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**ISO
17123-4**

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

Part 4:
Electro-optical distance meters (EDM measurements to reflectors)

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

Partie 4: Télémètres électro-optiques (mesurages MED avec réflecteurs)

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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 2.

The main task of technical committees is to prepare International Standards. 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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 17123-4 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 6, *Geodetic and surveying instruments*.

This second edition cancels and replaces the first edition (ISO 17123-4:2001), which has 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 measurements to reflectors)*
- *Part 5: Total stations*
- *Part 6: Rotating lasers*
- *Part 7: Optical plumbing instruments*
- *Part 8 : GNSS field measurement systems in real-time kinematic (RTK)*

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

Introduction

This part of ISO 17123 specifies field procedures for adoption when determining and evaluating the uncertainty of measurement results obtained by geodetic instruments and their ancillary equipment, when used in building and surveying measuring tasks. Primarily, these tests are intended to be field verifications of suitability of a particular instrument for the immediate task. They are not proposed as tests for acceptance or performance evaluations that are more comprehensive in nature.

The definition and concept of uncertainty as a quantitative attribute to the final result of measurement were developed mainly in the last two decades, even though error analysis has long been a part of all measurement sciences. After several stages, the CIPM (Comité Internationale des Poids et Mesures) referred the task of developing a detailed guide to ISO. Under the responsibility of the ISO Technical Advisory Group on Metrology (TAG 4), and in conjunction with six worldwide metrology organizations, a guidance document on the expression of measurement uncertainty was compiled with the objective of providing rules for use within standardization, calibration, laboratory, accreditation and metrology services. ISO/IEC Guide 98-3 was first published as the *Guide to the Expression of Uncertainty in Measurement* (GUM) in 1995.

With the introduction of uncertainty in measurement in ISO 17123 (all parts), it is intended to finally provide a uniform, quantitative expression of measurement uncertainty in geodetic metrology with the aim of meeting the requirements of customers.

ISO 17123 (all parts) provides not only a means of evaluating the precision (experimental standard deviation) of an instrument, but also a tool for defining an uncertainty budget, which allows for the summation of all uncertainty components, whether they are random or systematic, to a representative measure of accuracy, i.e. the combined standard uncertainty.

ISO 17123 (all parts) therefore provides, for each instrument investigated by the procedures, a proposal for additional, typical influence quantities, which can be expected during practical use. The customer can estimate, for a specific application, the relevant standard uncertainty components in order to derive and state the uncertainty of the measuring result.

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

Part 4:
Electro-optical distance meters (EDM measurements to reflectors)

1 Scope

This part of ISO 17123 specifies field procedures to be adopted when determining and evaluating the precision (repeatability) of electro-optical distance meters (EDM instruments) and their ancillary equipment when used in building and surveying measurements. This part of ISO 17123 is applicable to reflector-type EDM instruments only and is not designed to determine the precision of non-prism EDM types. 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 parameters. Therefore we differentiate between different measures of accuracy and objectives in testing, like repeatability, reproducibility (e.g. between day repeatability), and of course a thorough assessment of all possible error sources, as prescribed by ISO/IEC Guide 98-3 and by ISO 17123-1.

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 referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3534-1, *Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability*

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*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4463-1, ISO 7077, ISO 7078, ISO 9849, ISO 17123-1, ISO/IEC Guide 98-3 and ISO/IEC Guide 99 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 EDM instrument 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, forced centring equipment and reflectors as recommended by the manufacturer.

The results of these tests are influenced by meteorological conditions. These conditions will include variations in air temperature and air pressure. Actual meteorological data shall be measured in order to derive atmospheric corrections, which shall be added to the raw distances. The particular conditions to be taken into account may vary, depending on the location where the tasks are to be undertaken. These conditions shall include variations in air temperature, wind speed, degree of cloudiness and visibility. 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).

This part of ISO 17123 describes two different field procedures 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 EDM equipment is within the specified permitted deviation according to ISO 4463-1.

The simplified test procedure is based on a limited number of measurements. Therefore, a significant standard deviation and consequently standard uncertainty cannot be obtained. If a more precise assessment of the EDM instrument under field conditions is required, it is recommended to adopt the more rigorous full test procedure as given in Clause 6.

This test procedure relies on having a test field with distances which are accepted as true values. If such a test field is not available, it is necessary to determine the unknown distances, using an EDM instrument of higher accuracy than that investigated in this test procedure. If no EDM with higher accuracy is available, the full test procedure has to be applied.

4.3 Procedure 2: Full test procedure (Type A evaluation of standard uncertainty)

The full test procedure shall be adopted to determine the best achievable measure of precision of a particular EDM instrument and its ancillary equipment under field conditions, described by the operator.

The full test procedure is based on measurements of distances in all combinations on a test line without nominal values. The experimental standard deviation of a single distance measurement is determined from a least squares adjustment of the distances in all combinations. Scale errors of an EDM instrument cannot be detected by this procedure. But scale errors in general do not have any influence, neither on the experimental standard deviation, s, nor on the zero-point correction, δ. In order to determine the stability of the scale, the measuring frequency of the EDM instrument can be checked by means of a frequency meter.

The test procedure given in Clause 6 is intended for determining the measure of precision in use of a particular EDM instrument. This measure of precision in use is expressed in terms of the experimental standard deviation, s, of a single measured distance, which is considered the type A standard uncertainty:

$$s = u_{\text{ISO-EDM}}$$

Further, this procedure implies:

— the measure of precision in use of EDM instruments 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 EDM instruments 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 zero-point correction, δ, is equal to zero or equal to a predetermined value, δ_0 (see 6.4).

