PERFORMANCE TEST OF A LASER TRACKER, SMART 310

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1. INTRODUCTION

A laser tracker, SMART 310, was purchased from Leica AG in order to perform alignment job in the construction of the KEK B-factory ring. The laser tracker emits a laser beam and receives its reflection from a target mirror, a corner cube reflector or a cat's eye reflector. The distance is measured by means of the laser interferometer. The shift of the position for the reflected beam is feed-backed to the servo-motor system, and the mirror is rotated so that the shift of the reflected beam position might be canceled. The rotation angle of the tracker mirror gives the angle for the new position of the target. The laser tracker measures the distance and two angles, horizontal angle (ϕ) and the vertical angle (θ). In this way, the three dimensional

Table I. Specification for 3D Laser Tracking System, SMART 310 by Leica AG

Accuracy	
Angle resolution	0.7 sec (5μrad)
Distance resolution	1.26 μm
Reproducibility of coordinate	±5 ppm
Absolute accuracy of coordinate	
for non-moving target	±10 ppm
for moving target	±20-50 ppm
Tracking	
Max. target speed	
at right angles to the laser beam	> 4.0 m/s
in the direction of the laser beam	> 5.0 m/s
Max. acceleration (in all directions)	> 2 g
Range of measurement	
horizontal	±235°
vertical	±45°
distance	0.2 - 25 m
Dimensions and Weights	
Dimensions of the sensor unit	ϕ320mm × 879mm
Weight of the sensor unit	29 kg

coordinates of an optical target can be measured by one equipment set in a place. Principle of the laser tracker is described in detail in other papers[1,2]. Company's specification on the performance and the dimension is listed in Table 1.

As a first step the fundamental performance was tested. Results of this test is described in this report.

2. FLUCTUATION OF OUTPUT DATA

In order to check the fluctuation of output data, 500 raw data (i.e. without averaging) were collected at the time interval 0.1 second at each point. Measurement was carried out at 8 points, P1 - P8. The coordinate of these 8 points is listed in Table 2. The standard deviation for three variables, the distance (D), the horizontal angle (ϕ) and the vertical angle (θ), in each measurement are shown in Fig.1. These

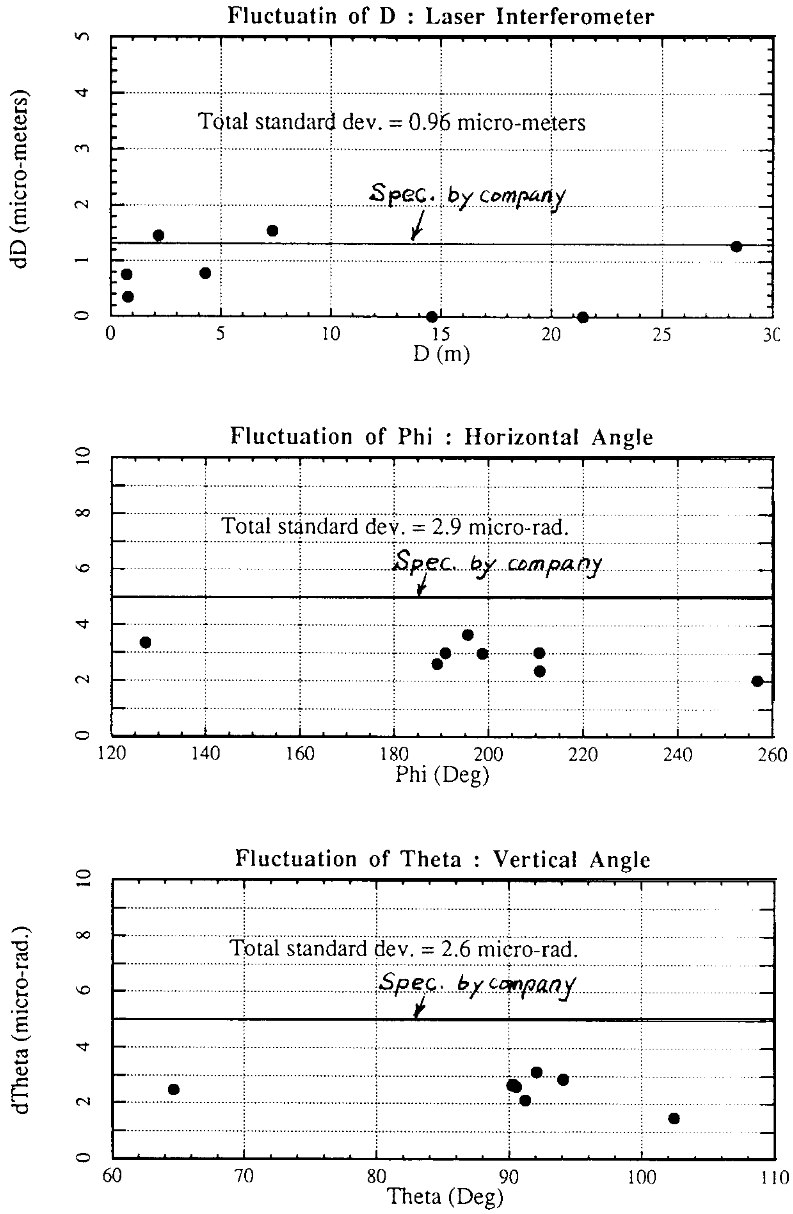

Fig. 1 Fluctuation of output from the laser tracker.

