TESTING AND CALIBRATION OF SURVEYING INSTRUMENTS AND TOOLS – MEANS TO THE QUALITY INCREASE OF SURVEYING WORKS IN CONSTRUCTION

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Abstract: The paper introduces the basic calibration procedures of selected surveying instruments and ancillary equipment (digital levels and bar code levelling staffs, total stations and electronic tacheometers, reflective systems). The results from testing of the light influence on work of digital level are presented. The testing procedure and results of the calibration of horizontal circles of the surveying instruments on the calibration device in the Slovak Institute of Metrology in Bratislava are introduced as well.

Key words: Calibration, testing, digital level, bar code levelling staff, electronic tacheometer, horizontal circle.

1 Introduction

Currently, in addition to the conventional measurement systems – theodolites, electronic distance meters, total stations and GPS units, are levels the most frequently employed instruments in surveying practise. The optical levels are gradually replaced by digital automatic levels and conventional invar staffs by bar code levelling staffs. These new levels equipped by CCD sensor allows a full automation of staff reading and offers new benefits: higher accuracy of reading, automatic registration, elimination of the gross errors and mistakes, measured data are in electronic form with the possibility for further processing in different software environments.

2 Testing and calibration of levels and ancillary equipment

Among the most frequently occurring errors in levelling using digital levels belongs the staff graduation error [2, 9]. This error has a systematic character and significantly affects the accuracy of the results of precise levelling measurements (measurement in the National Levelling Network, measurement of the vertical displacement of building structures etc.). Calibration of the levelling staffs allows reducing the influence of the mentioned error to the minimum. The calibration measurement is possible to perform, e.g. using a linear laser interferometer. This method is suitable for levelling staffs with conventional graduation as well as for bar code levelling staffs. Calibration itself can be realized by various arrangement of calibration equipment, i.e. in the horizontal or vertical position of a levelling staff.
In the following are given examples of some calibration equipments – comparators.

2.1 Comparator using laser interferometer at the Department of Theoretical Geodesy of FCE of SUT in Bratislava

Comparator using laser interferometer (CLI) with its accuracy and traceability to the National standard of length of the Slovak Republic at the Slovak Institute of Metrology (SIM) presents the highest item of metrological provision of the length at the Department of Theoretical Geodesy. From CLI are derived values of all onward comparators up to the parameters of the length baseline in Hlohovec. The CLI was calibrated at the SIM by measuring the differences in frequency of laser Δf to the National standard of length of the Slovak Republic (laser SIM B2) with extended relative uncertainty $U = 6{,}8.10^{-11}$ ($P = 0{,}95$) [7].

CLI allows contactless calibration of all linear measures whose scale (lines) can be set up under setting microscope of the comparator. Using CLI can be calibrated the invar levelling staffs of varying length, control invar measures and other working measures and standards. It is also possible to carry out verification (calibration) of the foldable levelling staffs (4 m), base staffs, measuring bands etc. [7].

2.2 Horizontal comparator for bar code levelling staffs

The basis of a laboratory is 30 m long calibration bench with two moving trucks (fig. 1), their distance from the reference point is measured by the laser interferometer HP5507B. Levelling staff, located on the moving trucks, is supported at Bessel's points. On the bench is mounted an electro-optical microscope, trucks with fixed levelling staff are moving under the microscope. This determines the position of all elements of the staff code.

Fig 1: Horizontal comparator

2.3 Vertical comparator for bar code levelling staff and system calibration

Vertical comparator (fig. 2) allows calibration of levelling staff in the vertical plane. The value of movements is measured by a laser interferometer, similar to the horizontal comparator. The vertical comparator can be used for calibration of levelling staffs in the vertical plane and for so called system calibration as well. The advantage of this procedure is that the levelling staff is during the calibration in the same position as in the field measurement.

Fig. 2: Vertical comparator

In general, it is assumed that the scale of measuring system is a scale of staff determined by calibration. Eventually, the properties of a level and levelling staff can vary and thus in order to control whole system is necessary to carry out a system calibration. At the system calibration are determined correct values of reading on the staff, from which is possible to determine scale of whole digital levelling system, stability of whole system in time and also is possible to estimate the accuracy of whole measuring system. Similar system is realized in Japan (Geographical Survey Institute) or in Slovenia (University of Ljubljana). Vertical comparator for calibration of levelling staffs in the vertical plane, allowing also system calibration, is in operation in the metrological laboratory of

Technical University in Graz (Austria). The Finish Geodetic Institute performs automatic calibration of levelling staffs by means of vertical comparator from 1996 and the system calibration from 2002. Similar calibration system is also in operation at Technical University in Ostrava.

