LABORATORIAL TESTS OF DIGITAL THEODOLITES

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Abstract

Calibration is a procedure, which assesses characteristics of components of a measurement system or even the complete operational system. This paper makes a review of the indispensable tests that must be applied at digital theodolites, which need to be calibrated in arrange time period frame for their proper function before or after their use in fieldworks. These tests also certify the industrial prescribed measuring precision of the instrument. The following tests should be applied: for the proper function of the optical or laser centering system, for the collimation of the instrument's cross – hairs, for the proper leveling of the correctness of the indications and the DIN ′18723 procedure that assesses the precision of horizontal and vertical angles. An aspect about the determination of the ″fundamental accuracy″ of a theodolite as given by the DIN ′18723 specification is submitted.

An application was carried out in order to prove the efficacy and the easiness of the above tests.

Two networks were established, the first one inside the laboratory as the DIN ′18723 procedure defines and the second one outside in the field. Special targets were used in order to mark the networks' points. These targets were chosen after the application of the appropriate distinction tests. Two digital high accuracy total stations, the Leica TDM 5000 and the Trimble DR$^+$ 5605, passed all the tests successfully. The results and the duration of all the tests as well as the procedure are presented and analyzed below.

1. Introduction

Digital theodolites that are used in high accuracy measurements must be calibrated and tested for their proper function. These tests are laboratorial and aim to the certification that concerns:

- The proper function of the optical or laser centering system.
- The proper leveling of the instrument so that the primary axis of the instrument realizes accurately the plumb line at the station point.
- The correctness of the measurement and display indications.
- The accuracy that may be achieved at the measurement according to the instrument industrial manufacture.

The laboratorial calibration and tests of the digital theodolites, which are embodied in the modern total stations, are the following:

- *Laboratorial tests for the proper function of the digital theodolites are the following*:

- Test for the proper function of the optical or laser centering so that the instrument can be centered accurately above the right point. Any deviation of the centering line can be fixed at the right position in the laboratory.
- The test of the proper digital leveling of the instruments. This test is performed by using a collimator. Today all the modern digital theodolites correct immediately and automatically the measured angle values, if the instrument has a limited deviation of its right position. If the leveling deviation surpasses the defined limit, a message comes out on the display and stops the measurements.

- Test of the instrument circles in two telescope faces (I and II), horizontal and vertical. This test is made by using a collimator. A collimator is a telescope focused to infinity, the reticle of which is illuminated. The rays of light emanating from the reticle will be parallel when they leave the objective lens. If another telescope focused to infinity is pointed at the collimator, its cross-hairs will be seen as a perfect target at infinity (Jackson).
  If the line of sight of the telescope is parallel to the collimation line of the collimator, the cross-hairs of the telescope will be seen to coincide with the collimator's ones, no matter if there is a small displacement up or down, right or left, between the two objectives. The telescope can be directly in front on the collimator (fig. 1)

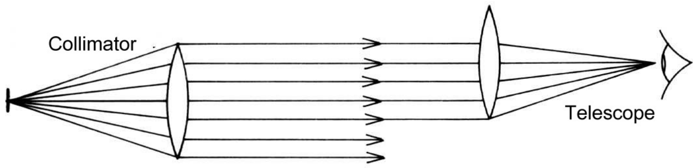

Figure 1. Sighting with a telescope into a collimator

  The collimators are usually established in laboratories of instrument control, on special pillars.
  The collimator's cross-hairs are sighted in two telescope faces (I, II) and the founded deviations of the right values, if in acceptable limits, are stored in the instrument's microcomputer and all the displayed indications are corrected according to them. As known, the perfect values for the horizontal circle readings is face II = face I $+200^g$ and for the vertical circle readings is face I + face II = 400^g

- *<u>Tests according to the DIN′ 18723 procedure for the determination of the angular measuring precision</u>*.
  - For the horizontal angles the procedure consists of two parts. Firstly measurements are carried out at an internal special formed network in a laboratory and secondly measurements are carried out at a network on site, in real environmental conditions. Both follow a concrete procedure, which consists of measurements on 5 targets placed at specific points at the same horizontal plane and at the same distance from the point where the instrument is set, in order to cover all the horizontal measuring circle.
  - For the vertical angles the test contents sightings on a rod, from the reading h_1 = 280cm to h_{18} = 110cm, by a 10cm step. The rod is put at vertical position at a X_2 distance (fig. 2) from the theodolite. The procedure contents three series of vertical angles measurements in I and II telescope faces.

