Tomasz Owerko*, Przemysław Kuras*, Anna Szafarczyk*

Comparison of the Effectiveness of Automatic Targeting, Using Systems of ATR Type, with Manual Targeting, Based on Full Test Procedure ISO 17123-3**

1. Assumptions of Standard ISO 17123-3

Polish Standard ISO 17123 was developed based on a translation of the international standard ISO 17123 [1]. The primary objective of the standard is to introduce a reliable method for testing the accuracy of the surveying equipment. The subject of the third part of the standard ISO are the theodolites, which can be tested according to a simplified or full procedure. The results of the calculation algorithm proposed by the International Organization for Standardization are the values of experimental deviation of a standard survey of horizontal or vertical direction ($s_{ISO\text{-}THEO\text{-}HZ}$ or $s_{ISO\text{-}THEO\text{-}V}$), which was observed once through the test instrument, in both face positions of the telescope.

2. Structure of Surveying Base

The article presents the results of surveys carried out on the basis of full test procedure. In this case, the base structure should provide the grounds for achieving the highest possible accuracy by using a specific theodolite as well as additional equipment in field conditions. The base includes five fixed targets (k = 1, 2, ..., t; t = 5) (t = 4 for the simplified procedure), located approximately in the horizontal plane of the instrument at a distance of 100–250 m from the observation point, and as evenly on the horizon as possible. Marking the targets should be unambiguous, preferably by using target plates.

* Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, Krakow
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The full procedure involves the implementation of four ($i = 1, 2, ..., m$; $m = 4$) series of surveys ($m = 1$ for the simplified procedure). Each series includes three sets of the instrument ($j = 1, 2, ..., n$; $n = 3$). Observations of each of the points are conducted in two positions of the telescope.

The instrument needs to be centred with special care and attention before each series. In the case of optical or laser plummets, the centring accuracy should not be worse than 0.5 mm, assuming that the plummet is adjusted. In the first telescope position, the targets are observed in the order compliant with the clockwise direction, while in the second one – in the opposite order. In the subject tests, electronic instruments were used, which, according to the standard, were turned on the tribrach by 120 degrees after each setting.

In addition to meeting the requirements of the base structure, which guarantee a reliable determination of the accuracy parameters in accordance with the standard, the implementation of the assumptions of the standard in the AGH University of Science and Technology was intended to allow the automation of surveying for the instruments equipped with servomotors and systems of automatic target recognition. Figure 1 presents the location of the targets on the buildings included in the base.

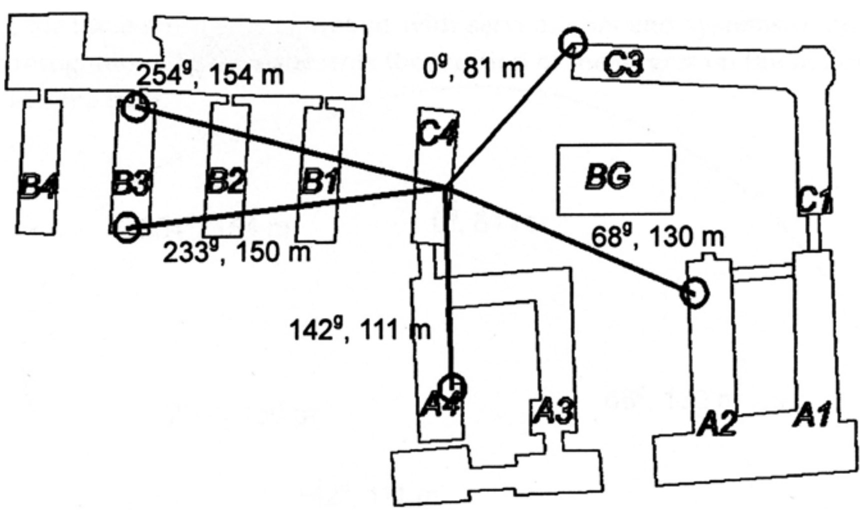

Fig. 1. Location of targets for the full test procedure, together with the values of directions and distances from the position

In order to enable the cooperation with modern instruments of the Total Station type, which are equipped with the ATR-type systems, Leica Mini circular prisms with the additive constant of 17.5 mm were fixed as target points (Fig. 2).

Fig. 2. Exemplary installation of circular prisms

3. Full Test Procedure

Electronic theodolites equipped with the ATR (Automatic Target Recognition) system – Leica TCRA1101 and Leica TCRP1200, were used in the study (Fig. 3). Three independent full test procedures were carried out for each of the instruments – with the use of the ATR system, and without it, in various weather conditions.

