INTERNATIONAL STANDARD

ISO 17123-3

First edition
2001-12-01

Optics and optical instruments — Field procedures for testing geodetic and surveying instruments —

Part 3: Theodolites

Optique et instruments d'optique — Méthodes d'essai sur site des instruments géodésiques et d'observation —

Partie 3: Théodolites

Reference number
ISO 17123-3:2001(E)

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Printed in Switzerland

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

Attention is drawn to the possibility that some of the elements of this part of ISO 17123 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 17123-3 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 6, *Geodetic and surveying instruments*.

This first edition of ISO 17123-3 cancels and replaces ISO 8322-4:1991 and ISO 12857-2:1997, which have been technically revised.

ISO 17123 consists of the following parts, under the general title *Optics and optical instruments — Field procedures for testing geodetic and surveying instruments*:

— *Part 1: Theory*

— *Part 2: Levels*

— *Part 3: Theodolites*

— *Part 4: Electro-optical distance meters (EDM instruments)*

— *Part 5: Electronic tacheometers*

— *Part 6: Rotating lasers*

— *Part 7: Optical plumbing instruments*

Annexes A, B and C of this part of ISO 17123 are for information only.

Optics and optical instruments — Field procedures for testing geodetic and surveying instruments —

Part 3: **Theodolites**

1 Scope

This part of ISO 17123 specifies field procedures to be adopted when determining and evaluating the precision (repeatability) of theodolites and their ancillary equipment when used in building and surveying measurements. Primarily, these tests are intended to be field verifications of the suitability of a particular instrument for the immediate task at hand and to satisfy the requirements of other standards. They are not proposed as tests for acceptance or performance evaluations that are more comprehensive in nature.

This part of ISO 17123 can be thought of as one of the first steps in the process of evaluating the uncertainty of a measurement (more specifically a measurand). The uncertainty of a result of a measurement is dependent on a number of factors. These include among others: repeatability (precision), reproducibility (between day repeatability), traceability (an unbroken chain to national standards) and a thorough assessment of all possible error sources, as prescribed by the ISO Guide to the expression of uncertainty in measurement (GUM).

These field procedures have been developed specifically for *in situ* applications without the need for special ancillary equipment and are purposefully designed to minimize atmospheric influences.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 17123. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 17123 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

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

ISO 7077, *Measuring methods for building — General principles and procedures for the verification of dimensional compliance*

ISO 7078, *Building construction — Procedures for setting out, measurement and surveying — Vocabulary and guidance notes*

ISO 9849, *Optics and optical instruments — Geodetic and surveying instruments — Vocabulary*

ISO 17123-1, *Optics and optical instruments — Field procedures for testing geodetic and surveying instruments — Part 1: Theory*

GUM, *Guide to the expression of uncertainty in measurement*

VIM, *International vocabulary of basic and general terms in metrology*

3 Terms and definitions

For the purposes of this part of ISO 17123, the terms and definitions given in ISO 3534-1, ISO 4463-1, ISO 7077, ISO 7078, ISO 9849, ISO 17123-1, GUM and VIM apply.

4 General

4.1 Requirements

Before commencing surveying, it is important that the operator investigates that the precision in use of the measuring equipment is appropriate to the intended measuring task.

The theodolite and its ancillary equipment shall be in known and acceptable states of permanent adjustment according to the methods specified in the manufacturer's handbook, and used with tripods as recommended by the manufacturer.

The results of these tests are influenced by meteorological conditions, especially by the gradient of temperature. An overcast sky and low wind speed guarantee the most favourable weather conditions. The particular conditions to be taken into account may vary depending on where the tasks are to be undertaken. Note should also be taken of the actual weather conditions at the time of measurement and the type of surface above which the measurements are made. The conditions chosen for the tests should match those expected when the intended measuring task is actually carried out (see ISO 7077 and ISO 7078).

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. In addition, laboratory tests yield precisions much higher than those that can be obtained under field conditions.

The measure of precision of theodolites is expressed in terms of the experimental standard deviation (root mean square error) 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.

This part of ISO 17123 describes two different field procedures both for the measurement of horizontal directions and vertical angles as given in clauses 5 and 6. The operator shall choose the procedure which is most relevant to the project's particular requirements.

4.2 Procedure 1: Simplified test procedure

The simplified test procedure provides an estimate as to whether the precision of a given theodolite is within the specified permitted deviation, according to ISO 4463-1.

