

# The Accuracy of Electronic Distance Meters over Short Distances

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## Abstract

The paper deals with testing of electronic distance meters on absolute baseline with forced centring. The sizes of systematic and random errors and their time changes are determined by experimental measurements. The accuracy of distance meters is determined for short lengths up to 38 m which are common in surveying for purposes of mechanical engineering.

**Key words:** Absolute lengths, baseline, random errors, systematic errors, stability of EDM.

## 1 INTRODUCTION

In order to increase the accuracy of geodetic measurements, the effect of instrument errors is reduced by a suitable procedure of the measurement and measurement configuration or calculation corrections can be applied on the measured values. Constant corrections or corrections depending on measured distance can be used to correct distance measured by the EDMs (Electronic Distance Meters) of the total stations. Baselines are used to determine the distance meters' errors. Manufacturers give the standard deviation of the measured distance in form:

$$\sigma_D = A + B \cdot D. \quad (1)$$

According to (Rüeger, 1990), the symbol A is in millimetres and includes phase resolution of EDM instrument, maximum amplitude (or average effect) of short periodic (cyclic) error of phase distance meters, maximum (or average) effect of non-linear distance dependent errors and accuracy of an additive constant (compatibility of reflectors). The symbol B is in ppm (part per million) and includes the range of the typical frequency drift of the main oscillator within the specified temperature range and the maximum error which may be caused by the limited step interval of the "ppm dial". This list is a mix of systematic and random errors. Besides these effects accuracy of the distance measurement is also influenced by surveyor, the atmosphere and usage of other equipment. Summary of all these effects leads to the error model according to (Staige, 2007):

$$\text{error budget} = \sum(\text{systematic errors}) + \sum(\text{random errors}) + \text{noise}. \quad (2)$$

Procedures for testing of the EDMs used in the precise industrial measurement were designed at the Department of Special Geodesy. The aim of the tests is to determine the size of systematic and random errors for short lengths (up to 40 m), which are commonly

measured in indoor industrial applications. Determination of the properties of EDMs leads to the use of real standard deviations in the analysis of the accuracy, more accurate measurements and greater reliability of results. This paper focuses on the initial tests of selected EDMs, i.e. tests of repeatability of the measurement of the same absolute distance and the temporal stability of errors of EDMs.

## 2 EDM BASELINE

Baseline in the laboratory of geodesy at the Faculty of Civil Engineering CTU in Prague is used for testing of EDMs. The baseline is made up of 16 concrete pillars with forced centring and its total length is 38.6 m. Pillars are mutually spaced at a distance of 0.9 m - 5.0 m (average 2.5 m). Directly measured distances are compared with absolute distances between pillars to test EDMs. The distances between pillars were determined (for used equipment) using Leica Absolute Tracker AT401 (borrowed from the Research Institute of Geodesy, Topography and Cartography, VUGTK). The standard deviation of distances between pillars is 0.02 mm.

In this measurement additive prism constant was also determined, which is defined into the instrument during the test measurements. Two tribrachs are used for the tests on the baseline (one for the instrument, one for the carrier with prism). Tribrachs are tightened on pillars in the same way every time (indicated by line marks) to avoid the influence of their eccentricity error. The tribrachs have one screw glued to ensure the consistently high placement of the prism. Another used equipment in calibration process is precision carrier GZR3 Leica and Leica mini prism GMP101. To eliminate the influence of the eccentricity the carrier is rotated always in the same way (eyepiece in the direction to the first pillar).

## 3 TESTING PROCEDURE

The EDM measurement repeatability and stability over time are important for determining the size of errors and corrections' calculation. The first tests were designed to confirm these requirements. The tests are based on measuring of the distance between the first pillar and all other pillars (15 lengths) and comparing the results to the nominal values. Distance differences were plotted to the graphs (Fig. 2 – Fig. 7). Time interval was chosen to be from one to two weeks between the first and the second measurement and one to one and half month between the second and the next measurement. Results from the first three tests of all instruments are presented in this paper. Instruments were used for common geodetic activities between tests. During the tests are registered slope distances with resolution of 0.1 mm and zenith angles, measurement is performed in both faces, to speed up the process the whole first face measurement is realized at first and then the whole second face measurement. Targeting is not changed during the measurement in one face. This procedure allows evaluating the properties of the EDM in each face and also the average of both faces. Temperature and atmospheric pressure are measured in the half of the measured distance and are used to calculate the physical corrections (by the instrument's software).

