FEATURES OF METROLOGICAL CERTIFICATION OF REFERENCE GEODETIC BASES

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Statement of the problem

Checking accuracy of geodetic instruments for linear measurement is performed on the working etalon. Work measurement standards is the linear geodetic basis 1-st and 2-nd digits [5]. The accuracy of measurement in accordance with the $\delta \le \pm(1.6 + 1\times10^{-6} \cdot D)$ mm and $\delta \le \pm(1 + 1\times10^{-6} \cdot D)$ mm, here D - is the length of the line of basis in mm. While increasing the accuracy of modern geodetic instruments necessary to ensure that the accuracy of the reference line of the bases was the best in at least 3 times in comparison with the means of measuring devices that are tested. Metrological certification of reference frameworks can perform or coexistence of kit invar wires [1], or kit (two or three) of the selected high-precision phase laser rangefinders [1], or device with increased accuracy, precision laser rangefinder PLD-1M [2], or using GPS/GNSS-technology for the special methodology [3]. For measuring intervals basis you can apply interferometer [5]. Note that currently the metrological attestation of linear bases often perform of tested precision electronic tachometer or precision rangefinder PLD-1M.

Analysis of the measured lengths of lines of reference geodetic basis by precision electronic tachometer for many years, especially the past three (2011–2013), allowed mention the characteristic of their difference in comparison with the relevant measurements performed precision laser rangefinder PLD-1M. While these differences increase with the length of the line (the greater of 100-200 m) on the amount that exceeds the average square errors of measurement. Especially noticeable difference in measured lines length 1000-2000 m, here they can reach up to 5-6 mm. If the same conditions to perform the appropriate duration of observation of GPS/GNSS, the defined line length 2000 m differs from the same measured precision laser rangefinder PLD-1M 1-1.5 mm.

The purpose of this article is to study the magnitude of this difference and identifying its causes or nature.

The main material. Measurement of lengths of lines of laser rangefinder

The following error of rangefinder phase [7]: measurement of phase difference, cyclic principal modulated frequency, working the speed of light, the amendment of the instrument for the impact the atmosphere. Also on the accuracy of the measurement, lines affect error for centering the reduction, construction lines to the horizon rangefinder, high refraction and curvature of the Earth.

All these errors and amendments can be divided into independent of the measured distance and those that grow from distance. When performing measurements of electronic tachometer observer participation minimal and virtually no impact on the accuracy of measurement and error of the instrument are estimated and provided by the manufacturer at a certain level, celebrated its qualitative characteristics and value.

Considering all the errors, accuracy of measuring distances laser rangefinders served in the form of a regression equation

$$m = \pm(a + b \cdot 10^{-6} \cdot D), \qquad (1)$$

where *a* and *b* are the residual error that pooled under the errors are independent and dependent on the length of the line. These coefficients take value depending on the accuracy of the device, usually from 0.5 to 5 mm. If not defined the average quadratic measurement error line, it is considered that the line is measured with error, which can be assessed according to formula (1). The average quadratic error of the measured distance calculated by repeated measurements of several techniques [7].

The distance measured by electronic tachometer

The measured distance is introduced an amendment for a sustainable instrument, corrected for the influence of atmosphere and the following values are displayed on electronic tachometer as slanted. Note that different manufacturers of electronic total stations used slightly different formulas (models) for the calculation of adjustments for atmospheric effects, but their difference in normal weather conditions, usually about 1 mm.

For a horizontal distance of its value as the slant, corrected for tilt to the target line, high refraction and curvature of the Earth. In order to use measured line at total station taking them off, and also to calculate the coordinates of points in flat coordinate system in projection, for example, the Gauss-Kruger you must enter two more amendments, namely:

1) height above the ellipsoid;

2) for projection to the plane of the Gauss-Kruger.

Metrological certification of lines of reference geodetic basis

For the following geodetic instruments need to know with high accuracy the distance between paragraphs of basis and track their changes over time. Research, analyzed in this work, performed at the

Yavoriv reference linear basis [4]. This first reference attestation by basis metrological performed in 2003 by the NSC "Institute of Metrology" (Kharkov) device of high accuracy with precision laser rangefinder PLD-1M. His accuracy is 0.1 mm. The final value of the lines measured from point T1 to all items basis, with the average quadratic error of 0.2 – 0.5 mm.

