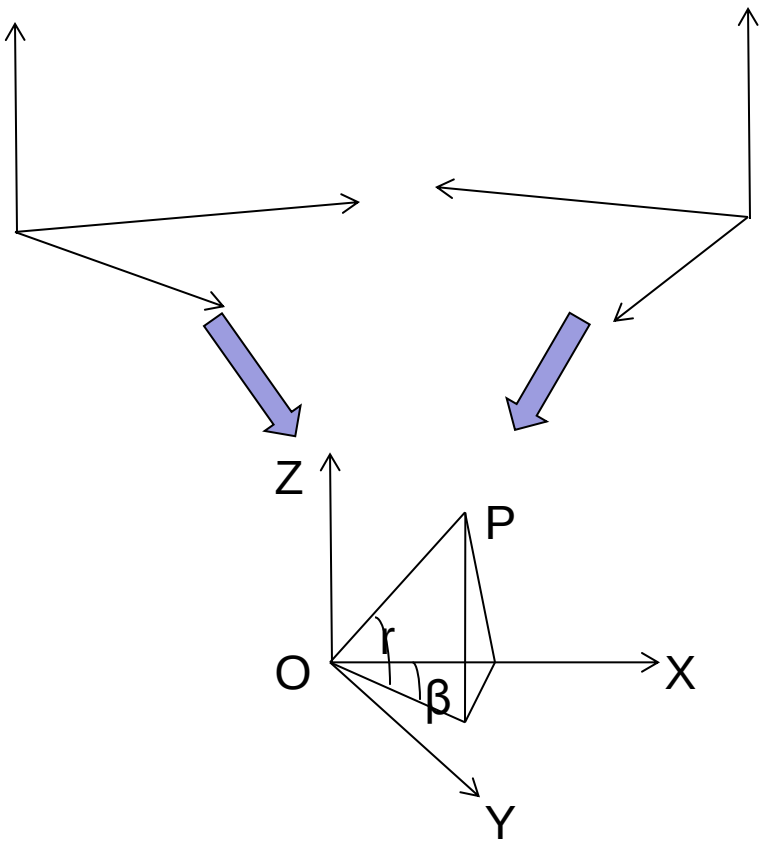
Each station laser tracker should measure 30 points and the number of common control points between neighboring stations is 25.It is more than 30 plus the magnet pionts.



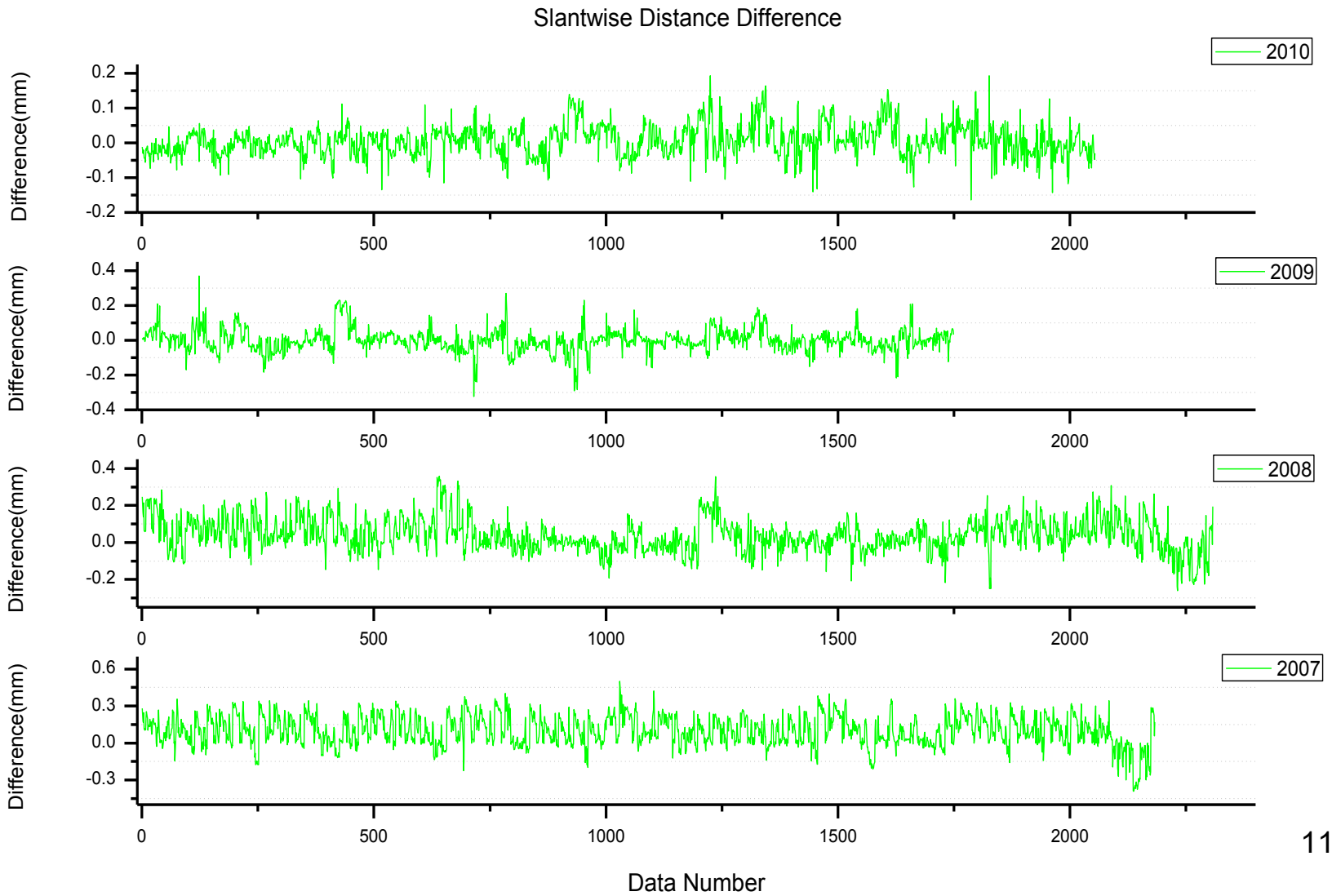
2. Repeatability stastistics in BEPCII storage ring ----repeatability stastistics from 2007-2010

