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Twenty Years of Experience Running Calibration Baseline

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Abstract. The authors of the paper are sharing their 20 years of experience in using Kyviškės Calibration Baseline. The Kyviškės Calibration Baseline (1320 m) is the longest calibration baseline in Lithuania. The baseline is calibrated regularly with 5–7 years period. The first time these measurements were performed in 1997 and repeated in 2001, 2007, 2008 and 2014. The same Kern Mekometer ME5000 EDM (electronic distance measurement) instrument was used for all the measurements performed. By building additional pillar aside from the baseline pillars the Kyviškės Baseline was converted to a triangle-shaped test field in 2000. The results confirm good stability of the baseline, which is now used for calibration of the EDM instruments, total stations and GNSS (global navigation satellite system) receivers.

Keywords: calibration, baseline, EDM, length measurement.

Conference topic: Technologies of Geodesy and Cadastre.

Introduction

EDM instruments calibration is a popular topic and every surveyor should be concerned about his instrument calibration periodically (Hazelton 2009). Calibration laboratory of Institute of Geodesy at VGTU (Vilnius Gediminas Technical University) has established and is running Kyviškės Calibration Baseline since 1996 (Jokela *et al.* 1999). The same Kern Mekometer ME5000 EDM instrument was used for all the measurements performed. The purpose of building calibration baseline was to establish calibration facilities for EDM instruments. Six observation pillars were fundamented on the grassland on the Western side of the Kyviškės airfield. Calibration of the Kyviškės Calibration Baseline is done on the regular basis at approximate 5 years interval. Repeated high precision measurements with traceability to Finnish National Standard are essential in validating new measurement standards. The original baseline was first measured in June 1997 in co-operation between the Institute of Geodesy of VGTU and the Finnish Geodetic Institute (FGI). Since 1997 a four more calibrations of the Kyviškės Calibration Baseline were performed by cooperating FGI and VGTU. Baseline calibration results proved stability of the baseline and suitability for EDM instruments calibration. Calibration laboratory of VGTU is accredited for EDM instruments calibration by Lithuanian National Accreditation Bureau since 2001-09-20. Metrological activities at the VGTU are guided by quality management system and meet the requirements of ISO 17025 standards. The surveying activities are becoming increasingly international recently. Surveyors take part in the international projects and participate in the tenders where positioning techniques are applied. Moreover, the accredited calibration and testing laboratories have to demonstrate their proficiency. The proficiency testing (comparative calibration or testing) is an important way of meeting the requirements of the international standards in the area of quality assurance of the laboratory results. Therefore the EDM calibration baselines in different countries are required.

Along with establishing of the seventh pillar and extending the calibration baseline to a triangle-shaped test field in 2000 the preconditions were created to use baselines for testing GPS receivers, theodolites, total stations and laser scanners.

Facilities and baseline calibration

Calibration laboratory of Institute of Geodesy, VGTU owns two baselines for EDM instrument verification and calibration. The shorter one (15 m length) is situated in the premises of the VGTU abd therefore is ofeten called VGTU calibration baseline. The Kyviškės Calibration Baseline is 1320 m length and is located 15 km outside Vilnius in the Kyviškės Airport (ICAO code EYVK). It is a regional airport managed by VGTU and used mainly for VGTU Aviation Institute pilot training purposes.

Kyviškės Calibration Baseline was calibrated by Finnish Geodetic Institute 5 times: in 1997, 2001, 2007, 2008 and 2014. The transfer standard used for Kyviškės Calibration Baseline was Kern ME5000 high precision EDM instrument with prism reflector, calibrated at the Nummela Standard Baseline.

The lengths at Kyviškės are traceable to the definition of the metre. The Nummela Standard Baseline in Finland, measured regularly with the Väisälä interference comparator, and the quartz gauge system determining the scale in it, are essential measurement standards in the traceability chain (Jokela *et al.* 2009).

The purpose of establishing the Kyviškės Calibration Baseline was to create calibration facilities for the EDM instruments. A suitable site was selected in the Kyviškės airfield (functioning since 1947), which is still used for pilots' training. The Kyviškės airfield was assigned to the VGTU in 2009. The flat unobstructed area of the airfield is very fitting for the calibration baseline. The area of the airfield and the Kyviškės Calibration Baseline was fenced by metal net limiting possible access for strangers. The pillars of the baseline are fundamented 3.25 m below the ground surface. An insulated steel pipe is anchored using reinforced concrete. The soil in Lithuania never freezes bellow 1.5 m in winter. The topsoil texture is mostly composed of sand and sandy loam in Kyviškės, which is typical for this part of Lithuania. 6 observation pillars are built in line deflecting around 10° from the North – South direction. The baseline extends up-slope with an approximate grade of 0.5% from 1 to 6 pillar.