This test procedure is normally intended for checking whether the measure of precision in use of the measuring equipment in conjunction with its operator is appropriate to carry out the measurement to the specified measure of precision requirement.

This simplified test procedure is based on a limited number of measurements and, therefore, the experimental standard deviation calculated can only be indicative of the order of the measure of precision achievable in common use. If a more precise assessment of the measuring instrument and its ancillary equipment under field conditions is required, it is recommended to adopt the more rigorous full test procedure. Statistical tests based on the simplified test procedure are not proposed.

4.3 Procedure 2: Full test procedure

The full test procedure shall be adopted to determine the best achievable measure of precision of a particular theodolite and its ancillary equipment under field conditions.

The full test procedure is intended for determining the experimental standard deviation of a horizontal direction or a vertical angle observed once in both face positions of the telescope:

$s_{\text{ISO-THEO-HZ}}$ and $s_{\text{ISO-THEO-V}}$

Further, this procedure may be used to determine:

— the measure of precision in use of theodolites by a single survey team with a single instrument and its ancillary equipment at a given time;

— the measure of precision in use of a single instrument over time;

— the measure of precision in use of each of several theodolites in order to enable a comparison of their respective achievable precisions to be obtained under similar field conditions.

Statistical tests should be applied to determine whether the experimental standard deviation, s, obtained belongs to the population of the instrumentation's theoretical standard deviation, σ, whether two tested samples belong to the same population and whether the vertical index error, δ, is equal to zero or has not changed (see 5.4 and 6.4).

5 Measurement of horizontal directions

5.1 Configuration of the test field

Fixed targets (4 targets for the simplified test procedure and 5 targets for the full test procedure) shall be set up located approximately in the same horizontal plane as the instrument, between 100 m to 250 m away, and situated at intervals around the horizon as regular as possible. Targets shall be used which can be observed unmistakably, preferably target plates.

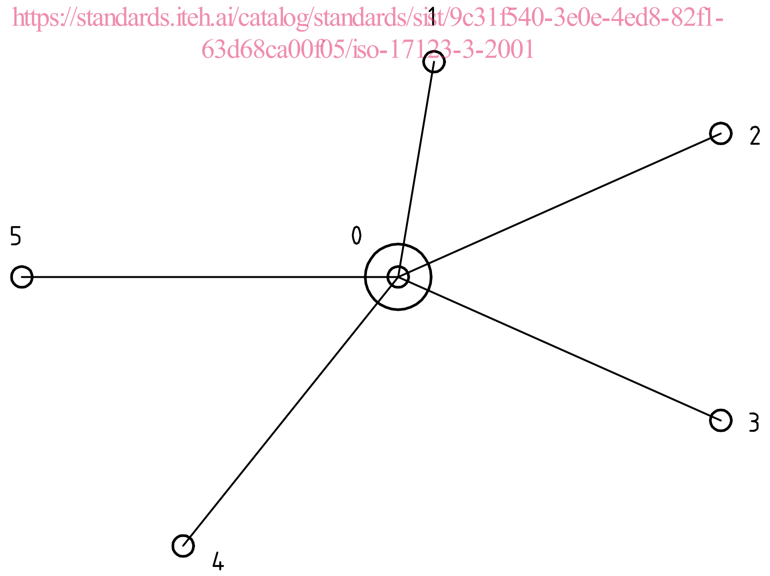

Figure 1 — Test configuration for measurement of horizontal directions

5.2 Measurements

For the simplified test procedure, $m = 1$ series of measurements shall be taken.

For the full test procedure, $m = 4$ series of measurements shall be taken under various but not extreme weather conditions.

Each series (i) of measurements shall consist of $n = 3$ sets (j) of directions to the $t = 4$ or $t = 5$ targets (k).

For the full test procedure, when setting up the theodolite for different series of measurements, special care shall be taken when centring above the ground point. Achievable accuracies of centring expressed in terms of experimental standard deviations are the following:

— plumb bob: 1 mm to 2 mm (worse in windy weather),

— optical or laser plummet: 0,5 mm (the adjustment shall be checked according to the manufacturer's handbook),

— centring rod: 1 mm.

NOTE With targets at 100 m distance, a miscentring of 2 mm could affect the observed direction by up to $4''$(1,3 mgon). The shorter the distance, the greater the effect.