### 3.1 NUMBER OF REPEATS

The number  $n$  of repeated measurement of distance is determined by considering the value of the standard deviation of the standard deviation of the measured distance  $\sigma_{\text{sd}}$  (Štroner, 2011) given by formula

$$\sigma_{\sigma d} = \frac{\sigma}{\sqrt{2 \cdot (n-1)}}, \quad (3)$$

where  $\sigma$  is standard deviation of the distance. Considering the selected condition that standard deviation  $\sigma_{\sigma d}$  can be maximally 10% of standard deviation  $\sigma$  is the size of the random selection (number of the measurements) given by the formula

$$\sigma_{\sigma d} = \frac{\sigma}{\sqrt{2 \cdot (n-1)}} = 0.1 \cdot \sigma \Rightarrow n = 51. \quad (4)$$

For each tested EDM and one distance were measured 102 observations (51 in each face), which together give the mean value. This average value is characterized by the sample standard deviation  $s$  which is given by the formula

$$s = \sqrt{\frac{1}{2 \cdot n - 1} \cdot \sum_{i=1}^{2n} (\bar{d} - d_i)^2}, \quad (5)$$

where  $\bar{d}$  is the average distance (from all measurements in both faces) and  $d_i$  is  $i$ -th measured distance.

#### 4 TESTED INSTRUMENTS

For initial tests were chosen instruments from the property of the Department of Special Geodesy, Faculty of Civil Engineering CTU in Prague, commonly used for precise measurements in engineering surveying (Fig. 1). These are one instrument Trimble S6 HP ( $\sigma_D = 1 + 1 \text{ ppm} \cdot D$ , phase EDM), two instruments Topcon GPT7501 ( $\sigma_D = 2 + 2 \text{ ppm} \cdot D$ , pulse EDM) and two instruments Leica TC1202 ( $\sigma_D = 2 + 2 \text{ ppm} \cdot D$ , phase EDM). Both instruments Leica and Topcon are from the same production series (difference in serial numbers is 4 and 1), those were selected to find out if the instruments from one production series have or have not the same properties. If not, correction has to be determined for each instrument separately.



Figure 1 Trimble S6 HP, Topcon GPT-7501 and Leica TC1202 total stations

#### 5 RESULTS OF THE TESTS

Each instrument was tested in three epochs. Fig. 2 shows that Trimble S6 HP's results differ maximally 0.4 mm between epochs. It shows good repeatability of the measured distance and stability over time. Distance to the pillar 2 differs by 2 mm. This was probably caused by the short distance (1.36 m) with difficult targeting or more probably by the blunder of the operator during the target placing. The resulting difference from the nominal distances influences mainly the additive constant and cyclic error. From a distance of 10 m and further

has the Trimble S6 EDM approximately constant error 0.5 mm compared to the nominal distances of the baseline. Sample standard deviations ranged in the interval of 0.26 mm - 0.36 mm.