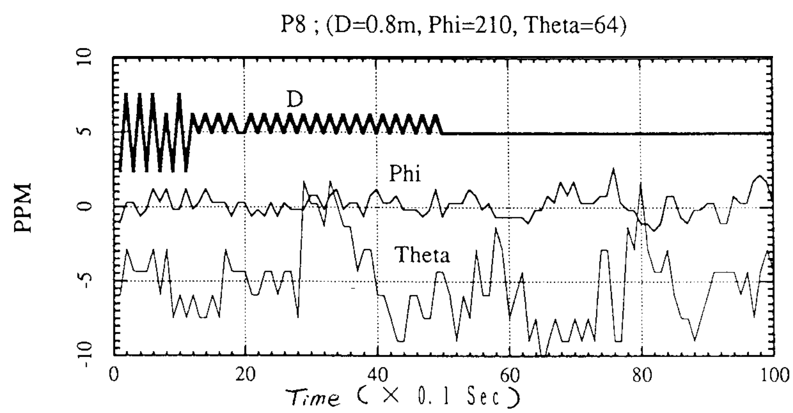

Fig. 2 Oscillation in the laser interferometer.

errors seem not to depend on the magnitude of each variable. The average standard deviations are 0.96 µm, 2.9 µrad and 2.6 µrad for D, ϕ and θ respectively.

Table 2. Coordinates for measured points

Point ID	D (m)	ϕ (degree)	θ (degree)
P1	15	195	90
P2	21	190	90
P3	28	189	90
P4	2.2	198	94
P5	4.3	127	92
P6	7.4	256	92
P7	0.7	210	102
P8	0.8	210	64

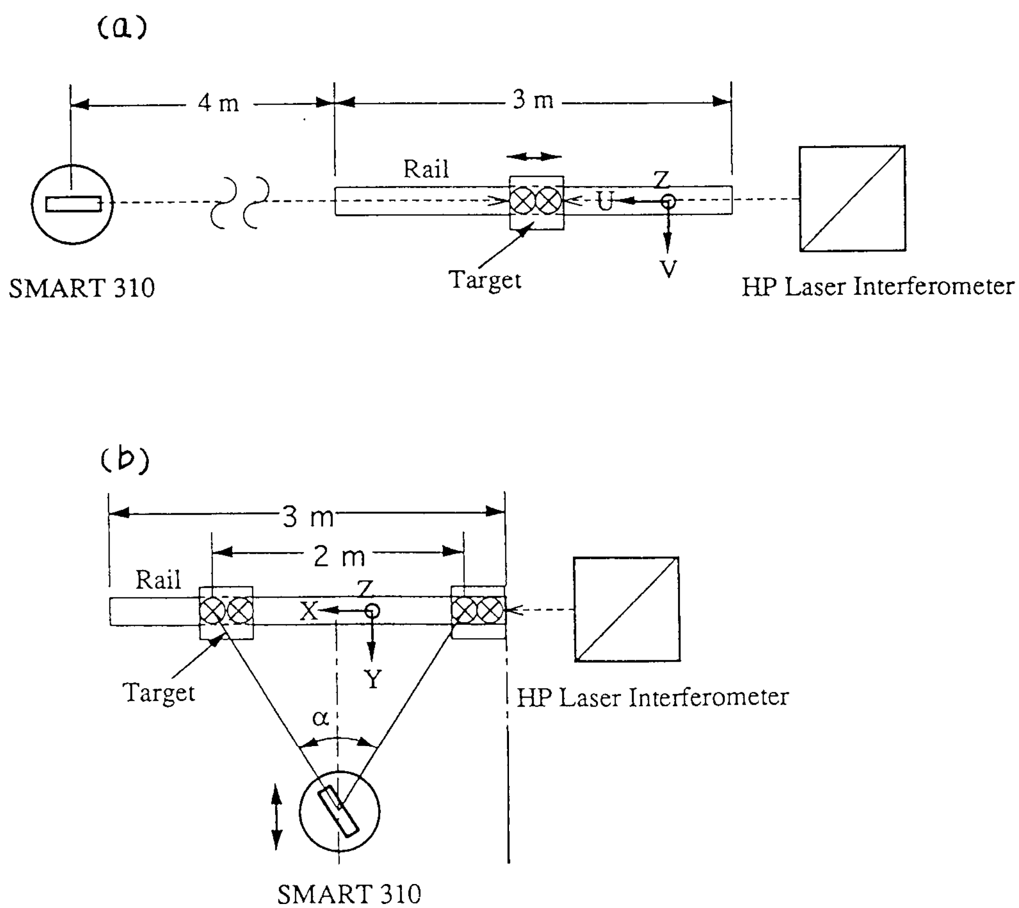

Fig. 3 Setup for experiment to examine the precision of the laser tracker using a straight rail and a HP laser interferometer.