2.4 Calibration system at the Department of Surveying of FCE of SUT in Bratislava

The preparing calibration system uses laser measuring system. The linear interferometer is based on frequency stabilized He-Ne laser of energetic class II (it can be used without special safety equipment). The laser head contains also an optoelectronic sensor of interference field and electronic network to process measured values (interpolation of the interference signal with resolution up to 1 nm, compensation of the length expansion of measured object). The interference system together with units for environment compensation and with electronic part of a system allows measuring of length with resolution up to 1 nm (dynamic measurement is also possible), angle measurement in range ± 10° and measurement of differences of evenness. System can be used in order to calibrate invar and bar code levelling staffs, to test electronic distance meters, to observe movements of constructers etc.

The Department of Surveying of Faculty of Civil Engineering of SUT in Bratislava has currently at disposal laser measuring system XL 10 co. RENISHAW (fig. 3, 4), working with accuracy ($P = 95\%$) of linear measurement 0,5 µm per 1 m of measured length in entire range of defined measurement conditions – the air temperature 0 to 40 °C and pressure 650 – 1150 hPa in measured path – with maximal range of linear measurements 80 m. System allows reading of values of the length with frequency 50 kHz at maximal speed of length change 4 m/s. Attained linear resolution 1 nm is well-preserved in whole range of the speed of measurement. The stability of frequency of the emitted laser wavelength is guaranteed by manufacturer $\pm 0{,}05.10^{-9}$ per year and $\pm 0{,}02.10^{-9}$ per hour. Laser XL 10 communicates with user's computer by means of USB port.

Fig 3: Laser head XL 10

Compensating unit XC 80 is one of the key components to ensure the stated accuracy of measurement with system XL. The compensating unit allows measuring of the air temperature, pressure and relative humidity in the path of ray and measuring of the temperature of measured object. Based on the acquired data can be adjusted the value of real laser wavelength, entering in real time into the processing of distance. In the same way can be compensated the influence of linear temperature expansion of measured object (in pursuance of before known coefficient of linear temperature expansion and measurement of average temperature of an object). Thereby are eliminated errors due to the changes of atmospheric conditions of environment. The time interval of reading is 7 s. Three sensors of material temperature and one sensor of atmospheric conditions (temperature, pressure, humidity) can be joined to the unit.

Obr.4: Measuring system XL 10 f. RENISHAW

3 Testing the influence of intensity of illumination on measurement with digital level

On the results of levelling measurements performed with digital levels affects in addition to conditions and impacts mentioned in the previous chapter, also the intensity of illumination. Requirements on the intensity of illumination are higher than for optical levels [2].

3.1 Light and photometric conditions

Light is an essential and unthinkable part of our life and environment and one of its fundamental factors. From a physical point of view as a part of electromagnetic waves constantly accompanies us, whether in the pure form of source of energy and light (sun radiation) or as an inherent part of the achievements of science and technology used in everyday life.

The intensity of light and illumination is a limiting factor for all areas of human activity, including surveying works. Modern surveying instruments used for terrestrial measurement needs to their operation not only the source of energy, but also particular photometric conditions in order to recognise the subject of measurement – target.
Recognition of measurement subject – target at the work with surveying instruments is in general given by the properties of observer, telescope and environment between the observer and target. When working with the conventional optical instruments, these properties can be specified in pursuance of [13]:

- photometric conditions (illumination, contrast),
- geometrical properties of a target (angular size, shape).

When using digital levels with automatic determination of elevation, it is necessary to point that size of the target is defined by a minimal section of graduation distance, which must be visible during the measurement.

Illumination E is derived photometric quantity determined as a ratio between uniformly distributed luminous flux $\Delta\Phi$, incident to the surface of the body, and area of this surface ΔS. The illumination unit is lux (lx). The area has one lux illumination if at each square meter area falls uniformly distributed luminous flux of one lux:

$$E = \frac{\Delta\Phi}{\Delta S} \tag{3.1}$$

For illustration are given some values of illumination under different conditions (tab. 1). For the experimental evaluation of illumination has been used portable luxmeter PU 150 with a measuring range up to 100 000 lx, equipped with two sensors: resistive – measuring range up to 40 lx, selenium – measuring range up to 100 000 lx [1].

Tab. 1

Place of measurement	Illumination (lx)
Moon illumination at full moon	0,15 up to 0,20

Illumination of street	2,00 up to 20
Illumination of a bedroom	up to 50
Illumination of a living room	up to 80
Illumination of an art room	up to 300
Room in the day-time	10 up to 10 000
Direct sun illumination	up to 100 000

3.2 Conclusions from experimental measurements of photometric conditions using digital level DiNi12

- measuring time under normal daily illumination (200 – 3000) lx and more corresponds with manufacturer data and ranges up to 4 s,
- when decreasing the intensity of illumination under 80 lx, the measuring time is increasing up to twice (6 s and more),
- the threshold value at uniformly artificial illumination (when instrument yet measures) is (8 to 5) lx, (at spotlighting are necessary values minimal 10 lx and higher),
- illumination of staff graduation by direct sun light of higher intensity (no diffuse illumination) is indicated by interruption of measurement – „unreadable staff",
- under daily illumination is the most suitable oblique (dispersive) light (200 – 400) lx (variance of repeated readings to ± 0,1 mm),
- increasing intensity of illumination, direct sun illumination and increasing distance of sights makes worse results (variance of repeated readings to 0,6 mm) and prolongs the time of measurement,
- measurement with digital level DiNi 12 is possible on the ground and in low light conditions, but it is necessary to take into account that under reduced intensity of illumination below (120 – 100) lx decreases accuracy of measurement results.