Further metrological certification reference frameworks performed periodically every 2-3 years, as of 2009 year terrestrial and satellite GPS/GNSS methods. During this period, accumulated a large number of series of measurements of lengths of lines of reference linear basis. Based on the analysis of series of metrological certification of reference geodetic basis for 2003-2009 shown [6] that can perform accurate measurements of lines and applying technology of GPS/GNSS. Also investigated changes of definition of lengths of lines on the duration of sessions of the GPS/GNSS observations [8].

Thus, metrological attestation basis can perform not only rangefinders, but also the instruments that are based on a different technology, measurement of distances, for example, based on GPS/GNSS observations. This is important also because the final result of rangefinder measurements significantly influences the external environment, especially refraction in the ground layer of the atmosphere. Along the measured lines can vary the underlying surface and the height of the beam over her, which leads to the change of index of refraction on the path of the beam by nonlinear law and this phenomenon is not simulated. During the satellite measurements of the impact of tropospheric refraction is well simulated by measurements of meteorological date under surveillance. This is provided by the residual discrepancy model troposphere out, along with the coordinates of the point options for this model, perhaps for a sufficient duration of session observations and mass measurements.

Modeling of unaccounted errors of the measured distances by means linear function

Metrological certification of modern geodetic instruments (electronic tachometers, GNSS receivers) has its own characteristics:

- test need not just a measuring system of the instrument, but also a program for processing measurement or program incorporated in the device for obtaining measured value;

- technology improvement of measuring system alters the means and methods of controlling electronic and radio engineering devices.

To maintain the accuracy of the measurement lines to control the stability of the frequency of the rangefinder determine and track the constancy of sustainable rangefinder. Also aware that the laser frequency drift may exist with the distance to the measured point. But these and the above error measurements like total value, were supposed to enter the coefficients *a* and *b* are regression equation (1) and does not exceed the residual value of errors.

In this case, metrological attestation of lengths of lines of reference frameworks performed various total station at different times. The nominal marking accuracy/measurement lines for each of 2010 as follows:

1) Leica TM30 – $\pm (0.8 + 1 \cdot 10^{-6} \cdot D)$ mm;

2) Trimble S8 – $\pm (0.6 + 1 \cdot 10^{-6} \cdot D)$ mm;

3) Leica TCR1201 – $\pm (1.0 + 1.5 \cdot 10^{-6} \cdot D)$ mm.

In table 1 and table 2 the difference in lengths of lines of reference frameworks, measured, appropriately, in 2011, 2012 and 2013, compared with reference.

Table 1

The difference of lengths of lines (in mm) as compared with the reference

Distance	Leica TM30 05.07.2011	Trimble S8 19.09.2011	Trimble S8 07.2012
T1-T2	-0,1	0,6	-
T1-T3	0,6	1,7	-
T1-T4	-1,1	-0,2	-
T1-T5	-1,7	0,0	-
T1-T6	-0,6	0,1	-
T1-T7	-0,3	0,4	-
T1-T8	0,5	1,3	-
T1-T9	0,5	1,3	-
T1-T10	-1,3	-0,7	-
T1-T11	-0,8	-0,2	-
T1-T12	-0,7	-0,4	-
T1-T13	-0,4	0,0	-
T1-T14	-0,9	-0,1	-0,8
T1-T15	-1,5	-0,6	-1,6
T1-T16	-1,1	-0,5	-1,1
T1-T17	1,8	3,0	0,2
T1-T20	-4,6	-4,1	5,1

In tables 1 and 2 is a significant trend of increasing absolute value measurement with increasing the length of the line, ranging from 130-240 m, and it is, accordingly, T15 and T16. The length of the longest line the reference basis (T1-T20) is 2280 m.

Since conspicuous the trend of increasing differences between the lengths of the lines measured by electronic tachometers and etalons values will present them a linear function. Doable approximation and do determinate parameters (coefficients). To do this, compile a kind of parametric equation

$$\delta D_i + v_i = a + b \cdot D_i, \qquad (2)$$

where δD_i – amendment in measured the distance is equal to the difference of the opposite sign, *a* and *b* are

coefficients of parametric equations, D – measured the distance, v is an error.

