PROCEDURES FOR ACCURACY ASSESSMENT OF ELECTRONIC TACHEOMETERS AS USED IN FIELDWORK CONDITIONS IN ACCORDANCE WITH ISO STANDARDS

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1. INTRODUCTION

International Standards Organization (ISO), in the realm of accuracy assessment of surveying instruments, set out the principle according to which every surveying instrument, before being put into practical use, should undergo accuracy test of functioning in specific fieldwork conditions.

As regards electronic tacheometers, ISO 17123-5 norm is based on the following preliminary assumptions:

1. electronic total station, together with its ancillary equipment, is rectified in accordance with the methods presented in the user's manual;

2. the coordinates of the observed points are regarded as measurands (in total station's function – measurement of the coordinates);

3. test measurements are carried out in fieldwork conditions, most closely related to the ones which may occur in the course of the planned measuring task.

The ISO/TC 172 Technical Committee „Optics and Photonics" worked out two different fieldwork procedures, i.e. abridged and unabridged, the appropriate choice of which with regard to a particular measuring task should always be made by a surveyor.

The main objectives of testing procedures are as follows:

- in abridged procedure - checking whether the accuracy of a given electronic total station and its ancillary equipment do not exceed the permissible limits of measurement deviation – in compliance with ISO 4463-1 [2] norm;

- in unabridged procedure - determining the highest achievable accuracy of a given electronic total station and its ancillary equipment in specific fieldwork conditions.

The criterion taken for checking the function accuracy of the particular total station is the standard testing deviation of the coordinate as the result of measurement taken during one test run.

2. CONFIGURATION OF TEST FIELD AND MEASUREMENTS TAKING

The test field in both procedures is based on three measurement positions S_1, S_2 i S_3, selected in such a way that:

- distances among them were close to those which may be obtained during the scheduled measurement;

- differences in height were potentially maximum.

The abridged procedure is usually based on any local coordinate system (x, y, z), e.g. for position S_1, with pre-arranged x axis agreeing with the direction of zero reading on the horizontal circle of the total station.
In the local coordinate system the measurement of the of the remaining two points should be taken from each measurement position S_1, S_2 and S_3, holding the following assumptions:

- the coordinates of S_2 and S_3 points, determined from S_1 position are regarded as the coordinates of the position for further measurements;
- the orientation of S_2 and S_3 positions is conducted through one back sight towards point S_1

The unabridged test procedure, in the way it is conducted, largely differs from the abridged one, for it is based on forced centring onto the triangle vertexes, which is typical of the three-tripod method.

The most important rules of the unabridged procedure are as follows:

- three measuring runs with locating a total station on one of the three tripods, above point S_j(j=1,2,3) in the fixed order, e.g. $S_1 \rightarrow S_2 \rightarrow S_3 \rightarrow S_1 \rightarrow S_2 \ldots$;

- not using the total station's orientation, e.g. taking the option „free station";

- taking zero coordinates of the position for each set-up of the total station, i.e. $x_j = 0$, $y_j = 0$, $z_j = 0$ and any orientation;

- measuring the coordinates of the prism at two remaining points – at two positions of the total station;

- using the same prism or two prisms of the same type, since δ difference value between the height of instrument and the prism is the unknown in the adjustment process;

- taking arithmetic mean from the observations at two positions of the total station, as quasi-observations, providing output data for analyzing the results of test measurement.

3. THE ANALYSIS OF TEST MEASUREMENT

3.1 The abridged procedure

The analysis of test measurement is, practically speaking, calculating the differences of the coordinates, as obtained from the measurements at three measurement positions.

$$
\begin{aligned}
&d_1 = x_{1,2} - x_{1,3} && d_4 = y_{1,2} - y_{1,3} && d_7 = z_{1,2} - z_{1,3} \\
&d_2 = x_{2,1} - x_{2,3} && d_5 = y_{2,1} - y_{2,3} && d_8 = z_{2,1} - z_{2,3} \\
&d_3 = x_{3,1} - x_{3,2} && d_6 = y_{3,1} - y_{3,2} && d_9 = z_{3,1} - z_{3,2}
\end{aligned} \tag{1}
$$

According to the norm, half of the maximum values of the above differences, i.e.:

$$
\begin{aligned}
&d_{x,y} = \tfrac{1}{2} \max. |d_i| && \text{for } i \text{ from 1 to 6} \\
&d_z = \tfrac{1}{2} \max. |d_i| && \text{for } i \text{ from 7 to 8}
\end{aligned} \tag{2}
$$

can not exceed permissible deviation $\pm p_{x,y}$ or $\pm p_z$ for the planned measurement task (in accordance with ISO norm 4463-1). In the case when the value of permissible deviation (interpreted as half of tolerance of symmetric tolerance) has not been given In the specification of the measurement task, values $d_{x,y}$ and/or d_z can not exceed the 2.5-fold standard deviation, $S_{x,y}$ and/or S_z respectively, be experimentally determined by use of the same instrument as in unabridged procedure.