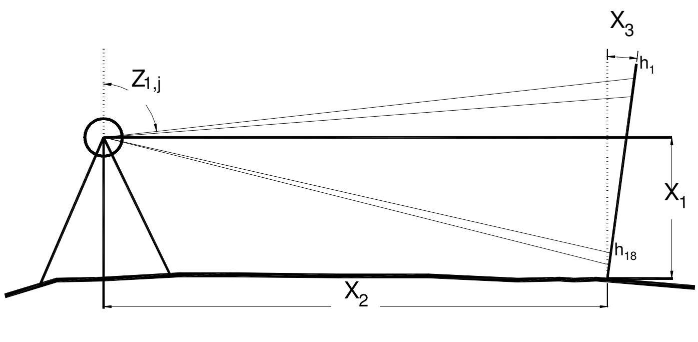

Figure 2. DIN′ 18723 test for the vertical angles.

In all cases one must take into account that the industrial prescribed measuring accuracy for each instrument or the measuring accuracy that reaches a theodolite in the test cannot always be achieved in fieldwork measurements. The main reason for that is the improper use of the instrument.

2. The DIN ′18723 procedure

2.1 Horizontal angles

The procedure contents **κ** (κ=1, 2, 3) measurement series on the targets **i** (i = 1, 2, 3, 4, 5) in **j** sets (j = 1, 2, 3).
The diagram presents the coherence of the calculations.

Calculation of the mean values $r_{i,j}$ from the readings on face I and face II on each target.

→ Calculation of the angles values, which are formed between the target 1 and each one of the other targets in each set j.

→ Calculation of the general average value ($\bar{r}_i$) of the three sets for the readings on each target.

→ Calculation of the mean value of each direction in each measurement set.

→ Calculation of the residuals ($C_{i,j}$) and their sum.

→ Calculation of the standard deviation of an horizontal direction in each set, by the three measurement sets.

→ Statistical control by using the χ^2 distribution for confidence level 95% in order to examine if the calculated standard deviation $S_{ISO-TEO-Hz}$ is smaller than the corresponding value σ_0 that the manufacturer gives for the instrument.

2.2 Vertical angles

The calculations for each observation serie are made separately according to the following procedure:

Calculation of the values of the parameters X_1 and X_2 (X_3=0)

→ Calculation of the difference ($l_{i,I}, l_{i,II}$) of the measured value of the vertical angle from the calculated value for each angle.

→ Calculation of the corrections $C_{i,I}$, $C_{i,II}$

→ Calculation of the standard deviation of a vertical angle in each observation serie.

→ Calculation of the standard deviation of a vertical angle of one observation, in two telescope positions, as it is computed in the three measurements series.

→ Calculation of the standard deviation $S_{ISO-TEO-V}$ of a vertical angle in one telescope position, in the three measurements series.

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Statistical control by using the χ^2 distribution for confidence level 95%, in order to examine if the calculated, standard deviation $S_{ISO-TEO-V}$ is smaller than the corresponding value σ_0 that the manufacturer gives for the instrument.

3. Application

An application of all the previous mentioned test was carried out by using two instruments, the Leica TDM 5000 (Leica Heerbrugg, 1997) and the Trimble 5605+ DR (Trimble Navigation, 2003).

3.1 Tests for the instrument proper function

The test of the tribrach proceeded as following:

- Test of the proper tribrach leveling. Checks if the tribrach is horizontal when its bubble is at the proper position.
- Test of the optical centering of the tribrach, in order to realize accurately the plumb line of the station point.

