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Increasing of the accuracy of vertical angle measurements of geodetic instrumentation

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1. Introduction

Many of modern measurement instruments used in geodesy, surveying, construction and machine engineering rely on precise measurements of angular values. Instruments such as theodolites, tacheometers, total stations, laser scanners, laser trackers measure both horizontal and vertical angle values. Same as all other measurement instrumentation these devices can produce sometimes quite significant errors of measurements (both random and systematic), which might affect the outcome results of measurements [1-3].

Precise testing and calibration of these instruments might both determine the random errors, thus stating the uncertainty values for each particular instrument and systematic errors (biases) which allow increasing of measurement accuracy by numerical removal of known systematic error values from the measurement results. At the moment there exist several standards for testing of such instrumentation by trigonometric methods implementing several static point of collimation [2]. Such method of testing nonetheless might allow analysis of only few measured angular values of instrument, with only several systematic and random errors values determined (though there can be a huge number of values generated by instrument encoder). Obviously such testing cannot provide unambiguous information on instrument accuracy (especially systematic errors values) [4-6].

Precise testing and especially calibration of angle measuring equipment require some quite special and high accuracy equipment which is hardly available for industrial use. Such horizontal and vertical angle calibration instrumentation is usually possessed and operated by large instrumentation producing companies or large users and not available for wider public. Additionally representatives a average users of instrumentation are hardly interested in additional investments to increase the accuracy of their instruments [7].

If calibration of horizontal angle measures can be realized implementing different types of horizontal precise rotary tables (of different accuracy) available in industry, calibration of vertical angle measurements is a serious problem since very special instrumentation is needed for this task. That instrumentation is often highly specialized, expensive bulky and require high qualification to operate, therefore it is not widely spread in the world [8-10]. Nonetheless since it is obvious that measurement accuracy increasing can be ensured by precise calibration, testing on implementing vertical calibration of geodetic instrumentation are performed at Institute of Geodesy, Vilnius Gediminas Technical University.

2. The set up

The calibrated instrument is precisely leveled and placed at certain height the telescope of the instrument in 90° position would be pointed to the center line of the leveled reference scale. The vertical angle measured between two lines of the reference scale is compared with reference angle expressed:

$$\varphi = arctg\frac{h}{l}, \qquad (1)$$

where h is vertical distance between the measured lines known from the calibrated reference scale; l is horizontal distance between the calibrated instrument and the reference scale. The principle of this method for calibration of vertical angle measuring systems has been in details described in papers previously presented by authors [11] and shown in Fig. 1.

In this method vertical position of the reference scale is very important because it might be one of the biggest sources of uncertainty due to vertical distance determination. Thermal expansion and compression effect also have to be evaluated. Horizontal distance measurements can be performed by using the function of reflectorless distance measurements of total station. However, many total stations do not have such function and another way of measuring horizontal distance has to be applied. The attention should be paid to uncertainty due to pointing. Uncertainty due to pointing can influence measurement results because the widths of the cross-line of the telescope and the line of the reference scale differ depending on the distance between the calibrated instrument and the reference scale. Pointing to the center of the line of the reference scale influences repeatability of the angle measurement results. Another uncertainty in this method is due to the repeatability of distance measurements of total station as well as uncertainty due to limited display resolution of the device. Both of them should be taken into an account because the horizontal distance is one of two main parameters for the determination of the reference angle.

The accuracy of the reference angle determination depends on the parameters of instrumentation used in this method. The horizontal distance between the total station and the reference scale should fit instrument's focusing range which usually is not less than 1.5 m. The closer the reference scale is to the calibrated instrument the bigger range can be calibrated. However, because of the focusing range of total stations the calibration range of this method is 90°±17°. The advantage of this method is that depending on the reference scale grating and the horizontal distance between the scale and calibrated instrument many angle values can be measured avoiding relatively big measurement pitches performed by other methods (pitches of 10° or 30°).

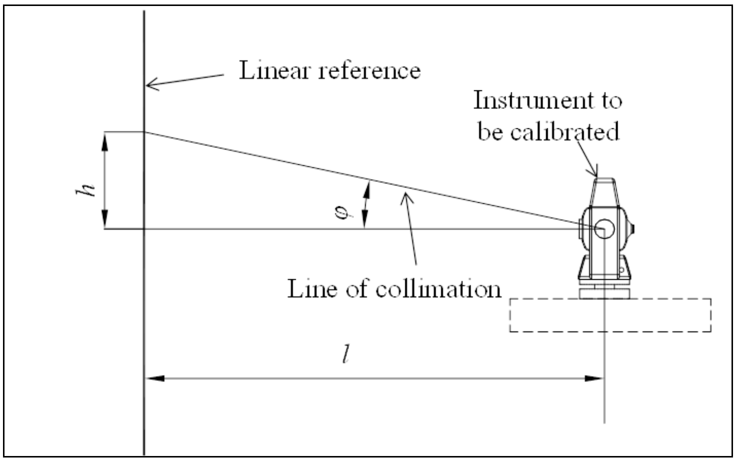

Fig. 1 Arrangement of the instrumentation for vertical angle measures calibration

