# EXAMINING COHERENCE OF ACCURACY TESTS OF TOTAL STATION SURVEYING AND GEODETIC INSTRUMENTS BASED ON COMPARISON OF RESULTS OF COMPLETE TEST PROCEDURES ACCORDING TO ISO 17123

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## ABSTRACT

**Total Station instruments can be qualified as the equipment whose accuracy parameters can be tested with measuring and calculation procedures, pursuant to part 3, 4 and 5 of ISO 17123. The present paper aims to study coherence of accuracy results obtained, on the one hand, by combining parts 3, 4, and part 5, on the other hand. The tests were carried out based on complete test procedures with test bases located on the premises of AGH University and city meadow in Krakow. The following instruments were tested: Trimble S6, Leica TCRA 1101 and Topcon GPT 7500.**

## 1. INTRODUCTION

**In terms of PN ISO 17123, the Total Base instruments can be regarded as: Theodolites, therefore tested with procedures referred to in Part 3 of PN ISO 17123; Electro-optic rangefinders [EDM], therefore tested with procedures referred to in Part 4 of PN ISO 17123; Tachymeters, therefore tested with procedures referred to in Part 5 of PN ISO 17123. The present paper aims to study coherence of accuracy results that can be obtained, on the one hand, by combining parts 3, 4, and part 5, on the other hand. All measurements were performed under complete test procedures. Considering Part 3 of the standard, the instruments were tested on a test base located on the premises of AGH University, whereas for those related to Part 4 and 5, test bases were located in eastern part of Krakow city meadow. Three instruments were tested:**

**Leica TCRA 1101**

**Trimble S6**

**Topcon GPT 7500**

**In each case, the measurements were made manually without using ATR technology [Automatic Target Recognition].**

## 2. TESTING THEODOLITES – PN ISO 17123-3

**Complete measuring procedures, aimed at establishing accuracy of direction setting by individual tachymeters, were carried out on a test base located on the premises of AGH University (figure 1).**

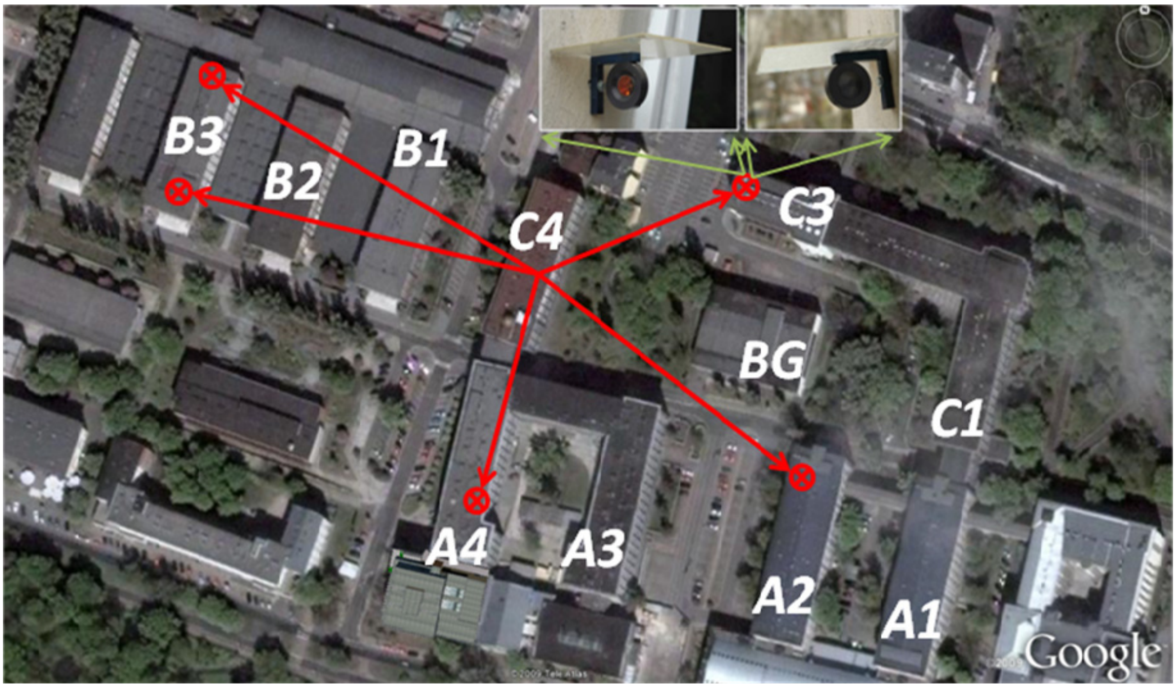


**Fig. 1. Location of angular base targets on the premises of AGH.**

**Instruments were adapted to present weather conditions and 4 series of measurements were performed for 5 targets located on building roofs around C4 pavilion. See table 1 for calculated estimators of the deviation of standard direction measurement for individual instruments.**