Fig. 1. Orthophoto of the Kyviškės Calibration Baseline

The distances from the first to the following pillars are 100 m, 360 m, 1 120 m, 1300 m and 1 320 m respectively. 10 more calibration line combinations are possible from other than the first pillar. The seventh pillar was built in 2000 on the eastern side of the runway, 644 m to 949 m from the other pillars (Būga *et al.* 2008). By building the seventh pillar additional 6 observable distances in the test field were created (Fig. 1). All the seven observation pillars are not protected from the direct Sun. Therefore portable umbrellas covering EDM instruments and thermometers are used during sunny days. Observation pillars are located in line from North to South, it makes observer feel comfortable during the measurements as Sun mostly shines to his back.

The Kyviškės Calibration Baseline is the longest (1320 metres) calibration baseline in Lithuania and among the several ones most frequently calibrated in Europe recently. The Kyviškės Calibration Baseline was established by the Institute of Geodesy, VGTU in 1996 for the calibration of the EDM instruments (Jokela *et al.* 1999). The Finnish Geodetic Institute together with the Institute of Geodesy, VGTU are measuring the Kyviškės Calibration Baseline in 5–7 year cycles.

In EDM precision measurements accurate and precise meteorologic parameter measurements are essential. Temperature must be measured in the shade at both interval ends: at the instrument and the reflector. Temperature is measured at instrument and reflector height. The atmospheric pressure must be measured at the instrument for each inter-pillar distance. To obtain a higher accuracy calibration, atmospheric pressure can also be observed at the reflector, for each inter-pillar interval. The significance of errors in the meteorological observations on the EDM distance can be summarised as follows: an error in temperature of 1°C affects the distance by 1ppm. An error in pressure of 1hPa

affects the distance measurement by 0.3ppm. Humidity has only a small effect on EDM measurements. An error in the partial water vapour pressure of 1 hPa causes 0.04 ppm impact on distance measurements. Relative humidity (%) or partial water vapour pressure of observations can be taken to further improvement of the accuracy of the calibration (Pollinger *et al.* 2012; Rueger 1990).

The Figure 2 presents variations in the length of the Kyviškės Calibration Baseline with reference to the mean value of all five baseline calibrations during 1997–2014.

