PERFORMANCE TEST OF VARIOUS LASER RANGE FINDERS IN 700 m LONG TUNNEL

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Abstract

The KEKB ring is now being reconstructed as a higher luminosity machine, SuperKEKB. But the alignment of magnets in the KEKB ring was lost in the Great East Japan Earthquake. Then the high precision distance measurement is sometimes required in this reconstruction. In order to choose adequate instruments, the performance of several laser range finders, such as TS30 of Leica, Net05X of Sokkia Co., Ltd. and ME5000 of Leica, were tested in 700m long road tunnel. Results of this performance test are reported.

1. INTRODUCTION

The [*]KEKB ring, the high luminosity electron-positron two ring collider [1], is now being reconstructed as a higher luminosity machine, SuperKEKB [2]. The circumference of this ring is about 3 km. But the alignment of magnets in the KEKB ring was lost in the Great East Japan Earthquake [3]. Then the high precision distance measurement is sometimes required in this reconstruction. In order to choose adequate instruments, the performance of several laser range finders were tested in 700 m long road tunnel.

2. TEST AREA AND TESTED INSTRUMENTS

The test area is 700 m long road tunnel in National Institute for Land and Infrastructure Management. This tunnel is a road tunnel originally to test some road tunnel construction technique. Several laser range finders were brought in this road tunnel, and their performance was tested in the steady climate environment.

The tested instruments are two models of total stations (two TS30 of Leica and two Net05X of Sokkia Co., Ltd.) and one model of mekometers (four ME5000 of Leica). Their precision and range in makers' specifications are as follows:

Total station, TS30
- Precision: 0.6 mm + 1ppm*L
- Range: 1.5 m – 1.8 km in range A

Total station, Net05X
- Precision: 0.8 mm + 1ppm*L
- Range: 1.3 m – 3.5 km

Mekometer, ME5000
- Precision:
  - 0.2 mm + 0.2ppm*L for distance
- Range:
  - 20 m – 1 km in low range
  - 100 m – 8 km in high range

3. TEST PROCEDURE

Figure 1 shows the layout of the test road and the configuration for the testing lines in the road tunnel. The 700 m road tunnel is located in the center of this layout. Two testing lines were set by placing concrete blocks at both ends of the tunnel. Target mirrors were set on these concrete blocks, and instruments on tripods just behind the blocks.

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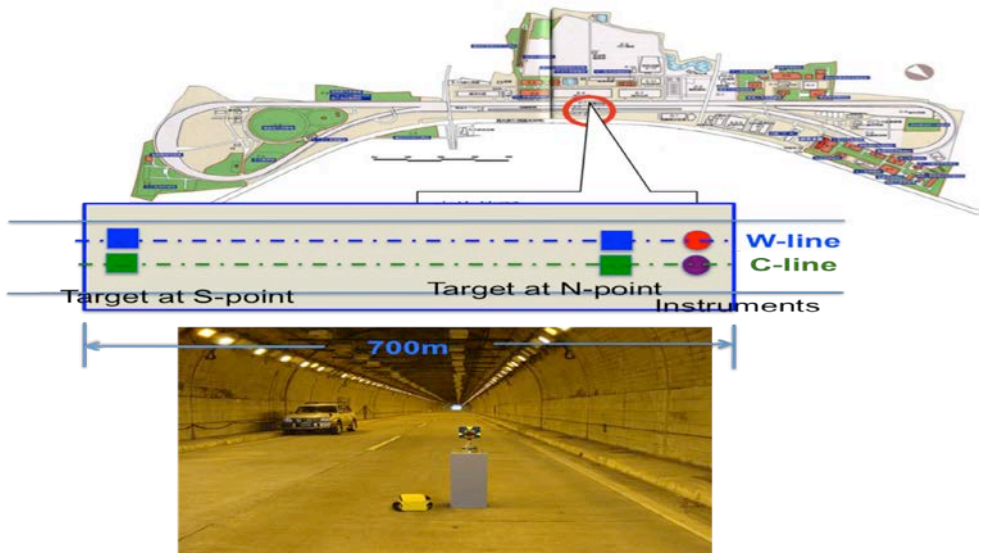

Figure 1: Layout of the test road, and the configuration and a picture for the test lines in 700 m long tunnel located in the center of the test road.