**Table 1**

| | Trimble S6 | Leica TCRA 1102 | Topcon GPT 7500 |
|---|---|---|---|
| $S_{ISO\text{-}THEO\text{-}HZ}$ [cc] | 10.46 | 12.90 | 8.69* / 15 |

**For Topcon GPT 7500 instrument, tests were carried out in two ways, due to its structural complexity. The instrument may not be turned by 120 at the levelling head. For that reason, table 1 gives two results for that instrument: one obtained in measurements without satisfying the condition to change instrument position at the levelling head between series, and the other based on measurements in which, between series, the entire instrument together with its levelling head was screwed on a forced centring pin thus changing the orientation by ca. 120 .**

**Table 2, 3 and 4 present results of testing the hypothesis of belonging of experimentally determined standard deviation estimators of individual instruments to one population. Such dependency is expressed as follows (ISO 2002a) :**

$$\frac{1}{F_{1-\frac{\alpha}{2}}(\vartheta,\vartheta)} \le \frac{s}{\tilde{s}} \le F_{1-\frac{\alpha}{2}}(\vartheta,\vartheta)$$

$$\frac{1}{F_{0.975}(32,32)} \le \frac{s}{\tilde{s}} \le F_{0.975}(32,32)$$

**(1)**

**Taking into account the number of freedom degrees $\vartheta$ =32 in a complete test procedure for horizontal angles acc. to PN ISO 17123-3, and the trust level 1-α = 0.95, the above inequality shall yield:**

$$0.49 \le \frac{s}{\tilde{s}} \le 2.02$$

**Table 2**

| **Instrument** | **Trimble S6** | **Leica TCRA 1102** |
|---|---|---|
| **$S_{ISO\text{-}THEO\text{-}HZ}$ [cc]** | **10.46** | **12.90** |
| $\frac{s}{\tilde{s}}$ | **0.81 – inequality (1) satisfied** | |

**Table 3**

| **Instrument** | **Trimble S6** | **Topcon GPT 7500** |
|---|---|---|
| **$S_{ISO\text{-}THEO\text{-}HZ}$ [cc]** | **10.46** | **8.69* / 15** |
| $\frac{s}{\tilde{s}}$ | **1.20* / 0.70 – inequality (1) satisfied** | |

**Table 4**

| **Instrument** | **Leica TCRA 1102** | **Topcon GPT 7500** |
|---|---|---|
| **$S_{ISO\text{-}THEO\text{-}HZ}$ [cc]** | **12.90** | **8.69* / 15** |
| $\frac{s}{\tilde{s}}$ | **1.48* / 0.86 – inequality (1) satisfied** | |

**It is easy to note that, based on the above results, there are no grounds to deny the hypothesis of belonging of all three instruments to one accuracy class for measurement of direction.**

## 3. TESTING RANGEFINDERS – PN ISO 17123-4

**Prior to determining accuracy as per PN ISO 17123-4, test base had to be properly designed and stabilised, taking into consideration the type of instruments being tested. See figure 2 for approximate location of the test base in the eastern part of Krakow city meadow.**

**Fig. 2. Arrangement and measurement set up on the distance basis.**

**Considering the fact that tested instruments modulate the measuring wave at the frequency of 50 MHz, the section lengths are as follows (table 5):**

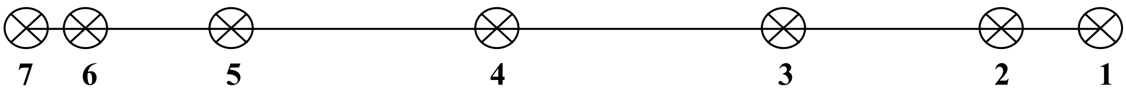


**Table 5 – design of distance basis for phase range finders 50 MHz**

| $D_{ij}$ | $D_{12}$ | $D_{23}$ | $D_{34}$ | $D_{45}$ | $D_{56}$ | $D_{67}$ |
|---|---|---|---|---|---|---|
| Section length [m] | 42,250 | 156,833 | 343,750 | 494,500 | 572,917 | 579,000 |

**Table 6 presents the results of accuracy determination for electro-optic rangefinders, built in the tachymeters being tested – standard deviation estimators for distance measurement according to complete test procedure. During the measurement, atmospheric pressure and temperature were measured constantly, in order to maintain the weather adjustment in consistency with actual measuring conditions.**