These tests were carried out by using a special target bubble (fot. 1), which was already tested.

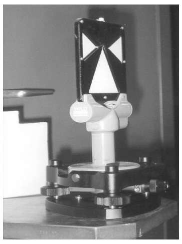


Foto 1. The target bubble

Continually each total station was put on the appropriate place in front of the collimator (fot. 2). The cross-hairs of the instrument were aligned to the collimator's ones and the horizontal readings set to zero.

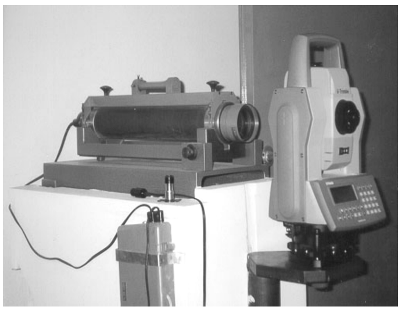


Foto 2. The collimator

The horizontal and vertical readings in I and II telescope faces were registered as the procedure was repeated twice.
The calculated corrections by the instrument's software were stored in the instrument computer and all the indications of the sighted directions have been corrected according to these values.
The time needed for the above mentioned tests for each instrument is about 20 minutes.

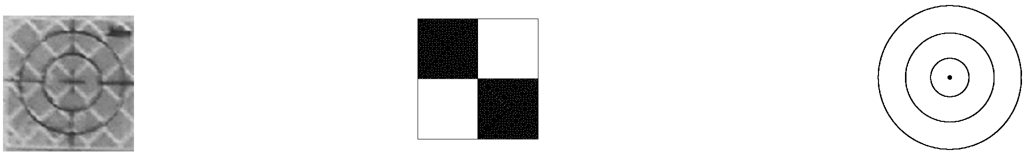
3.2 DIN `18723 test for the horizontal angles

3.2.1 Establishment of the network

The DIN `18723 test for the horizontal angles presuppose the establishment of two networks. An internal network in the laboratory and an external network in the field. The choice of the appropriate target, which was used to mark the network points, was done in order to satisfy the following criteria:

- To insure the stability of its position, for further use
- To insure unique sighting at all conditions from any direction by having the appropriate size and shape.
- At the internal network the size and the width of the target's lines must be very thin to be unique as the sighting distance is about 10m and the target appears in the telescope in big enlargement. On the contrary at the external network bigger targets are needed, as the sighting distance is about 200m.

Several targets of industrial geodesy are tested, as illustrated in fig. 3.



(a) (b) (c)

Figure 3. Types of targets

3.2.1.1 The internal network

Target (a) (fig. 3) is selected to mark the points of the internal network.