The ATR system is designed to automate the precise targeting. A laser beam is generated, which after being reflected from the prism, is received by the internal CCD camera. The size of the spot and the intensity of the reflected light with respect to the centre of the CCD camera are the basis for the calculation of the offsets, both for the horizontal and vertical directions. The servomotors ensure targeting of crosshairs to the centre of the prism with a tolerance of 5 mgon (50^{cc}). The other offsets are eventually added to the reading of the directions, ensuring their high precision [2].

The surveying was conducted in line with the standard assumptions ($m = 4$ series, $n = 3$ sets $t = 5$ targets, 2 position of the telescope), and therefore the performance of one full test procedure involves the execution of 120 observations.

Table 1 presents the calculation scheme, limited to one series only. The first column contains the number of the set (j), while the second – the number of the target (k). Columns 3 and 4 contain the results of target observation-based testing, in I and II telescope positions, respectively ($x_{j,k,I}$ i $x_{j,k,II}$). Column 5 contains the mean values from the observation of a specific target ($x_{j,k}$), reduced to a single position of the telescope. In column 6, the observations were reduced in such a way that for the target number 1, the value of the direction was 0^{gon} (400^{gon}), in accordance with the following formula:

$$x'_{j,k} = x_{j,k} - x_{j,1}, \quad j = 1,2,3, \quad k = 1,\dots,5 \quad .$$

In column 7 the mean values of directions reduced from 3 sets for each of the 5 targets were calculated. Then from the differences (column 8):

$$d_{j,k} = \overline{x}_k - x'_{j,k}, \quad j = 1, 2, 3, \quad k = 1, \ldots, 5$$

for each instrument set the arithmetic means were calculated:

$$\overline{d}_j = \frac{1}{5}\sum_{k=1}^{5} d_{j,k}, \quad j = 1, 2, 3$$

which were used to calculate the residues (column 9):

$$r_{j,k} = d_{j,k} - \overline{d}_j, \quad j = 1, 2, 3, \quad k = 1, \ldots, 5.$$

The sum of squared residues (column 10) in the *i*-th surveying series is:

$$\sum r_i^2 = \sum_{j=1}^{3}\sum_{k=1}^{5} r_{j,k}^2 .$$

For $t = 5$ targets surveyed in $n = 3$ sets, the number of degrees of freedom for each series is equal to:

$$v_i = (5-1)\cdot(3-1) = 8,$$

therefore the value of the standard experimental deviation of direction for this *i*-th series is:

$$s_i = \sqrt{\frac{\sum r_i^2}{v_i}} = \sqrt{\frac{\sum r_i^2}{8}}.$$

Finally, the searched experimental estimator of the standard deviation $s_{ISO\text{-}THEO\text{-}HZ}$ for the tested theodolite shall be obtained from the calculations carried out based on the results of four such surveying series:

$$s = s_{ISO-THEO-HZ} = \sqrt{\frac{\sum_{i=1}^{4} s_i^2}{4}} = \sqrt{\frac{\sum_{i=1}^{4}\sum r_{i2}}{32}}.$$

The results of the conducted surveying have been presented in table 2. The manual surveying for the instrument TCRA1101 were held in various atmospheric conditions, as well as automatic surveying for the instrument TCRP1200.

Table 1. The results of surveying and calculations carried out for one sample surveying series

j	k	$x_{j,k,I}$ [gon]	$x_{j,k,II}$ [gon]	$x_{j,k}$ [gon]	$x'_{j,k}$ [gon]	$\bar{x}_{j,k}$ [gon]	$d_{j,j}$ [mgon]	$r_{j,k}$ [mgon]	$r^2_{j,k}$ [mgon²]
1	2	3	4	5	6	7	8	9	10
1	1	399.9982	199.9973	399.9978	400.0000	0.0000	0.00	–0.17	0.0286
	2	68.1541	268.1546	68.1543	68.1566	68.1566	0.00	–0.17	0.0274
	3	142.8052	342.8047	142.8050	142.8072	142.8072	–0.02	–0.18	0.0342
	4	233.4551	33.4554	233.4553	233.4575	233.4576	0.09	–0.08	0.0060
	5	254.5342	54.5347	254.5344	254.5367	254.5374	0.77	0.60	0.3563
						$\bar{d}_1$ [mgon] =	0.16		
2	1	399.9962	199.9978	399.9970	400.0000		0.00	0.26	0.0656
	2	68.1538	268.1540	68.1539	68.1569		–0.33	–0.07	0.0055
	3	142.8037	342.8045	142.8041	142.8071		0.11	0.37	0.1378
	4	233.4546	33.4553	233.4550	233.4579		–0.30	–0.04	0.0018
	5	254.5351	54.5354	254.5352	254.5382		–0.77	–0.51	0.2610
						$\bar{d}_2$ [mgon] =	–0.25		
3	1	399.9973	199.9975	399.9974	400.0000		0.00	0.14	0.0183
	2	68.1537	268.1543	68.1540	68.1566		0.01	0.15	0.0219
	3	142.8045	342.8052	142.8048	142.8074		–0.20	–0.07	0.0047
	4	233.4552	33.4553	233.4552	233.4578		–0.16	–0.03	0.0009
	5	254.5350	54.5355	254.5352	254.5378		–0.32	–0.19	0.0344
						$\bar{d}_3$ [mgon] =	–0.13		
						s_1 [mgon] =	**0.35**		

