INTERNATIONAL STANDARD

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Optics and optical instruments — Geodetic instruments — Field procedures for determining accuracy —

Part 2:
Theodolites

Optique et instruments d'optique — Instruments géodésiques — Méthodes de détermination sur site de la précision —

Partie 2: Théodolites

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 12857-2 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 6, *Geodetic and surveying instruments.*

ISO 12857 consists of the following parts, under the general title *Optics and optical instruments — Geodetic instruments — Field procedures for determining accuracy*:

— *Part 1: Levels*

— *Part 2: Theodolites*

— *Part 3: Electro-optical distance meters (EDM instruments)*

Annexes A and B of this part of ISO 12857 are for information only.

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Optics and optical instruments — Geodetic instruments — Field procedures for determining accuracy —

Part 2:
Theodolites

1 Scope

This part of ISO 12857 specifies field procedures to be adopted when determining and assessing the accuracy of theodolites used in surveying.

These tests are intended to be operational and not tests for acceptance or performance.

The procedures are applicable to the determination of the accuracy of different instruments at one time or of one instrument at different times.

The field procedures can be applied everywhere without the need of special ancillary equipment and are designed to minimize atmospheric influences.

NOTE — Other International Standards for testing measuring instruments for building construction are available.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 12857. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 12857 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 3534-1:1993, *Statistics — Vocabulary and symbols — Part 1: Probability and general statistical terms*

ISO 9849:1991, *Optics and optical instruments — Geodetic instruments — Vocabulary*

3 Definitions

For the purposes of this part of ISO 12857, the terms and definitions given in ISO 3534-1 and ISO 9849 apply.

4 General

The theodolite and its ancillary equipment shall be in known and acceptable states of adjustment by the user according to methods specified in the manufacturers' handbooks.

The accuracy of theodolites is expressed in terms of the standard deviation of a horizontal direction (HZ), observed once in both face positions of the telescope, or of a vertical angle (V) observed once in both face positions of the telescope.

The test procedures given in this part of ISO 12857 are intended for determining the standard deviations $s_{\text{ISO-THEO-HZ}}$ and $s_{\text{ISO-THEO-V}}$.

Statistical tests should be applied to determine whether the standard deviation s obtained belongs to the population of the instrumentation's standard deviation, whether two tested samples belong to the same population, or whether the index correction o of the vertical circle is zero.

5 Procedures

5.1 Measurement of horizontal directions

5.1.1 General

The following field procedures shall be adopted for determining the accuracy of theodolites for horizontal directions, by a single survey team with a single instrument and its ancillary equipment.

The results of these tests are influenced by meteorological conditions. These conditions will include different air temperatures and pressures, wind speed, cloud cover and visibility. An overcast sky guarantees the most favourable weather conditions. Tests performed in laboratories would provide results which are almost unaffected by atmospheric influences, but the costs for such tests are very high and therefore they are not practicable for most users.

5.1.2 Test configuration

Five targets shall be set up located in approximately the same horizontal plane as the instrument, between 100 m and 250 m away, and situated at intervals around the horizon as regular as possible. Targets shall be used that can be observed unmistakably, preferably target plates.

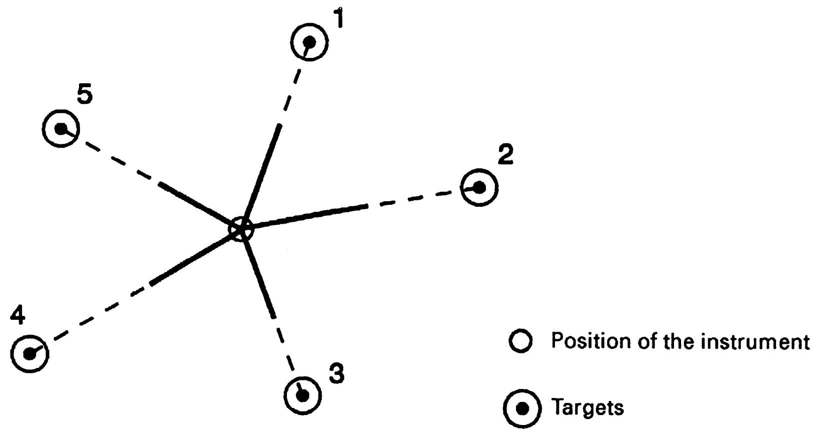

Figure 1 — Test configuration

5.1.3 Observations

Four series of observations shall be performed. The observations shall be carried out under various but not extreme weather conditions. Each series (k) of observations shall consist of three sets (j) of directions to the five targets (i).