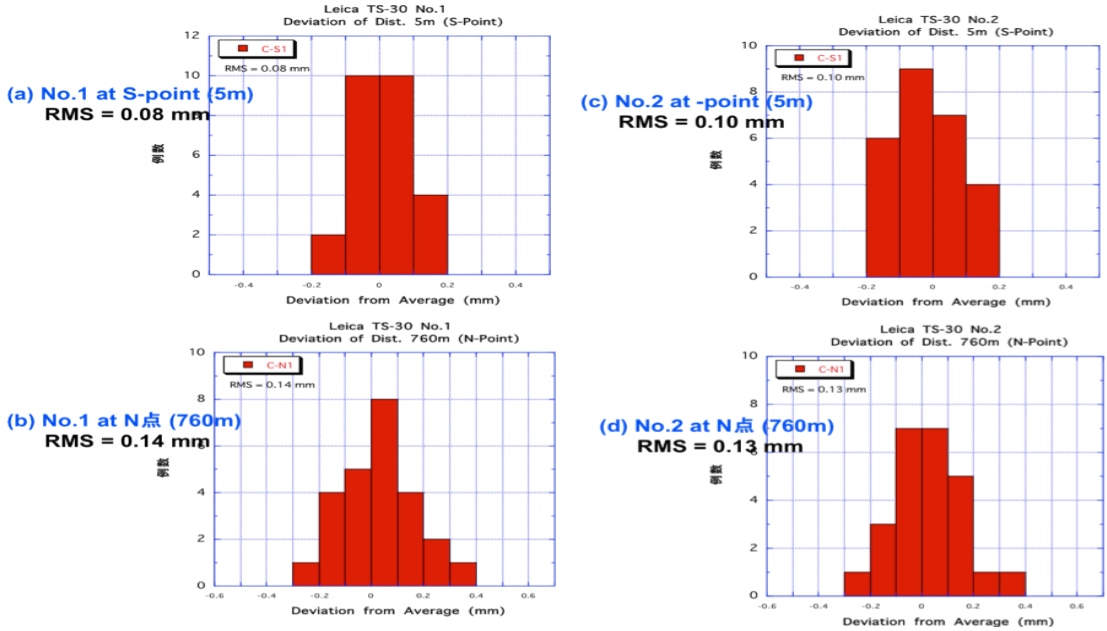

Figure 2: Deviations from the average value of 25 measurements for the same distance. (a) and (b) are those for 5 m and 760 m distances measured with TS30 No.1. (c) And (d) are those for TS30 No.2.

4. TEST RESULTS

4-1. REPRODUCIBILITY OF TOTAL STATINS

The distance to the mirror located at N-point (5 m far) and at S-point (760 m far) was measured with two Leica total stations, TS30 No.1 and No.2, 25 times each by pushing measurement button successively.

The distributions of deviations from the average value are shown in Figure 2. The RMS is derived from the distributions as follows:

0.08 mm + 0.09ppm*L for TS30 No.1, and

0.10 mm + 0.03ppm*L for TS30 No.2

Then the distance between N-point and

S-point was measured consecutively at one-hour time intervals with total stations TS30 No.1 and Net05X No.1. Before and after the measurement, the distance was measured with mekometer ME5000. Results are shown in Figure 3(a) for TS30, and (b) for Net05X. Blue points are measurements with the mekometer and red points are those with the total stations. RMS of 7 measurements is 0.15 mm for TS30 and 0.16 mm for Net05X.

These RMS values obtained are much smaller than the precisions specified by the makers.