5 Simplified test procedure

5.1 Configuration of the test field

The test field shall consist of one permanently marked instrument station and four permanently mounted reflectors at typical distances for the usual working range of the particular EDM instrument (e.g. from 20 m to 200 m). If permanent mounting of the reflectors is not possible, then the ground points of the reflector stations should be indelibly marked.

In order to set up the test field, each distance shall be measured and meteorologically corrected at least three times using a higher accurate EDM instrument (see Figure 1) to eventually obtain a mean value. For this purpose, air temperature and air pressure have to be measured individually at the instrument and the target point very thoroughly in order to determine the necessary corrections of the mean values [1 ppm for any deviation of 1 °C in temperature and/or for any deviation of 3 hPa (3 mbar) in air pressure].

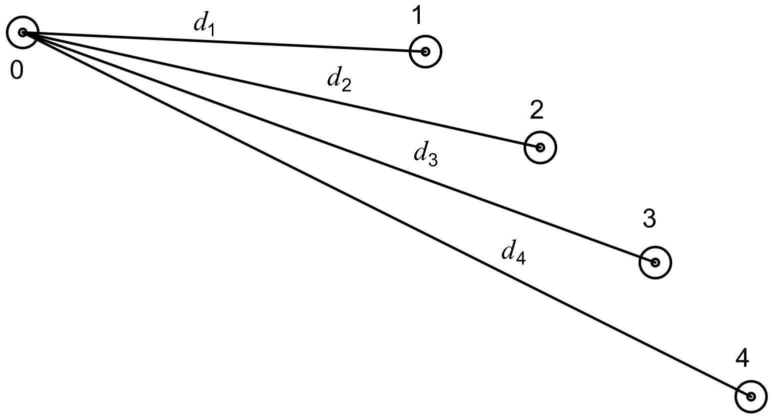

Figure 1 — Configuration of the test field for the simplified test procedure

The atmospherically corrected mean values of the four distances shall be considered to be true values:

$$\bar{x}_1 = d_1$$

$$\bar{x}_2 = d_2$$

$$\bar{x}_3 = d_3$$

$$\bar{x}_4 = d_4$$

5.2 Measurements

When setting up the EDM instrument, special care shall be taken when centring above the ground point.

Each distance shall be measured three times. Also, the air temperature and the air pressure shall be measured to derive the atmospheric corrections. The measured distances x_1, x_2, x_3, x_4 are the mean values of the three measurements corrected for atmospheric influences.

5.3 Calculation

All differences $\bar{x}_j = x_j$ shall be within the specified permitted deviation $\pm p$ (according to ISO 4463-1) for the intended measuring task. If p is not given, all differences shall be $\left|\bar{x}_j = x_j\right| \leq 2{,}5 \times s$, where s is the standard uncertainty $u_{\text{ISO-EDM}}$ of a single distance measurement, according to the full test procedure described in Clause 6.

If the differences $\left|\bar{x}_j - x_j\right|$ are too large for the intended task, it is necessary to make further investigations in order to identify the main sources of errors.

5.4 Further investigations

If all differences $\bar{x}_j = x_j$ have the same sign, then a systematic error is suspected. This can be an error of the zero-point correction or a scale error. If no source for the systematic error can be recognized, then it is recommended to carry out the full test procedure as given in Clause 6.

If a scale error is suspected, then the measuring frequency of the EDM instrument should be checked by means of a frequency meter, or the local service of the EDM manufacturer has to be contacted.

To check the zero-point correction, δ, a temporary baseline (about 50 m) consisting of three points on a straight line with an in-line tolerance of 3 cm should be established (see Figure 2). Three tripods with forced centring shall constitute the baseline.

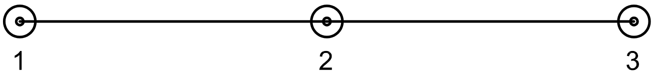

Figure 2 — Temporary baseline to check the zero-point correction

From the measured distances between the tripods, the zero-point correction is calculated

$$\delta = \overline{1{,}3} - \overline{1{,}2} - \overline{2{,}3} \tag{1}$$

where

δ	is the zero-point correction, and
$\overline{1{,}3}$; $\overline{1{,}2}$ and $\overline{2{,}3}$	are the measured distances between the three tripods.

6 Full test procedure

6.1 Configuration of the test line

A test configuration between 300 m and 600 m long with seven points on a straight line shall be established. The total line can also have an appropriate length to the distance of the intended use of the EDM (for line setup, see Figure 3). The points shall be stable during the test measurements.

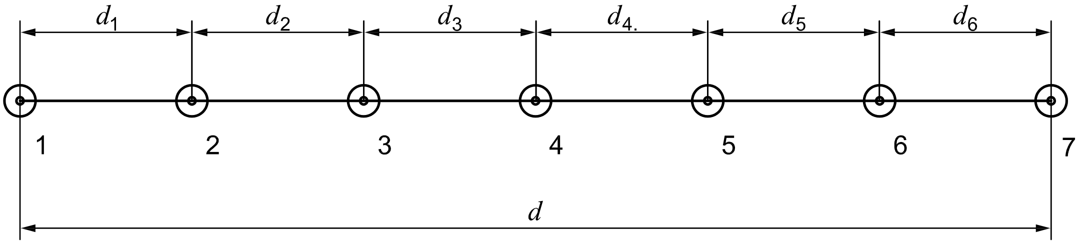

Figure 3 — Configuration of the test line for the full test procedure

A: Test line setup with 21 different distances

A good configuration of the test line will be achieved if the six distances d_1 to d_6 are selected in a way that all the 21 distances from the measurement combinations described in 6.2 are different.