The exemplification of test measurements is presented in table 1 below.

Table 1

The exemplification of the abridged procedure.

Total station position	Position coordinates			Cel	Measurement results		
	x	**y**	**z**		**x**	**y**	**z**
S_1	1000.000	2000.00	300.000	S_2	984.076	2082.959	302.227
				S_3	883.478	2015.557	286.794
S_2	984.076	2082.959	302.227	S_3	883.480	2015.549	286.790
				S_1	1000.000	1999.999	300.002
S_3	883.478	2015.557	286.794	S_1	1000.000	2000.000	300.002
				S_2	984.082	2082.955	302.228

The differences of coordinates according to (1) in meters:

$$
\begin{aligned}
&d_1 = 0.000 && d_4 = -0.001 && d_7 = 0.000 \\
&d_2 = -0.006 && d_5 = 0.004 && d_8 = -0.001 \\
&d_3 = -0.002 && d_6 = 0.008 && d_9 = 0.004
\end{aligned}
$$

Half of the values of maximum differences according to (2):

$d_{x,y} = 0.004$ $d_z = 0.002$

3.2 The unabridged procedure

In the unabridged procedure the accuracy assessment is carried out for each of *x*, *y*, *z* coordinates individually. As far as coordinates *x*, *y* are concerned, in order to obtain comparable results from three measuring runs each measuring run should be reduced to the same system, e.g. corresponding to the 1st series at position S_1 with coordinates $x = 0$, $y = 0$.
The above mentioned reduction involves as follows:

- shifting the origin of measurement system (*x*, *y*) positions S_2 i S_3 to point $S_1 \Rightarrow$ which makes the coordinates in the system (x', y') – columns 4 and 5 of table 2;
- calculating quasi-azimuth α' of $S_1 - S_2$ and $S_1 - S_3$ directions (column 6 of table 2) on the basis of coordinate points S_1, S_2 and S_3 in the local system (x', y') taken separately for each of nine observations;
- calculating quasi-azimuth *A* of the reference direction, be the bisector of the angle between $S_1 - S_2$ and $S_1 - S_3$ directions, as observed from position S_1 in the 1st run ($A_1 = 66^g,7754$ – column 6 of table 2);
- calculating quasi-azimuth A_i of the bisector of the above mentioned angle, for each of remaining eight observations (column 6 of table 2);
- individual rotation of each of eight systems (x', y') around point S_1 by angle $\varphi_i = A_i - A_1$, pertaining to the observation of S_2 and S_3 positions in the 1st, 2nd and 3rd runs, and from S_1 position in the w 2nd and 3rd runs – the rotation gives the value of quasi-azimuths α of $S_1 - S_2$ and $S_1 - S_3$ directions in the local measurement system of S_1 position in the 1st runs.

The geometric interpretation of the transformation of each of eight independent measurement systems onto the measurement system of S_1 position of the 1st run is presented in fig.1 by the example of S_2 and S_3 positions.

The further analysis of the unabridged procedure includes polar coordinates (α, *d* – columns 7 and 8 of table 2) of S_2 and S_3 points in the measurement system of S_1 position of the 1st run, be the basis for computing x'' and y'' coordinates (columns 9 and 10 of table 2), whereas mean values $\bar{x}''$ i $\bar{y}''$ of 18 individual determinations of the coordinates of S_2 and S_3 points are essential for calculating correction value υ (of residual errors) in the general number of 36.

According to the norm, there are 12 unknowns (8 rotation angles and 4 coordinates of points S_2 i S_3), and, consequently, 24 degrees of freedom.

The experimental standard deviation of *x* or *y* coordinates (table 2), be the result of the measurement at two positions of the total station is calculated as follows:

$$s_{x,y} = \sqrt{\frac{\sum_{i=1}^{18} \upsilon_{x(i)}^2 + \sum_{i=1}^{18} \upsilon_{y(i)}^2}{24}} \tag{3}$$

Table 2

The exemplification of the unabridged test procedure in accuracy assessment of x, y coordinates.

