

COMPARISON OF LASER DISTANCE MEASURING INSTRUMENTS EURAMET.L-S20

*Mariusz Wiśniewski*¹, *Zbigniew Ramotowski*¹

¹ Central Office of Measures, ul. Elekoralna 2, 00-139 Warsaw, Poland, m.wisniewski@gum.gov.pl

Abstract – The results of the first comparison of laser distance measuring instruments (EDM) are reported. The test of the stability of the EDMs showed significant changes in the mean results in timescale months or even days. The uncertainty of the results mainly comes from the uncertainty of the reproducibility.

For the analysis both the deviations from the KCRV and the En numbers were calculated. For the evaluation of the reference value, the modified weighted mean approach has been chosen. Most results agreed within the claimed uncertainty.

Keywords: length, EDM, comparison

1. INTRODUCTION

The metrological equivalence of national measurement standards and of calibration certificates issued by national metrology institutes is established by a set of key and supplementary comparisons chosen and organized by the Consultative Committees of the CIPM and by the regional metrology organizations, respectively.

At the meeting in September 2010, the EUROMET TC Length decided to carry out a comparison of laser distance measuring instruments (EDMs), with the Central Office of Measures (GUM), Poland as the pilot laboratory.

2. COMPARISON

13 laboratories take part in the comparison: GUM (Poland), BEV (Austria), CMI (Czech Republic), AS Metrosert (Estonia), MIKES (Finland), PTB (Germany), INRIM (Italy), JV (Norway), INM (Romania), CEM (Spain), SMU (Slovakia), SP (Sweden), METAS (Switzerland). 4 EDMs of different quality classes were used. For each of the two different manufacturers, two models of EDMs were selected: Bosch DLE 50, Bosch GLM 150, Leica DISTO D3a BT, Leica DISTO D8. Each EDM was calibrated at a distance of 0,3 m and regularly spaced intervals every 5 m (as close as possible to these points) for the range up to 50 m. Laboratories with a maximum range of less than 50 meters performed measurements up to the highest possible measurable multiple of 5 meters.

Typically, the laser beam is not perpendicular to the back of EDM. To achieve laser beam perpendicular to the target plate, angular position of the EDM body was corrected. The measurand for this comparison was a

distance from the point at the rear of the angularly corrected EDM farthest from the target plate to the target plate (Fig. 1).

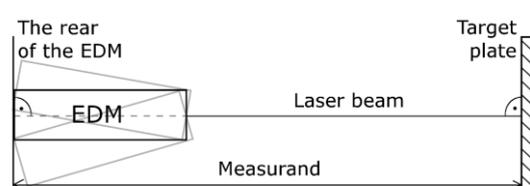


Fig. 1. The measurand for this comparison.

3. STABILITY OF THE EDM

The test of the stability of the EDMs showed significant changes in the mean results in timescale months or even days. A detailed analysis of the observed problems will be presented by way of example with Leica DISTO D8 and for a 10 m distance. This EDM has been chosen because it is theoretically the best of the compared models, with resolution of 0.1 mm over whole range.

3.1. Stability over few minutes time interval

The studies performed showed that deviations from expected value are well characterized by normal distribution. Probability density of deviations from expected value for Leica DISTO D8 for 10 m is consistent with a normal distribution with standard deviation $s = 0.19$ (Fig. 2).

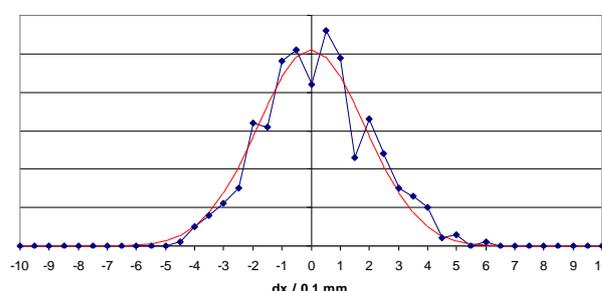


Fig. 2. Distribution of results over few minutes time interval.