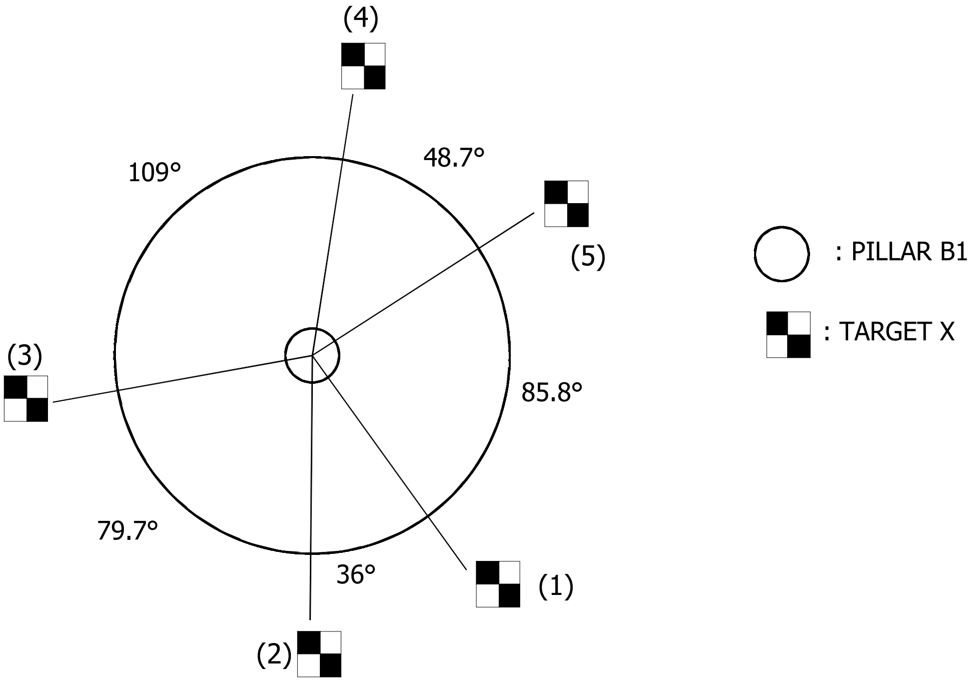


Figure 4. The order of the targets around the pillar at the internal network.

The internal network was established in a laboratory room where there are pillars in order to put the instrument forced centered. Figure 4 illustrates the order of the targets around the pillar.
Each instrument was put on the pillar by a special forced centering base. The measurement procedure started by sighting the first target and set zero at the indications. The sightings continue to all the targets clockwise at the telescope face I and inversely at telescope face II as defined by the DIN `18723 procedure.
The calculations of the measurements were carried out according to the previous analyzed methodology. The question that will be answered is the following: Is the calculated standard deviation $S_{\text{ISO-THEO-Hz}}$ smaller than the value σ_0 that the manufacturer gives for each instrument?
The confidence interval is defined $1-\alpha = 0.95$ and the freedom degree is calculated, F = 12. So, the equation is formed as $S_{\text{ISO-THEO-Hz}} \le \sigma_o \cdot 1.32$. The coefficient 1.32 is calculated by the formula $\sqrt{\frac{X^2_{F,1-\alpha}}{F}}$

In table 1 appear the results of this test for each instrument.

Instrument	$S_{ISO-THEO-Hz}$ (cc)	σ_0 (cc)	Control
Leica TDM 5000	1.12	1.5	$1.12^{cc} \le 1.5^{cc} \cdot 1.32 \Rightarrow 1.12^{cc} \le 1.98^{cc}$
Trimble DR$^+$ 5605	4.62	15	$4.62^{cc} \le 15^{cc} \cdot 1.32 \Rightarrow 4.62^{cc} \le 19.8^{cc}$

Table 1. The results of the DIN `18723 test for the horizontal angles in the laboratory.

These measurements last about one hour for each instrument.

3.2.1.2 The external network

The external network is created at the University Campus of NTUA. At first a convenient pillar is chosen and then the targets are set in several buildings around it. In this case is selected the target (b) that appears in fig. 3. This is the more convenient as the distance between the pillar and the target is about 200 m. Figure 5 illustrates the targets' positions around the pillar.

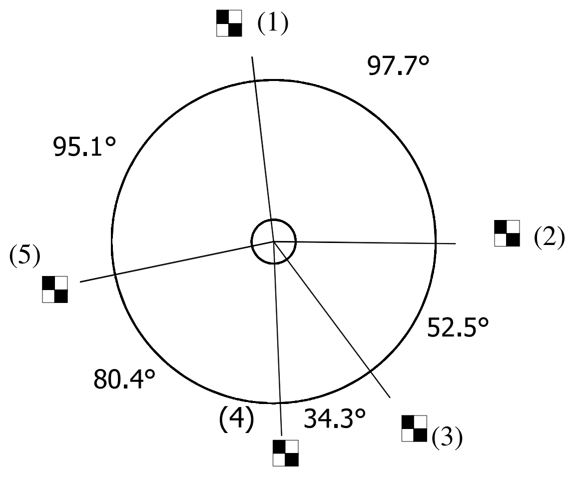


Figure 5. The targets' positions around the pillar in the external network

The two instruments were put successively on the pillar on the forced centering base and indispensable measurements on the five targets were carried out. The results appear in table 2 for each instrument.