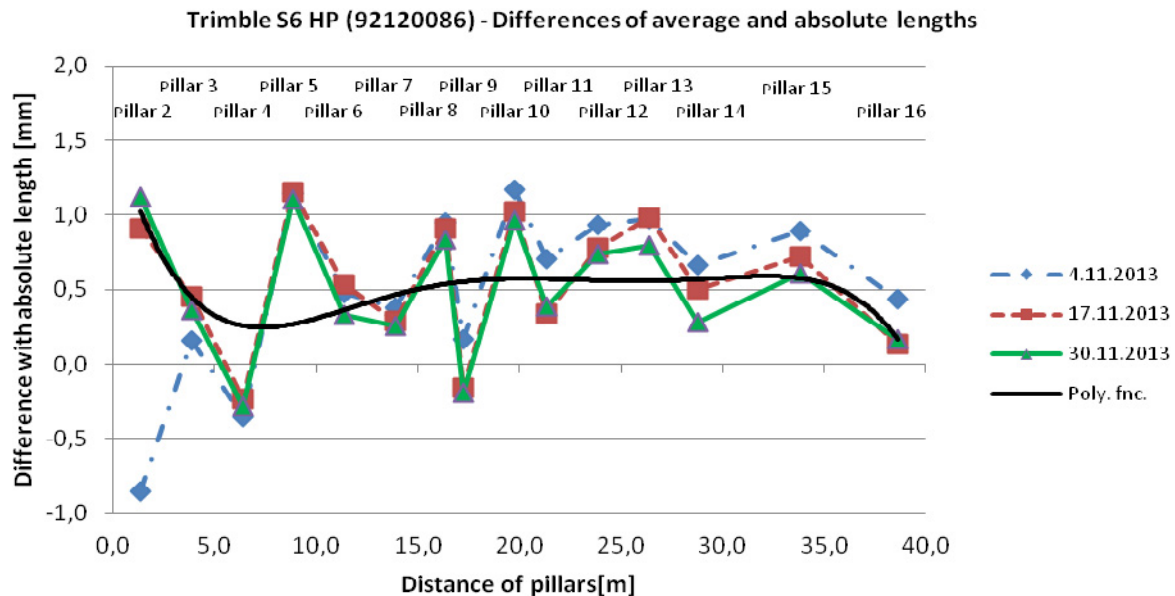


Figure 2 Difference of the measured and nominal distances – Trimble S6 HP (S. No. 92120086)

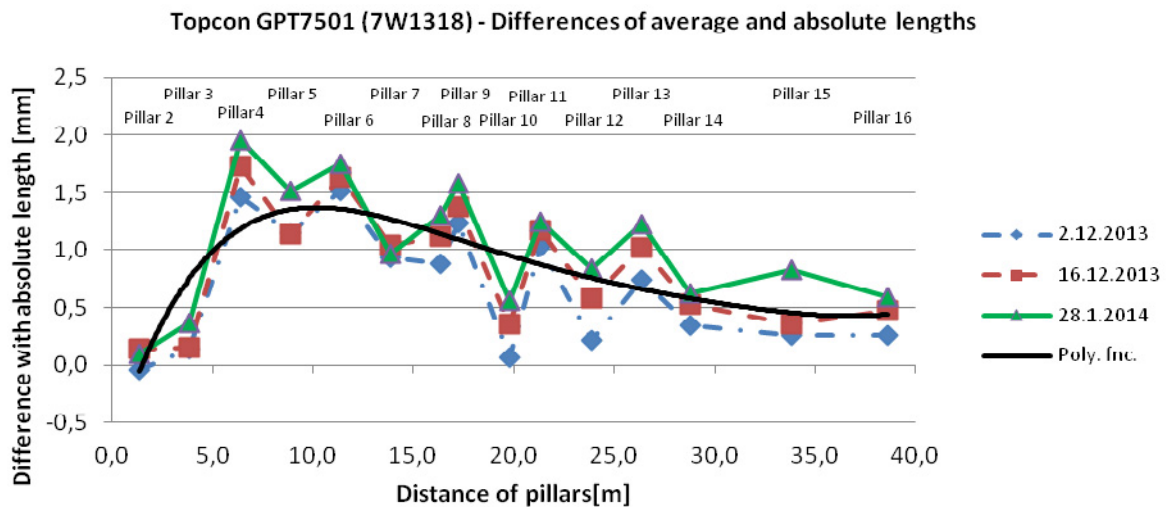


Figure 3 Difference of the measured and nominal distances – Topcon GPT7501 (S. No.7W1318)

Results of Topcon GPT7501 instruments testing are plotted in the Fig. 3 and Fig. 4. There can be seen that the results of the single epochs differ maximally in 0.5 mm. Both instruments showed good repeatability of the measured distance and stability over time.

Both instruments show an increase in errors in the range of 0 m - 10 m and significant changes in the interval of 15 m - 25 m. In this interval can be seen for EDMs in these product line typical problems with measuring distances that have been identified previously in various experimental measurements. The graphs also show that although it is the same instrument (difference of the production numbers is 1) EDMs have the different deviations from the nominal distances. Deviations of the instrument 7W1318 range in the interval between 0.0

mm - 2.0 mm and of instrument 7W1317 in range of 1.5 mm - 3.0 mm. Sample standard deviations range in interval of 0.20 mm - 0.47 mm.