(1)			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
I	j	k	x [m]	y [m]	x' [m]	y' [m]	α' [g]	α [g]	d [m]	x'' [m]	y'' [m]
I	1	1	0.000	0.000	0.000	0.000					
		2	-0.007	63.994	-0.007	63.994	100.0070	100.0070	63.9940	-0.0070	63.9940
		3	55.003	31.999	55.003	31.999	33.5439	33.5439	63.6339	55.0030	31.9990
						$A_1 =$	66.7754				
	2	1	30.689	-56.157	0.000	0.000					
		2	0.000	0.000	-30.689	56.157	131.8400	100.0073	63.9955	-0.0073	63.9955
		3	63.615	-1.707	32.926	54.450	65.3762	33.5435	63.6312	55.0009	31.9973
						$A_2 =$	98.6081	31.8327=φ_2			
	3	1	-2.791	-63.570	0.000	0.000					
		2	-56.651	-29.000	-53.859	34.570	163.6724	100.0082	63.9990	-0.0082	63.9990
		3	0.000	0.000	2.791	63.570	97.2068	33.5426	63.6312	55.0014	31.9966
						$A_3 =$	130.4396	63.6642=φ_3			
II	1	1	0.000	0.000	0.000	0.000					
		2	-18.919	61.133	-18.919	61.133	119.1065	100.0071	63.9935	-0.0071	63.9935
		3	43.088	46.823	43.088	46.823	52.6431	33.5437	63.6315	55.0011	31.9977
						$A_4 =$	85.8748	19.0994=φ_4			
	2	1	63.846	-4.519	0.000	0.000					
		2	0.000	0.000	-63.846	4.519	195.5016	100.0070	64.0057	-0.0070	64.0057
		3	35.620	52.606	-28.028	57.125	129.0384	33.5438	63.6304	55.0001	31.9972
						$A_5 =$	162.2700	95.4946=φ_5			
	3	1	-56.645	28.992	0.000	0.000					
		2	-2.797	63.567	53.848	34.575	36.3377	100.0022	63.9925	-0.0022	63.9925
		3	0.000	0.000	56.645	-28.992	369.8842	33.5487	63.6333	55.0001	32.0029
						$A_6 =$	203.1109	136.3355=φ_6			
III	1	1	0.000	0.000	0.000	0.000					
		2	-9.038	-63.365	-9.038	-63.365	290.9805	100.0003	64.0063	-0.0003	64.0063
		3	-58.964	-23.916	-58.964	-23.916	224.5307	33.5505	63.6296	54.9960	32.0026
						$A_7 =$	257.7556	190.9802=φ_7			
	2	1	58.201	26.638	0.000	0.000					
		2	0.000	0.000	-58.201	-26.638	227.3256	100.0042	64.0073	-0.0042	64.0073
		3	6.216	63.335	-51.985	36.697	160.8680	33.5466	63.6326	55.0006	32.0007
						$A_8 =$	194.0968	127.3214=φ_8			
	3	1	-2.791	-63.573	0.000	0.000					
		2	-56.651	-28.999	-53.860	34.574	163.6696	100.0068	64.0020	-0.0068	64.0020
		3	0.000	0.000	2.791	63.573	97.2069	33.5441	63.6342	55.0032	31.9994
						$A_9 =$	130.4382	63.6628=φ_9			

	$\overline{x''}$	$\overline{y''}$
S_2	-0,0056	63.9995
S_3	55.0007	31.9993
$s_{x,y}$	0.0042	