3. Results of the measurements

The vertical angle of three tacheometers (*NIKON DTM352, Trimble 5605, Topcon DT9)* were calibrated for testing purposes. The results of tests are shown in Figs. 2-7. Figs. 2, 4 and 6 show the unprocessed results obtained by the calibration, thus Figs. 3, 5 and 7 show the partially processed data with typical curve determined and removed (biases removed).

In Fig. 2 the results of vertical angle calibration of tacheometer *NIKON DTM352 (*with stated 5" st. dev. of measurements) with the horizontal distance of 3.3052 m are given. According to calculations the standard deviation of measurements was 4.18", which fits into boundaries of stated accuracy [12]. Nonetheless according to the results some systematic errors of measurements can be still visible. These systematic errors are represented by the Typical curve (Fig. 2), which is a standard 2nd degree polynomial curve.

After removing of systematic errors (biases) from the measurement results obtained data are given in Fig. 3. The standard deviation of measurements after the removal of systematic errors is in range of 3.10", which gives the possibility of increasing of accuracy by approx. 1" of vertical measurements implementing calibration data.

Similarly the results of calibration of tacheometer *Trimble 5605* (with stated 5" st. dev. of measurements) at horizontal distance of 3.2865 m are given in Fig. 4. The standard deviation of measurements in this case was 2.51", which is far better than the stated standard deviation (5"). After removing of systematic errors (2nd degree polynomial typical curve), the standard deviation reached 2.12", therefore in this case it is possible to increase the accuracy of measurements by 0.4".

The results of calibration of vertical angle measurements of tacheometer *Topcon DT9* (with stated 9" st. dev. of measurements) at horizontal distance 3.3128 m are given in Fig. 6. Here the determined standard deviation of measurements was 10.18", which is exceeds the stated accuracy by more than 1".

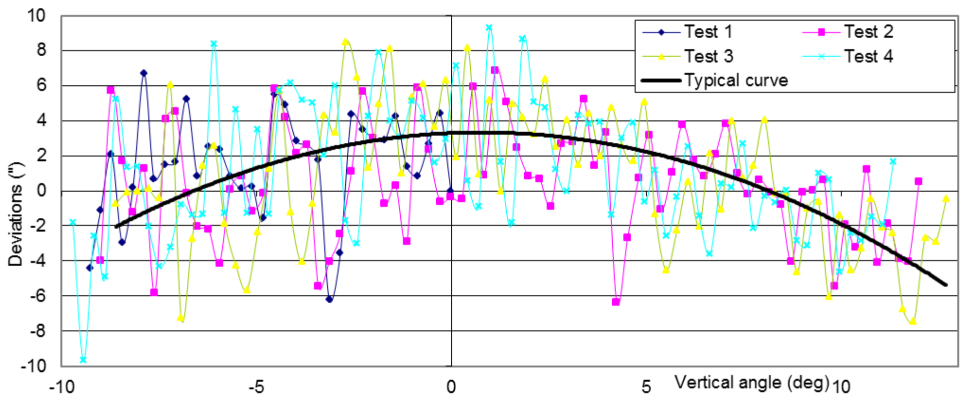

Fig. 2 Results of vertical angle calibration of *NIKON DTM352*, with typical curve attached

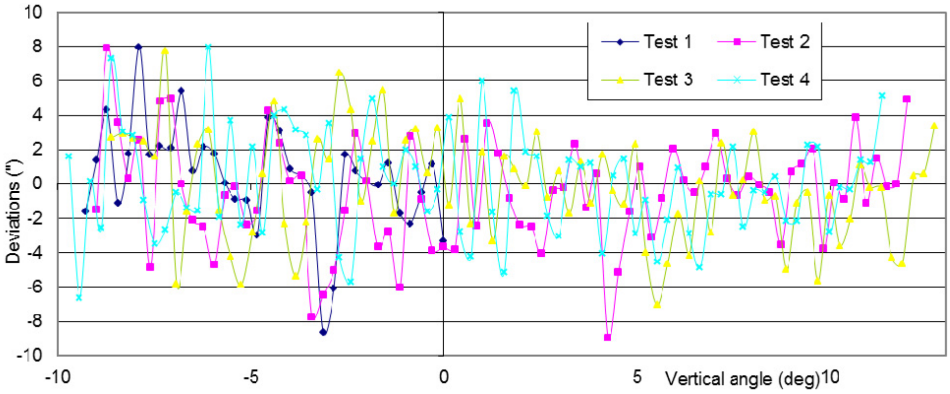

Fig. 3 Results of vertical angle calibration of *NIKON DTM352*, with biases excluded