Using the common points of neighboring stations , we can translate neighboring coordinate system to the same coordinate system to calculate the slantwise distance, horizontal angle and vertical angle difference of neighboring stations.

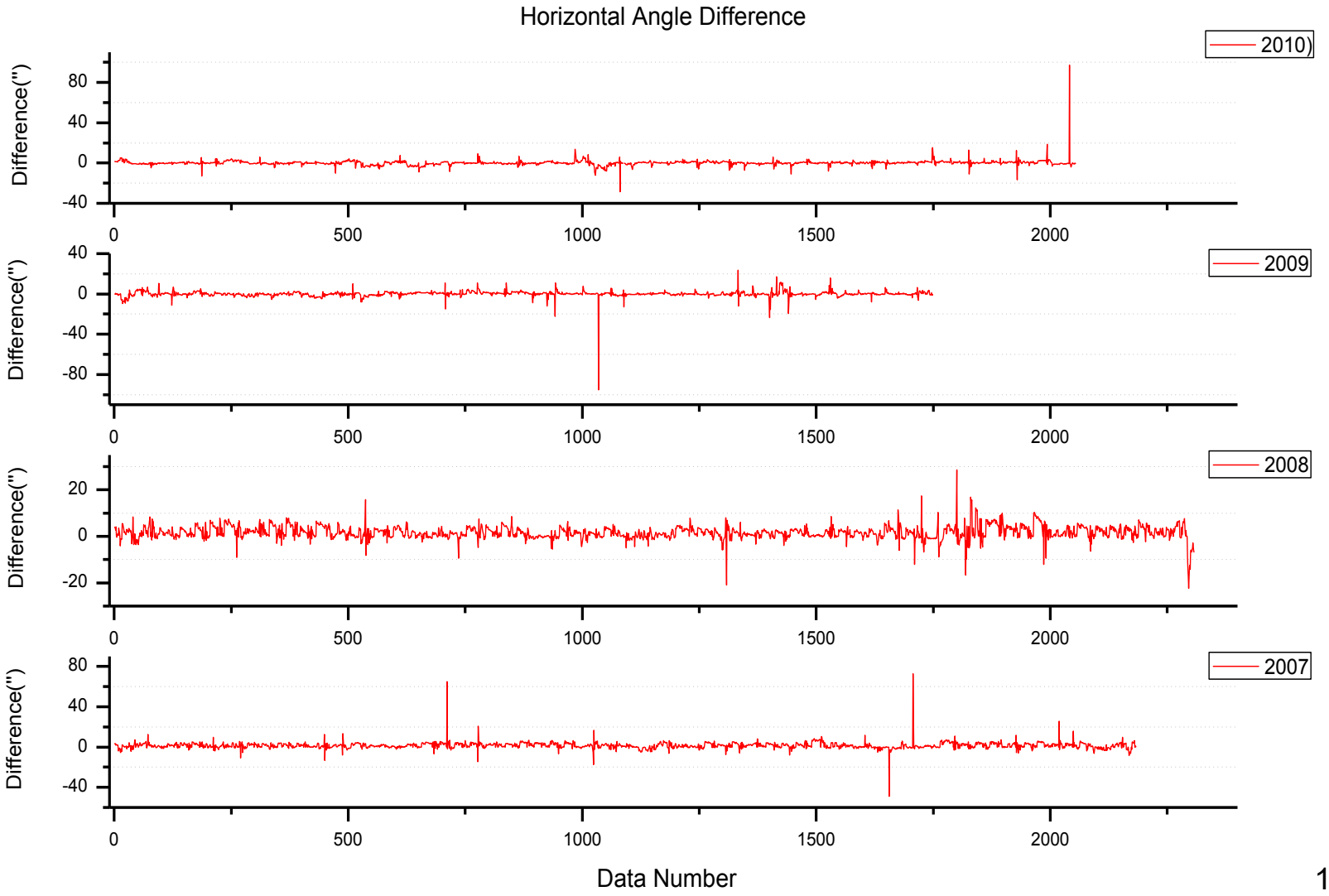
Repeatability stastistics of laser tracker in BEPCII storage ring from 2007-2010 is shown as follows.