In this measurement an oscillation in the output from the laser interferometer is observed as shown in Fig.2, where the raw data for laser interferometer output are plot. The unit of the horizontal axis is 0.1 second. Actually we sometimes have data points with big errors, which are thought to be caused this oscillation in the laser interferometer. So we have to examine errors carefully for each measurement.

3. EXAMINATION OF PRECISION USING A 3m LONG RAIL

The precision was examined using a 3m long straight rail and a laser interferometer of Hewlett-Packard (abbreviated as HP hereafter). Setup for the experiment is shown in Fig.3. At first, the laser tracker was placed at one end of the rail and the HP laser interferometer was placed at the other end. Two optical targets, one for laser tracker and the other for HP laser interferometer, were set on a movable stage on the rail (Fig. 3-a). The movable stage was moved from right to left, then from left to right for the distance of 2.4m. Coordinate data were taken at the interval of 5 cm with the laser tracker and the HP laser interferometer. In the laser tracker, the coordinate data was defined as the average of 500 measurements executed at the time interval of 0.01 second. In this measurement, U-axis is defined along the direction of the rail, V-axis along the horizontal direction perpendicular to the rail, and Z-axis as the vertical direction. U-, V- and Z-axes make a Cartesian coordinates. Results for U-, V-

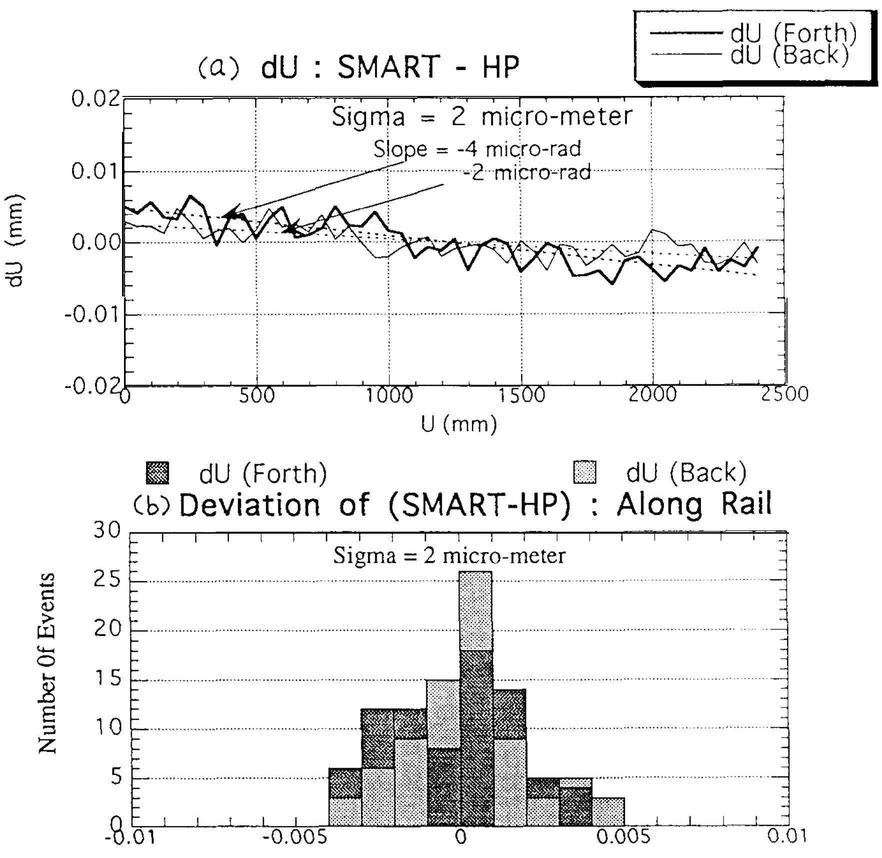

Fig. 4 Precision of U-coordinate in the setup (a}. U-axis is a horizontal axis taken along the rail.

and Z-coordinate are shown in Fig. 4, 5 and 6 respectively. The precision of U-coordinate comes from that of the laser interferometer, and the precision of V- and Z-coordinate from that of the angle measurement by the laser tracker. In Fig.4, dU is plotted as a function of U, where dU is defined as the U coordinate from the laser tracker subtracted by the coordinate from the HP laser interferometer. The slope of the plot can be caused by the misalignment of the laser tracker and the HP laser interferometer from the direction of the rail axis, or by the calibration error of these equipments. The plot is fitted to a liner curve and the deviation is examined. The standard deviation is 2 μm. In Fig.5 and 6, the bend of the plot can be caused by the bend of the rail or the long term drift of the laser tracker as discussed later. The plot is fitted to a smooth curve, and the deviation (dV and dZ) is examined. The standard deviations are 10-13 μm and 13-14 μm for dV and dZ, respectively. Using the average distance, d_o = 5.7m, between the laser tracker and the rail and the formula: $dV = d_o\Delta\phi$ and $dZ = d_o\Delta\theta$, the errors for ϕ and θ are obtained as about 2.0 and 2.5 μrad respectively.