3.2. Stability over tens of minutes time interval

Several series of measurements were made with a duration from 15 minutes to 30 minutes, at a constant distance and under constant measurement conditions. For most of the series, changes in the average value of indications of EDMs have been observed at the level of about 0.2 mm. However, for one of the series, change exceeds 0.5 mm (Fig. 3). This value leads to $u = 0,15$ mm.

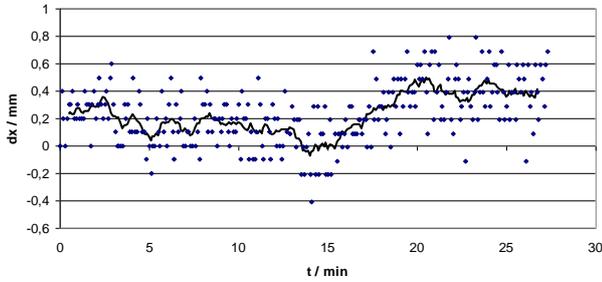


Fig. 3. Stability of results over tens of minutes time interval.

3.3. Stability in the timescale of days and months

The measurements were performed in three series of measurements over an interval of a few days. The cycle of measurements was repeated twice within a few months. The first three measuring series were carried out in February 2011, then in August 2011 and the last one in September 2012 (Fig. 4).

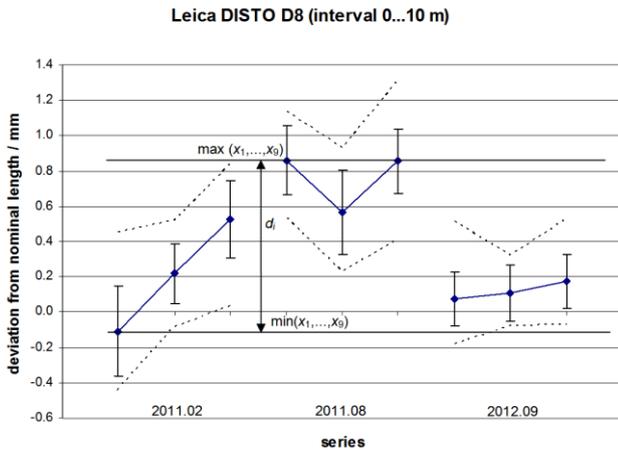


Fig. 4. Results of all series of measurements for Leica DISTO D8 for a distance of 10 m.

Such a large differences between the average values appear over a time scale longer than few days. This means that the laboratory couldn't observe this variability when briefly examining the instrument.

3.4. Repeatability of positioning of EDM

At first measurements were made for the EDM immobilized on a bench for 6 hours (Fig. 5). The standard deviation of results was $s = 0,09$ mm.

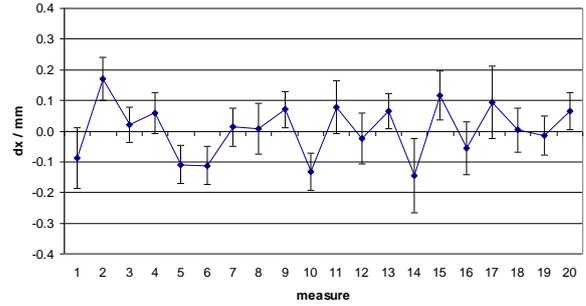


Fig. 5 Static stability test results.

In second try, after each series of measurements the EDM was removed from the bench, shaken and squeezed (Fig. 6). The aim was to simulate the conditions during transportation. This test covers about 6 hours of EDM work. The standard deviation for this test was $s = 0,15$ mm.