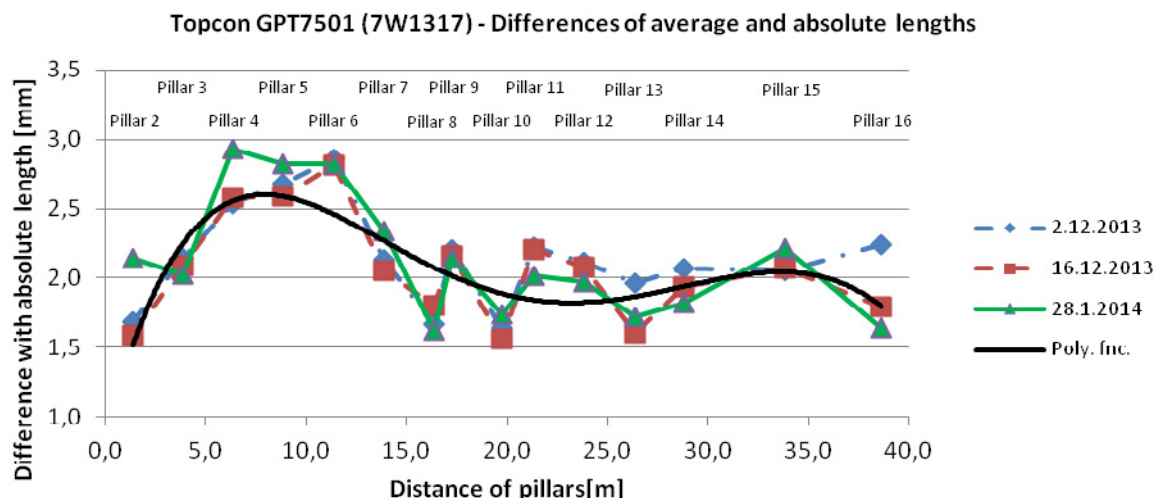


Figure 4 Difference of the measured and nominal distances –Topcon GPT7501 (S. No.7W1317)

Results of Leica TC1202 instruments testing are plotted in the Fig. 5 and Fig. 6. There can be seen that the measured distances correspond with the maximum difference of 0.2 mm with nominal ones. Both instruments showed good repeatability of the measured distance and stability over time. In the Fig. 5 can be seen the solitary difference against two others of the measured distance at the pillar 4 in the second epoch, possibly the blunder of the operator again. The graphs also show that although it is the same instrument production (the difference of serial numbers is 4) EDMs show different values of deviations from the nominal distances. Sample standard deviations ranged in the interval of 0.09 mm - 0.17 mm.

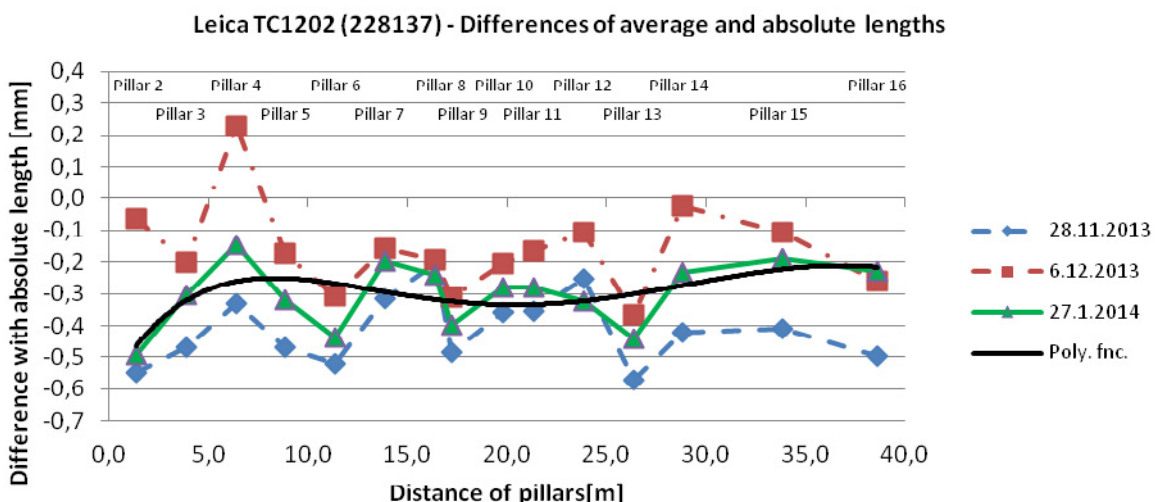


Figure 5 Difference of the measured and nominal distances – Leica TC1202 (S. No. 228137)