4 Calibration of electronic distance meters on the length comparative baseline in the field

Exploitation of electronic distance meters (EDM) in surveying practice, their rapid development in terms of construction, especially to range and accuracy of measured distance, brings a solution of new tasks in the area of measurement processing. One of the main characteristics is accuracy parameters of EDM. Low variance of the measurements when using EDM can often lead to a deep trust in the measurement results and factor of change of EDM parameters is often neglected. To the fore appears the reproducibility of distances when repeating measurement at different time intervals [10].

Manufacturer specifies the accuracy for particular types of instruments by means of standard deviation of the measured distance in the following form:

$$\sigma_d = a + b \cdot 10^{-6} \qquad (4.1)$$

where a represents additive member and b is scale member.

These parameters stated by the manufacturer are usually obtained from the processing of multiple measurements in laboratory conditions. During the long-term exploitation is necessary to verify stated parameters in the field conditions. EDM user role is therefore check the reliability and accuracy of EDM before its exploitation, what should become the norm when using all instruments in surveying practice. One of the possibilities of verification of the EDM parameters is hence its calibration on the field length baseline. Such length comparative baseline – baseline Hlohovec, was built by the Department of Theoretical Geodesy of Faculty of Civil Engineering in collaboration with then IGHP n.p. Žilina, plant Bratislava in 1978 [10].

4.1 Calibration methodology on the baseline Hlohovec

The calibration procedure on the baseline in Hlohovec (fig. 5) consists of two steps [7, 10]:

- realization of the measurement and acquisition of measured data,
- processing of measured data.

For the calibration measurement are used 5 pillars with necessary centring (***n*=*5***), labelled Z1 – Z5. This configuration allows to measure

$$n \cdot (n-1)/2 \qquad (4.2)$$

combinations, in this case 10 distances used for calibration of the EDM. Full calibration measurement is recommended to be carried out in two series over two days [10], best under different atmospheric conditions.

A series of measurement presents reciprocal distance measurement in all combination. The minimal calibration measurement, which is sufficient for most instruments in surveying practice, consists of one measurement in one series.

Fig. 5: Total station on the baseline in Hlohovec

4.2 Processing of measured data

Result from the processing of calibration measurements is determination of the values of selected instrument parameters, determination of the confidence interval of these parameters and testing of hypotheses about the selected parameters. Processing procedure starts with the determination of physical reductions (influence of the air temperature, pressure and humidity), the application of mathematical corrections (transfer of the slope distance to the reference plane), further includes correction from direction (misalignment of the baseline points from its axis) and corrections from elevation. Another part of the procedure represents an estimate of the additive constant and estimate of the parameters of the regression line, representing correction of EDM, proportional to the measured distance [10].

Additive constant of EDM can be defined follows

$$c = k + c_1 + c_2 \qquad (4.3)$$

where

k is a part of the additive constant, caused by the electronic part of the instrument. This part affects the accuracy of the measurement result. Determination of **k** is possible only in laboratory conditions.

c_1 is geometrical part of the additive constant,

c_2 is geometrical part of the additive constant of reflective system.

The value c_1+c_2 have at most of EDM for manufacturer recommended reflective system zero size. In the case of different reflective system is needed to determine the value of additive constant, because its unknown size acts in the measurement as a systematic error. Therefore, the additive constant is estimated on basis of the second linear model (indirect measurement of vector parameter) from the measurement on the baseline [10].

According to the mentioned model are obtained estimates of the measured distances, estimates of the additive constant together with the characteristics of accuracy of instrument. Estimates of the additive constant pays for calibrated system: EDM – reflective system. Estimates of the distances, characterised by their covariance matrix, are corrected about the additive constant and can be directly compare with parameters of the baseline. By means of linear regression, considering statistical properties of estimates, are then determined search parameters of EDM:

a (additive constant) and ***b*** (scale constant – proportional to the measured distance) – equation 4.1.

Geodetic baseline Hlohovec allows to determine the real value of the additive constant of system: EDM – reflective system and to assess the accuracy of the distance measurement with particular system. Determination of the correct value of the measured value is necessary conditions from a view of the assurance of metrological traceability – realization of the meter as the unit of distance [10].

