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Optics and optical instruments — Laboratory procedures for testing surveying and construction instruments —

Part 1: **Performance of handheld laser distance meters**

Optique et instruments d'optique — Méthodes d'essai de laboratoire des instruments d'observation et construction —

Partie 1: Performance de télémètres laser de poche

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Foreword

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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.

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ISO 16331-1 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 6, *Geodetic and surveying instruments*.

ISO 16331 consists of the following parts, under the general title *Optics and optical instruments — Laboratory procedures for testing surveying and construction instruments*:

— *Part 1: Performance of handheld laser distance meters*

Introduction

Starting in 1993 several companies developed handheld laser distance meters and introduced them into the market. With a growing number of different manufacturers, it became obvious that a standard was needed to establish requirements for device specifications and to describe how to check compliance with the specified performance of accuracy and range.

In comparison with ISO 17123, which specifies methods of checking compliance with the specifications by the user of the instrument without any additional measurement equipment, ISO 16331 specifies the procedures to be applied for checking compliance with the specifications by using additional laboratory equipment which the typical user does not have access to.

Optics and optical instruments — Laboratory procedures for testing surveying and construction instruments —

Part 1: Performance of handheld laser distance meters

1 Scope

This part of ISO 16331 specifies procedures for checking compliance with performance specifications of handheld laser distance meters.

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/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)*

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC Guide 98-3, ISO/IEC Guide 99, ISO 3534-1 and ISO 9849 apply.

4 Symbols and abbreviated terms

Table 1 — Symbols and abbreviated terms

AD	absolute distance (as index of measurements and calculations)
Add	additional contribution (as index extension of measurements and calculations)
BG	background illumination (as index of measurements and calculations)
CP_X	check point X
D	distance
D_{REF}	reference distance
$\overline{D}$	mean value of a set of distances
$\overline{D}_{AD}$	mean value of a set of distances taken at the absolute distance test
$\overline{D}_{BG}$	mean value of a set of distances taken at the background illumination test
$\overline{D}_{T}$	mean value of a set of distances taken at the temperature test
DR	display resolution

Table 1 *(continued)*

Δ	deviation
$\Delta\overline{D}$	deviation of the mean value of a set of measured distances in relation to the reference distance
$\Delta\overline{D}_{AD}$	deviation of the mean value of a set of measured distances in relation to the reference distance at the absolute distance test
$\Delta\overline{D}_{BG,Add}$	additional deviation of the mean value of a set of measured distances at the high background illumination case in reference to the deviation of the mean value of a set of measured distances at the low background illumination case
$\Delta\overline{D}_{C,max}$	combined positive deviation of the mean value including background illumination and temperature influences
$\Delta\overline{D}_{C,min}$	combined negative deviation of the mean value including background illumination and temperature influences
$\Delta\overline{D}_{T05,Add}$	additional deviation of the mean value of a set of measured distances at the temperature test at 5 °C in reference to the deviation of the mean value at the temperature test at 25 °C
$\Delta\overline{D}_{T45,Add}$	additional deviation of the mean value of a set of measured distances at the temperature test at 45 °C in reference to the deviation of the mean value at the temperature test at 25 °C
ΔM_i	deviation of an individual distance measurement in relation to the reference system value
k	extension factor for a level of confidence of 95 %
M	Measurement value
M_i	individual measurement value
N	number of measurements taken at each check point
RT	As index for measurements and calculations at range test
s	experimental standard deviation
s_{AD}	experimental standard deviation at the absolute distance test
s_{BG}	experimental standard deviation at the background illumination test
s_T	experimental standard deviation at the temperature test
T	temperature (as index of measurements and calculations)
T05	Temperature 5 °C
T45	Temperature 45 °C
u	uncertainty of measurement
u_{AD}	uncertainty of measurement at the absolute distance test
u_{BG}	uncertainty of measurement at the background illumination test
$u_{BG,Add}$	additional uncertainty of measurement at the high background illumination case in relation to the uncertainty of measurement at the low background illumination case
u_C	combined uncertainty
u_{DR}	uncertainty due to display resolution
$u_{REF,AD}$	uncertainty of the reference system at the absolute distance test
$u_{REF,BG}$	uncertainty of the reference system at the background illumination test
$u_{REF,T}$	uncertainty of the reference system at the temperature test
u_{RT}	uncertainty of measurements at range test
u_T	uncertainty of measurement at the temperature test
$u_{T,Add}$	additional uncertainty of measurement at higher or lower temperature in relation to the uncertainty of measurement at 25 °C
U	expanded uncertainty
x	Index for individual cases

5 General information

5.1 General

The maximum measurement range on natural targets and the uncertainty of measurements provided by handheld laser distance meters are influenced by various factors.

5.2 Target reflectivity

The higher the target reflectivity, the better the signal to noise ratio at the receiver; therefore better measurement performance on natural targets is achievable. For more details, refer to Annex F.

As handheld laser distance meters are used on construction sites and for indoor applications, typical targets are painted walls, bricks, concrete, wood, and similar targets. Special attention has to be paid to the effect of penetration of the laser into certain materials e.g. white marble.