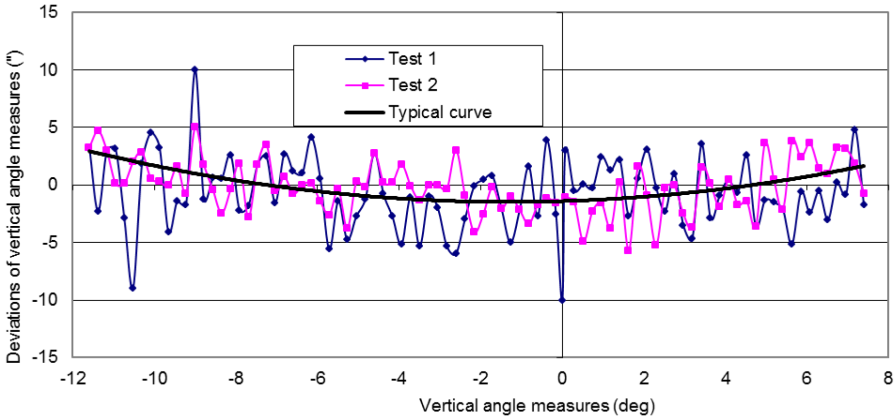

Fig. 4 Results of vertical angle calibration of *Trimble 5605*, with typical curve attached

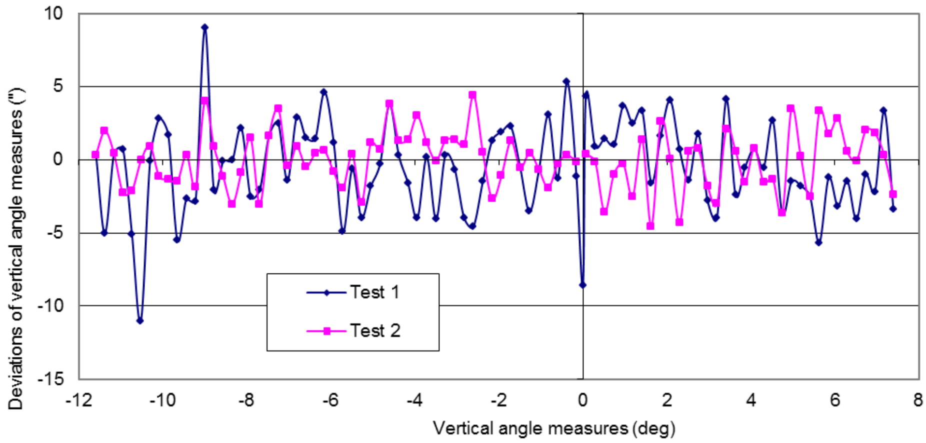

Fig. 5 Results of vertical angle calibration of *Trimble 5605*, with biases excluded

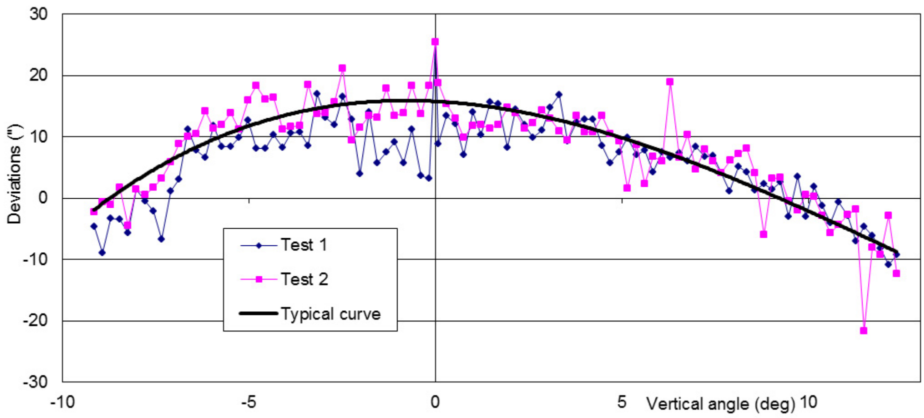

Fig. 6 Results of vertical angle calibration of *Topcon DT9*, with typical curve attached

After removing of obvious systematic errors from the data (Fig. 6, 3rd degree polynomial typical curve), it was possible to achieve remarkable increase of accuracy of measurements (Fig. 7), the standard deviation of measurements this time dropped down to 4.22”. Therefore considering the systematic errors of measurements determined and removing them could allow providing the measurements of same accuracy (5”) implementing tacheometers of lower accuracy.