The following procedure gives one way to derive the six distances between the seven points of the test line:

d is the total length of the projected test line;

$$d_1 = \frac{d}{63}, \quad d_2 = 2d_1 \tag{2}$$

$$d_3 = 4d_1, \quad d_4 = 8d_1$$

$$d_5 = 16d_1, \quad d_6 = 32d_1$$

B: Test line setup for EDM instruments to include possible cyclic errors in measured data

In order to obtain representative values for the experimental standard uncertainty, $u_{\text{ISO-EDM}}$, and the zero-point correction, δ, for EDMs with possible cyclic errors, the points of the test line shall be selected in such a way that the parts of the measured distances determined by phase measurements with the fine frequency are evenly distributed over the unit length (measuring scale) of the EDM instrument.

A good configuration will be achieved if the six distances between the seven points of the test line are derived by the following procedure:

$$\beta_0 = \frac{d - 6{,}5\lambda}{15} \tag{3}$$

where

d is the total length of the projected test line;

λ is the wavelength of the EDM instrument (derived from the EDM modulation frequency);

$\lambda/2$ is the unit length (measuring scale) of the EDM instrument.

and

$$\beta = \mu \times \lambda / 2 \tag{4}$$

Select an integer number μ in such a way that β approaches β_0 as close as possible,

with

$$\gamma = \frac{\lambda}{72} \tag{5}$$

the six distances of the test line and the whole length, d, are calculated:

$$d_1 = \lambda + \beta + 3\gamma \tag{6a}$$

$$d_2 = \lambda + 3\beta + 7\gamma \tag{6b}$$

$$d_3 = \lambda + 5\beta + 11\gamma \tag{6c}$$

$$d_4 = \lambda + 4\beta + 9\gamma \tag{6e}$$

$$d_5 = \lambda + 2\beta + 5\gamma \tag{6f}$$

$$d_6 = \lambda + \gamma \tag{6g}$$

$$d = 6\lambda + 15\beta + 36\gamma \tag{6h}$$

6.2 Measurements

All possible 21 distances between the seven points (see Figure 4) shall be measured on the same day. The forced centring interchange should be used to eliminate centring errors. All distances should be measured with a good return signal. The measurement of the distances should only be started when the visibility is good and a low insulation is to be expected. The air temperature and pressure should often be measured to ensure that reliable atmospheric corrections can be derived.