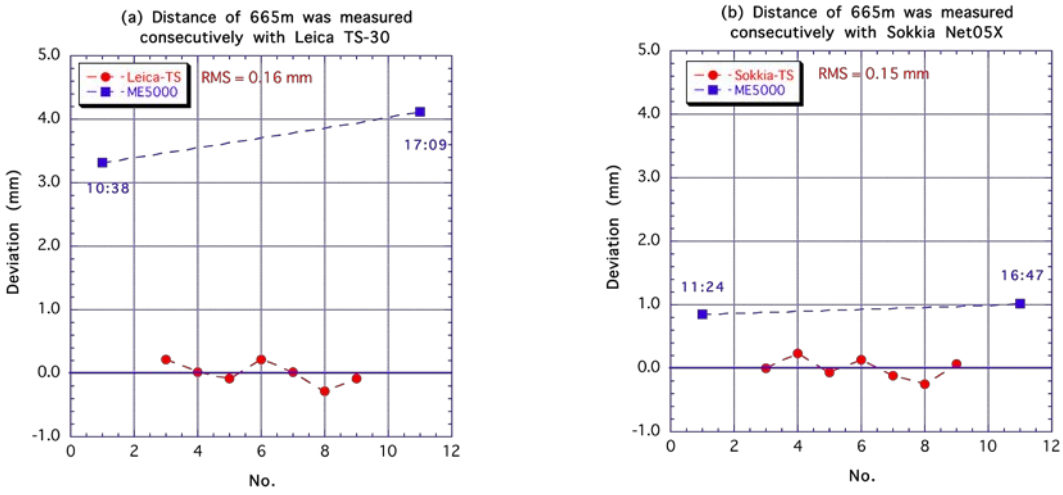

Figure 3: Variation of consecutive measurements of the distance 665m at one-hour time interval with (a) TS30 No.1 and (b) Net05X No.1.

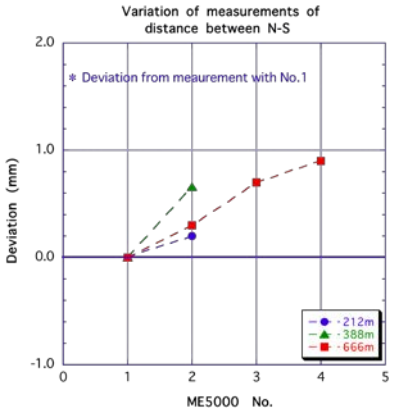

Figure 4: Differences among measurements of three distances, 212 m (blue points), 388 m (green points) and 666 m (red points), with two or four mekometers. The measurements with ME5000 No.1 are taken as the reference.

4-2. VARIATION OF MEASUREMENT WITH MEKOMETERS

The distance between N-point and S-point was measured for three distance values, 212 m, 388 m and 666 m with two or four mekometers. The differences from the measurement with ME5000 No.1 are plotted in Figure 4.

Maximum difference is 0.9 mm between No.1 and No.4 in the measurement of the distance 666 m. These differences look systematic. So some adequate calibration will make these differences much smaller.

4-3. COMPARISON BETWEEN TOTAL STATIONS AND A MEKOMETER

The distance between N-point and S-point was measured for three distance values, 208 m, 411 m and 662 m with two TS30, two Net05X and ME5000 No.1. The differences between distances measured with these four total stations and those with the ME5000 No.1 are plotted in Figure 5 as a function of the distance. Blue points are those for TS30, and red points are those for Net05X. The precisions specified by makers are shown by blue lines for TS30 and

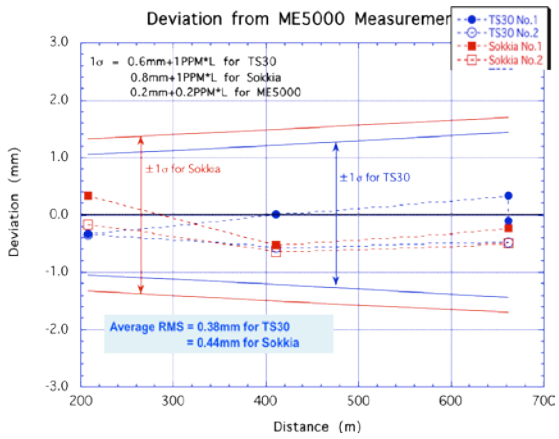

Figure 5: Deviations of measurements for three distances, 208 m, 411 m and 662 m, with TS30 and Net05X from those with ME5000 No.1. Blue plots are for TS30 No.1 and No.2, and red plots for Net05X No.1 and No.2.

red lines for Net05X. Average RMS is 0.38 mm for TS30 and 0.44 mm for Net05X. These values are much smaller than the precisions specified by makers.