5.3 Background illumination

Background light in indoor applications is typically below 3 klx and therefore negligible. However, in outdoor applications, the sunlight reflected by the target might reach an illuminance of up to 100 klx and might cause a degradation of the signal to noise ratio and therefore a poorer performance of the instrument.

5.4 Temperature of key components

The temperature of the laser system and of the receiver system has an influence on the uncertainty of distance measurement. Most of these instruments have a built-in temperature compensation system to minimize this kind of influence.

5.5 Atmospheric influence

The maximum range and the accuracy of laser distance meters are influenced by meteorological conditions at the moment of the measurements being taken. These conditions include variations in air temperature, air pressure and humidity of the air. Distances calculated by handheld laser distance meters are based on predefined meteorological conditions. To achieve accurate measurements, in particular at long distances, these meteorological variables in the distance calculation shall be determined and the measured distance shall be corrected accordingly.

5.6 Display resolution

The display resolution of a measurement instrument should be at least two times better than the specified accuracy. For very accurate measurements, like in a calibration situation, a laser distance meter should offer a unit setting which allows a display resolution that is at least five times better than the specified accuracy.

5.7 Average deviation and uncertainty of measurement

Even though the calculation of average values is necessary to find out systematic deviations, the typical user of handheld laser distance meters is not willing to do so. The user rather wants to take only one single measurement and wants to rely on the specified maximum tolerances. Therefore, it is the value of the combined and expanded uncertainty of a single measurement that the user wants to see below the tolerance limits.

5.8 Relevant contribution to uncertainty

Table 2 — Relevant contribution to uncertainty

Uncertainty contribution	Distribution	Type
Reference system	Normal	B
Display resolution	Rectangular	B
Absolute distance test (internal noise at typical conditions)	Normal	A
Background illumination (additional offset and noise)	Normal	A
Temperature (additional offset and noise)	Normal	A

5.9 Instruction for instrument specifications

As customers of handheld laser distance meters usually are not used to the term “uncertainty of measurement”, the manufacturers may use the expression “measurement accuracy” in their product specification.

Since the performance of a handheld laser distance meter depends on various conditions, the specification of the product shall indicate the conditions that apply, e.g. distance dependency, target reflectivity, background illumination and temperature range. It is mandatory to indicate typical error tolerances (indoor conditions) and the maximum error tolerances (outdoor conditions).

For an example, see Annex A.

6 Test procedure for determining the compliance with accuracy specifications

6.1 Test concept

As mentioned before, the accuracy of handheld laser distance meters depends on various factors. To avoid difficult test setups, the test concept of this International Standard focuses on the main influences, such as measurement distance, temperature of instrument and background illumination.

The target reflectivity, which also can have an impact on the accuracy, is not tested directly by changing targets with different reflectivity factors. The reason is that it is quite difficult to get targets with well defined, homogeneous and stable reflectivity factors. In addition, the effect of a target with a lower reflectivity factor of 25 % can be tested using a target with 100 % reflectivity at double distance. Therefore the effects of lower reflectivity factors are indirectly tested at the absolute distance test described in 6.4.2.

6.2 Requirements

6.2.1 General

To determine compliance with the accuracy specifications for handheld laser distance meters, the following measurement setup is used.

6.2.2 Apparatus

6.2.2.1 Target plate, meeting the following specifications:

Size: 0,25 m x 0,25 m.

Reflectivity: 95 % ± 5 % (see Annex E).

Orientation: perpendicular to the measurement direction.

Special attention is to be paid to the effect of penetration of the laser beam into certain materials (see Annex F).

6.2.2.2 Background illumination lamp, that shall achieve at least an illuminance of 30 klx on the used target plate. Check with an illuminance meter (lux meter) directed perpendicularly to the target at 0,1 m distance from the target.

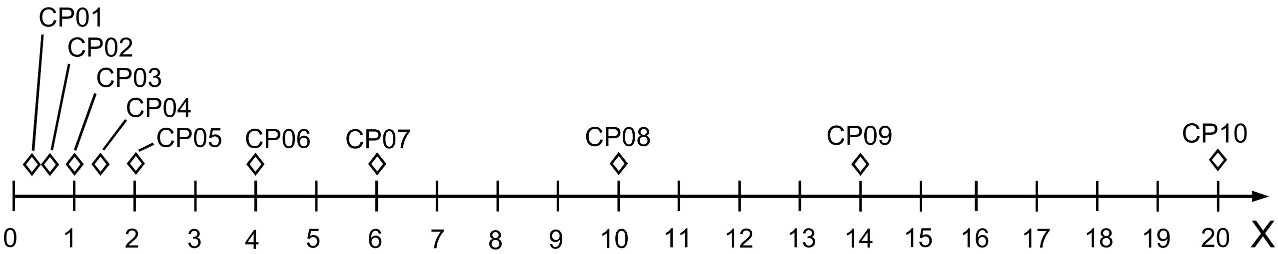
6.2.2.3 Temperature chamber, capable of heating the devices under test up to +45 °C and cooling them down to +5 °C. The measurements can be taken inside a big temperature chamber or by taking the heated (or cooled) devices out of the chamber and immediately taking the measurements on a known reference distance.