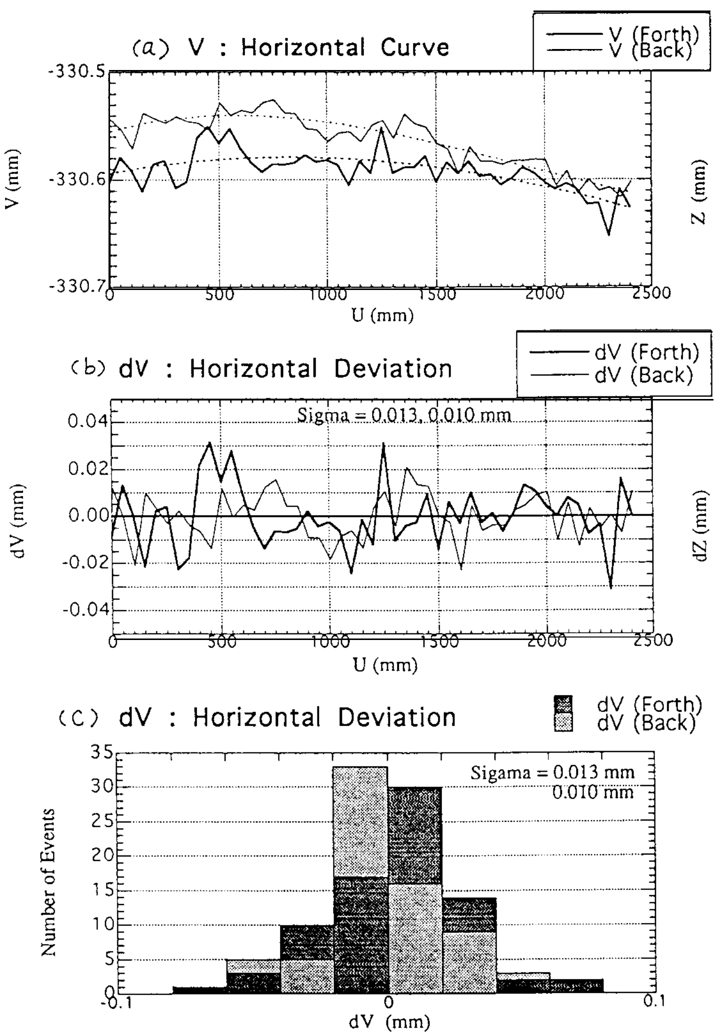

Fig. 5 Precision of V-coordinate in the setup (a). V-axis is a horizontal m's taken perpendiculer to the rail.

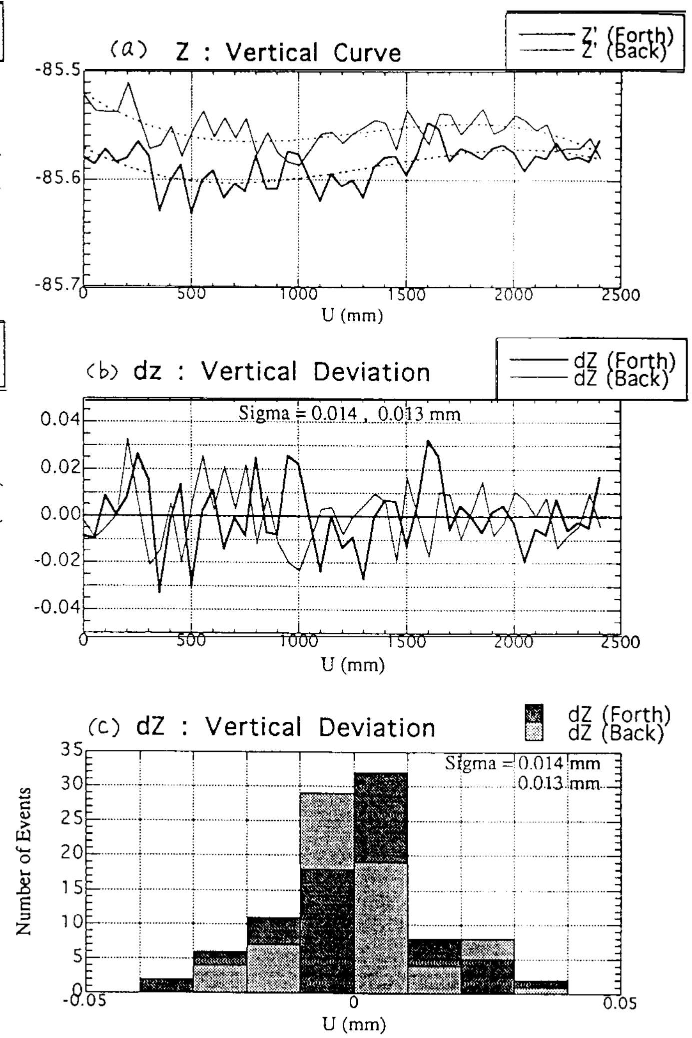

Fig. 6 Precision of Z-coordinate in the setup (a). Z-axis is a vertical axis.