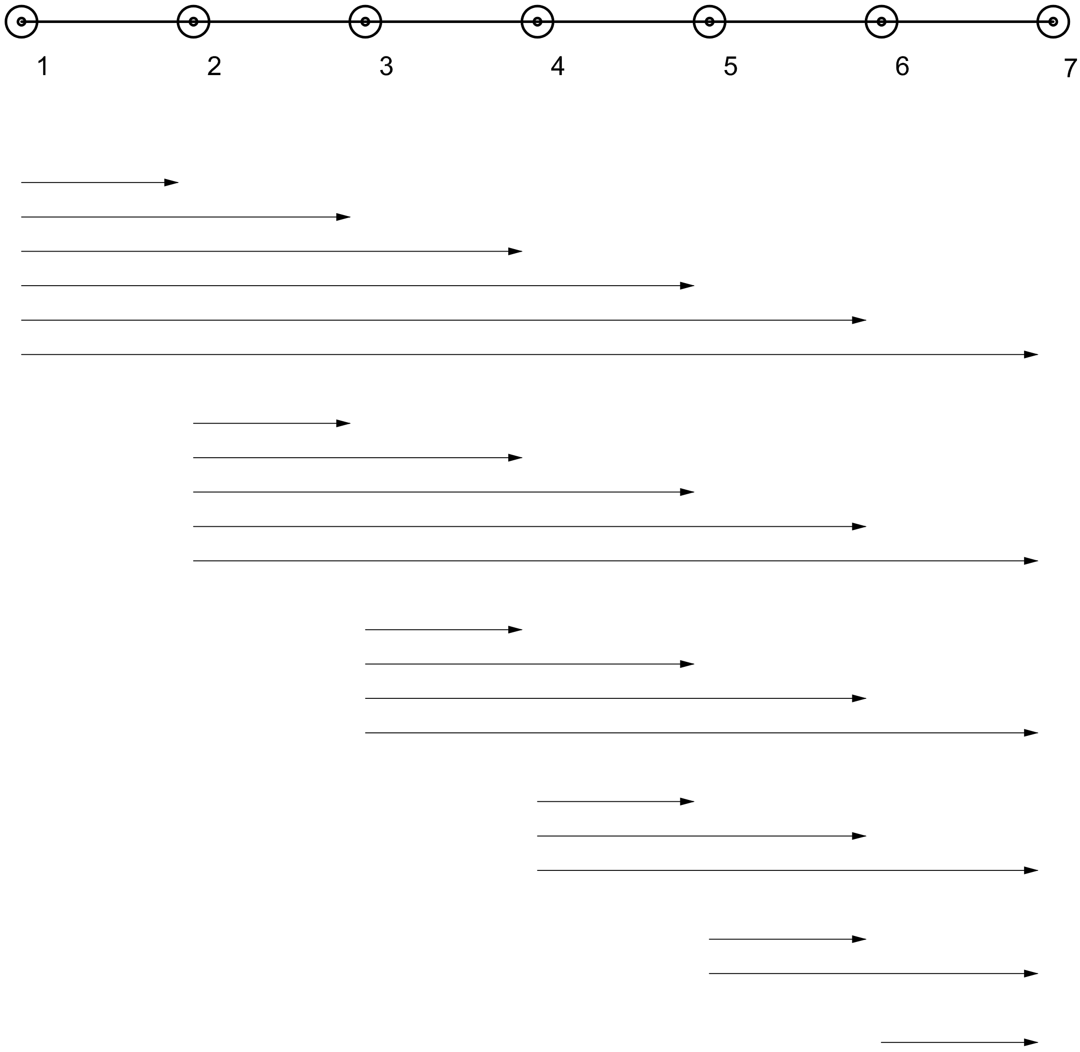

Figure 4 — Distances to be measured

6.3 Calculation

The measurements, $\tilde{x}_{p,q}$ (raw distances = readings on the EDM instrument), shall be corrected for systematic effects (atmospheric correction). These corrected values, $x_{p,q}$, are evaluated by a least square adjustment. Unknown parameters are the six distances $\bar{y}_{1,2}, \bar{y}_{2,3}, \bar{y}_{3,4}, \bar{y}_{4,5}, \bar{y}_{5,6}, \bar{y}_{6,7}$ and the zero-point correction δ.

The 21 observation formulae are:

$$x_{1,2} + r_{1,2} = 1 \cdot y_{1,2} + 0 \cdot y_{2,3} + \ldots + 0 \cdot y_{6,7} - 1 \cdot \delta \tag{7}$$

$$x_{1,3} + r_{1,3} = 1 \cdot y_{1,2} + 1 \cdot y_{2,3} + \ldots + 0 \cdot y_{6,7} - 1 \cdot \delta$$

$$\vdots$$

$$x_{6,7} + r_{6,7} = 0 \cdot y_{1,2} + 0 \cdot y_{2,3} + \ldots + 1 \cdot y_{6,7} - 1 \cdot \delta$$

In matrix notation for the linear system:

$$x + r = F(y) \tag{8}$$

Dissolved to the residuals:

$$r = Ay - x \tag{9}$$

where A is the design matrix [21 × 7] to adjust the 21 distance measurements:

		1	**2**	**3**	**4**	**5**	**6**	**7**
$A =$	**1**	1	0	0	0	0	0	–1
	2	1	1	0	0	0	0	–1
	3	1	1	1	0	0	0	–1
	4	1	1	1	1	0	0	–1
	5	1	1	1	1	1	0	–1
	6	1	1	1	1	1	1	–1
	7	0	1	0	0	0	0	–1
	8	0	1	1	0	0	0	–1
	9	0	1	1	1	0	0	–1
	10	0	1	1	1	1	0	–1
	11	0	1	1	1	1	1	–1
	12	0	0	1	0	0	0	–1
	13	0	0	1	1	0	0	–1
	14	0	0	1	1	1	0	–1
	15	0	0	1	1	1	1	–1
	16	0	0	0	1	0	0	–1
	17	0	0	0	1	1	0	–1
	18	0	0	0	1	1	1	–1
	19	0	0	0	0	1	0	–1
	20	0	0	0	0	1	1	–1
	21	0	0	0	0	0	1	–1

x is the vector [21 × 1] of the observations;

y is the vector [7 × 1] of the unknown output estimates;

r is the vector [21 × 1] of the residuals.

$$\boldsymbol{x} = \boldsymbol{l} = \begin{bmatrix} x_{1,2} \\ x_{1,3} \\ \vdots \\ x_{5,7} \\ x_{6,7} \end{bmatrix} \qquad \boldsymbol{y} = \begin{bmatrix} y_{1,2} \\ y_{2,3} \\ y_{3,4} \\ y_{4,5} \\ y_{5,6} \\ y_{6,7} \\ \delta \end{bmatrix} \qquad \boldsymbol{r} = \begin{bmatrix} r_{1,2} \\ r_{1,3} \\ \vdots \\ r_{5,7} \\ r_{6,7} \end{bmatrix} \tag{10}$$

The least squares adjustment according to the Gauss-Markov Model, the solution vector y is calculated as follows:

$$y = (A^T PA)^{-1} A^T Px \tag{11}$$

As all measurements can be regarded as having equal weights and non correlative, the weight matrix P can be taken as the unit matrix. This means P can be ignored in the calculation:

and with the Normal Equation

$$N = A^T A \tag{12}$$

the final formula is:

$$y = N^{-1} A^T x \tag{13}$$

From this, the experimental standard deviation of a single measured distance, s_0, can be calculated:

$$s_0 = \sqrt{\frac{r^T r}{\nu}} \tag{14}$$

with

$d = 21$ the number of observed distances,

$u = 7$ the number of unknown estimated output parameters, and

$v = d - u = 14$ the degree of freedom.

The experimental standard deviations of each distance (output estimate) y_k and of the zero-point correction δ are derived from the diagonal elements of the Cofactormatrix Q:

$$Q = N^{-1} \tag{15}$$

$$S(y_k) = s_0 \sqrt{Q_{k,k}} \quad k = 1, \ ..., 6 \tag{16}$$

$$s_\delta = s_0 \sqrt{Q_{7,7}} \tag{17}$$

Finally we can state the standard uncertainty, type A evaluation, of each distance (output estimate)

$$u(y_k) = s(y_k) \qquad k = 1, 2, \ldots, 6 \tag{18}$$

and of the zero point correction δ

$$u_\delta = s_\delta \tag{19}$$

and:

$$u_{\text{ISO-EDM}} = s_0 \tag{20}$$

6.4 Statistical tests

6.4.1 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 distance measured on the test line, and
- the zero-point correction, δ, of the EDM instrument and its experimental standard deviation,

in order to answer the following questions (see Table 1):

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

b) Do two experimental standard deviations, s and $\tilde{s}$, 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 $\tilde{s}$, may be obtained from:

- two samples of measurements by the same instrument at different times;
- two samples of measurements by different instruments.

c) Is the zero-point correction, δ, equal to zero as supplied by the manufacturer ($\delta = 0$)? Or, if prisms with a given zero-point correction, δ_0 are used, is $\delta = \delta_0$?