The five targets shall be observed in each set in face position I of the telescope in a clockwise sequence (1), (2), (3), (4), (5), and in face position II of the telescope in an anticlockwise sequence (5), (4), (3), (2), (1). The graduated circle shall be changed for 60° (67 gon) after each set. If physical rotation of the graduated circle is not possible, e.g. for electronic theodolites, the lower part of the theodolite may be turned approximately 120° (133 gon) on the tribrach.

5.1.4 Calculations

The evaluation of the measured values is an adjustment of observation equations. Within a series of observations k, one direction is marked by $r_{i,j,\mathrm{I}}$ or $r_{i,j,\mathrm{II}}$, the index i being the target and the index j being the number of the set. I or II points out the face position of the telescope. Each series of observations is evaluated separately.

First of all the mean values

$$r_{i,j} = \frac{r_{i,j,\mathrm{I}} + r_{i,j,\mathrm{II}} \pm 200\,\mathrm{gon}}{2} \; ; \; i = 1,2,3,4,5 \; ; \; j = 1,2,3$$

of the readings in both face positions I and II of the telescope are calculated. By reduction into the direction to target No. 1 we obtain the results:

$$r'_{i,j} = r_{i,j} - r_{1,j}; \quad i = 1,2,3,4,5; \quad j = 1,2,3$$

The mean values of the directions resulting from three sets to target No. i are:

$$\bar{r}_i = \frac{r'_{i,1} + r'_{i,2} + r'_{i,3}}{3} \;;\; i = 1,2,3,4,5$$

From the differences

$$d_{i,j} = \bar{r}_i - r'_{i,j} \;;\; i = 1,2,3,4,5 \;;\; j = 1,2,3$$

we obtain for each set of observations the arithmetic mean values

$$\bar{d}_j = \frac{d_{1,j} + d_{2,j} + d_{3,j} + d_{4,j} + d_{5,j}}{5} \;;\; j = 1,2,3$$

from which the corrections result:

$$c_{i,j} = d_{i,j} - \bar{d}_j ; \; i = 1,2,3,4,5 ; \; j = 1,2,3$$

Except for the rounding errors, each set must meet the condition:

$$\sum_{i=1}^{5} c_{i,j} = 0 \;;\; j = 1,2,3$$

The square sum of the corrections of the series of observations No. k is:

$$cc_k = \sum_{j=1}^{3} \sum_{i=1}^{5} c_{i,j}^2$$

For three sets of directions to five targets in each case the degree of freedom is:

$$f_k = (3-1) \cdot (5-1) = 8$$

and the standard deviation s_k of a direction $r_{i,j}$, taken in one set of the series of observations No. k, amounts to:

$$s_k = \sqrt{\frac{cc_k}{f_k}} = \sqrt{\frac{cc_k}{8}}$$

The standard deviation s_0 of a horizontal direction observed in one set (arithmetic mean of the readings in both face positions of the telescope) according to this part of ISO 12857, calculated from all four series of observations at a degree of freedom of

$$f = 4; \; f_k = 32$$

amounts to:

$$s_0 = \sqrt{\frac{\sum_{k=1}^{4} cc_k}{f}} = \sqrt{\frac{\sum_{k=1}^{4} cc_k}{32}}$$

$$s_{\text{ISO-THEO-HZ}} = s_0$$

5.1.5 Statistical tests

For interpretation of the results, statistical tests shall be carried out using the standard deviation s_0 of a horizontal direction observed in one set in order to answer the following questions.

A) Is the calculated standard deviation $s_{\text{ISO-THEO-HZ}}$ smaller than the value σ_0 stated by the manufacturer or smaller than another predetermined value σ_0 ?

B) Do two standard deviations s_1 and s_2, as determined from two different samples of measurements, belong to the same population, assuming that both samples have the same degree of freedom f?

The standard deviations s_1 and s_2 may be obtained from:

- two series of measurements by the same instrument but different observers;
- two series of measurements by the same instrument at different times;
- two series of measurements by different instruments.

Table 1 - Statistical tests

Question	Null hypothesis	Alternative hypothesis
A	$s_0 \leq \sigma_0$	$s_0 > \sigma_0$
B	$\sigma_1 = \sigma_2$	$\sigma_1 \neq \sigma_2$

For the following tests a confidence level of $1-\alpha = 0{,}95$ and according to the design of measurements a degree of freedom f = 32 are assumed.