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

5.3 Calculation

5.3.1 Simplified test procedure

The evaluation of the measured values is a least squares adjustment of observation equations. One direction is marked by $x_{j,k,\mathrm{I}}$ or $x_{j,k,\mathrm{II}}$, the index j being the number of the set and the index k being the number of the target. I and II indicate the face position of the telescope.

First of all, the mean values of the readings in both face positions I and II of the telescope are calculated:

$$x_{j,k} = \frac{x_{j,k,\mathrm{I}} + x_{j,k,\mathrm{II}} \pm 180^\circ}{2} \left(= \frac{x_{j,k,\mathrm{I}} + x_{j,k,\mathrm{II}} \pm 200\ \mathrm{gon}}{2} \right); \quad j = 1,\ 2,\ 3; \quad k = 1,\ \ldots,\ 4 \tag{1}$$

Reduction into the direction of the target No. 1 results in:

$$x'_{j,k} = x_{j,k} - x_{j,1}; \quad j = 1,\ 2,\ 3; \quad k = 1,\ \ldots,\ 4 \tag{2}$$

The mean values of the directions resulting from $n = 3$ sets to target No. k are:

$$\overline{x}_k = \frac{x'_{1,k} + x'_{2,k} + x'_{3,k}}{3}; \quad k = 1,\ \ldots,\ 4 \tag{3}$$

From the differences

$$d_{j,k} = \overline{x}_k - x'_{j,k}; \quad j = 1,\ 2,\ 3; \quad k = 1,\ \ldots,\ 4 \tag{4}$$

for each set of measurements the arithmetic mean values result in:

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

from which the residuals result:

$$r_{j,k} = d_{j,k} - \overline{d}_j; \quad j = 1,\ 2,\ 3; \quad k = 1,\ \ldots,\ 4 \tag{6}$$

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

$$\sum_{k=1}^{4} r_{j,k} = 0; \quad j = 1, 2, 3 \tag{7}$$

The sum of squares of the residuals is:

$$\Sigma r^2 = \sum_{j=1}^{3}\sum_{k=1}^{4} r_{j,k}^2 \tag{8}$$

For $n = 3$ sets of directions to $t = 4$ targets the number of degrees of freedom is:

$$\nu = (3 - 1) \times (4 - 1) = 6 \tag{9}$$

and the experimental standard deviation s of a direction $x_{j,k}$ taken in one set observed in both face positions of the telescope amounts to:

$$s = \sqrt{\frac{\Sigma r^2}{\nu}} = \sqrt{\frac{\Sigma r^2}{6}} \tag{10}$$

5.3.2 Full test procedure

The evaluation of the measured values is an adjustment of observation equations. Within the i^{th} series of measurements, one direction is marked by $x_{j,k,\text{I}}$ or $x_{j,k,\text{II}}$, the index j being the number of the set and the index k being the target. I and II indicate the face position of the telescope. Each of the $m = 4$ series of measurements shall be evaluated separately.

First of all, the mean values

$$x_{j,k} = \frac{x_{j,k,\text{I}} + x_{j,k,\text{II}} \pm 180^\circ}{2} \left(= \frac{x_{j,k,\text{I}} + x_{j,k,\text{II}} \pm 200 \text{ gon}}{2} \right); \quad j = 1, 2, 3; \quad k = 1, \ldots, 5 \tag{11}$$

of the readings in both face positions I and II of the telescope are calculated. Reduction into the direction of the target No. 1 results in:

$$x'_{j,k} = x_{j,k} - x_{j,1}; \quad j = 1, 2, 3; \quad k = 1, \ldots, 5 \tag{12}$$

The mean values of the directions resulting from $n = 3$ sets to target No. k are:

$$\overline{x}_k = \frac{x'_{1,k} + x'_{2,k} + x'_{3,k}}{3}; \quad k = 1, \ldots, 5 \tag{13}$$

From the differences

$$d_{j,k} = \overline{x}_k - x'_{j,k}; \quad j = 1, 2, 3; \quad k = 1, \ldots, 5 \tag{14}$$

for each set of measurements, the arithmetic mean values result in:

$$\overline{d}_j = \frac{d_{j,1} + d_{j,2} + d_{j,3} + d_{j,4} + d_{j,5}}{5}; \quad j = 1, 2, 3 \tag{15}$$

from which the residuals result:

$$r_{j,k} = d_{j,k} - \overline{d}_j; \quad j = 1, 2, 3; \quad k = 1, \ldots, 5 \tag{16}$$