Instrument	$S_{ISO-THEO-Hz}$ (cc)	σ_0 (cc)	Control
Leica TDM 5000	1.41	1.5	$1.41^{cc} \leq 1.5^{cc} \cdot 1.32 \Rightarrow 1.41^{cc} \leq 1.98^{cc}$
Trimble DR^{+} 5605	5.25	15	$5.25^{cc} \leq 15^{cc} \cdot 1.32 \Rightarrow 5.25^{cc} \leq 19.8^{cc}$

Table 2. The results of the DIN `18723 test for the horizontal angles at the external network

If the above inequality is not true, then the hypothesis is rejected. If the inequality is true then the industrial prescribed accuracy will be succeeded by probability 95%. It must always be taken into consideration that the probability to achieve this accuracy in the fieldwork measurements depends on the proper operation conditions and the skill of the user. The time needed for this test is about one hour for each instrument.

3.2.2 DIN `18723 test for the vertical angles

The measurements were carried out according to the DIN `18723 procedure on a vertical rod. Sightings on the rod, at equal distances were done on I and II telescope faces. There were carried out four measurement sets with each instrument. The measurements were also registered on the rod when the vertical angle indication on the instrument's display was 100^g and 300^g (X_1) as the slope distance X_2 between the instrument position and the rod was measured.
The calculations of the measurements were carried out according to the previous analyzed methodology. The confidence interval is defined 1- α = 0.95 and the freedom degree is calculated F = 30.
In table 3 appear the results for each instrument

Instrument	$S_{ISO-THEO-V}$ (cc)	σ_0 (cc)	Control
Leica TDM 5000	1.80	1.5	$1.80^{cc} \leq 1.5^{cc} \cdot 1.208 \Rightarrow 1.80^{cc} \leq 1.81^{cc}$
Trimble DR^{+} 5605	13.6	15	$13.6^{cc} \leq 15^{cc} \cdot 1.208 \Rightarrow 13.6^{cc} \leq 18.12^{cc}$

Table 3. The results of the DIN `18723 test for the vertical angles

As the above inequality is true the industrial prescribed accuracy for each instrument may be succeeded.
The required time for this test is about one hour for each instrument.

4. Conclusion

- Both instruments passed all the tests successfully.
- The use of an instrument on site has many differences compared to its use in the laboratory. The user has to pay attention and keep strictly the setting rules and all the conditions for the proper function of the instrument. Further more the experience and the skill of the observer are very important.
- All the above mentioned tests are indispensable before the use of a total station in the fieldworks.
- The success in the above tests and the industrial prescribed precision of an instrument cannot insure the measurements accuracy if the use of the instrument on site (centering, leveling, etc.) is careless.

- The permanent establishment of an internal and an external control network help the easiness and the quickness of these tests, which must be repeatable.
- The 4 hours needed for all these tests is not a waste of time, as they are very significant and gives the opportunity to insure the credibility of the measurements by the presupposition of the proper setting and use of the instrument.

References

1. Balodimos, D-D, Stathas, D., Arabatzi, O., *Geodesy: Networks-Detailing Procedures-Setting out procedures*, Athens, 2000, N.T.U.A. Edition.
2. Jackson P. *Wild instruments for optical tooling and for precise measurements in industry and laboratories: with special emphasis on autocollimation equipment*, Wild Heerbrugg Ltd., Switzerland.
3. Leica Heerbrugg AG, *Users manual for TM 5000/ TDM 5000 system*, V2.2, Switzerland, 1997.
4. *Optics and optical instruments – Geodetic instruments. Field procedures for determining accuracy. ISO/DIS 12857 – 2 (theodolites). ISO/DIS 12857 – 3 (EDM instruments)*
5. Trimble Navigation, *Operation Manual for DR^{+} 5605,* 2003.

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