6.2.2.4 Calibrated reference distance measurement system, to determine the distance between target and device under test. The uncertainty of measurement of the reference system shall be 20 % or less than the expected uncertainty of measurement of the device under test.

6.3 Configuration of check points

Select 10 check points CP01 to CP10.

Check point CP10 shall be set either to the longest specified distance of the device under test or to the maximum range of the reference distance measurement system. The following configuration of check points takes into consideration that typical customers measure shorter distances more frequently than longer ones.



D(CP01) = 0.02 * D(CP10)
D(CP02) = 0.03 * D(CP10)
D(CP03) = 0.05 * D(CP10)
D(CP04) = 0.07 * D(CP10)
D(CP05) = 0.10 * D(CP10)
D(CP06) = 0.20 * D(CP10)
D(CP07) = 0.30 * D(CP10)
D(CP08) = 0.50 * D(CP10)
D(CP09) = 0.70 * D(CP10)
D(CP10) = max. distance

X Distance (m)

Figure 1 — Example: CP10 = 20 m

6.4 Measurement procedure

6.4.1 General

To determine compliance with accuracy specifications on natural targets for handheld laser distance meters, the following procedure is recommended.

6.4.2 Absolute distance test

Target reflectivity: 95 % ± 5 %.

Background illumination: < 3 klx (indoor conditions).

Temperature: 25 °C ± 3 °C.

Define the check points (see 6.3).

At each check point, take and record one measurement with the reference distance measurement system and 10 measurements with the device under test. Ensure that the alignment of the handheld laser distance meter to the target is correct.

6.4.3 Background illumination test

Target reflectivity: 95 % ± 5 %.

Temperature: 25 °C ± 3 °C.

Background illumination, case A: < 3 klx.

Background illumination, case B: > 30 klx.

Build up the measurement setup for the background illumination test (see Annex D for a selection of possible setups). At the checkpoint CP01 or CP02 or CP03 (depending on which point fits better for the test under 6.4.4) set the background illumination reflected by the target to an illuminance less than 3 klx. Then take and record one measurement with the reference distance measurement system and 10 measurements with the device under test. In the next step, set the background illumination reflected by the target to an illuminance higher than 30 klx and take and record another 10 measurements with the device under test.

6.4.4 Temperature test

Target reflectivity: 95 % ± 5 %.

Background illumination: < 3 klx.

Temperature, case A: +5 °C ± 2 °C.

Temperature, case B: +25 °C ± 2 °C.

Temperature, case C: +45 °C ± 2 °C.

NOTE If the specified temperature range of the instrument is narrower than +5 °C to +45 °C, the test temperatures for cases A to C may be adapted correspondingly (e.g. +5 °C, +20 °C, +35 °C).

Put the device under test into a temperature chamber and let the instruments adapt to the test temperature of case A. Then take the instrument out of the chamber and immediately take and record 10 measurements at the distance CP01 or CP02 or CP03 (same distance as under 6.4.3). Check that the background illumination reflected by the target is below 3 klx. Repeat the same procedure for the remaining two test cases.

Alternatively, the measurements could be taken directly inside a temperature chamber if the instrument is mounted on a reference distance measuring bar. In this case, the expansion of the reference distance measuring bar over temperature has to be compensated in the calculations.

6.5 Calculation of deviations and uncertainty of measurement

6.5.1 Absolute distance test

Calculate the deviation ΔM_{i} of all measurements M_{i} from the corresponding reference value at each check point.

$$\Delta M_{\mathrm{i}} = M_{\mathrm{i}} - D_{\mathrm{REF}} \quad (1)$$

Check, if all calculated deviations ΔM_{i} are inside the specified typical error tolerance field. Assuming a level of confidence of 95 % for the typical tolerance definition, only 5 of the 100 measured points (10 at each check point) are allowed to lie outside the specified typical error tolerance field.

At each check point calculate the experimental mean value of the absolute distance test $\overline{D}_{AD}$.

$$\overline{D}_{AD} = \frac{1}{N}\sum_{i=1}^{N} M_i \qquad (2)$$

Calculate at each check point the deviation $\Delta\overline{D}_{AD}$ of the experimental mean value from the corresponding reference value.

$$\Delta\overline{D}_{AD} = \overline{D}_{AD} - D_{REF} \qquad (3)$$

At each check point calculate the corresponding experimental standard deviation s_{AD} of the measured values and take it as the standard uncertainty u_{AD} associated with the measured values.

$$u_{AD} = s_{AD} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(M_i - \overline{D}_{AD})^2} \qquad (4)$$

6.5.2 Background illumination test

Calculate for both cases, low background illumination BG, low < 3 klx, and high background illumination BG, high > 30 klx, and for each measurement $M_{i,X}$ the deviation $\Delta M_{i,X}$ from the reference value.

For each background illumination case calculate the experimental mean value $\overline{D}_{BG,X}$.

$$\overline{D}_{BG,X} = \frac{1}{N}\sum_{i=1}^{N} M_{i,X} \qquad (5)$$

where X = background low, high.