Next was the laser tracker moved to the position along the axis perpendicular to the rail axis (Fig. 3-b). X- and Y-axis are defined as U- and V-axis in the previous measurement, i.e. X-axis is along the rail axis and Y-axis is horizontal and perpendicular to the rail axis. But this time, the precision for X-coordinate comes from that of ϕ, and the precision of Y-coordinate from that of the laser interferometer. Z-coordinate is the same as in the previous measurement. Results for X-, Y- and Z-coordinate are shown in Fig. 7, 8 and 9 respectively. In Fig.7, dX is plotted as a function of X, where dX is defined as the X coordinate from the laser tracker subtracted by the coordinate from the HP laser interferometer. The plot is fitted to a liner curve and the deviation is examined. The standard deviation is 17-21 pm. In Fig.8 and 9, the plot is fitted to a smooth curve, and the deviation (dY and dZ) is examined. The standard deviations are 3 μm and 14-17 μm for dY and dZ, respectively. Using the average distance d_o = 7.6m, between the laser tracker and the rail and the formula: $dX = d_o\Delta\phi$ and $dZ = d_o\Delta\theta$, the errors for ϕ and θ are obtained as about 2.5 and 2.0 μrad respectively.

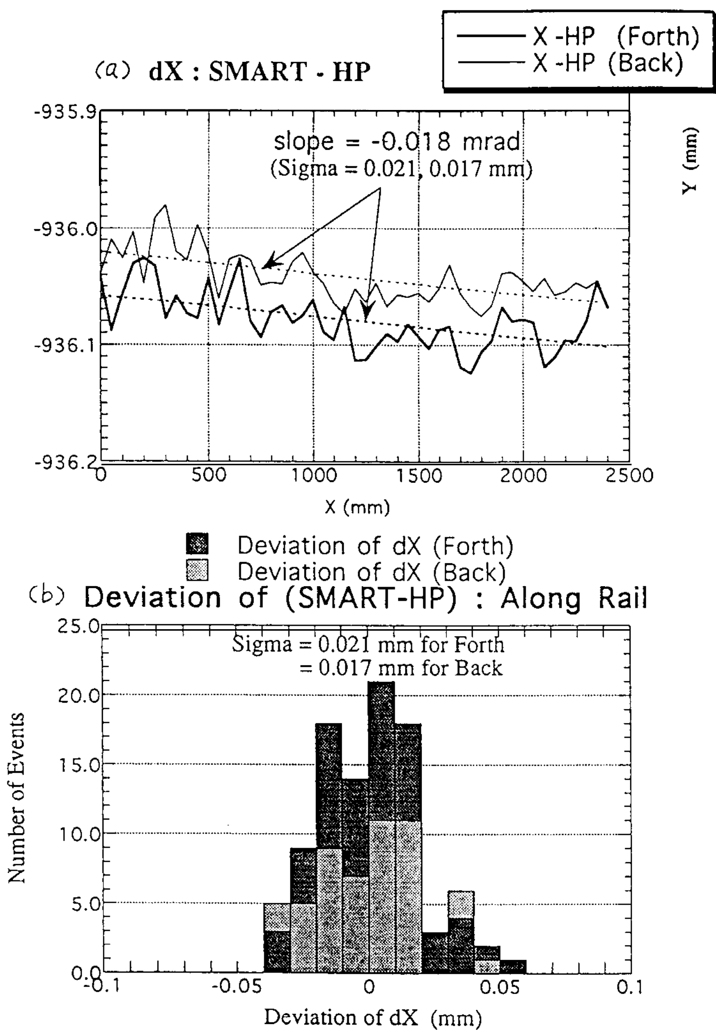

Fig. 7 Precision of X-coordinate in the setup (b). X-axis is a horizontal axis taken along the rail.