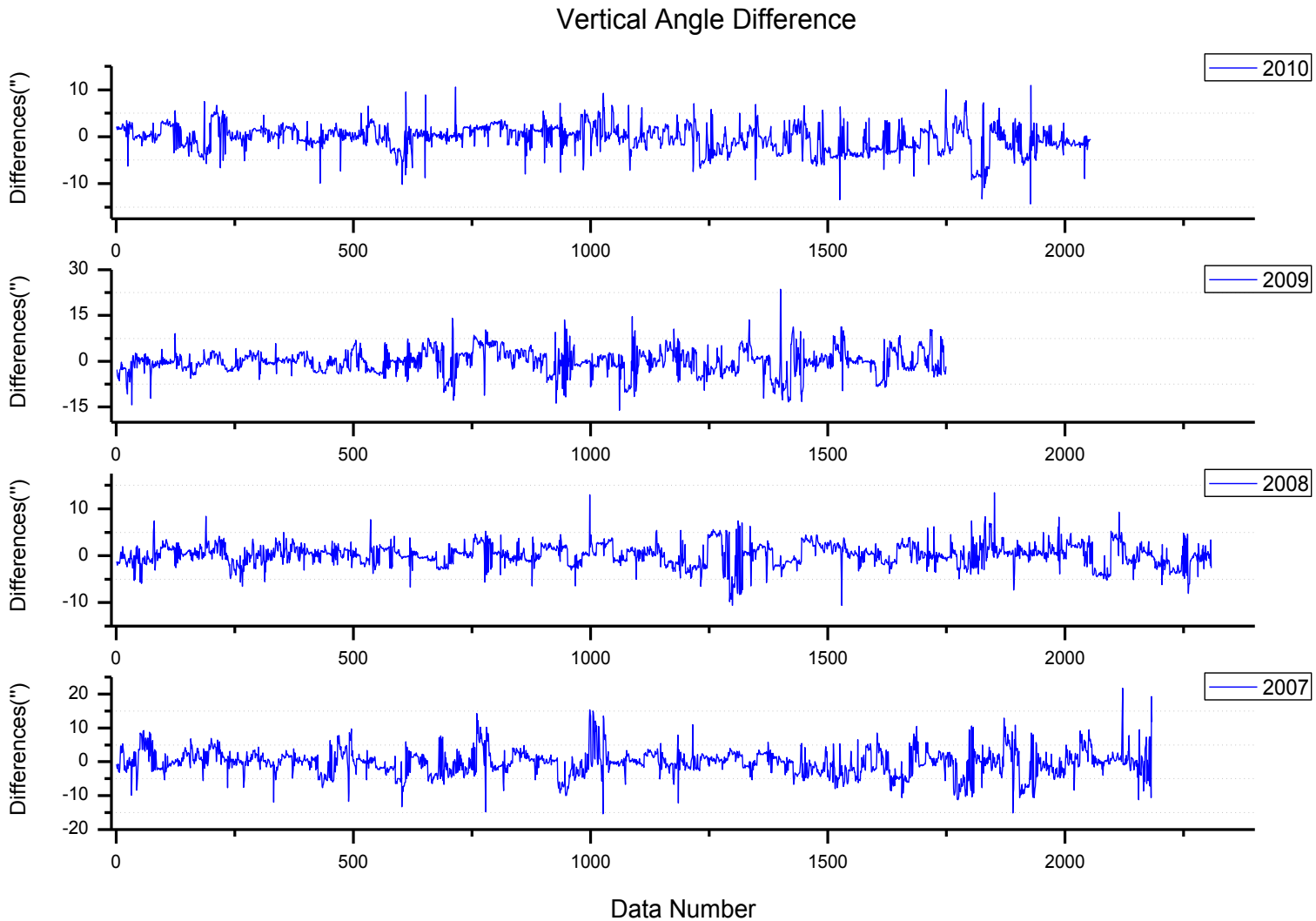
2. Repeatability stastistics in BEPCII storage ring ---- slant distance Repeatability stastistics