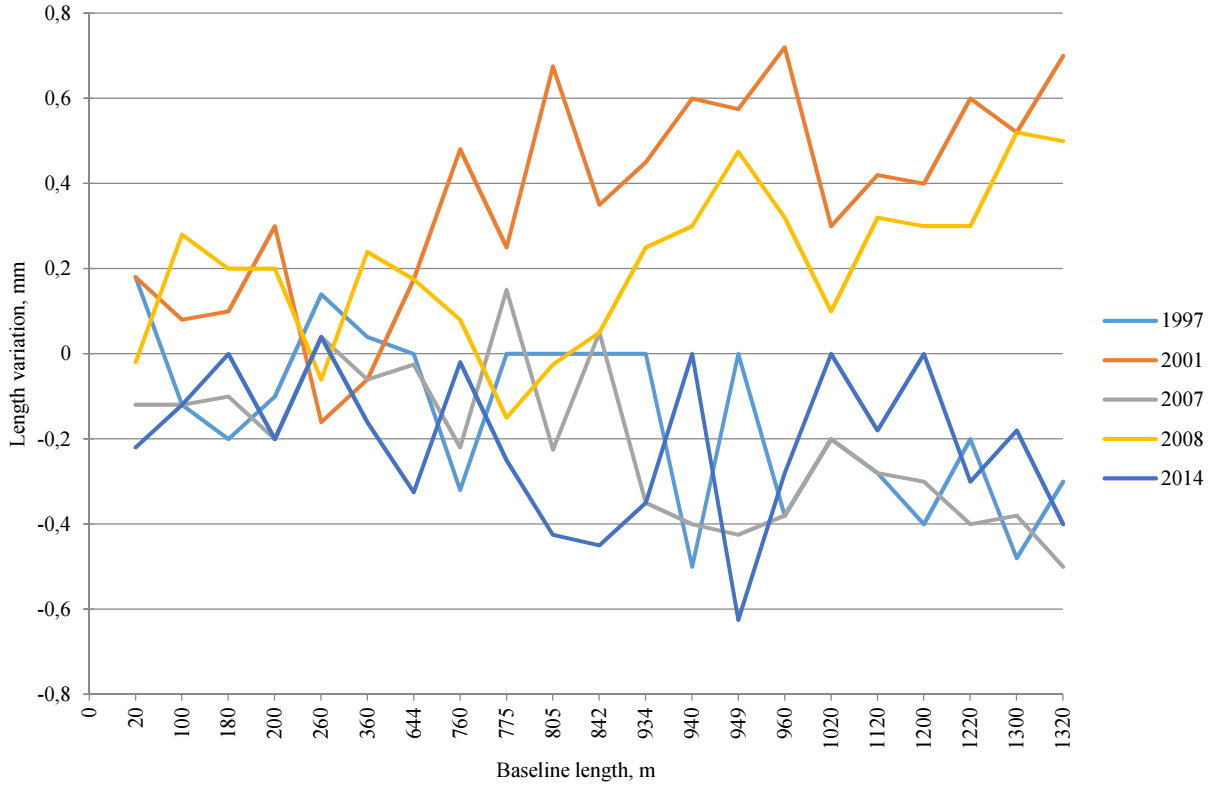

Fig. 2. The Kyviškės Baseline length variations

The Figure 3 presents variations in the length of the VGTU Calibration Baseline with reference to the mean value of all three baseline calibrations during 2001–2014.

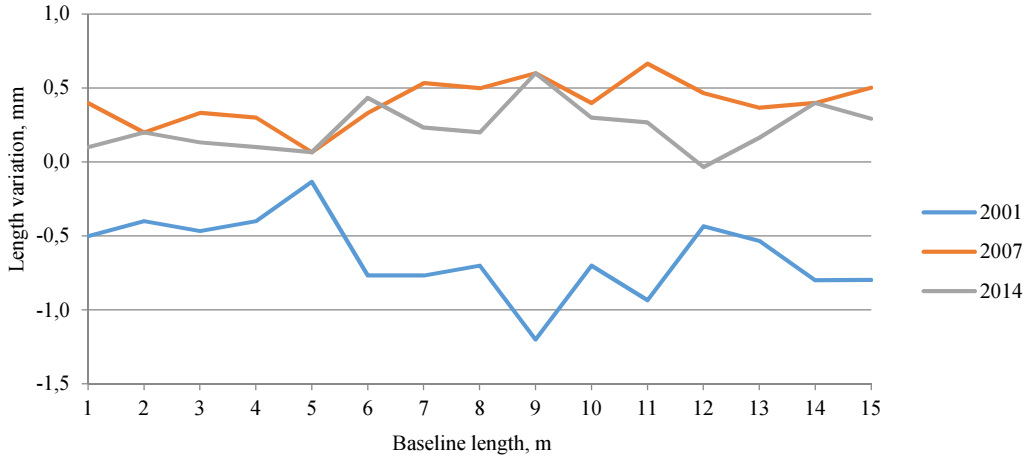

Fig. 3. VGTU Baseline length variations

EDM instruments calibration during 2011–2016

Calibration Laboratory is permanently using Kyviškės Calibration Baseline for EDM instruments calibration. This means that calibration baseline is visited at least once every second week. 1429 EDM instruments at the Calibration laboratory were calibrated since its establishment till the end of 2016. Different total station models and handheld laser distance meters brought for calibration are listed in Table 1 and 2.

Table 1. Distribution of calibrated total stations (listed by producer) during 2011–2016

	2011	2012	2013	2014	2015	2016
Geodimeter			1		1	
GeoMax			1	2	5	4
Leica	16	9	20	13	21	16
Nikon	12	6	22	11	7	5
Sokkia	10	2	4	1	4	4
Spectra precision					1	3
Topcon	8	4	9	4	14	6
Trimble	5	5	7	8	7	3

Table 2. Distribution of calibrated handheld laser distance meters (listed by producer) during 2011–2016

	2011	2012	2013	2014	2015	2016
Bosch					1	5
Leica Disto A*	10	2	2	1	5	
Leica Disto D*	5	30	10	2		3
Leica Disto Lite	19		7		7	
Leica Disto Classic	1		1		1	1
Spectra Precision	19		17		20	
Stabila			2		11	3
Other	3			1	4	3

Number of calibrated instruments is related to the steps taken by Metrologic Inspection. More active raids of Metrologic Inspection to check validity of instruments verification means more clients at Calibration Laboratory because instrument calibration is normally done along with instrument verification.

Calibration uncertainty estimation

Lately some improvement to process of estimation of calibration uncertainties was introduced. Instrument constants and errors are determined during EDM instrument calibration process. Instrument constant is determined by performing series of measurements at seven baseline intervals. Measurements are done in three turns (Putrimas 2010). One turn is composed of three measured intervals s_1, s_2, s_3 on a straight line (Fig. 4).

