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ANALYSIS OF ERRORS OF THE TESTING EQUIPMENT FOR ANGLE MEASURING GEODETIC INSTRUMENTS

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Abstract

For testing of the geodetic angle measuring instruments, such as theodolites and tacheometers widely implemented in construction engineering, other measuring instruments and devices are used. The errors of these instrumentand devices must be also determined and evaluated. Evaluation of the influence of various features of the instruments on the accuracy of measurements allows to eliminate the determined errors or at least to reduce theirinfluence. Such evaluation is especially important in the case of precise measurements. However it is also a very complicated task due to the lack of references of the high enough accuracy. In this paper a principle of determination of the influence of angle measuring instruments, such as autocollimators, mirrors and turn tables (used for testing of geodetic instruments), on the accuracy of angle measurements by means of correlation analysis with some practical tests is presented.

Keywords: *autocollimator, angle measurements, correlation, accuracy.*

INTRODUCTION

Many opto-electronic digital instruments, such as rotary encoders, theodolites, total stations, laser trackers, etc. are used in construction and machine engineering,geodesy, surveying, robotics and other branches of industry. Most of optical–electronic geodetic measuring instruments consist, among the other elements, of the circular scales and angular transducers for angle determination in two perpendicular planes – horizontal and vertical.Accuracy of the instruent mostly depends on the accuracy of these angle measuring instruments. Metrology of the optical instruments for horizontal and vertical angle measurements has some specific features and needs specific arrangements for its calibration (Ingensand 1990).Most of geodetic instruments have two angle reading devices installed for horizontal and vertical angle measurement.

A number of methods of calibration of the horizontal angle measurements are implemented in practice, their origin come from the circular scales and rotary encoders calibration (Bručas 2006). Calibration and testing of the geodetic angle measuring instruments has always been a serious problem requiring some special instrumentation. Such instrumentation usually also implement means of precise angle measurement accuracy of which is being better then the accuracy of tested instruments. Such geodetic instruments calibration equipment usually relies on the precise angle measurements by means of photoelectric angle encoders (Figure 1, b), or autocollimators and mirrors (Fig 1, a) attached to a special stand (Walser 2004). The test bench for calibration of the geodetic angle measuring instruments implementing both photoelectric angle encoder and multiangular prism/autocollimator as the angle reference has also been constructed at Institute of Geodesy of Vilnius Gediminas Technical University (Bručas 2006).Same as the angle measuring geodetic instruments their calibration equipment must be tested and its accuracy evaluated. Such tests are usually performed by means of precise multiangular prism and photoelectric autocollimators having even better accuracy. Furthermore the evaluation of accuracy of precise autocollimators and angle measuring mirrors or mirror faces of multiangular prisms is far more complicated task to accomplish. Evaluation of the influence of mentioned precise

measurement devices on the results of the measurement has always been a serious problem.This is especially relevant in case of the high sensitivity and accuracy measurements when the more precise reference means of measurement are not available. Such a case was encountered at Vilnius Gediminas Technical University Institute of Geodesy when trying to evaluate the precise small angle measurements performed by the photoelectrical autocollimators and the "Hilger & Watts" reflecting mirrors implemented at the constructed test bench (Giniotis et al. 2007). Since the autocollimators with mirrors are still being considered the most accurate means of angle determination, the main task was to evaluate the influence of the different mirrors and autocollimators on the angle measurement
accuracy.

Figure 1. a) Equipment for vertical angle calibration of geodeticmeasuring instruments, a) implementing a number of autocollimators positioned at certain angle;

Figure 1.b) Implementing the precision angle encoder

Usually the systematic errors of the autocollimators are determined by means of their calibration against some accurate and sufficiently small angle generator (Just et al.2003). Those autocollimator systematic errors are being determined quite precisely and reflected in the calibration curve of each specific instrument. Influence of the mirrors, or rather their surface on the precise angle measurements is not defined so well. There were many researches carried out on the determination and reduction of the errors caused by the flatness deviations of the mirrors used for the angle measurements. Nonetheless the unambiguous influence of flatness deviations on the measurements is still not determined (Report of the WECC Interlaboratory Comparison: M12 Angle Gauge Blocks 1993). It is obvious that in case of each particular autocollimator the principle of its performance (operation) will slightly differ (different signal send and received, different area and the shape of the mark, different principle of signal obtaining, such as CCD line or CCD matrix, etc.) though the general principle remains the same. Therefore the numerical influence of the flatness deviation may vary depending on the autocollimator used. Usually it is considered to be a good practice to avoid using the near side parts of the mirror surface (where the greatest flatness deviations are being concentrated) and implement the mirrors having the smallest surface flatness deviations possible. Those flatness deviations are usually determined by means of the interferometric surface measurements,
(Figure 2). There are many methods of reducing the influence of mirror surface flatness deviation on measurements (using several reflected marks, several mirror surfaces etc.), nonetheless there is no method of neither compensation nor complete avoidance of them (Probst and Wittekop 1999). Here in this paper a method of general evaluation of the influence of mirrors and autocollimators produced errors on the accuracy of angle measurements by means of the correlation analysis of several interchangeable measurements, involving several mirrors and autocollimators. The presented research gives only the general evaluation of the quality of the instruments used without precise evaluation of the errors themselves nor the possible compensation of them.