Calculate the deviation $\Delta\overline{D}_{BG,X}$ of the experimental mean value from the corresponding reference value.

$$\Delta\overline{D}_{BG,X} = \overline{D}_{BG,X} - D_{BG,REF} \qquad (6)$$

where X = background low, high.

Calculate the additional deviation $\Delta\overline{D}_{BG,Add}$ caused by the background illumination.

$$\Delta\overline{D}_{BG,Add} = \Delta\overline{D}_{BG,high} - \Delta\overline{D}_{BG,low} \qquad (7)$$

Calculate the corresponding experimental standard deviations for both cases of background illumination and take them as the standard uncertainties associated with both cases.

$$u_{BG,X} = s_{BG,X} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(M_{i,X} - \overline{D}_{BG,X})^2} \qquad (8)$$

where X = background low, high.

Calculate the additional uncertainty $u_{BG,Add}$ caused by the background illumination, assuming that $u_{BG,high} > u_{BG,low}$.

$$u_{BG,Add} = \sqrt{u_{BG,high}^2 - u_{BG,low}^2} \qquad (9)$$

6.5.3 Temperature test

Calculate for each temperature case and for each measurement $M_{i,X}$ the deviation $\Delta M_{i,X}$ from the corresponding reference value.

For each temperature case calculate the corresponding experimental mean value $\overline{D}_{\mathrm{T,X}}$.

$$\overline{D}_{\mathrm{T,X}} = \frac{1}{N}\sum_{i=1}^{N} M_i \tag{10}$$

where X = +5° C, +25 °C, +45 °C.

Calculate the deviation $\Delta\overline{D}_{\mathrm{T,X}}$ of the experimental mean value from the corresponding reference value.

$$\Delta\overline{D}_{\mathrm{T,X}} = \overline{D}_{\mathrm{T,X}} - D_{\mathrm{T,REF}} \tag{11}$$

where X = +5 °C, +25 °C, +45 °C.

Calculate the additional deviation $\Delta\overline{D}_{\mathrm{T05,Add}}$ and $\Delta\overline{D}_{\mathrm{T45,Add}}$ caused by the temperature influences at +5 °C and +45 °C in reference to the value calculated at 25 °C.

$$\Delta\overline{D}_{\mathrm{T05,Add}} = \Delta\overline{D}_{\mathrm{T,5\,°C}} - \Delta\overline{D}_{\mathrm{T,25\,°C}} \tag{12}$$

$$\Delta\overline{D}_{\mathrm{T45,Add}} = \Delta\overline{D}_{\mathrm{T,45\,°C}} - \Delta\overline{D}_{\mathrm{T,25\,°C}} \tag{13}$$

Calculate the corresponding experimental standard deviations for each temperature case and take them as the standard uncertainties associated to the three cases.

$$u_{\mathrm{T,X}} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(M_{i,X} - \overline{D}_{T,X})^2} \tag{14}$$

where X = 5 °C, 25 °C, 45 °C.

Calculate the additional uncertainties $u_{\mathrm{T,Add}}$ caused by the temperature influences in reference to the value calculated at 25 °C. For calculation select the bigger value of the two possible values $u_{\mathrm{T,05\,°C}}$ and $u_{\mathrm{T,45\,°C}}$. If $u_{\mathrm{T,25\,°C}}$ is the biggest of the three uncertainties then $u_{\mathrm{T,Add}} = 0$.

$$u_{\mathrm{T,Add}} = \sqrt{{u_{T,X}}^2 - {u_{T,25°C}}^2} \tag{15}$$

where X = 5 °C or 45 °C.

6.5.4 Combined deviation and combined uncertainty of measurements

Calculate the combined deviation range $\Delta\overline{D}_{\mathrm{C,min}} \ldots \Delta\overline{D}_{\mathrm{C,max}}$ of the experimental mean value (depending on temperature and background illumination) using the following formula.

$$\Delta\overline{D}_{\mathrm{C,max}} = \Delta\overline{D}_{\mathrm{AD}} + \max(\Delta\overline{D}_{\mathrm{BG,Add}}, 0) + \max(\Delta\overline{D}_{\mathrm{T05,Add}}, \Delta\overline{D}_{\mathrm{T45,Add}}, 0) \tag{16}$$

$$\Delta\overline{D}_{\mathrm{C,min}} = \Delta\overline{D}_{\mathrm{AD}} + \min(\Delta\overline{D}_{\mathrm{BG,Add}}, 0) + \min(\Delta\overline{D}_{\mathrm{T05,Add}}, \Delta\overline{D}_{\mathrm{T45,Add}}, 0) \tag{17}$$

NOTE For $\Delta\overline{D}_{\mathrm{C,max}}$ only positive contributions of $\Delta\overline{D}_{\mathrm{BG,Add}}$ and only the maximum positive contribution of $\Delta\overline{D}_{\mathrm{T05,Add}}$ or $\Delta\overline{D}_{\mathrm{T45,Add}}$ are taken into account.