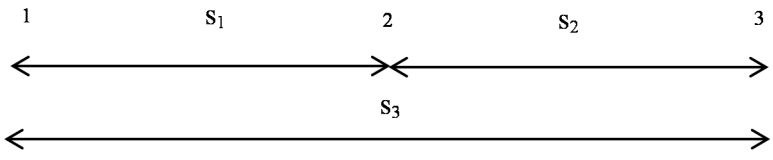

Fig. 4. Intervals measured for instrument constant determination

Instrument constant is computed using formula:

$$C = \frac{1}{r}\sum_{i=1}^{r} C_i' , \quad (1)$$

where $C_i' = \overline{S}_3 - \overline{S}_1 - \overline{S}_2$, r – number of turns, $\overline{S}_i$ – mean values of measured intervals.

Total uncertainty of mean constant is obtained using formula:

$$u_C = \frac{1}{r}\sqrt{\sum_{i=1}^{r} u_{C_i'}^2} \quad , \tag{2}$$

where $u_{C'} = \sqrt{u_{\overline{S}_3}^2 + u_{\overline{S}_1}^2 + u_{\overline{S}_2}^2 + 3u_d^2}$; u_d – uncertainty contribution estimate due to electronic digital indicator resolution is 0.29 mm when value of indicator division is 1 mm, u_{S_i} – standard uncertainty of mean interval is computed from formula:

$$u_{S_i} = \sqrt{\frac{\sum_{j=1}^{n}\left(S_j - \overline{S}\right)^2}{n(n-1)}} \, , \tag{3}$$

where $\overline{S} = \frac{1}{n}\sum_{i=1}^{n} S_i$, here S_j – value of measured interval, n – number of interval measurements.

If $u_C \le C$, then instrument constant is corrected with value C and new value is entered to the instrument's memory.

Instrument calibration is continued using five intervals (20, 360, 760, 960, 1320 m) of Kyviškes calibration baseline.

Systematic calibration correction for every measured interval is computed using formula:

$$V_{S_i} = S_{E_i} - \overline{S}_i \, , \tag{4}$$

where S_E – interval etalon value, $\overline{S}$ – mean value of measured interval.

Total uncertainty of calibration correction is computed:

$$u_V = \sqrt{u_d^2 + u_E^2 + u_S^2 + u_{AP}^2 + u_{At}^2 + u_Z^2} \, , \tag{5}$$

here $u_d = 0.29$ mm – uncertainty contribution estimate due to electronic digital indicator resolution; u_E – etalon line uncertainty contribution according to calibration certificate; u_S – mean correction uncertainty contribution computed from (3) formula; u_{AP} – uncertainty contribution due to atmospheric pressure influence, computed from (6) formula; u_{At} – uncertainty contribution due to air temperature influence, computed from (7) formula; $u_z = 0.21$ mm – uncertainty contribution due to centering of the instrument and reflector.

Standard uncertainty due to atmospheric pressure and air temperature are computed from formulas:

$$u_{AP} = \frac{79 \cdot S \cdot 10^{-6}}{273 + t} u_p \, ; \tag{6}$$

$$u_{At} = \frac{79 \cdot P \cdot S \cdot 10^{-6}}{\left(273 + t\right)^2} u_t \, , \tag{7}$$

here u_p – uncertainty of the atmospheric pressure measurement is 2 hPa; u_t – uncertainty of the air temperature measurement is 0.5 °C.

The reported expanded uncertainty of mean correction is stated as the standard uncertainty of measurement multiplied by the coverage factor $k = 2$ (EA-4/02 2013), which for a normal distribution corresponds to a coverage probability of approximately 95%:

$$U = k \cdot u_V \, . \tag{8}$$

Calibration laboratory after performed calibration is producing a certificate of calibration where calibration results with expanded uncertainties are listed. Together with the calibration results a computed new value of the reflector constant together with expanded uncertainty is provided.

Conclusions

The Kyviškės Calibration Baseline is a national measurement standard for calibration of EDM instruments in Lithuania. The Kyviškės Calibration Baseline was calibrated five times during the last twenty years. The regular calibrations proved good stability of the pillars and reliability of the baseline. The length variation of the baseline sections during 5 measurement cycles is within ±0.7 mm. The obtained total uncertainty of the baseline is in the interval between ±0.3 mm and ±0.9 mm. The Kyviškės Calibration Baseline measurements in 1997–2014 allowed for accumulating sufficient data set to be used for the future analysis of stability, repeatability, reproducibility and influence of the weather conditions. The experience that was gained during twenty years of operation will be used in further activities of the Calibration Laboratory.

Calibration Laboratory calibrates approximately 47 total stations and 33 handheld laser distance meters a year. Additionally GNSS receivers, theodolites, levelling instruments, laser scanners are calibrated at Kyviškės Calibration Baseline and shorter baseline located at the laboratory.

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