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

$$\sum_{k=1}^{5} r_{j,k} = 0; \quad j = 1,\ 2,\ 3 \tag{17}$$

The sum of squares of the residuals of the i^{th} series of measurements is:

$$\Sigma r_i^2 = \sum_{j=1}^{3}\sum_{k=1}^{5} r_{j,k}^2 \tag{18}$$

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

$$\nu_i = (3 - 1) \times (5 - 1) = 8 \tag{19}$$

and the experimental standard deviation s_i of a direction $x_{j,k}$ taken in one set observed in both face positions of the telescope, valid for the i^{th} series of measurements amounts to:

$$s_i = \sqrt{\frac{\Sigma r_i^2}{\nu_i}} = \sqrt{\frac{\Sigma r_i^2}{8}} \tag{20}$$

The experimental standard deviation, s, 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 17123, calculated from all $m = 4$ series of measurements at a degree of freedom of

$$\nu = 4 \times \nu_i = 32 \tag{21}$$

amounts to:

$$s = \sqrt{\frac{\sum_{i=1}^{4} \Sigma r_i^2}{\nu}} = \sqrt{\frac{\sum_{i=1}^{4} \Sigma r_i^2}{32}} = \sqrt{\frac{\sum_{i=1}^{4} s_i^2}{4}} \tag{22}$$

$$s_{\text{ISO-THEO-HZ}} = s \tag{23}$$

5.4 Statistical tests

5.4.1 General

Statistical tests are recommended for the full test procedure only.

For the interpretation of the results, statistical tests shall be carried out using the experimental standard deviation, s, of a horizontal direction observed in one set in both face positions of the telescope in order to answer the following questions:

a) Is the calculated experimental standard deviation, s, smaller than the value, σ, stated by the manufacturer or smaller than another predetermined value, σ?

b) Do two experimental standard deviations, s and $\widetilde{s}$, as determined from two different samples of measurements, belong to the same population, assuming that both samples have the same degree of freedom, ν?

The experimental standard deviations, s and $\widetilde{s}$, may be obtained from:

— two samples of measurements by the same instrument but different observers;

— two samples of measurements by the same instrument at different times;

— two samples of measurements by different instruments.

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

Table 1 — Statistical tests

Question	Null hypothesis	Alternative hypothesis
a)	$s \leqslant \sigma$	$s > \sigma$
b)	$\sigma = \widetilde{\sigma}$	$\sigma \neq \widetilde{\sigma}$

5.4.2 Question a)

The null hypothesis stating that the experimental standard deviation, s, of a horizontal direction observed in both positions is smaller than or equal to a theoretical or a predetermined value, σ, is not rejected if the following condition is fulfilled:

$$s \leqslant \sigma \times \sqrt{\frac{\chi^2_{1-\alpha}(\nu)}{\nu}} \tag{24}$$

$$s \leqslant \sigma \times \sqrt{\frac{\chi^2_{0,95}(32)}{32}} \tag{25}$$

$$\chi^2_{0,95}(32) = 46{,}19 \tag{26}$$

$$s \leqslant \sigma \times \sqrt{\frac{46{,}19}{32}} \tag{27}$$

$$s \leqslant \sigma \times 1{,}20 \tag{28}$$

Otherwise, the null hypothesis is rejected.

5.4.3 Question b)

In the case of two different samples, a test indicates whether the experimental standard deviations, s and $\widetilde{s}$, belong to the same population. The corresponding null hypothesis, $\sigma = \widetilde{\sigma}$, is not rejected if the following condition is fulfilled:

$$\frac{1}{F_{1-\alpha/2}(\nu,\nu)} \leqslant \frac{s^2}{\widetilde{s}^2} \leqslant F_{1-\alpha/2}(\nu,\nu) \tag{29}$$

$$\frac{1}{F_{0,975}(32{,}32)} \leqslant \frac{s^2}{\widetilde{s}^2} \leqslant F_{0,975}(32{,}32) \tag{30}$$

$$F_{0,975}(32{,}32) = 2{,}02 \tag{31}$$

$$0{,}49 \leqslant \frac{s^2}{\widetilde{s}^2} \leqslant 2{,}02 \tag{32}$$

Otherwise, the null hypothesis is rejected.