For $\Delta\overline{D}_{\mathrm{C,min}}$ only negative contributions of $\Delta\overline{D}_{\mathrm{BG,Add}}$ and only the most negative contribution of $\Delta\overline{D}_{\mathrm{T05,Add}}$ or $\Delta\overline{D}_{\mathrm{T45,Add}}$ are taken into account.

Calculate the uncertainty u_{DR} caused by the resolution of the display of the device under test.

$$u_{DR} = \frac{DR}{2\sqrt{3}} \qquad (18)$$

where DR = Display Resolution.

Calculate the combined uncertainty u_C of the measured values.

$$u_C = \sqrt{u_{REF,AD}{}^2 + u_{REF,BG}{}^2 + u_{REF,T}{}^2 + u_{DR}{}^2 + u_{AD}{}^2 + u_{BG,Add}{}^2 + u_{T,Add}{}^2} \qquad (19)$$

where

$u_{REF,AD}$ is uncertainty of the reference system at the absolute distance test;

$u_{REF,BG}$ is uncertainty of the reference system at the background illumination test;

$u_{REF,T}$ is uncertainty of the reference system at the temperature test;

u_{AD} is uncertainty of measurements at the absolute distance test of the check point that was used for the background illumination test and the temperature test;

$u_{BG,Add}$ is additional uncertainty of measurement at the high background illumination case in relation to the uncertainty of measurement at the low background illumination case;

$u_{T,Add}$ is additional uncertainty of measurement at higher or lower temperature in relation to the uncertainty of measurement at 25 °C.

6.5.5 Expanded uncertainty of measurements

Calculate the expanded uncertainty, U, for a level of confidence of 95 %.

$$U = k\, u_C \qquad (20)$$

where

$k = 2$.

6.6 Statement of test result

Give a statement on the test result as follows:

Deviation range of average values:	$\Delta\overline{D}_{C,min} \ldots \Delta\overline{D}_{C,max}$ = ___ mm … ___ mm
Expanded uncertainty of a single measurement:	U = ___ mm
(level of confidence 95 %, $k = 2{,}0$)	
Result:	within/out of specification

NOTE Out of specification is given if $\Delta\overline{D}_{C,min} - U <$ specified negative maximum error tolerance or if $\Delta\overline{D}_{C,max} + U >$ specified positive maximum error tolerance.

7 Test procedure for determining compliance with range specifications

7.1 Requirements

To test compliance with the range specifications on natural targets for handheld laser distance meters, the following measurement setup is recommended.

7.1.1 Target plate: Size: 1,0 m × 1,0 m.

Reflectivity: 95 % ± 5 % (white balanced reflectance target).

Orientation: rectangular to the measurement direction.

7.1.2 Background: Background illumination of approximately 30 klx.

(Check with a lux meter directed perpendicularly to the centre of the target plate at 0,1m distance from the target plate).

7.1.3 Reference: To determine the distance between the target and the device under test, a calibrated reference distance measurement system shall be used. For reference measurements it might be necessary to shadow the target plate or to use a target prism.

7.2 Description of measurement procedure

To test the specified range on natural targets for a handheld laser distance meter, the following measurement procedure is recommended.

Step 1: Build up the measurement setup at the specified range on natural targets. Verify the target reflectivity of 100 % and the background illumination of approximately 30 klx.

Step 2: Determine the distance between the device under test and the target plate using a suitable and calibrated reference system.

Step 3: Start 10 measurements and record the results.

NOTE If the instrument performs less than eight measurements, the range specification is not fulfilled.

7.3 Calculation of deviation and uncertainty of measurement

From the measurements taken at the range test on natural targets, calculate the average value $\overline{D}_{\mathrm{RT}}$ and the deviation $\Delta\overline{D}_{\mathrm{RT}}$ of the average value from the reference value D_{REF}.

Consider the uncertainty u_{REF} of the reference system stated on the corresponding calibration certificate.

Calculate the uncertainty u_{DR} caused by the resolution of the display of the device under test [see Formula (18)]. Be aware that handheld laser distance meters typically change the display resolution when measuring large distances.

Calculate the experimental standard deviation s_{RT} of the measurements taken at the range test on natural targets and take it as the standard uncertainty u_{RT} associated with the measured values.

Calculate the combined uncertainty $u_{C,\mathrm{RT}}$ of the measurements taken at the range test with the following formula:

$$u_{C,\mathrm{RT}} = \sqrt{u_{\mathrm{REF}}{}^2 + u_{\mathrm{DR}}{}^2 + u_{\mathrm{RT}}{}^2} \qquad (21)$$

Calculate the expanded uncertainty U_{RT} for a level of confidence of 95 %.

$$U_{\mathrm{RT}} = k\, u_{\mathrm{C,RT}} \qquad (22)$$

where

$k = 2$.

7.4 Statement of test result

Give a statement as follows:

Deviation of average value at range test: $\Delta\overline{D}_{\mathrm{RT}}$ = ___ mm

Expanded uncertainty of a single measurement: U_{RT} = ___ mm

(level of confidence 95 %, $k = 2{,}0$).