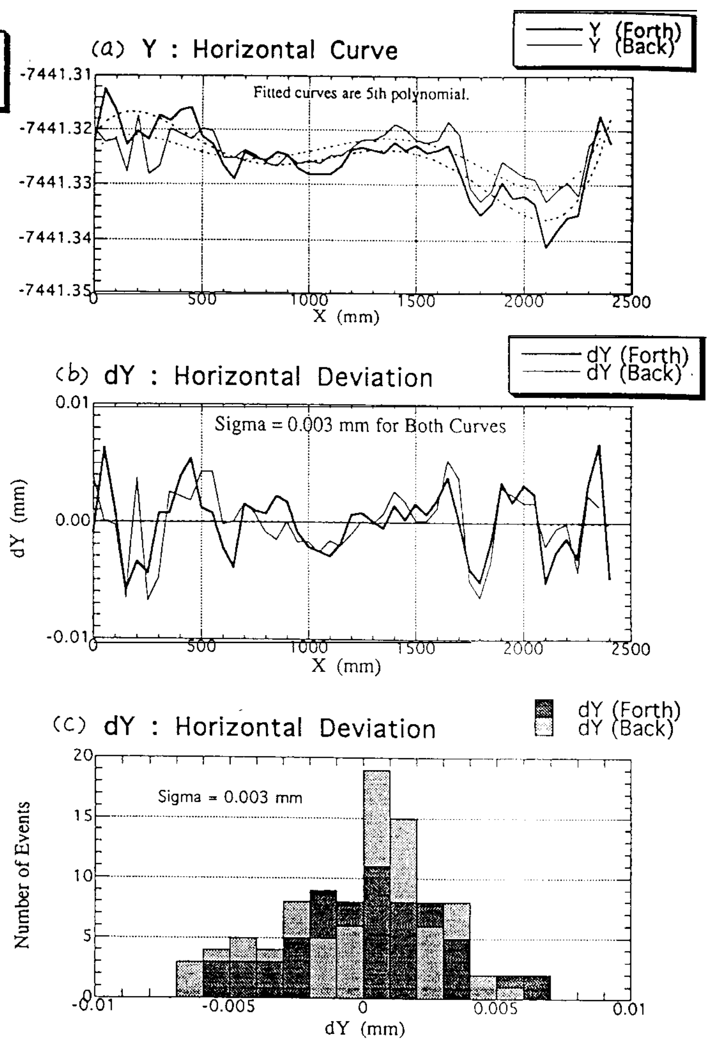

Fig. 8 Precision of Y-coordinate in the setup (b). Y-axis is a horizontal axis taken perpendiculer to the rail.

The distance of 2m was measured by placing the laser tracker at various positions along two lines: both are perpendicular to the rail axis, and the one passes the center and the other the edge of the rail. The position of the laser tracker is defined by the opening angle (α) for the 2m distance on the rail. The distance of 2m is defined by the HP laser interferometer. Results are plotted in Fig.10. Error bars are calculated assuming the error for the angle measurement, $\Delta\phi = 3\mu rad$. Round and triangle marks show results of measurement along the center line and the edge line, respectively. The deviation seems to be as big as about 1.5 standard deviations.

4. DRIFT OF OUTPUT DATA

Fig.11 shows an initial drift of three variables, D, ϕ and θ. The laser tracker becomes ready about 25 minutes after the power is turned on. In about three hours, the drift of D becomes less than 10μm and those for angles much less than their fluctuation. Fig.12 shows the drift after the laser tracker gets steady. The drift of the laser interferometer is about 10μm/day. The variation of the temperature (T), the atmospheric pressure (P) and the humidity (H) during the period of this measurement is shown in Fig.13. Those variations cannot explain the drift of the laser interferometer. The drift of the

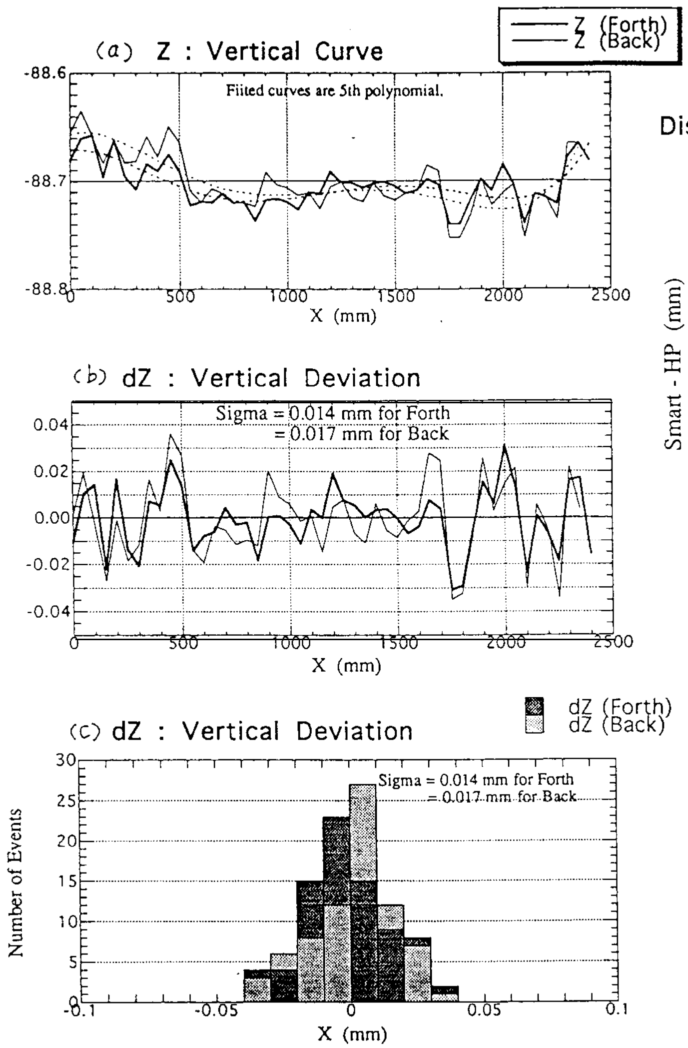

Fig. 9 Precision of Z-coordinate in the setup (b).