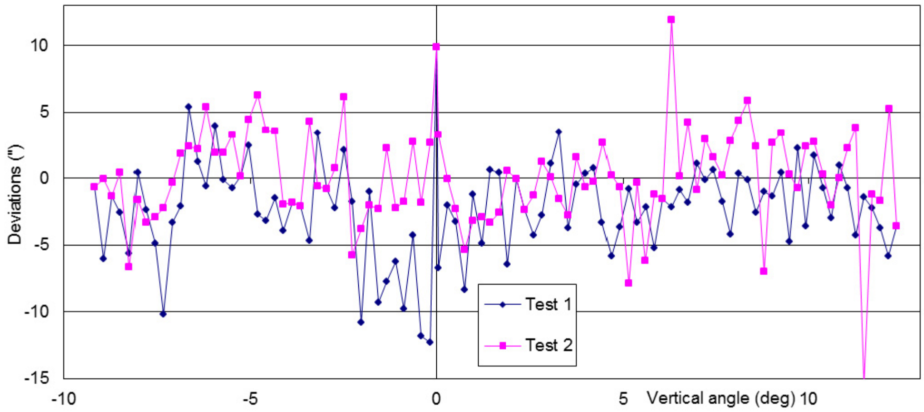

Fig. 7 Results of vertical angle calibration of *Topcon DT9*, with biases excluded

As can be seen from graphs, most of the calibrated instruments fulfill the standard deviation requirements. Nonetheless implementing the vertical angle calibration data it is possible to achieve the increase of accuracy from 0.4” to almost 6”. Such drastic increase of accuracy could allow implementing the instrumentation in completely new areas of measurement.

4. Conclusions

1. A method of vertical angle calibration of geodetic angle measuring equipment was tested on several geodetic instruments (tacheometers).
2. Determined measurement deviations allowed determining the biases of measurements present at all of the tested instruments.
3. Removing of the systematic errors (biases) from the measurement results allowed increasing the accuracy (st, deviation) of measurements from 0.4” to up to 6”.
4. Considerable increase of accuracy of measurements of one of the instruments could allow its implementation in areas requiring equipment of higher level.

Acknowledgments

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GEODEZINIŲ PRIETAISŲ VERTIKALIŲ KAMPŲ MATAVIMO TIKSLUMO DIDINIMAS

R e z i u m ė

Egzistuoja daugybė geodezinių kampų matavimo prietaisų (kaip tacheometrai, teodolitai, lazeriniai skaneriai ir kt.) plačiai naudojamų geodezijoje, civilėje inžinerijoje, statyboje ir kt. Šių prietaisų matavimo tikslumas tiesiogiai įtakoja statybų, žemės sklypų matavimo, stambių įrengimų gamybos tikslumą. Nors oficialiai yra įteisinta tokių prietaisų patikros metodika, tačiau ji užtikrina tik kelių atsitiktinai pasirinktų prietaiso kampinių rodmenų paklaidų patikrinimą. Prietaiso matavimo tikslumas (tiek atsitiktinės tiek sistemingosios paklaidos) kitose kampinėse padėtyse (kurių prietaisui dirbant generuojamas labai didelis) taip ir lieka nežinomos. Straipsnyje pateikiamos teorinės tokių kampų matavimo prietaisų kalibravimo visame galimų matavimų spektre prielaidos, kartu su kai kuriais galimos naudoti įrangos pavyzdžiais.

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INCREASING OF THE ACCURACY OF VERTICAL ANGLE MEASUREMENTS OF GEODETIC INSTRUMENTATION

S u m m a r y

There is a vast number of geodetic angle measurement equipment (like techeometers, theodolites, laser scanners etc.) implemented in the geodesy, civil engineering, construction engineering etc. The accuracy of measurement of mentioned equipment directly influence the quality of buildings, private state measures etc. Though there is a methodology of testing of such equipment officially adopted, such methodology allows determination of solely random errors of measurements at several angular positions of the instrument. The accuracy (random errors and biases) is still unknown for huge part of the angular values generated by the instrument while measurements. In the paper the theoretical assumptions on possible increasing the measurements accuracy by means of precise calibration in a bigger range of possible measurements is described together with some examples of practical solution of the problem.

Keywords: vertical angle, calibration, systematic errors, random error, calibration method, increasing accuracy of measurements.

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