Table 2. Values of estimators of actual standard deviations s [mgon]

TCRA1101	TCRP1200
1.29 (manual 1)	0.61 (ATR 1)
0.79 (manual 2)	0.80 (ATR 2)
0.51 (ATR)	0.29 (manual)

4. Statistical Tests

Statistical tests serve to interpret the results. The values of experimental standard deviations s calculated on the basis of the test procedure are used for the calculations. Statistical tests are exclusively recommended for the full test procedures.

In order to compare the accuracy of manual and automatic targeting, it is necessary to answer the question whether the two values of experimental standard deviations, s i s', determined independently, belong to the same population, assuming for both the same number of degrees of freedom v. The adopted for the test confidence level should be equal to $1 - \alpha = 0.95$ and the number of degrees of freedom $v = 32$, in line with the test assumptions.

Null hypothesis of the test is: $\sigma = \sigma'$, where σ means the theoretical or predefined value or standard deviation. To verify the hypothesis the following condition is used:

$$\frac{1}{F_{1-\alpha/2}(v,v)} \le \frac{s^2}{s'^2} \le F_{1-\alpha/2}(v,v),$$

where $F_{1-\alpha/2}(v,v)$ is the value of the F statistics for the significance level $\alpha = 0.05$ and the number of degrees of freedom $v = 32$. If the ratio of the squares of the estimators obtained from two independent test procedures falls within the range of $\langle 0.49, 2.02 \rangle$, i.e. beyond the critical area, then there are no grounds for rejecting the null hypothesis whatsoever. Otherwise, the value of statistics will fall in the critical area, which means that the null hypothesis must be rejected as false, and the alternative hypothesis is true.

The analysis of the surveying results for each instrument individually (Tab. 3) shows that the values of actual estimators of standard deviation, obtained by different methods, do not belong to the same population.

Table 3. Values of statistics s^2 / s'^2 for various methods with the same instrument

TCRA1101					TCRP1200				
s' [mgon] / s [mgon]		MAN1	MAN2	ATR	s' [mgon] / s [mgon]		ATR1	ATR2	MAN
		1.29	0.79	0.51			0.61	0.80	0.29
MAN1	1.29		2.67	6.45	ATR1	1.61		0.58	4.42
MAN2	0.79	0.37		2.41	ATR2	0.80	1.72		7.61
ATR	0.51	0.16	0.41		MAN	0.29	0.23	0.13	

Table 4. Values of statisticsfo s^2 / s'^2 for various instruments with the same method

MANUAL					ATR				
s [mgon] \ s′ [mgon]		1101-1	1101-2	1200	s [mgon] \ s′ [mgon]		1101	1200-1	1200-2
		1.29	0.79	0.29			0.51	0.61	0.80
1101-1	1.29		2.67	19.79	1101	0.51		0.69	0.40
1101-2	0.79	0.37		7.40	1200-1	0.61	1.44		0.58
1200	0.29	0.05	0.14		1200-2	0.80	2.48	1.72	

It should be taken into account, however, that the surveying was carried out in different atmospheric conditions, impeding targeting. The influence of the weather conditions on manual targeting is clearly visible in table 4, in contrast to the automatic targeting, where in most cases there are no grounds for rejecting the hypothesis of the results belonging to the same population.

5. Conclusions

On the grounds of the conducted calculations it might be concluded that targeting with the use of automatic systems of the ATR type is less dependent upon the prevailing weather conditions, however, the best accuracy for a specific instrument may be achieved with manual targeting in stable and favourable weather conditions. The comparison of various instruments confirms the presumption that the accuracy of automatic systems reflects the declared accuracy of the test instrument. The surveying carried out in a manual manner, although it potentially might assure high accuracy, is characterized by a greater dispersion associated with the atmospheric conditions prevailing during the surveying procedure.

References

[1] *International Standard ISO 17123-3. Optics and optical instruments – Field procedures for testing geodetic and surveying instruments – Part 3: Theodolites*. International Organization for Standardization, Geneva 2001.

[2] *ATR Behaviour – FAQ's. TPS NEWS 2002. Issue 6*. Leica Geosystems, Heerbrugg 2002.