5 Calibration of horizontal circles of optical and electronic theodolites

In the past, to assess the quality of horizontal circles, respectively accuracy of the measurement of angles was used procedure based on the standard STN ISO 8322. This standard assumes measurement in two faces of the telescope, in four ranks and in two series. Accuracy of the measurement of angles or directions is according to this standard specified by standard error „m_α“ [7, 8].

Currently, the process of quality assessment of optical and electronic theodolites, EDM and electronic tacheometers is defined in the following standards [5]:

STN ISO 17123-3: 2001 Optics and optical instruments – Field procedures for testing geodetic and surveying instruments. Part 3: Theodolites.

STN ISO 17123-4: 2001 Optics and optical instruments – Field procedures for testing geodetic and surveying instruments. Part 4: Electro-optical distance meters.

STN ISO 17123-5: 2005 Optics and optical instruments – Field procedures for testing geodetic and surveying instruments. Part 5: Electronic tacheometers.

Calibration of horizontal circles of optical and electronic theodolites can be carried out under laboratory conditions, e.g. on an automated device for calibration of optical polygons EZB-3 in the Slovak Institute of Metrology in Bratislava (SIM). This standard device is part of the primary standard and hereby the national standard of plane angle in the Slovak Republic. The basis of this device is 72 edged optical polygon representing design of directions in range (0 to 360)° with 5° increment and extended uncertainty of transmission to calibrated instrument to 0,1" (P = 95%), depending on the metrological parameters of calibrated instrument. This device has been used for calibration of many optical and electronic theodolites, details in [3, 4, 8, 11, 12]. The result of such calibration is a set of horizontal scale corrective values for particular nominal values of the scale, determined from several series of measurement, eventually also the parameters of approximating function.

An important part of processing is the statistical testing of parameters of normal distribution and analysis of variance. Detailed information about the testing of normal distribution and ANOVA (ANalysis Of Variance) is given in the literature [3, 6, 8]. As an example is given results from calibration of electronic theodolite Leica TC 800. Graphical representation of measured data – the corrections to particular places on the horizontal circle is in fig. 6.

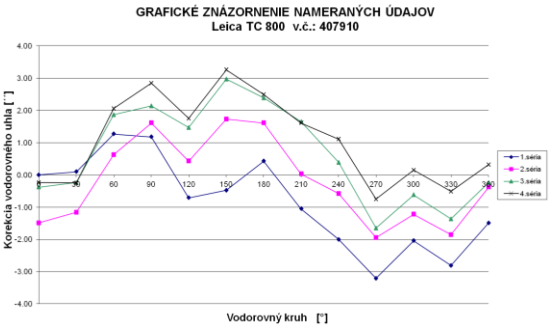

Fig. 6: Values of corrections for four series of measurement from calibration device in SIM

In the approximation of the measured values was applied cyclic function (sinusoid) (fig. 7), which is based on the relationship:

$$y = b_0 + b \cdot \sin(t + B), \tag{5.1}$$

where $t = \dfrac{2 \cdot \pi}{P} \cdot x = \dfrac{2 \cdot \pi}{360°} \cdot x$,

x is the rotation of horizontal circle,

b_0 is the coordinate where axis of sinusoid intersects the y-axis,

b is the amplitude of the sinusoid,

B is the shift of the origin of the sinusoid.

Equation (5.1) can be written following:

$$y = b_0 + b \cdot \sin(t) \cdot \cos(B) + b \cdot \cos(t) \cdot \sin(B) \tag{5.2}$$

After substitution:

$$b_1 = b \cdot \cos(B) \text{ and } b_2 = b \cdot \sin(B)$$

equation (5.2) can be written as follows:

$$y = b_0 + b_1 \cdot \sin(t) + b_2 \cdot \cos(t) \tag{5.3}$$

The coefficients b_0, b_1, b_2 can be estimated using the least squares method and their values are listed in the chart. From these coefficients may re-determine the parameters of equation (5.1):

$$\tan(B) = \frac{b_1}{b_2}, b = \sqrt{b_1^2 + b_2^2} \tag{5.5}$$

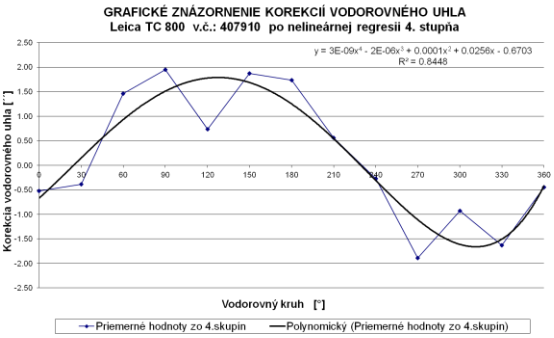

Fig. 7: Calibration curve and approximating cyclic function

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