All the EDMs showed significant changes in deviations on the first 10 meters of the baseline. These changes correspond to assumptions of the changes of the addition constant on the very short distances (Staige, 2007). All graphs were complemented by the polynomial (fifth degree) function fitted to the mean differences, which express the deviation of the measured lengths from the correct (true) values. These polynomials will be further

investigated and the possibility of interpolation of the corrections from the polynomial will be tested.

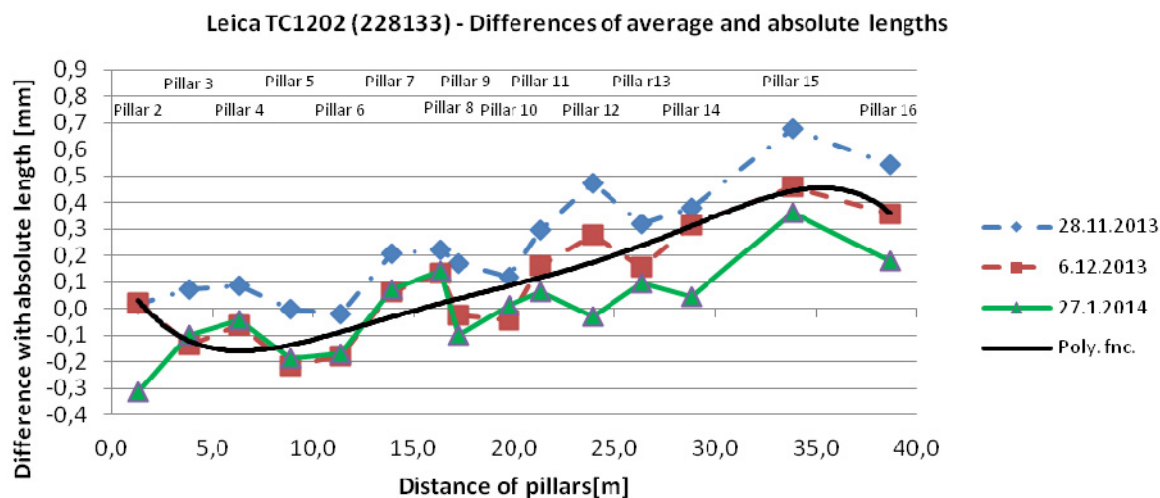


Figure 6 Difference of the measured and nominal distances – Leica TC1202 (S. No. 228133)

## 6 CONCLUSION

Tests of repeated measurements on EDM baseline with accurate absolute lengths were designed for determining the sizes of systematic and random errors of EDMs used in indoor industrial measurements. Tests have shown that the commonly used instruments have good repeatability and stability behaviour of EDM in time. The result is also that each instrument behaves uniquely and cannot fully generalize the behaviour of one production series.

Next tests will concentrate on more detailed mapping of the measurement errors on the short distances with much shorter step and also on creating of the numerical correction procedures.

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## REFERENCES

- RÜEGGER, J. M. (1990) *Electronic Distance Measurement*. 3. ed. Heidelberg: Springer-Verlag, 266 pp. ISBN 3-540-51523-2.
- STAIGER, R. (2007). *Recommended Procedures for Routine Checks of Electro-Optical Distance Meters*. FIG. 14 pp. Available: [http://www.fig.net/pub/figpub/pub09/FIG-Publication\\_Nr9\\_english.pdf](http://www.fig.net/pub/figpub/pub09/FIG-Publication_Nr9_english.pdf)
- ŠTRONER, M., HAMPACHER, M. (2011). *Zpracování a analýza měření v inženýrské geodézii (Processing and Analysis of Measurements in Engineering Surveying)*. 1<sup>st</sup> edition. Prague: CTU Publishing House. 313 pp., ISBN 978-80-01-04900-6.