Result: within/out of specification

NOTE Out of specification is given if $\Delta\overline{D}_{\mathrm{RT}} - U_{\mathrm{RT}} <$ specified negative maximum error tolerance, or if $\Delta\overline{D}_{\mathrm{RT}} + U_{\mathrm{RT}} >$ specified positive maximum error tolerance, or if less than 80 % of the started measurements could be performed.

Annex A
(informative)

Example of performance specification

Instrument with accuracy specification of 1,5 mm and 50 m maximum range.

Typical error tolerance: (100 % target reflectivity, low background illumination, 25 °C)

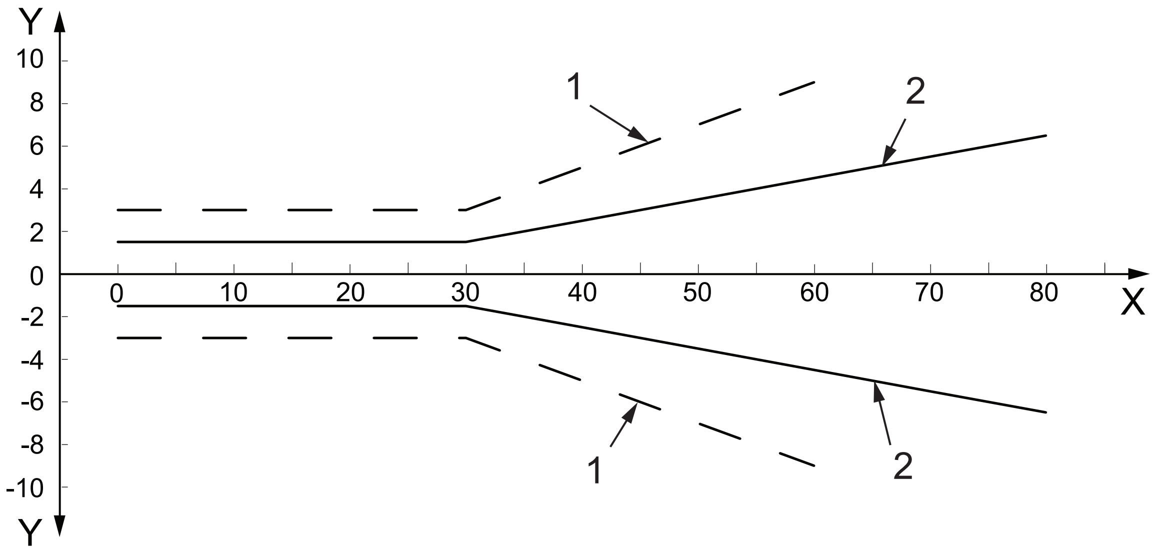
±1,5 mm (95 % level of confidence) from 0,05 m to 30 m

from 30 m additional tolerance of 0,1 mm/m

Maximum error tolerance: (10 % to 100 % target reflectivity, high background illumination, - 10 °C to + 50 °C)

±3,0 mm (95 % level of confidence) from 0,05 m to 30 m

from 30 m additional tolerance of 0,20 mm/m



Key

X distance (m)

Y error tolerance (mm)

1 maximum error tolerance definition

2 typical error tolerance definition

Figure A.1 — Example of accuracy specifications over distance

Specified range on natural targets: 50 m

(100 % diffuse target reflectivity, background illumination of approximately 30 klx)

Annex B
(informative)

Examples of determining compliance with accuracy specifications

B.1 Example 1

Typical error tolerance: ±1,5 mm on 100 % target reflectivity, low background illumination, 25 °C, from 15 m additional 0,10 mm/m

Maximum error tolerance: ±2,0 mm on 100 % target reflectivity, high background illumination, –10 °C .. 50 °C from 15 m additional 0,15 mm/m

Range of device under test: 0,05 m to 60 m

Range of reference system: 0,00 m to 30 m

Check points: CP01 = 0,60 m, CP02 = 0,90 m, CP03 = 1,50 m, CP04 = 2,10 m, CP05 = 3,00 m,

CP06 = 6,00 m, CP07 = 9,00 m, CP08 = 15,00 m, CP09 = 21,00 m, CP10 = 30,00 m.