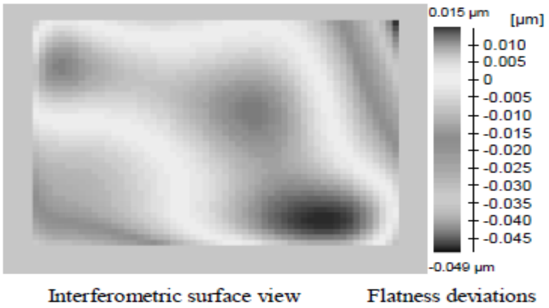

Figure 2. Example of the flatness deviations of the mirror Surface

MATERIALS AND METHODS

An experiment of calibration of two custom made digital (photoelectrical) autocollimators was performed at Vilnius Gediminas Technical University Institute of Geodesy. For the calibration of autocollimators a rotary table constructed by Wild Heerbrugg (Leica at present) company in Switzerland and transferred to by Swiss Federal Institute of Thechnology was used. Two mirrors (4 and 5, Figure 3) were placed on the rotary table (1) and two autocollimators (2 and 3) were placed opposite each other and pointed to each mirror. The rotary table used implements the dynamic encoder for angular position determination and was used for testing of geodetic angle measuring instruments in the past (Ingensand 1990). It has the rotation step of 4.5″ and measuring sensitivity of 0.0324″. Theoretical repeatability of the system is in the range of 0.03″, and the experimental standard deviation stated by the manufacturer does not exceed 0.32″

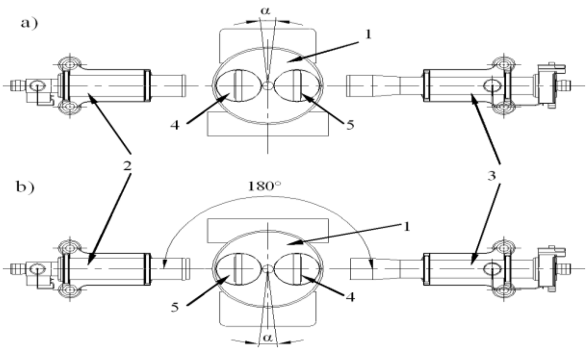

Figure 3. Principal layout of the measuring devices: a – initial rotary table position, b – position of rotary table after the rotation of 180°; 1 – rotary table, 2 – autocollimator I, 3 – autocollimator II, 4 – mirror I, 5 – mirror II.

Both autocollimators calibrated were modified by fitting the CCD matrixes to the optical “Hilger & Watts” autocollimators this way obtaining the digital output of measurements. Autocollimators give the position (in horizontal axis) of the reflected mark (stroke) in form of the number of the pixel from the beginning of the axis. Therefore, the angular position is normally expressed in pixels and later should be transformed into arc seconds.The determined standard deviation of measurements performed by the mentioned autocollimators being 0.04″. Since none of the autocollimators were calibrated (at least with such precision)before, their systematic errors characteristics were not well known.The mirrors used during the experiment were standard“Hilger & Watts” optical measurement mirrors, with the unknown (not determined) flatness deviations.During the experiment the rotary table (with the mirrors) was rotated with the steps of α = 9″ (a, Figure 3) in the full range of the autocollimators measurements (approx.250″). The entire process was automated and controlled by the computer; the data from the autocollimators was also stored in the computer for later processing. After four series of measurements the rotary table was turned 180°, so that the autocollimators faced different mirrors (i.e. autocollimator I faced mirror II and autocollimator II faced mirror I) and the process of measurements was repeated (b). That way after the analysis of the received data it was possible to determine the influence of errors produced by the mirrors, autocollimators or the systematic rrors of rotary table (though these should not be present due to the principle of the angle determination by the encoder used).

RESULTS AND DISCUSSION

To analyze the data obtained by means of interchanging the mirrors and autocollimators (described inprevious chapter) the correlation coefficients were calculated between each measurement consequently. The correlation calculation types are shown in Figure 4.

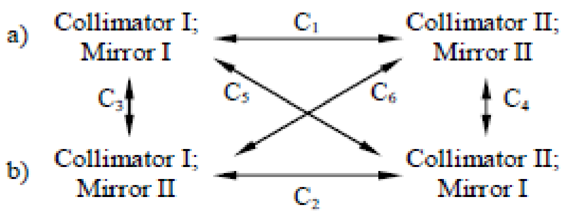

Figure 4. Graphical layout of correlations of measurements: a – initial (0°) rotary table position, b – position of rotary table after the rotation of 180°.