Таблиця 2

The difference of lengths of lines (in mm) as compared with the reference

Paragraphs	Leica TCR1201 02.07.2013	Trimble S8 17.07.2013	Trimble S8 12.12.2013
T1-T2	1,9	-	0,3
T1-T3	2,7	0,6	1,7
T1-T4	-0,7	-2,4	-1,0
T1-T5	-	-2,2	-1,1
T1-T6	-	-1,4	-0,8
T1-T7	-	-0,7	-0,2
T1-T8	-	-0,6	-0,3
T1-T9	-	0,1	0,2
T1-T10	-	-1,6	-1,2
T1-T11	-	-1,2	-0,2
T1-T12	-	-1,7	-1,0
T1-T13	-	-0,6	-0,2
T1-T14	-0,4	-2,2	-0,8
T1-T15	-1,0	-3,1	-1,6
T1-T16	-1,7	-4,1	-2,0
T1-T17	-1,4	-	-
T1-T20	-4,3	-	-

Solve the system of equations of the form (2) the method of least squares for a series of measurements, made 17.07.2013, total station Trimble S8. The r.m.s. is μ = 0,9 mm. In the table 3 present obtained the coefficients a and b of equation (2) and their estimation accuracy.

Table 3

Are the coefficients of the linear function in mm

Coefficient	Value	R.m.s.
a	0,9	0,3
b	$1,4\times10^{-5}$	$3,8\times10^{-6}$

Comparing the coefficients of values defined and manual with equation that coefficient, which characterizes the systematic bias or error the device is practically the same as passport (with taking into account the evaluation of the accuracy of the definition). But the coefficient b, which describes the errors are dependent on the length of the line, significantly different. This allow that drift frequency signal laser and really so much is changing in the modern technologies, it is impossible. Moreover, the device is new and extensively tested.

Determination of the parameters of linear function in this case performed from the point of T2 basis to T3, T4, ..., T16 and, thus, 14 measured lines from one point T2. The same day, performed measurements thus device from point T14 to all those points. Having another set (array) dimensions define the values of the coefficients of the linear function again to more carefully to make conclusions about the error of rangefinder of electronic tachometer, which varies linearly with the distance.

For this case the parametric equations present in table 4. For the received solution the r.m.s. is μ = 0.98 mm, and identified the factors present in the table 5.

Table 4

Parametric equations

№	l, mm	v, mm
1	0,0	0,6
2	0,5	0,1
3	-0,2	0,8
4	1,5	-0,9
5	0,8	-0,1
6	0,7	0,0
7	-0,2	0,9
8	-0,5	1,2
9	-0,2	0,9
10	2,4	-1,8
11	0,9	-0,1
12	2,0	-0,6
13	3,8	-1,6
14	4,1	0,7

Table 5

Are the coefficients of the linear function in mm

Coefficient	Value	R.m.s.
a	0,6	0,3
b	$7,7\times10^{-6}$	$1,8\times10^{-6}$

It should be noted that the accuracy of the determination of the coefficient b is the best, i.e. the coefficient more firmly defined, than in the previous case, and is explained by the fact that no was measured the distance to the point of T13 (distance from T14 is equal 1 m), but its replacement measured the distance to the point of T17, is 2 times greater than the maximum distance in the previous set. The factor that characterizes the linear dependence of the error of measurements (functional error) more determined by the longer distances. Along with this, the precision of the determination of the coefficient a is almost the same, but the value is almost twice less than nominal for this device. With constant sampling device (coefficient a) can be summed up of averaging error centering of tachometer and reflector in projection on the measurement distance. Precision centering point from which the executed measurements is included in each of the distances, and it is different for different items, although the basis for each of the items, like the random, is estimated to ±0.2 mm.

For this device for both sets of measured lines obtained regression equation coefficients are significantly different from the manual.