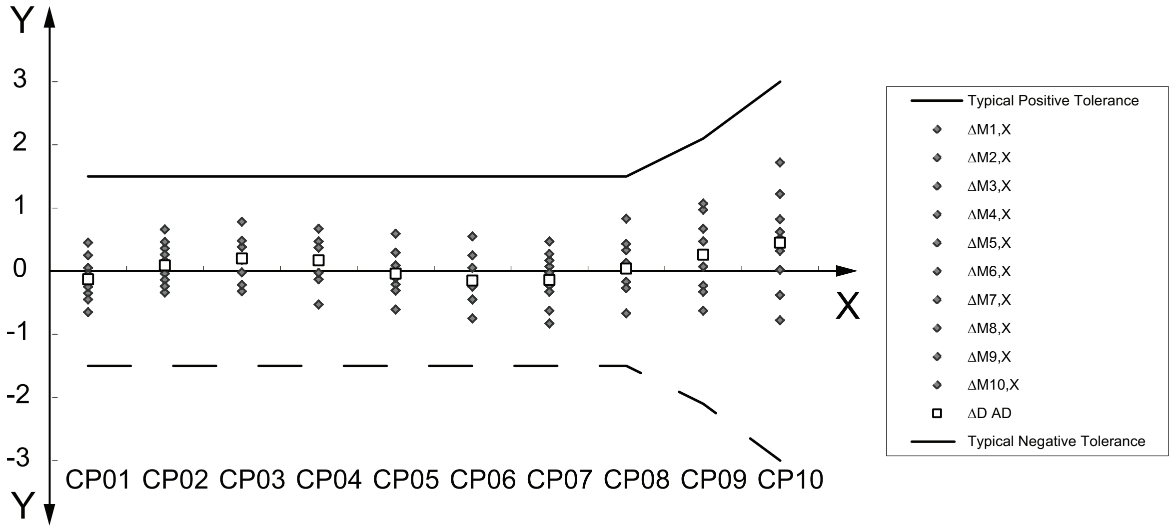
Table B.1 — Absolute distance test

Dimensions in millimetres

CP	01	02	03	04	05	06	07	08	09	10
D_{REF}	600,05	900,04	1500,02	2100,03	3000,01	5999,95	9000,03	15000,07	21000,03	30000,08
M 1	600,3	900,2	1500,8	2100,2	2999,7	5999,8	8999,7	14999,8	21000,1	30000,5
M 2	600,5	900,4	1500,4	2099,9	2999,9	5999,2	8999,4	15000,4	21001,0	29999,7
M 3	600,1	899,8	1500,2	2100,0	3000,1	6000,2	8999,8	15000,2	21000,5	30000,6
M 4	599,9	899,7	1500,4	2100,4	3000,6	5999,5	9000,1	15000,1	20999,8	30001,3
M 5	599,7	900,7	1499,7	2100,5	2999,8	6000,5	9000,2	15000,9	21000,7	30000,4
M 6	599,6	900,3	1500,5	2100,2	2999,4	5999,8	8999,7	14999,4	20999,4	29999,3
M 7	599,8	900,0	1500,2	2099,5	2999,9	6000,0	9000,3	15000,5	21000,5	30000,9
M 8	599,4	899,9	1499,8	2100,2	3000,3	5999,7	9000,5	15000,1	21000,1	30001,8
M 9	600,0	900,5	1500,0	2100,4	2999,7	5999,8	9000,0	14999,9	21001,1	30000,1
M10	599,9	899,8	1500,2	2100,7	3000,3	5999,5	8999,2	14999,8	20999,7	30000,7
Δ M 1	0,25	0,16	0,78	0,17	-0,31	-0,15	-0,33	-0,27	0,07	0,42
Δ M 2	0,45	0,36	0,38	-0,13	-0,11	-0,75	-0,63	0,33	0,97	-0,38
Δ M 3	0,05	-0,24	0,18	-0,03	0,09	0,25	-0,23	0,13	0,47	0,52
Δ M 4	-0,15	-0,34	0,38	0,37	0,59	-0,45	0,07	0,03	-0,23	1,22
Δ M 5	-0,35	0,66	-0,32	0,47	-0,21	0,55	0,17	0,83	0,67	0,32
Δ M 6	-0,45	0,26	0,48	0,17	-0,61	-0,15	-0,33	-0,67	-0,63	-0,78
Δ M 7	-0,25	-0,04	0,18	-0,53	-0,11	0,05	0,27	0,43	0,47	0,82
Δ M 8	-0,65	-0,14	-0,22	0,17	0,29	-0,25	0,47	0,03	0,07	1,72
Δ M 9	-0,05	0,46	-0,02	0,37	-0,31	-0,15	-0,03	-0,17	1,07	0,02
Δ M10	-0,15	-0,24	0,18	0,67	0,29	-0,45	-0,83	-0,27	-0,33	0,62

Table B.1 *(continued)*

CP	01	02	03	04	05	06	07	08	09	10
$\overline{D}_{AD}$	599,92	900,13	1500,22	2100,20	2999,97	5999,80	8999,89	15000,11	21000,29	30000,53
$\Delta\overline{D}_{AD}$	-0,13	0,09	0,20	0,17	-0,04	-0,15	-0,14	0,04	0,26	0,45
u_{AD}	0,33	0,34	0,33	0,34	0,36	0,37	0,41	0,42	0,56	0,73



Key

X check point

Y deviation from reference (mm)

Figure B.1 — Check points CP01 to CP10 measured at typical conditions

Background illumination test (CP01)

Target: 0,25 m x 0,25 m with 100 % reflectivity

Illumination: low (<3 klx)

and high (>30 klx)