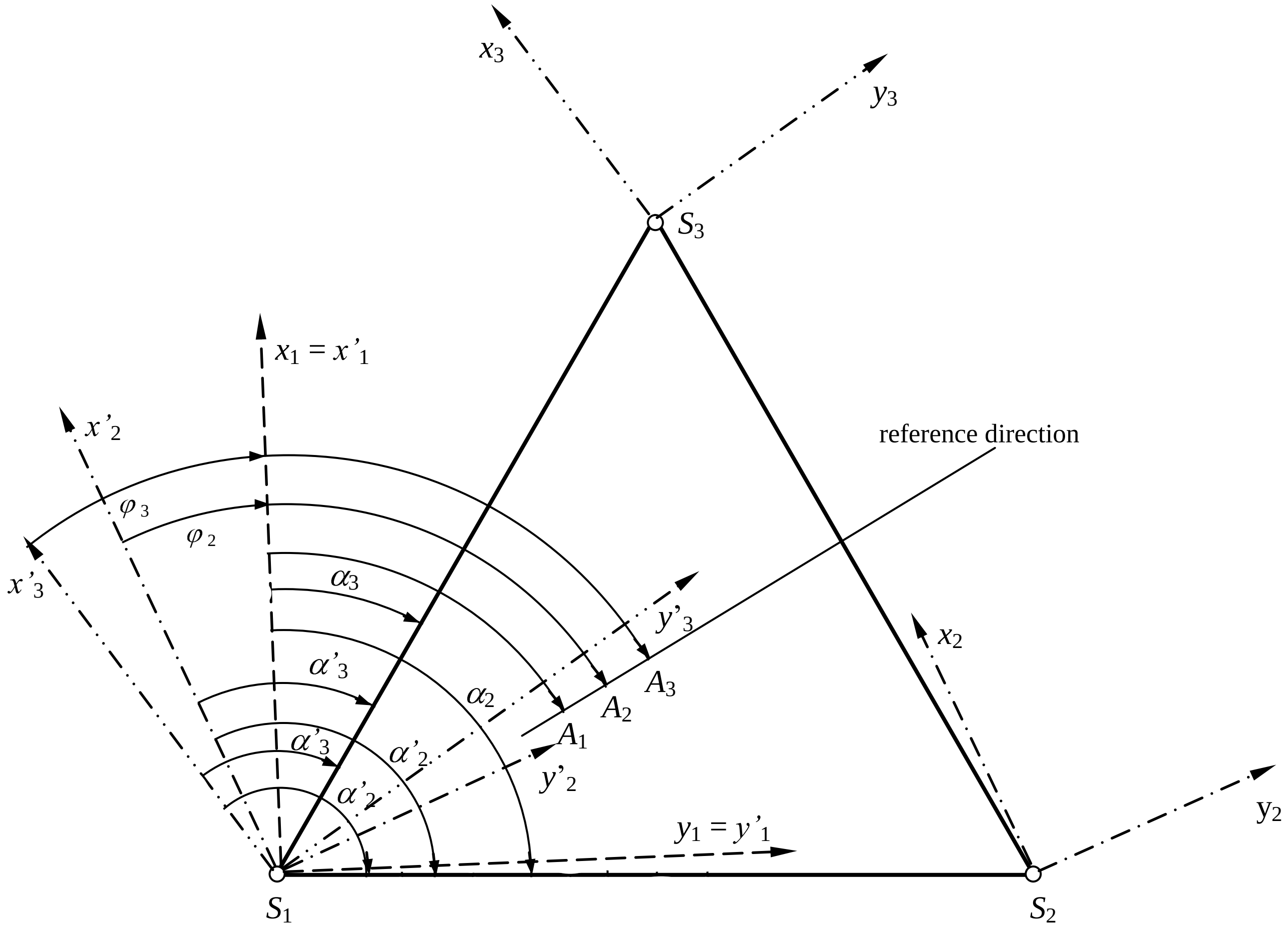

Fig. 1. The geometric interpretation of the (x_{2}, y_{2}) and (x_{3}, y_{3}) transformation onto the measurement system (x_1, y_1) of S_1 position in the 1st run of the test measurement.

As far as y coordinate is concerned, the unknowns are the coordinates z from S_2 and S_3 points, and difference δ of the instrument height and the prism. The most plausible values of the above unknowns are calculated by the following equation:

$$z_2 = \frac{1}{18}\sum_{i=1}^{3}(2\cdot z_{i,1,2} + z_{i,1,3} - 2\cdot z_{i,2,1} - z_{i,2,3} - z_{i,3,1} + z_{i,3,2}) \tag{4}$$

$$z_3 = \frac{1}{18}\sum_{i=1}^{3}(z_{i,1,2} 2\cdot z_{i,1,3} - z_{i,2,1} + z_{i,2,3} - 2\cdot z_{i,3,1} - z_{i,3,2}) \tag{5}$$

$$\delta = \frac{1}{18}\sum_{i=1}^{3}(-z_{i,1,2} - z_{i,1,3} - z_{i,2,1} - z_{i,2,3} - z_{i,3,1} - z_{i,3,2}) \tag{6}$$

where:

for example, $z_{i,1,2}$ should be interpreted as coordinate from point S_2, determined from S_1 position during the 1st measurement run (column 4 of table 3).