For the following tests, a confidence level of $1 - \alpha = 0{,}95$ and, according to the design of measurements, a number of degrees of freedom of $\nu = 14$ are assumed.

Table 1 — Statistical tests

Question	Null hypothesis	Alternative hypothesis
a)	$s \le \sigma$	$s > \sigma$
b)	$\sigma = \tilde{\sigma}$	$\sigma \ne \tilde{\sigma}$
c)	$\delta = \delta_0$	$\delta \ne \delta_0$

6.4.2 Question a)

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

$$s_0 \le \sigma \times \sqrt{\frac{\chi^2_{1-\alpha}(\nu)}{\nu}} \tag{21}$$

$$s_0 \le \sigma \times \sqrt{\frac{\chi^2_{0,95}(14)}{14}} \tag{22}$$

and

$$\chi^2_{0,95}(14) = 23{,}68 \tag{23}$$

$$s_0 \le \sigma \times \sqrt{\frac{23{,}68}{14}} = \sigma \times 1{,}30 \tag{24}$$

Otherwise, the null hypothesis is rejected.

6.4.3 Question b)

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

$$\frac{1}{F_{1-\alpha/2}(\nu,\nu)} \le \frac{{s_0}^2}{{\tilde{s}_0}^2} \le F_{1-\alpha/2}(\nu,\nu) \tag{25}$$

$$\frac{1}{F_{0,975}(14,14)} \le \frac{{s_0}^2}{{\tilde{s}_0}^2} \le F_{0,975}(14,14) \tag{26}$$

and

$$F_{0,975}(14,14) = 2{,}98 \tag{27}$$

$$0{,}34 \le \frac{{s_0}^2}{{\tilde{s}_0}^2} \le 2{,}98 \tag{28}$$

Otherwise, the null hypothesis is rejected.

6.4.4 Question c)

The hypothesis of equality of the zero-point corrections, δ, and, δ_0, is not rejected if the following condition is fulfilled:

$$\left|\delta - \delta_0\right| \le s_\delta \times t_{1-\alpha/2}(\nu) \tag{29}$$

$$\left|\delta - \delta_0\right| \le s_\delta \times t_{0,975}(14) \tag{30}$$

$$s_\delta = s_0 \times \sqrt{Q(7,7)} = s_0 \times 0{,}45 \tag{31}$$

and

$$t_{0,975}(14) = 2{,}14 \tag{32}$$

$$\left|\delta-\delta_0\right| \le s_\delta \times 2{,}14 \tag{33}$$

Otherwise, the null hypothesis is rejected.

The number of degrees of freedom and, thus, the corresponding test values $\chi^2_{1-\alpha}(\nu)$, $F_{1-\alpha/2}(\nu,\nu)$ and $t_{1-\alpha/2}(\nu)$ (taken from reference books on statistics or from ISO 17123-1) change, if a different number of measurements is analysed.

6.5 Combined standard uncertainty evaluation (Type A and Type B)

6.5.1 Final distance and combined standard uncertainty

$$D_{\text{final}} = f(D_{\text{m}},\delta,f,t,p,rh,e,r,rf) \tag{34}$$

$$u(D)=\sqrt{u_{\text{ISO-EDM}}{}^2(D_{\text{m}})+u^2(\delta)+u^2(f)+u^2(t)+u^2(p)+u^2(rh)+u^2(e)+u^2(r)+u^2(rf)} \tag{35}$$

An example for this typical uncertainty budget of the EDM is given in Annex C.

6.5.2 Uncertainty budget

Table 2 — Typical influence quantities

Sources of uncertainty (influence quantity)	Evaluation	Distribution
I. Relevant sources of the EDM		
Precision of the measured distance D_m. Estimation from previous least square adjustment.	Type A $u_{\text{ISO-EDM}}$	normal
Zero-point correction δ. Estimation from previous least square adjustment.	Type A	normal
EDM modulation frequency, f	Type B	normal
II. Error sources of the atmosphere		
Temperature, t	Type B	normal
Pressure, p	Type B	normal
Relative Humidity, rh	Type B	normal
III. Error patterns from the mechanical setup		
Tribrach eccentricity, e	Type B	rectangular
Reflector eccentricity, r	Type B	rectangular
IV. General influence quantities		
Round-off-error, rf	Type B	rectangular

To calculate the standard uncertainties of the individual influence quantities in dependence of distribution, in many cases it is advised to determine or estimate upper and lower limits; additionally it is necessary to state the probability that the value considerably lies in this interval. Elaborated advice is also given in ISO/IEC Guide 98-3:2008, 4.3.

Sometimes it is useful, after the calculation of the combined standard uncertainty, to indicate the expanded uncertainty in order to meet better the accuracy indication of a measuring tolerance.

Annex A
(informative)

Example of the simplified test procedure

NOTE Calculations are done with full precision from beginning to end, but intermediate and final results are shown as rounded values.

A.1 Configuration of the test field

An EDM instrument of known precision is used to determine the reference lengths of the four distances of the test field.