As can be seen from Figure 4 the correlation coefficients were calculated between the measurement data obtained while Autocollimator I was pointed to mirror I and Autocollimator II to Mirror II (correlation coefficient C1),Autocollimator I pointed to mirror II and Autocollimator II to Mirror I (correlation coefficient C2), Autocollimator I pointed to mirror I and Autocollimator I to Mirror II after rotation of turn table 180° (correlation coefficient C3) etc.Finally the correlation coefficients of the measurement results obtained by means of same autocollimators pointed to the same mirrors (i.e. correlations between the multiple tests series) are asigned the numbers that are given in Table 1.The estimates of the correlation coefficients (according to the Figure 4 and Table 1 are shown in Figure 5.

Table 1.Table of given correlations numbers

Type of correlation	Given correlation number
Autocollimator I – Mirror I	C_7
Autocollimator II – Mirror II	C_8
Autocollimator I – Mirror II	C_9
Autocollimator II – Mirror I	C_{10}

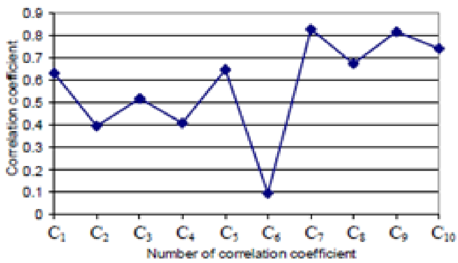

Figure 5. Results of evaluations of correlations of different measurements(four series of measurements)

As can be seen from Figure 5 the highest correlation coefficient estimates belong to C7, C8, C9 and C10 Table1). These correlation coefficients were calculated between the repeated measurements performed by the same instrument at the same positions. Therefore they represent the accuracy (repeatability) of the angular positioning of rotary table in combination to the accuracy (repeatability) of the autocollimators. As can be seen the accuracy of rotary table positioning and autocollimators angular position determination is quite high, with correlation coefficients C8 and C10 for Autocollimator II being little lower which is normal due to slightly lower accuracy of Autocollimator II (which has been previously determined) (Giniotis et al. 2007).

The estimate of correlation coefficient C1 is high enough indicating that the accuracy of measurements of both autocollimators is high enough (since both mirrors in that case move absolutely simultaneously and flatness deviations of the mirrors has no influence repeatability of measurements).Correlation coeficients C2, C3 and C4 have lower estimates which most probably indicates the flatness deviations of one of the mirrors, which produces stable systematic errors every time the collimator is pointed to the different area of the mirror (since it is almost impossible to point the autocollimator exactly at the same point after the rotation of the turn table by 180 degrees).The estimate of correlation coefficient C5 is high again indicating that despite the change of autocollimators (high accuracy measurements of which was previously determined) the measurements shown no (or little)systematic constituent. This clearly indicates low flatness deviations of Mirror I.

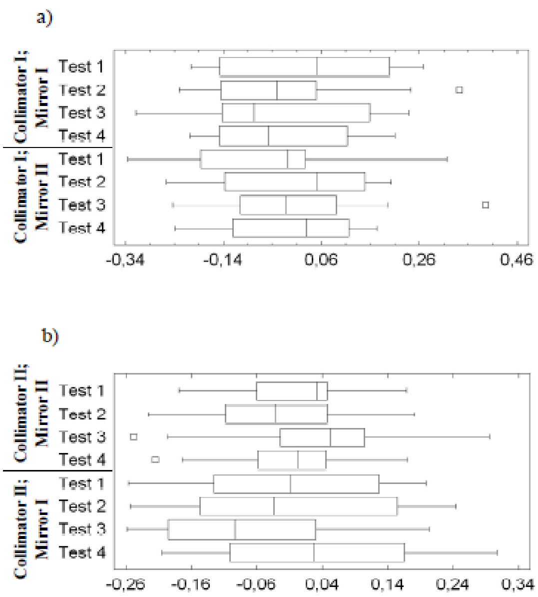

Figure 6.Box-and-Whisker plot dispersion of the measurementdata analysis evaluates

For the statistical evaluation of the obtained results (determine weather the results are plausible) some furtheranalysis was performed. The dispersion of the measurement data analysis evaluates is shown in Figure 6 (a and b) with quartile width segregated (describing the 50% data dispersion) and gross blunders eliminated (Sakalauskas2003). The highest and lowest correlations (6 and 7, Figure 5) between the measurements are graphically shown in the scatterplot matrixes Figure 7 (Sakalauskas 2003). As can be seen from the correlations examples, incase of the highest correlation estimate (correlatio3n coefficient C7, Figure 5) the matrix graphical view is close to linear (a, Figure 7), and in case of the lowest correlation estimate (correlation coefficient C6, Figure 5) the matrix could hardly be described as linear (b, Figure 7).