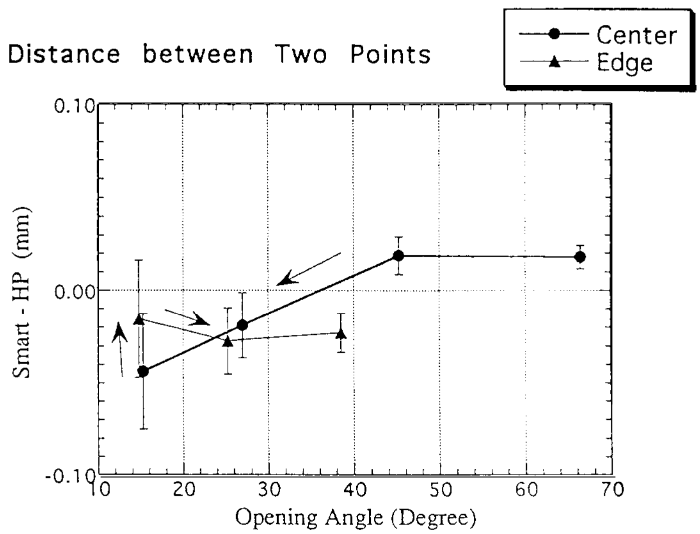

Fig.10 Precision for measurement of 2m distance.

