LINE OF SIGHT DEPENDENCY ON THE ELECTRONIC LEVEL BUBLE POSITION
ZAVISNOST VIZURE OD POLOŽAJA ELEKTRONSKE LIBELE

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ABSTRACT

The contemporary digital automatic levels are based on the electronic level bubble. In the regular conditions of measurements, the electronic level bubble should be strictly centred on the display, and it means that compensator is in working range. This means that the measurement could be provided properly. In this research we tried to find out if there was a difference between height differences if the electronic bubble was set at the limits of its working range. First measurement was provided when the electronic bubble was set properly in the centre while the following four measurements of the same height difference were provided with the electronic bubble at its longitudinal and transversal limits. The obtained results showed that there is a small, yet statistically significant, difference between the height differences in different positions of electronic level bubble.

APSTRAKT

Savremeni digitalni automatski niveliri zasnivaju se na elektronskim libelama. U regularnim uslovima merenja elektronska libela treba da bude u strogom centru prikaza na displeju što znači da je kompenzator pozicioniran u okviru radnog opsega. Ovo znači da se merenja mogu sprovesti pravilno. U ovom istraživanju učinjen je napor da se utvrdi da li postoji razlika visinskih razlika ukoliko se elektronska libela nalazi u graničnim područjima radnog opsega kompenzatora. Prvo merenje visinske razlike izvršeno je sa mehurom u centru libele dok su ostala merenja iste visinske razlike izvršena kada je mehur postavljen u graničnim područjima transverzalnog i longitudinalnog pravca. Dobijeni rezultati pokazuju da postoje određene male ali ipak statistički značajne razlike za različite položaje mehura elektronske libele.

INTRODUCTION

Digital levels of high accuracy are very utilisable in the different domain of professional practice including the mechanical industry where the highest accuracy is required. Those measurements are often conducted in the poor light, under difficult conditions and with very short deadlines for surveying. In such cases it is very difficult to have enough time for perfect adjustment of geodetic instruments and it is of crucial importance to know if geodetic instruments deliver identical results nevertheless of their adjustments inside the working range of compensator (electronic level bubble). The importance of measuring uncertainty determination, well researched for classical geodetic instruments [1-4], did not disappear with the development of digital geodetic instrument, Furthermore, bearing in mind the quality assurance of geodetic measurements it was only increased in its importance.

For this purpose, the experiment was designed and conducted with aim to find out if the accuracy of height difference is the same in the cases when electronic level bubble finds itself in the different longitudinal and transversal positions at the limits of working range. The experiment encompassed measurements of one height difference materialized by two invar rods located in the warehouse as shown on figure 1.

Fig. 1. The condition of measurements

Measurements were provided under the relatively poor light conditions and the conditions were not changed during the measurement. The distance between instrument and rods were approximately 2 and 5 meters. The short distance and indoor area were chosen to eliminate possible other influences during the measurements except the changing caused by level's bubble position. For statistical analysis was utilized the statistics of student's and F-distribution [5, 6]. Student's statistic was utilized for testing statistical hypothesis about equality height differences obtained for positions of level's bubble on the edges of working range of compensator. The F-test was provided for testing statistical hypotheses about equality of mean square errors of height differences obtained where level's bubble was in centre and on the edges of working range of compensator.

MATERIALS AND METHODS

The materials for this research were obtained by measuring the fixed height difference in five positions of level's bubble: centre, forward, right, backward and left. The measurements were provided by the digital level on the digital levelling rods with bar codes. The height difference was measured five times at the pattern: "back-for-for-back". Every levelling rod was read three times. This means that sixty measurements were provided for the height difference in every position of level's bubble. The average values and the mean square errors of heights differences are determined for every position of level's bubble position. The relatively high degree of freedom should provide the high reliability of obtained results and represent relatively big sample for statistical analysis. The results of measurements are given in table 1. The positions of level's bubble are shown on the figure 2.

Table 1. Results of height differences measurements [mm]

Position	Measurement										$\bar{x}$	$m_{\bar{x}}$
	1	2	3	4	5	6	7	8	9	10		
Center	-4.16	-4.16	-4.16	-4.17	-4.16	-4.15	-4.15	-4.16	-4.15	-4.16	-4.158	0.006
Forward	-4.12	-4.13	-4.13	-4.12	-4.12	-4.12	-4.12	-4.12	-4.12	-4.13	-4.123	0.005
Right	-4.15	-4.15	-4.15	-4.15	-4.15	-4.15	-4.14	-4.15	-4.14	-4.14	-4.147	0.005
Backward	-4.17	-4.16	-4.17	-4.16	-4.17	-4.17	-4.16	-4.17	-4.17	-4.16	-4.166	0.005
Left	-4.15	-4.15	-4.15	-4.14	-4.14	-4.15	-4.15	-4.15	-4.15	-4.16	-4.149	0.006

The original data are rounded on the hundredths of millimetre and in further calculations it was rounded on the thousandths of millimetre.

Figure 1. The positions of level's bubble during measurements

The method for data analysis is based on the student's and F-statistics. Test statistics are described as follows.

$$t = \frac{d_j}{m_{d_j}} = \frac{\bar{x}_j - \bar{x}_0}{\sqrt{\frac{m_{\bar{x}_j}^2}{n} + \frac{m_{\bar{x}_0}^2}{n}}} \sim t_{f,1-\alpha} \tag{1}$$

where:

- t – test statistics;
- $\bar{x}_0$ – average of height difference when the level's bubble was in centre;
- $\bar{x}_j$ – average of height difference when the level's bubble was in position j;
- $m_{\bar{x}_0}$ – root mean square error of height difference when the level's bubble was in centre;
- $m_{\bar{x}_j}$ – root mean square error of height difference when the level's bubble was in position j;
- n – the number of measurements and
- $t_{f,1-\alpha}$ – quantiles of student's distribution for f – degrees of freedom and level of significance α.