Table 3

The exemplification of the unabridged procedure in the accuracy assessment of *z* coordinate.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Series	Positions	aim	z [m]	coefficients						
				z_2	z_3	δ	2.6634	5.7133	0.0494	υ_z
I	1	2	2.615	2	1	-1	1	0	-1	-0.0010
	1	3	5.658	1	2	-1	0	1	-1	0.0059
I	2	1	-2.714	-2	-1	-1	-1	0	-1	0.0012
	2	3	3.004	-1	1	-1	-1	1	-1	-0.0035
I	3	1	-5.767	-1	-2	-1	0	-1	-1	0.0043
	3	2	-3.097	1	-1	-1	1	-1	-1	-0.0023
II	1	2	2.616	2	1	-1	1	0	-1	-0.0020
	1	3	5.657	1	2	-1	0	1	-1	0.0069
II	2	1	-2.712	-2	-1	-1	-1	0	-1	-0.0008
	2	3	3.004	-1	1	-1	-1	1	-1	-0.0035
II	3	1	-5.767	-1	-2	-1	0	-1	-1	0.0043
	3	2	-3.094	1	-1	-1	1	-1	-1	-0.0053
III	1	2	2.618	2	1	-1	1	0	-1	-0.0040
	1	3	5.661	1	2	-1	0	1	-1	0.0029
III	2	1	-2.711	-2	-1	-1	-1	0	-1	-0.0018
	2	3	3.005	-1	1	-1	-1	1	-1	-0.0045
III	3	1	-5.764	-1	-2	-1	0	-1	-1	0.0013
	3	2	-3.101	1	-1	-1	1	-1	-1	0.0017

The values of coordinate z from points S_2 and S_3 and difference δ of the instrument height and the prism, as calculated according to equations (4), (5) and (6) allow to compute 18 corrections (column 11 of table 3) by use of the following equations:

$$
\begin{aligned}
\upsilon_{i,1,2} &= z_2 - \delta - z_{i,1,2} \\
\upsilon_{i,1,3} &= z_3 - \delta - z_{i,1,3} \\
\upsilon_{i,2,1} &= -z_2 - \delta - z_{i,2,1} \\
\upsilon_{i,2,3} &= -z_2 + z_3 - \delta - z_{i,2,3} \\
\upsilon_{i,3,1} &= -z_3 - \delta - z_{i,3,1} \\
\upsilon_{i,3,2} &= z_2 - z_3 - \delta - z_{i,3,2} \qquad \text{for } i = 1,2,3
\end{aligned}
\tag{7}
$$

The number of observations amounts to 18, and for there are 3 unknowns, it makes 15 degrees of freedom.

The experimental standard deviation of z coordinate, be the result of the measurement at two positions of the total station, is calculated as follows:

$$s_Z = \sqrt{\frac{\sum_{i=1}^{15} \upsilon_{z(i)}^2}{15}} \tag{8}$$

In this example the above parameters take the following values :

z_2 = 2.6634 m $\sum \upsilon^2 = 0.00023684$

z_3 = 5.7133 m $s_Z = 0.0040$

δ = 0.0494 m

For the right interpretation of the test measurement results in accordance with the unabridged procedure, two statistic tests should be conducted so as to answer two fundamental questions:

a) if the experimental standard deviation $s \leq$ of value δ, given by a total station's producer or established in the specification of the planned measurement task;
b) if two experimental standard deviations, deriving from two different tests, belong to the same population, considering both tests have the same number of degrees of freedom.

4. CONCLUSION

The seven-part norm ISO 17123 allows to assess accuracy of practically all kinds of surveying instruments (except for GPS technique) in specific fieldwork conditions. The test procedures act on unified basic assumptions concerning technical qualification of instruments, configuration of test field, and the way of working out results of test measurements. At the current phase of learning and implementing so as to make them the part of standardizing process on the national scale, they are certainly useful for substantiating accuracy capabilities of a particular surveying instrument for carrying out specific measurement tasks.

REFERENCES

ISO 17123-5 Optics and instruments – Field procedures for testing geodetic and surveying instruments – Part 5: Electronic total stations.

ISO 4463-1: Measurement methods for building – Setting – out and measurement – Part 1: Planning and organization, measuring procedures, acceptance criteria.