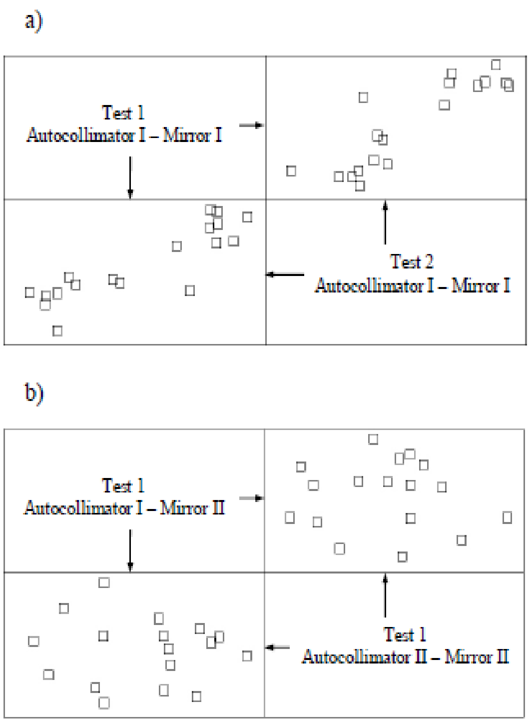

Figure 7. Scatterplot matrixes: a – highest correlation(correlation coefficient C7, Fig 5), b – lowest correlation (correlation coefficient C6, Fig 5).

Looking for the practical explanation of the results it can be stated that according to Fig 5 the estimate of correlation coefficient C6 is very low, which clearly indicates the systematic errors of Mirror II most probably caused by the flatness deviations of the mentioned mirror surface.The explanation of the results is shown in Fig 8. As can be seen in Figure 8, in case of the flatness deviations of the mirror surface (1) i.e. the curvature of the surface the autocollimator emitted light beam (2) reflects (3) from the surface of the mirror at the different angle if pointed to different areas of the mirror (a and b) even at absolutely identical angle of rotation (α) i.e. the angle of measurement. Due to that the measures of the autocollimator even at the same measurement angle are different despite the high measuring accuracy of autocollimator itself (Probst and Wittekopf 1999). This is most probably the case of Mirror II.

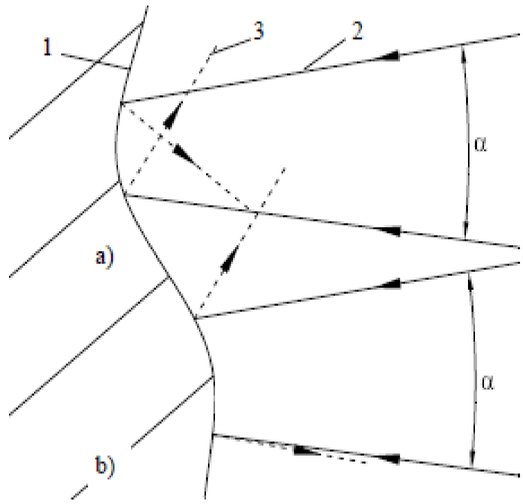

Figure 8. Origin of mirror caused errors at different areas of mirror surfaces (a, b): 1 – mirror surface, 2 – beam sent from autocollimator, 3 – reflected beam (returning to autocollimator).

Judging from the correlation analysis performed, using of Mirror II for precise angle measurements should be avoided to its flatness deviations. The results of the correlation analysis can not give the unambiguous results on the degree of flatness deviations of the analysed mirror neither on the area of the largest deviations, it gives only approximate results on the quality of the certain instrument. To obtain discrete results on the degree or the areas of the largest flatness deviation of mirror some tests like interferometric analysis (Figure 2) implementing advanced and expensive equipment should be performed.Having the unambiguous results of the flatness deviation of the mirror surface (like the ones shown in Figure 2) some actions like blanking the areas with largest deviations and pointing autocollimator to the areas with lowest deviations could be taken.

CONCLUSIONS

Method of evaluation of accuracy of the measuring instruments applying the correlation analysis without implementation of reference means is proposed.

An experiment was performed using autocollimators, mirrors and turn-table all having an non-clearly defined accuracy. Evaluating the experimental results by means of correlation analysis angle measurement errors of Mirror II were identified. It might be assumed that such errors are caused by the flatness deviations of the surface of mentioned mirror.It was determined that the use of Mirror II for precise measurements should be avoided at least till unambiguous determination of the flatness deviation degree and areas.

The proposed method could be implemented for determination (at least preliminary) of systematic errors of measuring equipment without implementation of expensive reference means of measurement.

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