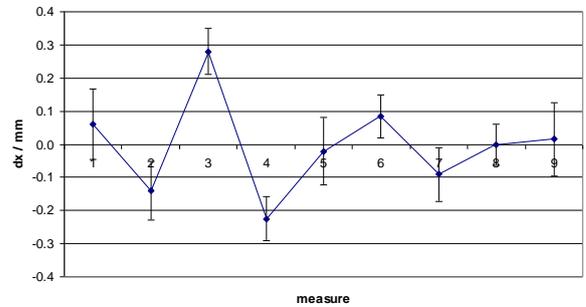


Fig. 6. Dynamic stability test results.

These results may lead to the conclusion that the level of the effects of electronics, mechanics and geometry have a similar impact on the long-term stability. Due to this fact, it is difficult to identify which of these factors has the greatest impact on the observed measurement results.

3.4. Estimation of uncertainty of artifact

The reproducibility of EDM is affected by random changes of mean values in time scale of days. The maximum difference between measurements d_i (Fig. 7) was used to estimate uncertainty $u(d_{art})$ related to random changes of EDM results.

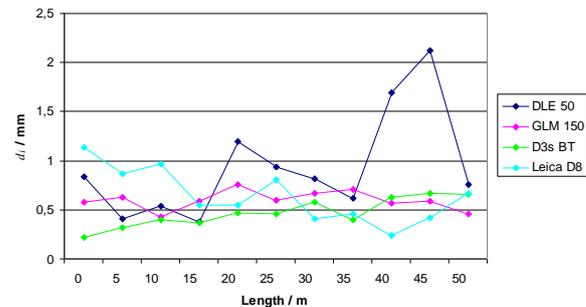


Fig. 7 d_i values for all distances for each EDM.

In order to disentangle $u(d_{art})$, one should try to subtract the observed short term stability from $\max(d_i)$ and influences of the different alignments like zero point u_{zero} , cosine error u_{cos} and parallelism u_{paral}

$$u^2(d_{art}) = \left(\frac{\max(d_i)}{2\sqrt{3}} \right)^2 - u_{zero}^2 - u_{cos}^2 - u_{paral}^2 \quad (1)$$

In the case of Leica DISTO D8, we obtain $u(d_{art}) = 0,324$ mm. Table below contains values of $u(d_{art})$ estimated for all the four EDMs.

Table 1. Values of $u(d_{art})$ for all the four EDMs.

EDM	$u(d_{art})$ (mm)
Bosch DLE 50	0,308
Bosch GLM 150	0,197
Leica DISTO D3a BT	0,149
Leica DISTO D8	0,324

4. REFERENCE VALUE

The standard approach is to use weighted mean for determining the reference value x_{ref} [1,2]. This is calculated by the mean of all measurement values x_i weighted by the inverse square of the standard uncertainties $u(x_i)$ associated with the measurements and using these values, the largest consistent subset of the sample is determined. However, checking the consistency of the sample without taking into account the uncertainty associated with the artifact, leads to erroneous recognition of the consistent subset. We propose to add u_{art} to the uncertainty of each laboratory at the beginning of the calculation.

$$u_c^2(x_i) = u^2(d_{art}) + u^2(x_i) \quad (2)$$

Thereby, the uncertainty associated with the artifact will be taken into account during the consistency check.

$$x_{ref} = \frac{\sum_{i=1}^n \frac{x_i}{u_c^2(x_i)}}{\sum_{i=1}^n \frac{1}{u_c^2(x_i)}} \quad (3)$$

The standard uncertainty $u(x_{ref})$ of the reference value is calculated by combining the individual uncertainties:

$$u^2(x_{ref}) = \frac{1}{\sum_{i=1}^n \frac{1}{u_c^2(x_i)}} \quad (4)$$

The χ^2 test was applied in order to estimate x_{ref} from the largest consistent subset [1]. Figure 8 show results from NMIs for all of the distances. Reference value is represented by a bold black line.