**Table 6**

| | Trimble S6 | Leica TCRA 1102 | Topcon GPT 7500 |
|---|---|---|---|
| $s_{ISO-EDM}$ [mm] | 0,75 | 0,27 | 0,58 |

**Table 7, 8 and 9 present results of testing the hypothesis of belonging of experimentally determined standard deviation estimators of individual instruments to one population. Such dependency is of analogical form as the previous one (ISO 2002b):**

$$\frac{1}{F_{1-\frac{\alpha}{2}}(\vartheta,\vartheta)} \le \frac{s}{\tilde{s}} \le F_{1-\frac{\alpha}{2}}(\vartheta,\vartheta)$$

$$\frac{1}{F_{0.975}(14,14)} \le \frac{s}{\tilde{s}} \le F_{0.975}(14,14)$$

**(2)**

**Of course, the number of freedom degrees has changed to $\vartheta$=14. [complete test procedure for distance acc. to PN ISO 17123-4] Trust level remains unchanged 1-α = 0.95, therefore the above inequality (2) is expressed as follows:**

$$0.34 \le \frac{s}{\tilde{s}} \le 2.98$$

**Table 7**

| Instrument | Trimble S6 | Leica TCRA 1102 |
|---|---|---|
| $s_{ISO\text{-}EDM}$ [mm] | 0,75 | 0,27 |
| $\frac{s}{\tilde{s}}$ | 2.80 – inequality (2) satisfied | |

**Table 8**

| Instrument | Trimble S6 | Topcon GPT 7500 |
|---|---|---|
| $s_{ISO\text{-}EDM}$ [mm] | 0,75 | 0,58 |
| $\frac{s}{\tilde{s}}$ | 1.30 – inequality (2) satisfied | |

**Table 9**

| Instrument | Leica TCRA 1102 | Topcon GPT 7500 |
|---|---|---|
| $s_{ISO\text{-}EDM}$ [mm] | 0,27 | 0,58 |
| $\frac{s}{\tilde{s}}$ | 0.46 – inequality (2) satisfied | |

**It is easy to note that, again, there are no grounds to deny the hypothesis of belonging of all three instruments to one accuracy class for measurement of distance.**

## 4. TESTING TACHYMETERS – PN ISO 17123-5

**The measurement according to the standard for tachymeters, i.e. instruments for setting coordinates, was carried out on a triangular measuring base of side length of approximately 150 m. Figure 3 presents the location of the test base in the eastern part of Krakow city meadow.**

**Fig. 3.**

**The estimator, obtained experimentally acc. to PN ISO 17123-5, refers to the point location. Situation of the points has been considered in the present paper. Table 10 presents the results of equalisation:**

Table 10

| | **Trimble S6** | **Leica TCRA 1102** | **Topcon GPT 7500** |
|---|---|---|---|
| $S_{ISO\text{-}TACH\text{-}XY}$ [m] | **0,0034** | **0,0039** | **0,0055** |

**The determination by equalisation is of course based on 4 average values of X, Y coordinates of two points (one of them fixed), and 8 parameters describing revolutions of local systems of coordinates. Therefore, the number of freedom degrees is $\vartheta$=24. Inequality (3) describes testing of analogical zero hypothesis as the previous one(ISO 2005).**

$$\frac{1}{F_{1-\frac{\alpha}{2}}(\vartheta,\vartheta)} \le \frac{s}{\tilde{s}} \le F_{1-\frac{\alpha}{2}}(\vartheta,\vartheta)$$

$$\frac{1}{F_{0,975}(24,24)} \le \frac{s}{\tilde{s}} \le F_{0,975}(24,24)$$

**(3)**

**Numerically, it is expressed as follows:**

$$0.44 \le \frac{s}{\tilde{s}} \le 2.27$$

**Similarly, as it was easy to prove that instruments at trust level of 1-α=0.95 belong to one accuracy class, standard deviation estimators for the coordinates being determined do not vary. See tables 11, 12 and 13 for numerical presentation:**

**Table 11**

| Instrument | Trimble S6 | Leica TCRA 1102 |
|---|---|---|
| $S_{ISO\text{-}TACH\text{-}XY}$ [m] | 0,0034 | 0,0039 |
| $\frac{s}{\tilde{s}}$ | 0.87 – inequality (3) satisfied | |

**Table 12**

| Instrument | Trimble S6 | Topcon GPT 7500 |
|---|---|---|
| $S_{ISO\text{-}TACH\text{-}XY}$ [m] | 0,0034 | 0,0055 |
| $\frac{s}{\tilde{s}}$ | 0.61 – inequality (3) satisfied | |