A) The null hypothesis stating that the empirically determined standard deviation s_0 is smaller than or equal to a theoretical or predetermined value σ_0 is not rejected if the following condition is fulfilled:

$$s_0 \leq \sigma_0 \cdot \sqrt{\frac{\chi^2_{f,1-\alpha}}{f}}$$

$$s_0 \leq \sigma_0 \cdot \sqrt{\frac{\chi^2_{32;0,95}}{32}}$$

$$\chi^2_{32;0,95} = 46{,}19$$

$$s_0 \leq \sigma_0 \cdot \sqrt{\frac{46{,}19}{32}}$$

$$s_0 \leq \sigma_0 \cdot 1{,}20$$

Otherwise, the null hypothesis is rejected.

B) In the case of two different samples No. 1 and No. 2, a test indicates whether the estimated standard deviations s_1 and s_2 belong to the same population. The corresponding null hypothesis $\sigma_1 = \sigma_2$ is not rejected if the following condition is fulfilled:

$$\frac{1}{F_{f,f,1-\alpha/2}} \leq \frac{s_1^2}{s_2^2} \leq F_{f,f,1-\alpha/2}$$

$$\frac{1}{F_{32;32;0,975}} \leq \frac{s_1^2}{s_2^2} < F_{32;32;0,975}$$

$$F_{32;32;0,975} = 2,02$$

$$0,49 \leq \frac{s_1^2}{s_2^2} \leq 2,02$$

Otherwise, the null hypothesis is rejected.

The degree of freedom and, thus, the corresponding test values $\chi^2_{f,\,1-\alpha}$ and $F_{f_1,f_2,\,1-\alpha 2}$ (taken from reference books on statistics) change if a different number of observations is analysed.

5.2 Measurements of vertical angles

5.2.1 General

The following field procedures shall be adopted for determining the accuracy of theodolites for vertical angles measured by a single survey team with a single instrument and its ancillary equipment.

The results of these tests are influenced by meteorological conditions. These conditions will include different air temperatures and pressures, wind speed, cloud cover and visibility. An overcast sky guarantees the most favourable weather conditions. Tests performed in laboratories would provide results which are almost unaffected by atmospheric influences, but the costs for such tests are very high and therefore they are not practicable for most users.

5.2.2 Test configuration

A precision invar levelling staff shall be set up vertically in a fixed position by means of struts during every series of observations. When testing a theodolite with a resolution of 3" (1 mgon) the distance x_2 should be approx. 5 m, and for theodolites with a resolution of 1" (0,3 mgon) approx. 15 m (see figure 2).

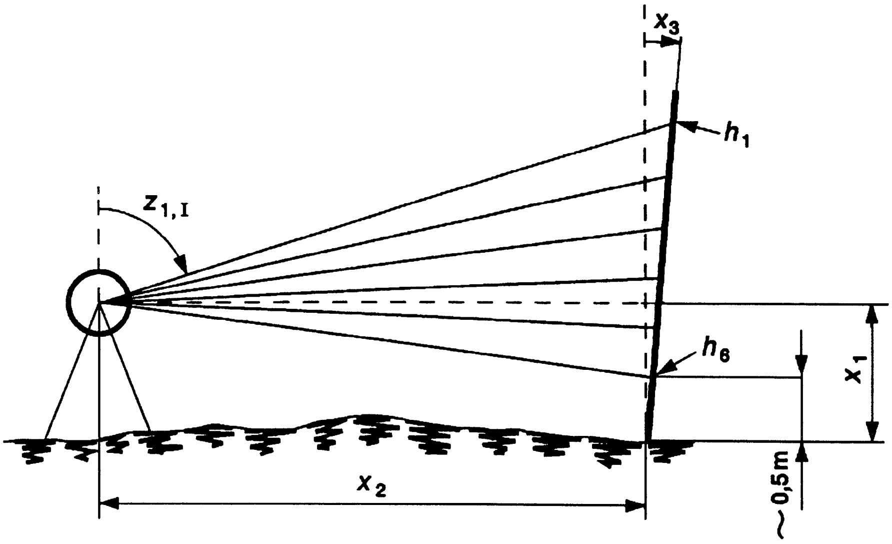

Figure 2 - Test configuration

5.2.3 Observations

In total four series of observations shall be carried out under various but not extreme weather conditions. The height difference between the instrument and the staff shall be varied in order to cover a larger range of the vertical circle.