The hypothesis about equality of height differences read as follows:
H_0: The height difference obtained in level's bubble position j is equal to height difference obtained when the level's bubble was in centre.
H_a: Otherwise.

The F statistics is provided as follows:

$$F = \begin{cases} \dfrac{m_{\bar{x}_0}^2}{m_{\bar{x}_j}^2}, & m_{\bar{x}_0} \geq m_{\bar{x}_j} \\ \dfrac{m_{\bar{x}_0}^2}{m_{\bar{x}_j}^2}, & m_{\bar{x}_j} < m_{\bar{x}_0} \end{cases} \sim F_{f,f,1-\alpha} \tag{2}$$

The hypothesis about equality of root means square errors read as follows:
H_0: The root means square errors of height difference obtained in level's bubble position j is equal to root means square errors obtained in when the level's bubble was in centre
H_a: Otherwise.
These two statistics should prove the significance of influence caused by level's bubble position on the determination of height differences in described conditions.

RESULTS AND DISCUSSION

Statistical analysis is provided by introducing real values from table 1 in formula (1) as follows:

$$t = \frac{d_j}{m_{d_j}} = \frac{\bar{x}_j - \bar{x}_0}{\sqrt{\frac{m_{\bar{x}_j}^2}{60} + \frac{m_{\bar{x}_0}^2}{60}}} \sim t_{58,0.95} = 2.0018 \tag{3}$$

It is obvious, according to formula (3), that in case when statistics $t < 2.0018$ there is no reasons for accepting hypothesis H_a: $d_j \neq 0$ while in opposite case there is no reason for accepting hypothesis H_0: $d_j = 0$. The obtained results of statistical analysis provided by formula (3) are given in table 2.

Table 2. Differences between two measurements, student's statistics t and accepted hypothesis

Δh	d_j	m_{d_j}	t	H_0
$\bar{x}_1 - \bar{x}_0$	0.035	0.0010	33.4939	No
$\bar{x}_2 - \bar{x}_0$	0.011	0.0010	10.5267	No
$\bar{x}_3 - \bar{x}_0$	0.008	0.0011	7.4619	No
$\bar{x}_4 - \bar{x}_0$	0.009	0.0011	8.0653	No

According to obtained results it immediate follows that, in statistical sense, all differences are significant i.e. there is no reasons for accepting hypothesis about equality of height differences obtained when the level's bubble is in centre and on the edges of the working range.

The F-statistics with applied obtained values reads as follows:

$$F = \begin{cases} \dfrac{m_{\bar{x}_0}^2}{m_{\bar{x}_j}^2}, & m_{\bar{x}_0} \geq m_{\bar{x}_j} \\ \dfrac{m_{\bar{x}_j}^2}{m_{\bar{x}_0}^2}, & m_{\bar{x}_j} < m_{\bar{x}_0} \end{cases} \sim F_{58,58,0.95} = 1.5467 \tag{4}$$

It is obvious, according to formula (4), that in case when statistics $F < 1.5467$ there is no reason for accepting hypothesis $H_a\colon m_{\bar{x}_0} \neq m_{\bar{x}_j}$, while in opposite case there is no reason for accepting hypothesis $H_0\colon m_{\bar{x}_0} = m_{\bar{x}_j}$. The obtained results of statistical analysis provided by formula (4) are given in table 3.

Table 3. The results of F - test

j	$m_{\bar{x}_j}$	$\frac{m_{\bar{x}_0}^2}{m_{\bar{x}_j}^2}, \frac{m_{\bar{x}_j}^2}{m_{\bar{x}_0}^2}$	H_0
0	0.0063		
1	0.0048	1.7143	No
2	0.0048	1.7143	No
3	0.0052	1.5000	Yes
4	0.0057	1.2414	Yes

According to results obtained by F-test it immediately follows that in two cases there is no reason for accepting null hypothesis about equality and in two there is no reasons for rejecting null hypothesis.

Even though the obtained results suggests that there is statistically significant deviations between height difference obtained in the different positions of level's bubble those results were obtained in the specific conditions and in case of relatively small difference of line of sight distance between two levelling rods. These results implicate that further research are needed to increase the reliability of conclusions.

CONCLUSION

The provided experiment showed high sensitivity of utilized equipment and that there is significant influence of the level's bubble position on height differences measurements. Also, the stability of results is proven through the small values of root mean square errors, especially the average value. This suggests very low level of measurements uncertainty which is smaller than one hundredth of millimetre. The overall conclusion might be that it is necessary to adjust the level's bubble as near to centre as possible i.e. not to measure the height differences when the compensator of level is near or at the edge of working range.

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LITERATURE

[1] Činklović, N.: Anliza i prethodna ocena tačnosti preciznih geodetskih merenja, Zavod za kartografiju „Geokarta", Beograd, 1978.
[2] Činklović, N.: Metode preciznih geodetskih merenja, Naučna knjiga, Beograd, 1983.
[3] Mrkić, R.: Geodetska metrologija, Naučna knjiga, Beograd, 1991.
[4] Delčev, S.: Geodetska metrologija, udžbenik, Akademska misao, Beograd, 2016., ISBN 978-86-7466-640-1
[5] Perović, G.: Račun Izravnanja, Knjiga 1, Teorija Grešaka Merenja, Naučna knjiga, Građevinski fakultet, Beograd, 1989.
[6] Perović, G.: Metod Najmanjih Kvadrata, Naučna knjiga, Građevinski fakultet, Beograd, 2005.