**Table 13**

| Instrument | Leica TCRA 1102 | Topcon GPT 7500 |
|---|---|---|
| $S_{ISO\text{-}TACH\text{-}XY}$ [m] | 0,0039 | 0,0055 |
| $\frac{s}{\tilde{s}}$ | 0.71 – inequality (3) satisfied | |

## 5. COHERENCE OF ACCURACY TESTS BASED ON COMPLETE TEST PROCEDURES

**Electronic tachymeters measure distance regardless of horizontal direction in which the measurement is performed. In other words, location accuracy of a point measured with a tachymeter can be obtained, knowing the direction and distance error, based on the principle of moving errors of non-correlated values. Using the estimators SISO-EDM and SISO-THEO-HZ already established, the location error of a point measured with an instrument can be easily determined:**

$$m_p^2 = m_x^2 + m_y^2$$

$$m_x^2 = \left(\frac{\partial x}{\partial d}\right)^2 m_d^2 + \left(\frac{\partial x}{\partial \alpha}\right)^2 m_\alpha^2$$

**and**

$$m_y^2 = \left(\frac{\partial y}{\partial d}\right)^2 m_d^2 + \left(\frac{\partial y}{\partial \alpha}\right)^2 m_\alpha^2$$

**Where $S_{ISO\text{-}EDM}$ serves as $m_d$ and $S_{ISO\text{-}THEO\text{-}HZ}$ serves as $m_\alpha$**

**On the other hand, the standard deviation estimator for a point location is derived directly from a test carried out pursuant to PN ISO 17123-5.**

**It is important to understand that the results obtained with both methods for a given instrument may not be directly compared. This is due to the fact that standard deviation estimators for distance, direction or point location, are only the basis for determining measuring inaccuracy. It is a common knowledge that measuring inaccuracy, in terms of classic theory of errors, should be presented as a variance element of an error of true value estimator, assuming that RiCBS [randomisation and centralisation of systematic error] techniques are utilised (ISO 1995). Therefore, the studies should be followed internally for individual solution classes. Tables 14, 15 and 16 present inequalities which describe relations inside solution classes for individual geodetic instruments.**

**Table 14**

| Leica TCRA 1101plus vs. Trimble S6 DR 300+ | |
|---|---|
| Based on the principle of error transfer and ISO 17123-3, 4 | Based on ISO 17123 – 5 |
| 0,00305 > 0,00258 | 0,00387 > 0,00337 |
| Coherent | |

**Table 15**

| Leica TCRA 1101plus vs. Topcon GPT -7500 | |
|---|---|
| Based on the principle of error transfer and ISO 17123-3, 4 | Based on ISO 17123 – 5 |
| 0,00305 > 0,00213<br>0,00305 < 0,00358 | 0,00387 < 0,00551 |
| No coherence (coherent) | |

**Table 16**

| Trimble S6 DR 300+ vs. Topcon GPT -7500 | |
|---|---|
| Based on<br>The principle of error transfer and ISO 17123-3, 4 | Based on<br>ISO 17123 – 5 |
| 0,00246 > 0,00213<br>0,00246 < 0,00358 | 0,00337 < 0,00551 |
| No coherence (coherent) | |

**On satisfying the condition of complete test procedures being performed, all solutions were found coherent [marked green]. It is, however, worth mention that if the assumptions in relation to one standard only are disregarded, this results instantly in lack of coherence within ISO 17123 standard. In the case in question, it was certainly connected with the levelling head design in Topcon instrument. Failure to reverse the instrument between measuring series results in distortion of the standard deviation estimator for direction measurement – the value is significantly lower and does not correlate with the factual accuracy of setting coordinates with that instrument, as compared to Leica and Trimble.**

**REFERENCES**

**ISO (International Organization for Standardization) 2002a – International Standard ISO 17123-3 ISO copyright Office Case postale 56 • CH-1211 Geneva 20.**

**ISO (International Organization for Standardization) 2002b – International Standard ISO 17123-4 ISO copyright Office Case postale 56 • CH-1211 Geneva 20.**

**ISO (International Organization for Standardization) 2005 – International Standard ISO 17123-5 ISO copyright Office Case postale 56 • CH-1211 Geneva 20.**

**ISO (International Organization for Standardization) 1995 "A Guide to Expression of Uncertainty in.Measurement" International Standard ISO 17123-5 ISO copyright Office Case postale 56 • CH-1211 Geneva 20.**