In this same 2013 have performed measurements of lines of reference frameworks other total station by Leica TCR-1201. The difference in time between the rows of observations by different devices is one month. Total station Leica TCR-1201 measured all the long lines as well as lines to the starting and end points of the phase plot. Thus, having 8 lines, thus it is important that a longer lines should more accurately be determined coefficient *b* of equation (2). With the solution obtained the r.m.s. is μ = 1.8 mm. Defined ratios will present in table 6.

Table 6

Are the coefficients of the linear function in mm

Coefficient	Value	R.m.s.
a	0,05	0,7
b	$-7{,}4\times10^{-7}$	$8{,}6\times10^{-7}$

Comparing the coefficients are determined from the standard for this device, we can notice that the error of the instrument and taking into account the inaccuracy of its definition and averaging error centering is relevant. But the value of error dependent from distance is several times greater, even taking into account error definitions. And this is for any set of measurements and for any electronic tachometer.

Analyzing the cause, it should be noted that the linear nature of the amendment changes the error frequency drift has a high refraction, the curvature of the Earth and for the impact of the atmosphere, i.e. atmospheric refraction. Thus, we can conclude that the use of total station for metrological certification requires simultaneously with measurements to determine or estimate the total error, which changes from distance. This conclusion leads to compare measured reference lines now have these devices with reference values obtained by using precise laser rangefinder PLD-1M. In addition, the line now identified with other GPS/GNSS observations coincide with measurements of precision laser rangefinder PLD-1M within the next 1-1.5 mm for all the long lines (greater than 500 m) including maximum line reference basis of 2260 m. At the same time as the laser rangefinders system total station give fidelity measured lengths of lines with errors in a few tenths of a millimeter for short lines, and starting from the line length of 200 m and the larger their error is growing rapidly and for the line in 2260 m can be at 5 mm. Thus according to manual data, this error should be 2-3 mm or less.

Comparing these same measured lines obtained by different tachometers one class have differences (errors) in the lines of a few tenths of a millimeter, even for lines in 2260 m. Thus, it appears that the error of the drift frequency probably corresponds to the type, or has the same drift for lasers with approximately the same wavelength of the signal, but the margin of error for the impact of the atmosphere, which also has a linear nature of growth with distance, is not sufficiently precise. Thus, a distance greater than 200 m, measured by tachometers in warm weather is always shorter reference, i.e. the measured precision laser rangefinder PLD-1 m, or defined by long sessions of GPS/GNSS observations.

To correct this error of measurement of long lines of electronic tachometer offer each time the metrological certification frameworks simultaneously determine the coefficients of linear function for a minimum number of measured lines and use them for the introduction of amendments in all the other lines. According to the guidelines of engineering materials in Russia, the minimum number of lines for testing rangefinder is 4. If you take 4 line, measured from the original item to items basis, already during the 13 years are stable with an accuracy to ±(0,3-0,5) mm, it can get corrects, which should be for a given number of dimensions in a line longer than 200 m when this error measured lines will be up to 0.5 mm. Also note that in modern electronic tachometer amendment by atmospheric effects introduced in the calculation of the slant distance, while bringing to the horizon of the device also introduced an amendment for a high refraction and curvature of the Earth. Since the last two phenomena, more affect the results of leveling, than on the measurement of distances, so their influence is evident in the precise linear measurements on long lines (> 500 m).

Results of the study

To confirm the conclusions we present some of our many research results. For the first case (table 7) selected 4 equation (lines), which are shown in the first column. The r.m.s. is μ = 0.9 mm, places the odds will present in table 8.

Table 7

Parametric equations (total station Trimble S8) in mm

№	*l*	*v*
2	2,4	-1,1
7	0,0	1,3
13	3,7	-0,3
14	5,2	0,1

In table 9 show the difference between the measured and the reference values of the lengths of the lines and the residual error after determining the

coefficients of linear function for all 14 lines and entered as amended, defined for 4 lines.