The standard uncertainty $u_{\text{ISO-EDM}}$ of a single measured distance is determined according to the full test procedure as given in Clause 6.

$$u_{\text{ISO-EDM}} = 1{,}8 \text{ mm}$$

Reference lengths of the four distances:

$$\overline{x_1} = 21{,}784 \text{ m}$$

$$\overline{x_2} = 54{,}055 \text{ m}$$

$$\overline{x_3} = 76{,}502 \text{ m}$$

$$\overline{x_4} = 152{,}248 \text{ m}$$

A.2 Measurements

Observer:	S. Miller
Weather:	sunny
Temperature:	+ 18 °C
Air pressure:	1 009 hPa
Instrument type and number:	NN xxx 630401
Date:	1999-04-15

Table A.1 — Measurements

1	2	3	4
$x_{j,k}$	$x_j = \frac{\sum_{k=1}^{3} x_{j,k}}{3}$	$\overline{x}_j$	$\overline{x}_j - x_j$
m	m	m	mm
21,786 21,785 21,785	21,785	21,784	-1
54,054 54,051 54,053	54,053	54,055	2
76,502 76,505 76,504	76,504	76,502	-2
152,243 152,247 152,245	152,245	152,248	3

Case 1: The permitted deviation is given: $p = \pm 5 \text{ mm}$.

Case 2: p is not given, all differences are $\left|\overline{x}_j - x_j\right| < 2{,}5 \times 1{,}8 \text{ mm} = 4{,}5 \text{ mm}$.

In both cases, the EDM instrument is suited for the intended measuring task.

Annex B
(informative)

Example of the full test procedure

NOTE Calculations are done with full precision from beginning to end, but intermediate and final results are shown as rounded values.

B.1 Configuration of the test line

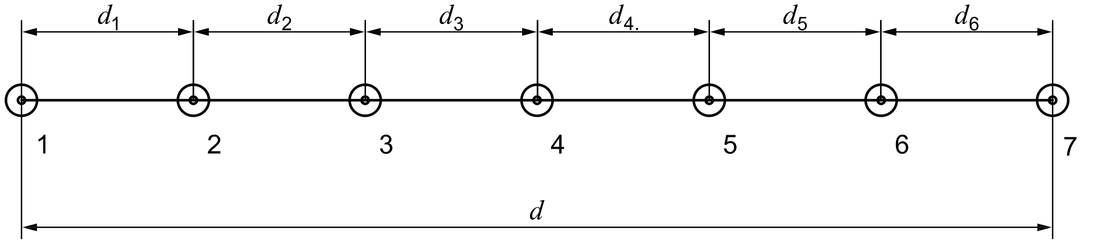

Figure B.1 — Configuration of the test line for the full test procedure

The suggested lengths of the distances d_1 to d_6 are in relation to the total length, d, of the test line and to the length, $\lambda/2$, of the EDM instrument.

According to Formulae (3) to (5):

$$\beta_0 = \frac{600\,\text{m} - 6{,}5 \times 20\,\text{m}}{15} = 31{,}33\ \text{m}$$

$$\beta = \mu \times 10\,\text{m} = 30{,}00\,\text{m}$$

select $\mu = 3$, so that β is close to β_0

$$\gamma = \frac{20\,\text{m}}{72} = 0{,}277\ 8\ \text{m}$$

where d is approximately 600 m and $\lambda/2$ is 10 m.

With these values, the six distances and the total length, d, of the test line are calculated according to Formula (6):

$d_1 = 50{,}83$ m

$d_2 = 111{,}94$ m

$d_3 = 173{,}06$ m

$d_4 = 142{,}50$ m

$d_5 = 81{,}39$ m

$d_6 = 20{,}28$ m

$d = 580{,}00$ m

B.2 Measurements

Table B.1 contains in columns 1 to 4 the 21 measured values, $x_{p,q}$, corrected for meteorological influences and the slope of the test line. Column 5 contains the residual vector $r_{p,q}$, which is the result of calculation B.3.

Observer: S. Miller

Weather: sunny

Temperature:

Air pressure:

Instrument type and number: NN xxx 630401

Date: 1999-04-15

Table B.1 — Measurements and residuals

1	**2**	**3**	**4**	**5**
Dist No. j	**Pt** p	**Pt** q	**Observations** $x_{p,q}$ (m)	**Residuals** $r_{p,q}$ (mm)
1	1	2	50,801	+2,9
2	1	3	162,806	+2,3
3	1	4	335,904	−1,5
4	1	5	478,407	−5,8
5	1	6	559,810	−1,0
6	1	7	580,098	+3,1
7	2	3	112,007	−3,9
8	2	4	285,096	+1,3
9	2	5	427,594	+2,0
10	2	6	509,004	−0,2
11	2	7	529,292	+3,8
12	3	4	173,091	+1,9
13	3	5	315,592	−0,4
14	3	6	396,999	+0,4
15	3	7	417,295	−3,5
16	4	5	142,494	+3,4
17	4	6	223,904	+1,2
18	4	7	244,200	−2,8
19	5	6	81,409	−2,5
20	5	7	101,697	+1,6
21	6	7	20,293	−2,2
$\sum$				0,0

$x_{p,q}$ are the elements of the observations vector x.

$r_{p,q}$ are the elements of the residuals vector r.