2. Repeatability stastistics in BEPCII storage ring ---- horizontal angle Repeatability stastistics



2. Repeatability stastistics in BEPCII storage ring ---- vertical angle Repeatability stastistics



2. Repeatability stastistics in BEPCII storage ring ---- Repeatability stastistics result

From the graph above, the maximum slant distance deviation is 0.2mm. the maximum horizontal and vertical angle deviation are 90” and 30”. Distance measurement of laser tracker is more stable.

RMS of Repeatability is shown as follows. 2” and 3”in 10m measurement range amount to 0.1mm and 0.15mm, distance measurement repeatability is better than angle measurement.

year	**slant distance Repeatability** （mm）	**horizontal angle Repeatability** (″)	**vertical angle Repeatability** (″)
2010	0. 045	2. 02	2. 82
2009	0. 066	2. 293	4. 01
2008	0. 097	3. 257	2. 35
2007	0. 16	3. 057	3. 838

3. Three dimension distance network adjustment

Laser tracker distance measurement accuracy and repeatability are better than angle measurement. We consider only use distance measurement in data processing to reduce measuring error. So three dimension distance network adjustment program is on progress.

3. Three dimension distance network adjustment ---- theoretical basis

Assume S_{ij} to be the distance from station(L_i) to point (P_j), the station(L) coordinates are $(\bar{x}_i, \bar{y}_i, \bar{z}_i)$, (i=1， …， m), point (P) coordinates are $(\bar{x}_j, \bar{y}_j, \bar{z}_j)$ (j=m+1， …， m+n)， so the observation equation is：

$$(\bar{x}_j - \bar{x}_i)^2 + (\bar{y}_j - \bar{y}_i)^2 + (\bar{z}_j - \bar{z}_i)^2 = (S_{ij} + \Delta S_{ij})^2$$

we can get error equation from linearized observation equations：

$$v_{ij} = c_{ij}\delta X_i + d_{ij}\delta Y_i + e_{ij}\delta Z_i - c_{ij}\delta X_j - d_{ij}\delta Y_j - e_{ij}\delta Z_j - l_{ij}$$

3. Three dimension distance network adjustment ---- theoretical basis

The error equation coefficient are：

$$\begin{cases} c_{ij} = -\dfrac{X_j^0 - X_i^0}{S_{ij}^0} \qquad d_{ij} = -\dfrac{Y_j^0 - Y_i^0}{S_{ij}^0} \qquad e_{ij} = -\dfrac{Z_j^0 - Z_i^0}{S_{ij}^0} \\ l_{ij} = S_{ij} - S_{ij}^0 \end{cases}$$

Where:

$\left(X_i^0, Y_i^0, Z_i^0\right)$ are the approximate coordinates of stations.

$\left(X_j^0, Y_j^0, Z_j^0\right)$ are the approximate coordinates of points.