Table 8

Determined coefficients of linear function with the 4 equations in mm

Coefficient	Value	R.m.s.
a	0,4	0,7
b	$4{,}3\times10^{-6}$	$5{,}1\times10^{-6}$

Table 9

The difference (mm) between the measured and reference lines and the residual error after entering amendments

№	$D_{obs}-D_{\text{Standard}}$	*v* from 14 equations	*v* from 4 equations
1	0,5	0,001,6	1,7
2	-2,4	-0,001,2	-1,1
3	-2,3	-0,001,1	-1,0
4	-1,5	-0,3	-0,2
5	-0,8	0,4	0,5
6	-0,7	0,5	0,6
7	0,0	1,3	1,3
8	-1,7	-0,4	-0,3
9	-1,3	0,0	0,1
10	-1,8	-0,4	-0,4
11	-0,7	0,6	0,7
12	-2,3	-1,0	-0,9
13	-3,7	-0,3	-0,3
14	-5,2	0,2	0,1

Note that the residual deviations must be interpreted as error of projection of total balance in pairs of two items (one of which is the original) in each line.

The conclusions

The analysis of the received results will make the following conclusions:

1) the measurement lines of electronic tachometers grow in proportion to the length of the line and ranging from 200 m in excess of the declared in the passport of the device accuracy;

2) possible causes of error are two: the influence of the atmosphere and drift frequency signal (provided the introduction of amendments by high refraction and curvature ground in line length of 500 m);

3) most probably because the error is lack of accurate models of refraction that is embedded in the Software of total stations.

References

1. Bazysy etalonnye. Metodyka poverky //MY BHEY 40-03.- M., 2003.- www.OpenGost.ru/

2. Druzyuk V. Suchasni heodezychni prylady i tekhnolohiyi: naukovo-tekhnichne metrolohichne zabezpe-chennya/ V.Druzyuk, A.Mazur, I.Trevoho, I.Tsyupak// Metrolohiya ta prylady.- 2010, # 3.- S. 19-26.

3. Patent na korysnu model' # 83876 «Sposib vyznachennya dovzhyn liniy etalonnoho heodezychnoho bazysu».- Zareyestrovano 10.10.2013// Byulleten' #19.- 2013.

4. Trevoho I. Etalonnyy heodezychnyy bazys oryhinal'noyi konstruktsiyi/ I.Trevoho, O.Denysov, I.Tsyupak, V.Heher, V.Tymchuk // Suchasni dosyahnennya heodezychnoyi nauky i vyrobnytstva. – Liha-Pres, 2010.- Vyp.1(19). – S. 43-49.

5. Trevoho I.S. Stan i problemy metrolohichnoho zabezpechennya liniynykh vymiryuvan' v Ukrayini/ I.S.Trevoho, V.S. Kupko, O.L. Kostrikov, I.M. Tsyupak// Materialy V Mizhnarodnoyi naukovo-praktychnoyi konferentsiyi «Novi tekhnolohiyi v heodeziyi, zemlevporyadkuvanni ta pryrodokorystuvanni».- m.Uzhhorod, 28-30 zhovtnya 2010 r.- Uzhhorod.- 2010.- S. 6-11.

6. Trevoho I.S. Etalonnyy heodezychnyy bazys: analiz rezul'tativ i nova atestatsiya/ Trevoho I.S., Tsyupak I.M., Heger V.// Suchasni dosyahnennya heodezych-noyi nauky ta vyrobnytstva.- L'viv: Vydavnytstvo L'vivs'koyi politekhniky.- 2011.- Vyp.I (21).- S. 65-68.

7. Trevoho Y.S., Shevchuk P.M. Horodskaya polyhonometryya.- M.: Nedra.- 1986.- 200 s.

8. Tsyupak I. M. Tochnist' vyznachennya koordynat punktiv i dovzhyn liniy za sesiyamy GPS-sposterezhen' riznoyi tryvalosti// Suchasni dosyahnennya heodezychnoyi nauky ta vyrobnytstva, 1(23), 57-59.- L'viv: Vydavnytstvo NU «L'vivs'ka politekhnika».- 2012.- Vyp. I (23).- S. 57-59.

Features metrological certification standard geodetic bases

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Investigates measurement error lines tachometers on the reference linear basis. Study found an additional error, which increases with distance. With precise measurements necessary to consider an amendment to the lines longer than 200 m is assumed that the error probably caused by insufficient accuracy of accounting atmospheric correction. The approach to the correction in the reference basis of metrological certification.