B.3 Calculation

Following the Gauss-Markov Model the solution vector y is: $y = Q\,A^T x^{-1}$ with $Q = N^{-1}$

$$\overset{\boldsymbol{y}}{\begin{bmatrix} 50{,}805\,22 \\ 112{,}004\,37 \\ 173{,}094\,22 \\ 142{,}498\,65 \\ 81{,}407\,80 \\ 20{,}292\,08 \\ 0{,}001\,29 \end{bmatrix}} = \overset{\boldsymbol{Q}}{\begin{bmatrix} 0{,}302\,0 & -0{,}126\,5 & 0{,}016\,3 & 0{,}016\,3 & 0{,}016\,3 & 0{,}016\,3 & 0{,}057\,1 \\ -0{,}126\,5 & 0{,}302\,0 & -0{,}126\,5 & 0{,}016\,3 & 0{,}016\,3 & 0{,}016\,3 & 0{,}057\,1 \\ 0{,}016\,3 & -0{,}126\,5 & 0{,}302\,0 & -0{,}126\,5 & 0{,}016\,3 & 0{,}016\,3 & 0{,}057\,1 \\ 0{,}016\,3 & 0{,}016\,3 & -0{,}126\,5 & 0{,}302\,0 & -0{,}126\,5 & 0{,}016\,3 & 0{,}057\,1 \\ 0{,}016\,3 & 0{,}016\,3 & 0{,}016\,3 & -0{,}126\,5 & 0{,}302\,0 & -0{,}126\,5 & 0{,}057\,1 \\ 0{,}016\,3 & 0{,}016\,3 & 0{,}016\,3 & 0{,}016\,3 & -0{,}126\,5 & 0{,}302\,0 & 0{,}057\,1 \\ 0{,}057\,1 & 0{,}057\,1 & 0{,}057\,1 & 0{,}057\,1 & 0{,}057\,1 & 0{,}057\,1 & 0{,}200\,0 \end{bmatrix}} \times \overset{A^T x}{\begin{bmatrix} 2\,167{,}826 \\ 3\,980{,}018 \\ 5\,008{,}182 \\ 4\,824{,}689 \\ 3\,643{,}708 \\ 1\,892{,}875 \\ -6\,147{,}793 \end{bmatrix}}$$

The residuals are calculated according to:

$r = Ay - x$ and are presented in Table B.1 [according to Formula (9)]

The zero-point correction, δ, is the last unknown output element from the solution vector y:

$$y_{1,7} = \delta = 0{,}001\ 3\ \text{m} = 1{,}3\ \text{mm}$$

According to Formula (14) the experimental standard deviation, s_0, of a single measured distance is calculated:

$$s_0 = \sqrt{\frac{0{,}000\,146}{21-7}}$$

$$s_0 = u_{\text{ISO EDM}} = 0{,}003\ 2\ \text{m} = 3{,}2\ \text{mm}$$

with $v = d - u = 14$ degree of freedom,

And from this the experimental standard deviation of the zero-point correction s_δ is calculated (according to Formula (16)):

$$s_\delta = s_0 \sqrt{Q_{7,7}}$$

$$s_\delta = 3{,}2\ \text{mm} \times \sqrt{0{,}2} = 1{,}45\ \text{mm}$$

B.4 Statistical tests

B.4.1 Statistical test according to question a)

$$\sigma = 3{,}0\ \text{mm}$$

$$s_0 = 3{,}2\ \text{mm}$$

$$v = 14$$

$$3{,}2\ \text{mm} \le 3{,}0\ \text{mm} \times 1{,}30$$

$$3{,}2\ \text{mm} \le 3{,}9\ \text{mm}$$

Since the above condition is fulfilled, the null hypothesis stating that the empirically determined experimental standard deviation $s = 3{,}2$ mm is smaller than or equal to the manufacturer's value $\sigma = 3{,}0$ mm is not rejected at the confidence level of 95 %.

B.4.2 Statistical test according to question b)

$$s_0 = 3{,}2\ \text{mm} \quad \text{(standard deviation from this sample)}$$

$$\tilde{s}_0 = 4{,}0\ \text{mm} \quad \text{(standard deviation from another sample)}$$

$$\nu = 14$$

$$0{,}34 \le \frac{10{,}2\ \text{mm}^2}{16{,}0\ \text{mm}^2} \le 2{,}98$$

$$0{,}34 \le 0{,}64 \le 2{,}98$$

Since the above condition is fulfilled, the null hypothesis stating that the experimental standard deviations $s_1 = 3{,}2$ mm and $s_2 = 4{,}0$ mm (from another sample) belong to the same population is not rejected at the confidence level of 95 %.

B.4.3 Statistical test according to question c)

$$s = 3{,}2\ \text{mm}$$

$$\nu = 14$$

$$\delta = 1{,}3\ \text{mm}$$

$$s_\delta = 1{,}45\ \text{mm}$$

$$1{,}3\ \text{mm} \le 1{,}45\ \text{mm} \times 2{,}14$$

$$1{,}3\ \text{mm} \le 3{,}1\ \text{mm}$$

Since the above condition is fulfilled, the null hypothesis stating that the zero-point correction, δ, is zero is not rejected at the confidence level of 95 %.

Annex C
(informative)

Example for the calculation of a combined uncertainty budget (Type A and Type B)

NOTE Calculations are done with full precision from beginning to end, but intermediate and final results are shown as rounded values.

C.1 The measuring task and measuring conditions

The EDM used for this measuring purpose was checked by the full test procedure according to this part of ISO 17123. The results obtained are reported in Annex B. The EDM was used for a monitoring job with distances up to 600 m. During the measurements and use of the EDM, it was sunny with medium temperature (27 °C), high air pressure (1 006 hPa) and relative humidity of 50 %RH. Regarding the results of the full test procedure, the supervising surveyor was interested in the combined uncertainty of a distance measurement to one specific prism on a pillar at a distance of 578,345 m. For this he used the following information:

— $D_M = 578{,}345$ m

$u_{\text{ISO EDM}} = \pm$ 3,2 mm, distance measurement: to target.

No corrections have been applied within the EDM instrument (atmospheric correction set to 0,0 ppm with manufacturer's reference parameters 10 °C, 1 018 hPa, 0 %RH, zero-point correction = 0,0 mm).