S_{ij}^0 are the approximate measuring distances:

$$S_{ij}^0 = \sqrt{\left(X_j^0 - X_i^0\right)^2 + \left(Y_j^0 - Y_i^0\right)^2 + \left(Z_j^0 - Z_i^0\right)^2}$$

3. Three dimension distance network adjustment ---- theoretical basis

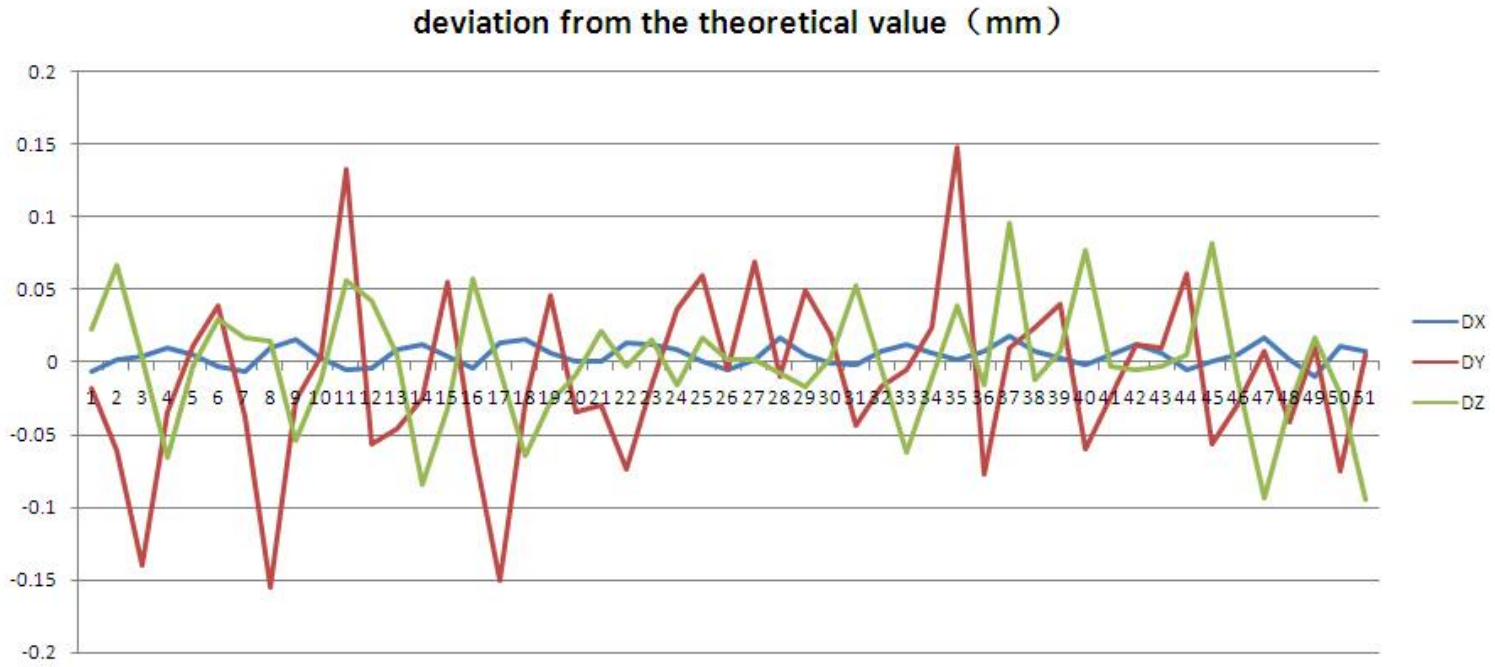
Matrix form of error equation : $\underset{mn\times 1}{V} = \underset{mn\times t'}{A}\,\underset{t'\times 1}{\delta X} - \underset{mn\times 1}{l}$

According to the least square method, the equation can be solved :

$$A^T PA\delta X = A^T Pl$$

3. Three dimension distance network adjustment ---- simulation result

We simulate a Linac control network which consist of 55 points to test the program. Random error from -0.1mm to 0.1mm is added to simulation measurements, and the deviation of adjustment result to the theoretical value is shown as follows , the average deviation is 0.03mm. The precision evaluation results are from -0.1mm to 0.1mm.



Summary

- 1.From the laser tracker test experiment, it is more accurate in the longitudinal direction. Distance measurement has higher accuracy than angle measurement.

- 2. Repeatability stastistics of laser tracker in BEPCII storage ring from 2007-2010 shows that distance measurement repeatability is better than angle measurement repeatability.

- 3. Three dimension distance network adjustment program is on progress ,simulation results are correct. More test will be done, such as using actual measurement data.

Thank you !