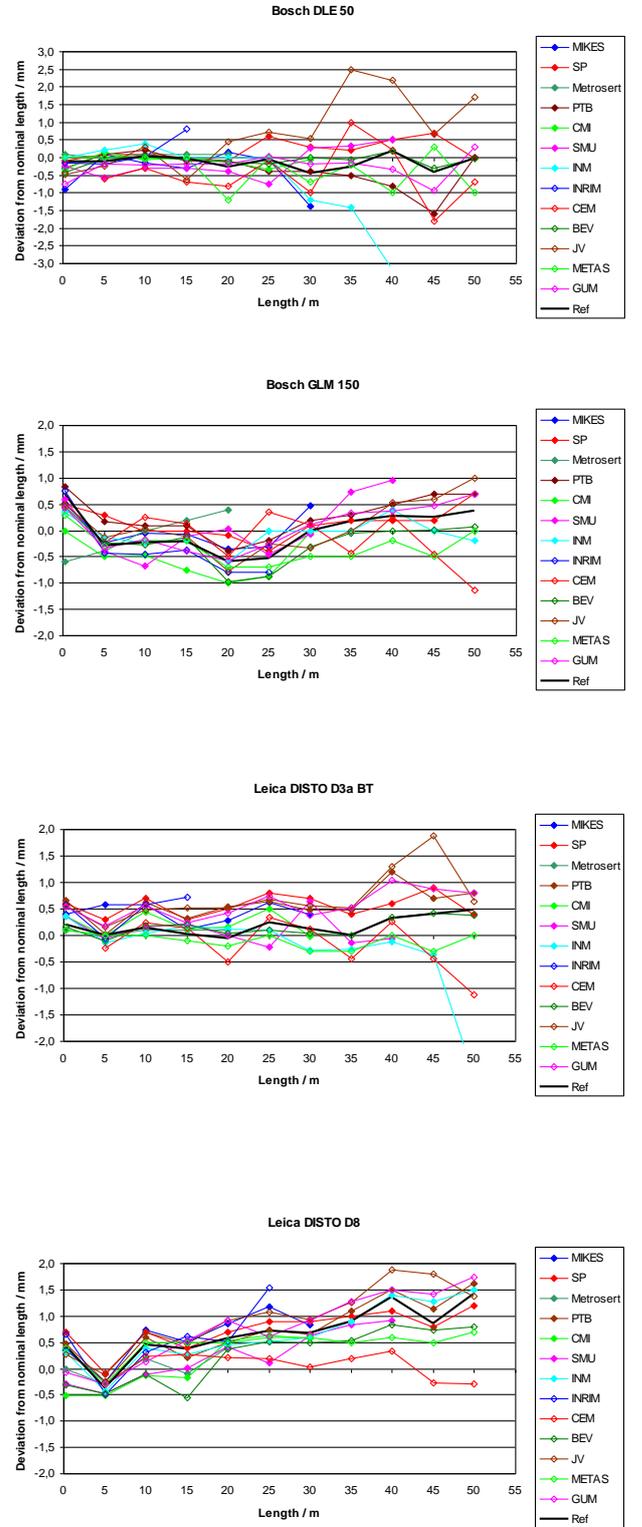


Fig. 8 Deviations from reference values.

5. CONCLUSIONS

It was the first comparison of EDMs. For most of the laboratories, it was an important opportunity to validate their measurement instrumentation and procedure. It allowed to become aware of potential problems and to take corrective actions in changing the procedure.

For the evaluation of the reference value, the weighted mean approach has been chosen, although the consistency check according to procedure A of [1] failed in many cases. A more complicated procedure for the evaluation of the reference value was proposed which slightly changes the uncertainty of the reference value.

In total, there were 23 E_n values larger than 1. This represents 4.7 % of the full set of 482 results. It is less than the 5 % of possible values being out of the expanded uncertainty of the reference value for $k=2$.

The uncertainty of the results mainly comes from the uncertainty of the reproducibility. It is difficult to distinguish between Lab's calibration and measurement capability.

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