— $\delta = 1{,}3$ mm

$s_\delta = u_\delta = \pm$ 1,45 mm, zero point correction.

— $\dfrac{\Delta f}{f} = 0{,}0$ ppm , $u_{\Delta f} = 0{,}5$ ppm.

The EDM frequency modulation deviation can be determined in the manufacturer service shop.

— $\Delta t = -17$ °C, $u_{\Delta t} = 1{,}0$ °C, difference to manufacturer's standard atmosphere.

1 ppm/C° is taken as sensitivity coefficient.

— $\Delta_p = -12$ hPa, $u_{\Delta p} = 1$ hPa, difference to manufacturer's standard atmosphere.

0,3 ppm/hPa is taken as sensitivity coefficient.

— $\Delta rh = +50$ %, $u_{\Delta rh} = 20$ %, difference to manufacturer's standard atmosphere.

0,005 ppm/1 % is taken as sensitivity coefficient.

— $e = (0 \pm 0{,}7)$ mm, tribrach eccentricity.

— $r = (0 \pm 0{,}7)$ mm, reflector eccentricity.

— Disp = (0 ± 0,5) mm, round off error from the display with a reading resolution of 1 mm.

The standard uncertainties $u(x_i)$ of type B in this example are estimated from experience or are general knowledge.

C.2 Uncertainty budget example

Table C.1 — Uncertainty budget example

1	2	3	4	5	6	7
Input quantity X_i	**Input estimates** xi [dim]	**Standard uncer-tainty** $u(x_i)$ [dim]	**Distri-bution**	**Sensitivity coefficients** $c_i \equiv \partial f / \partial x_i$ [dim]	$u(\tilde{x}_i) \equiv c_i \times u(x_i)$ [mm] at 578 m	**Type of evaluation, source of uncertainty** Formula reference to ISO 17123-1:2010 Probability
D_m	578,345 m	3,2 mm	normal	1	3,2	A, distance to target, $u(DM)$ according to Formula (17), estimation from previous least squares estimation
δ	1,3 mm	1,5 mm	normal	1	1,5	A, zero-point correction, $u(\delta)$ according to Formula (19) estimation from previous least squares estimation
$\frac{\Delta f}{f}$	0	0,5 ppm	normal	D_m	0,3	B, EDM frequency modulation, $u(\frac{\Delta f}{f})$ experience $a_+ = 0{,}5$; $a_- = 0{,}5$; $a = 0{,}5$; $P = 67$ %
Δt	($\Delta t = 17$ °C) +9,8 mm	1,0 °C	normal	$1 \times 10^{-6} \times D_m$	0,6	B, air temperature, $u(\Delta t)$ general knowledge $a_+ = 1{,}0$; $a_- = 1{,}0$; $a = 1{,}0$; $P = 67$ %
Δp	($\Delta P = -12$ hPa) +1,4 mm	1 hPa	normal	$0{,}3 \times 10^{-6} \times D_m$	0,2	B, pressure, $u(\Delta p)$ general knowledge $a_+ = 1{,}0$; $a_- = 1{,}0$; $a = 1{,}0$; $P = 67$ %
Δrh	($\Delta rh = 50$ %) + 0,1 mm	20 %	normal	$0{,}005 \times 10^{-6} \times D_m$	0,1	B, relative humidity, $u(\Delta rh)$ general knowledge $a+ = 20{,}0$; $a- = 20{,}0$; $a = 20{,}0$; $P = 67$ %
e	0	0,4 mm	rectan-gular	1	0,4	B, tribrach eccentricity, $u(e)$ experience $a+ = 0{,}7$; $a- = -0{,}7$; $a = 0{,}7$; $P = 100$ %
r	0	0,4 mm	rectan-gular	1	0,4	B, reflector eccentricity, $u(r)$ experience $a_+ = 0{,}7$; $a- = -0{,}7$; $a = 0{,}7$; $P = 100$ %
Disp	0	0,3 mm	rectan-gular	1	0,3	B, round off error of reading u(Disp.) derived from distribution $a+ = 0{,}5$; $a- = -0{,}5$; $a = 0{,}5$; $P = 100$ %
D_{Final}	578,358				3,7 mm	

Final distance: $D_{\text{Final}} = \sum$ Values of input estimates = 578,357 6 m

The combined standard uncertainty u_{cEDM} is obtained by the law of propagation of uncertainty and will indicate the expected uncertainty of a distance measured by the EDM instrument under the given conditions:

$$u_{\text{c EDM 578}} = \sqrt{u_D^2 + u_\delta^2 + u_{\Delta f}^2 + u_{\Delta t}^2 + u_{\Delta p}^2 + u_{\Delta rh}^2 + u_e^2 + u_r^2 + u_{Disp}^2} = 3{,}66 \text{ mm}$$

Though some of the uncertainty components do not influence the total error budget significantly, it is important to prove this fact.

C.3 Expanded uncertainty

In industrial interdisciplinary application, it is often useful to state a measure of uncertainty that defines an interval about the measurement result. The measure of uncertainty that meets the requirements of providing this interval is the expanded uncertainty

$$U_{\mathrm{EDM\,578}} = k \cdot u_{\mathrm{c\ EDM\,578}}$$

with $k = 2$, which corresponds to a particular level of confidence of $p = 95\ \%$, assuming a normal distribution.

$$U_{\mathrm{EDM\,578}} = 2 \cdot 3{,}66 = \pm\ 7{,}3\ \mathrm{mm}$$

Bibliography

[1] ISO/IEC Guide 98-1, *Uncertainty of measurement — Part 1: Introduction to the expression of uncertainty in measurement*

ISO 17123-4:2012(E)

ICS 17.180.30

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