5. VARIATION OF CIRCUMFERENCE OF THE KEKB RING MEASURED WITH TORAL STATIONS

The circumference of the KEKB ring was measured four times with the total station, TS30 No.1. The position of magnets mainly in the high-energy ring was measured at the spatial interval of about 40 m in the arc section. Only in the measurement #5b, the spatial interval in the arc sections was taken as long as possible. The measurement length was about 90 m. At 200 m straight sections, the position of magnets at both ends of the straight section was measured. Measurement was carried out counter-clock wise starting from the Tsukuba straight section. The edge magnet was overlapped in the next measurement. The distance between the magnets at both edges was calculated in the horizontal plane, and compared with the designed value in the lattice. dL is defined as follows:

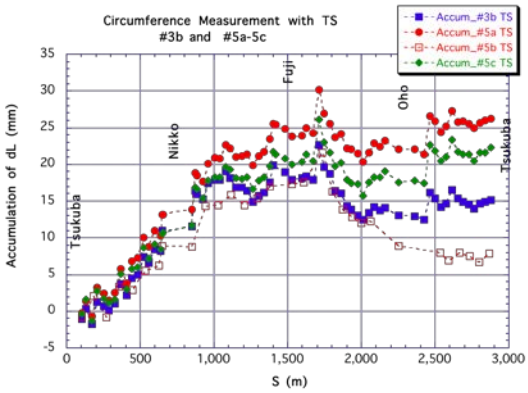

Figure 6: Accumulation of dL in the circumference measurements performed for December 7-9, 2011 (blue points) and in two weeks in June 2012 (other three color plots), where dL is the deviation of the distance measurement from the designed value in each measurement stage.

dL = (measured distance) – (designed value)

dL was accumulated from the starting point till the final point. The final value of this accumulation provides estimation for the error of the circumference of the ring.

The measurement #3b was performed for December 7-9, 2011. The rest measurements were performed in two weeks in June 2012. The accumulation of dL in these measurements is shown in Figure 6. The final values of the accumulation of dL scatter from 8 mm to 26 mm, 17±9 mm, in four measurements. The change of the circumference was measured precisely with a laser tracker and a mekometer [4]. It is reported that the circumference was lengthened in the Great East Japan Earthquake and it settled down around the circumference +15mm longer than the designed value since the end of September 2011. So the variation of the circumference shown in Figure 6 is thought to be caused by the error of the measurement with the total station. The error of the measurement of the KEKB ring circumference with the TS30 is estimated to be 5.0mm from the precision specified by the maker. The variation of four measurements corresponds to about two

standard deviations of the precision of the TS30.

SUMMARY

The performance of several laser range finders was tested in 700 m long road tunnel where the climate environmental condition was stable. The tested instruments were two models of total stations (two TS30 of Leica and two Net05X of Sokkia Co., Ltd.) and one model of mekometers (four ME5000 of Leica).

- From the variation of 25 time measurements of two distances, 5 m and 760 m, with the TS30, the following errors were derived:
  0.08 mm + 0.09ppm*L for No.1, and
  0.10 mm + 0.03ppm*L for No.2.
- RMS of seven consecutive measurements of the distance 665 m at one-hour time interval:
  0.16 mm for TS30 No.1, and
  0.15 mm for Net05X No.1.
  These errors derived are much smaller than the precision specified by the makers.
- Three distances, 212 m, 388 m and 666 m, were measured with two or four ME5000 mekometers, and results were compared. The maximum difference was about 0.9mm between No.1 and No.4 in the measurement of the distance 666 m. As these differences look systematic, some adequate calibration will make these differences much smaller.
- Three distances, 208 m, 411 m and 662 m, were measured with two models of the total stations, TS30 (No.1 and No.2) and Net05X (No.1 and No.2), and the mekometer, ME5000 No.1. RMS of these measurements is:
  0.38 mm for TS30 No.1+No.2
  0.44 mm for Net05X No.1+No.2
- Those values are about 1/3 of the precision specified by the makers.
- The circumference of the KEKB ring was measured with the total station TS30 four times. The first measurement #3b was performed for December 7-9, 2011. The rest measurements were performed in two weeks in June 2012. The deviations of the measured circumference from the designed value were evaluated. The evaluated deviations scatter from 8 mm to 26 mm, 17±9 mm. The circumference of the ring was measured precisely with a laser tracker and a mekometer [4], and it was reported that the circumference looks settling down since the end of September 2011 at the length about +15 mm longer than the designed value. So the scattering of 17±9 mm, about two standard deviations of the precision specified by the maker, looks caused by the error of the measurement with the total station. Not only the performance of instruments but also the variation of the temperature along the laser beam passage looks important factor in the measurement. Because the influence of the temperature is as large as 1ppm/1° and it is difficult to measure the temperature variation along the laser beam passage in the KEKB ring tunnel.

The authors thank National Institute for Land and Infrastructure Management for giving us the chance to do the performance test of various laser range finders in their test road tunnel.

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