Each series of observations (k) shall comprise twelve vertical angle (zenith angle) measurements taken to six graduation lines (i) on the precision invar staff, six angles in face position I and six angles in face position II of the telescope. The graduation lines shall be spread evenly over the staff, but sights near the ground shall be avoided.

5.2.4 Calculations

The evaluation of the measured angles is an adjustment of observation equations. Within a series of observations No. k, one zenith angle is denoted by $z_{i,I}$ or $z_{i,II}$, the index i being the graduation line. I or II points out the face position of the telescope. Each series of observations is evaluated separately.

NOTE – For facilitating the following calculations, a suitable computer program is given in Annex B of this part of ISO 12857.

In the calculations all distances are in centimetres. The units of the observations z depend on the type of the theodolite. If the reading is centesimal grades (gon) then we take for ρ = 200 gon/π . If the reading is sexagesimal degrees (°), then we take $\rho = 180°/\pi$.

The non-linear observation equations of the adjustment are for measurement in face position I

$$z_{i,\mathrm{I}} + c_{i,\mathrm{I}} + o = \rho \cdot \left(\frac{\pi}{2} - \arctan\left(\frac{h_i \cdot \cos x_3 - x_1}{x_2 + h_i \cdot \sin x_3} \right) \right); \qquad i = 1, \dots ,6$$

and for measurements in face position II

$$z_{i,\mathrm{I}} + c_{i,\mathrm{I}} + o = \rho \cdot \left(\frac{3\pi}{2} + \arctan\left(\frac{h_i \cdot \cos x_3 - x_1}{x_2 + h_i \cdot \sin x_3} \right) \right); \qquad i = 1, \dots ,6$$

where

- o is the unknown index correction (orientation of the vertical circle);
- x_1 is the height of the tilting axis of the theodolite, related to the zero-point of the levelling staff;
- x_2 is the distance of the theodolite from the levelling staff;
- x_3 is the inclination of the levelling staff against the vertical direction (angle between the zenith and the levelling staff, this angle shall be the same over one series of observation).

Since the functional model is not linear in the three unknown parameters x_1 , x_2 and x_3, it is necessary to determine approximate values x_1^0 and x_2^0. The approximate value for x_3 is zero. x_1^0 and x_2^0 should be measured directly. Alternatively, they can be determined by measurements in face I to the upper line h_1 and to the lowest line h_6 of the graduation:

$$x_1^0 = h_6 - \cos z_{6,\mathrm{I}} \cdot \frac{(h_1 - h_6) \cdot \sin z_{1,\mathrm{I}}}{\sin(z_{6,\mathrm{I}} - z_{1,\mathrm{I}})}$$

$$x_2^0 = \sin z_{6,\mathrm{I}} \cdot \frac{(h_1 - h_6) \cdot \sin z_{1,\mathrm{I}}}{\sin(z_{6,\mathrm{I}} - z_{1,\mathrm{I}})}$$

In order to get normal equations with appropriate units, we use in the following linearized observation equations for the two angles to graduation line No. i a scaling factor fa, which is for centesimal grades $fa = 100$ and for sexagesimal degrees $fa = 60$:

$$c_{i,\mathrm{I}} = -o + a_{i,1}dx_1 + a_{i,2}dx_2 - a_{i,3}x_3 - l_{i,\mathrm{I}}$$

$$c_{i,\mathrm{II}} = -o - a_{i,1}dx_1 - a_{i,2}dx_2 - a_{i,3}x_3 - l_{i,\mathrm{II}}$$

with

$$a_{i,1} = \mathrm{r} \cdot \frac{x_2^0}{(h_i - x_1^0)^2 + (x_2^0)^2} \cdot fa$$

$$a_{i,2} = \mathrm{r} \cdot \frac{h_i - x_1^0}{(h_i - x_1^0)^2 + (x_2^0)^2} \cdot fa$$

$$a_{i,3} = \frac{h_i \cdot a_{i,2}}{\mathrm{r}}$$

$$l_{i,\mathrm{I}} = \left(z_{i,\mathrm{I}} - \mathrm{r} \cdot \left(\frac{\mathrm{p}}{2} - \arctan \frac{h_i - x_1^0}{x_2^0} \right) \right) \cdot fa$$

$$l_{i,\mathrm{II}} = \left(z_{i,\mathrm{II}} - \mathrm{r} \cdot \left(\frac{3\mathrm{p}}{2} + \arctan \frac{h_i - x_1^0}{x_2^0} \right) \right) \cdot fa$$