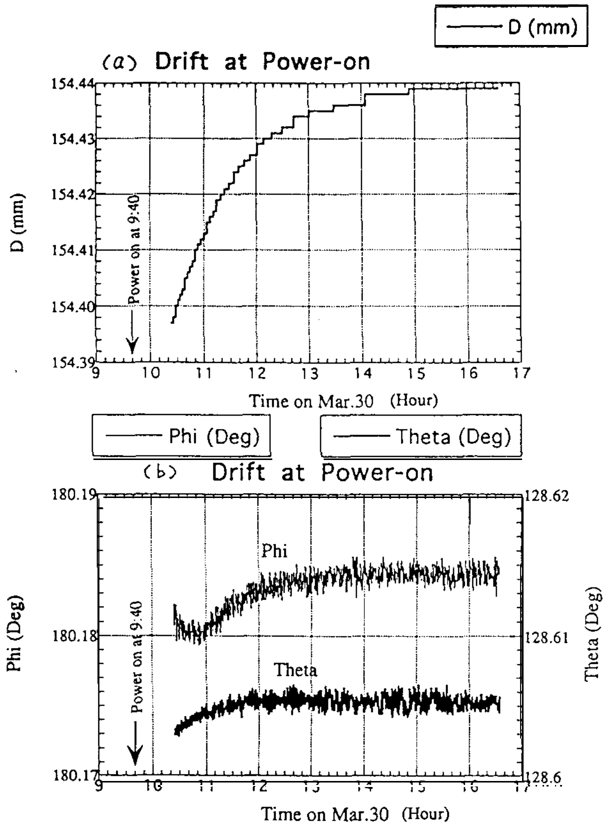

Fig.11 Initial drift of the laser tracker

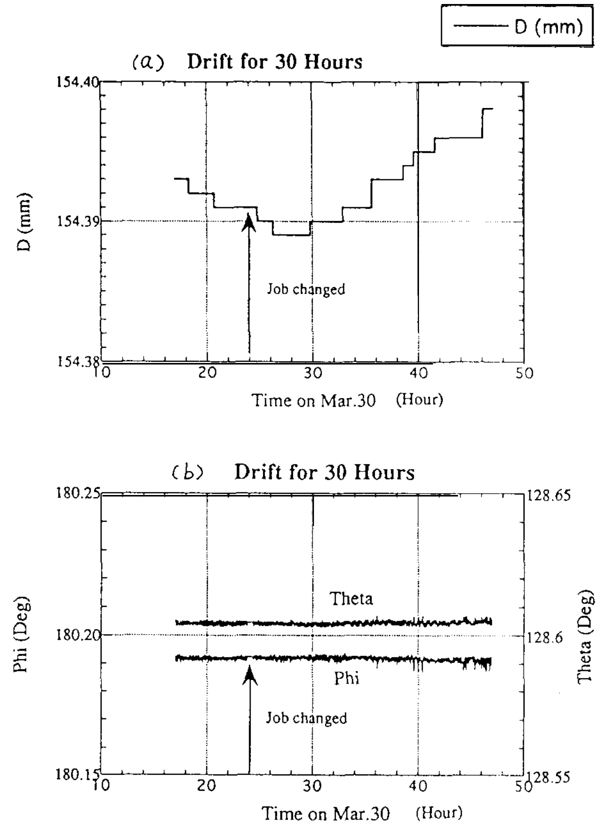

Fig.12 Drift of the laser tracker in the steady status

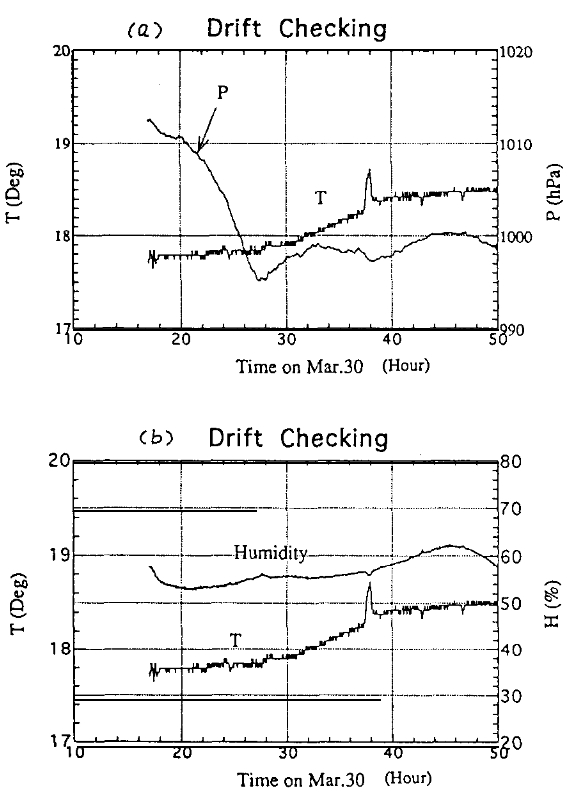

Fig.13 Variation of temperature (T), pressure (P) and humidity (H) in the experiment on the drift.

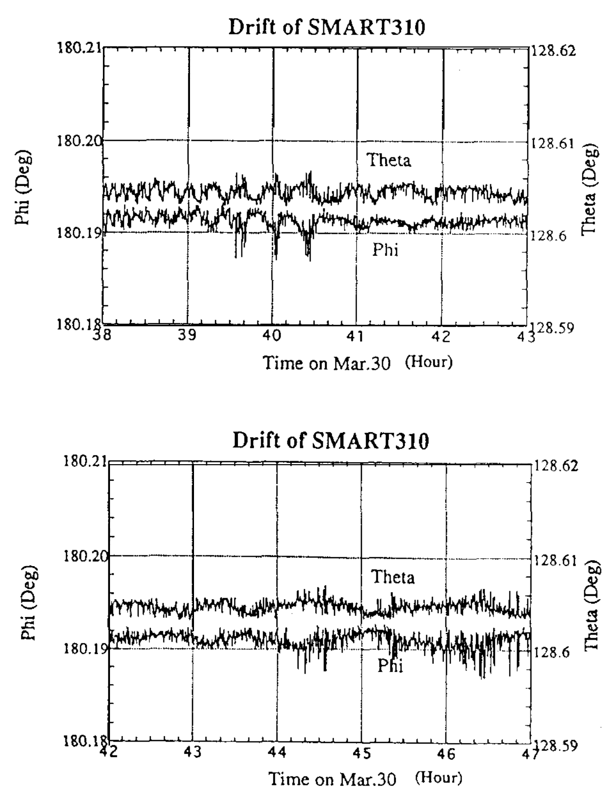

Fig.14 Long term oscillation in the angle measurement.

angles ϕ and θ seems to be less than the fluctuation of data. But looking at the expanded plot, some oscillations with long period of 30 to 60 minutes are observed as shown in Fig.14. The amplitude is 30 to 50 µm in peak-to-peak. The source of this long term oscillation is not the variation of T, P nor H, because the period of those variation is much longer and the amplitude of the oscillation is much bigger than that caused by the variation of T, P and H.

5. SUMMARY

The results of various measurements are summarized in Table 3. Comparing with the

Table 3. Summary of resolution and precision measured.

Measurement	ΔD(µm)	Δf(µrad)	$\Delta\theta$ (µrad)
Fluctuation of output	0.96	2.9	2.6
Tracker along the rail	2	2.0	2.5
Tracker perpendicular to the rail	3	2.5	2.0
Measurement of 2m distance		~5	
Long term drift	~8/day	30 - 50	30 - 50
Specification for resolution	1.26	5.0	5.0
Specification for precision		10.0	10.0

specification of the company listed at the bottom, the precision for the angle in short time measurement (i.e. shorter than about ten minutes) is about twice as better as the total precision claimed by the company. Although the precision for the distance seems a little worse than that claimed by the company, it is not the matter at all because the error of the laser interferometer is negligibly smaller than that of the angle measurement.

But two problems were found:

1. Output from the laser interferometer occasionally oscillates. The period seems to be less than 0.1 second.
2. Output from angle measurement oscillates with long term period. The period varies from 30 to 60 minutes. The amplitude is 30 - 50 µrad in peak-to-peak.

REFERENCES

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[2] Werner Schertenleib, “Measurement of Structures (Surfaces) Utilizing the Smart 310 Laser-Tracking-System”, Contribution to this Fourth International Workshop on Accelerator Alignment, Tsukuba, Nov. 14-17, 1995.