Temperature: 25 °C

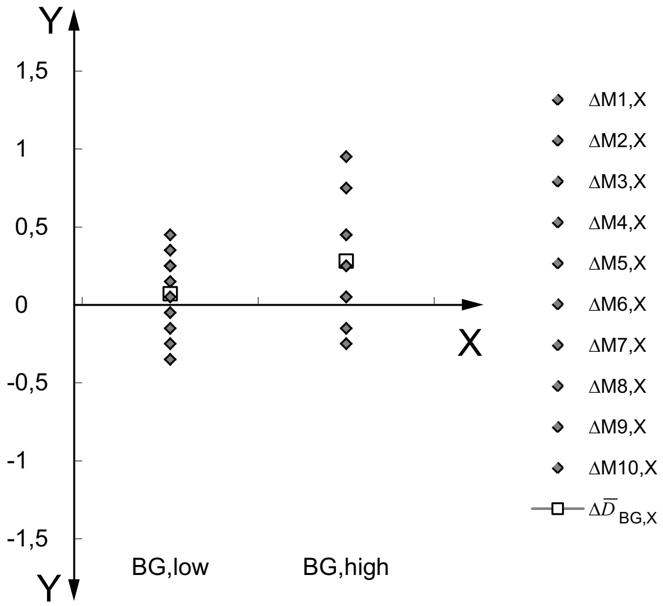
Table B.2 — Background test at CP01

Dimensions in millimetres

Condition	BG low	BG high
D_{REF}	600,05	600,05
M 01	600,3	600,8
M 02	600,2	600,5
M 03	599,7	599,8
M 04	600,3	600,3
M 05	599,8	599,9
M 06	600,4	600,1
M 07	600,1	600,5
M 08	599,9	600,3
M 09	600,5	601,0

Table B.2 *(continued)*

Condition	BG low	BG high
M 10	600,0	600,1
Δ M 1	0,25	0,75
Δ M 2	0,15	0,45
Δ M 3	-0,35	-0,25
Δ M 4	0,25	0,25
Δ M 5	-0,25	-0,15
Δ M 6	0,35	0,05
Δ M 7	0,05	0,45
Δ M 8	-0,15	0,25
Δ M 9	0,45	0,95
Δ M10	-0,05	0,05
$\overline{D}_{BG,X}$	600,12	600,33
$\Delta\overline{D}_{BG,X}$	0,07	0,26
$\Delta\overline{D}_{BG,Add}$	- -	0,21
$u_{BG,X}$	0,27	0,38
$u_{BG,Add}$	- -	0,27



Key

X measurement condition

Y deviation from reference (mm)

Figure B.2 — Background illumination test

Temperature test (CP01)

Target: 0,25 m x 0,25 m with 100 % reflectivity

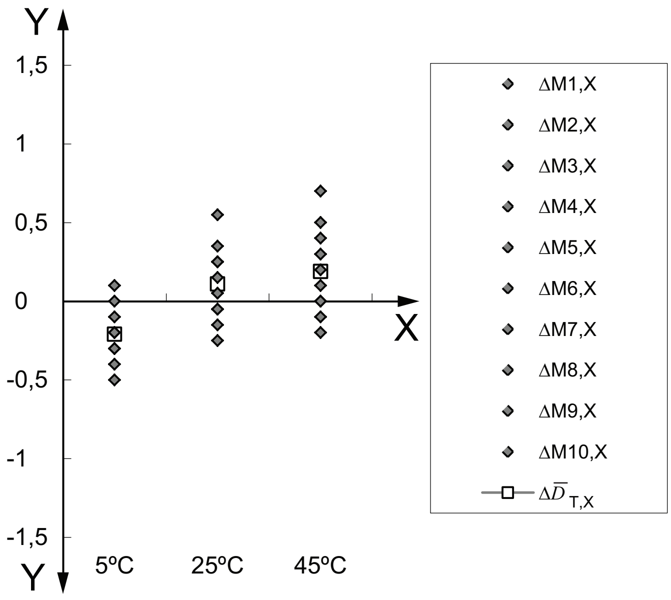
Illumination: low (<3 klx)

Temperature: 5 °C, 25 °C, 45 °C

Table B.3 — Temperature test at CP01

Dimensions in millimetres

Condition	5 °C	25 °C	45 °C
D_{REF}	601,40	601,45	601,50
M 01	601,3	601,8	602,2
M 02	601,2	601,2	601,4
M 03	601,1	601,7	601,3
M 04	601,5	601,4	601,6
M 05	601,0	601,6	602,0
M 06	601,2	601,3	601,5
M 07	601,1	601,7	601,9
M 08	600,9	602,0	601,7
M 09	601,4	601,4	601,8
M 10	601,2	601,5	601,5
Δ M 1	-0,10	0,35	0,70
Δ M 2	-0,20	-0,25	-0,10
Δ M 3	-0,30	0,25	-0,20
Δ M 4	0,10	-0,05	0,10
Δ M 5	-0,40	0,15	0,50
Δ M 6	-0,20	-0,15	0,00
Δ M 7	-0,30	0,25	0,40
Δ M 8	-0,50	0,55	0,20
Δ M 9	0,00	-0,05	0,30
Δ M10	-0,20	0,05	0,00
$\overline{D}_{T,X}$	601,19	601,56	601,69
$\Delta\overline{D}_{T,X}$	-0,21	0,11	0,19
$\Delta\overline{D}_{TX,Add}$	-0,32	- -	0,08
$u_{T,X}$	0,18	0,25	0,28
$u_{T,Add}$	- -	- -	0,14



Key

X measurement condition

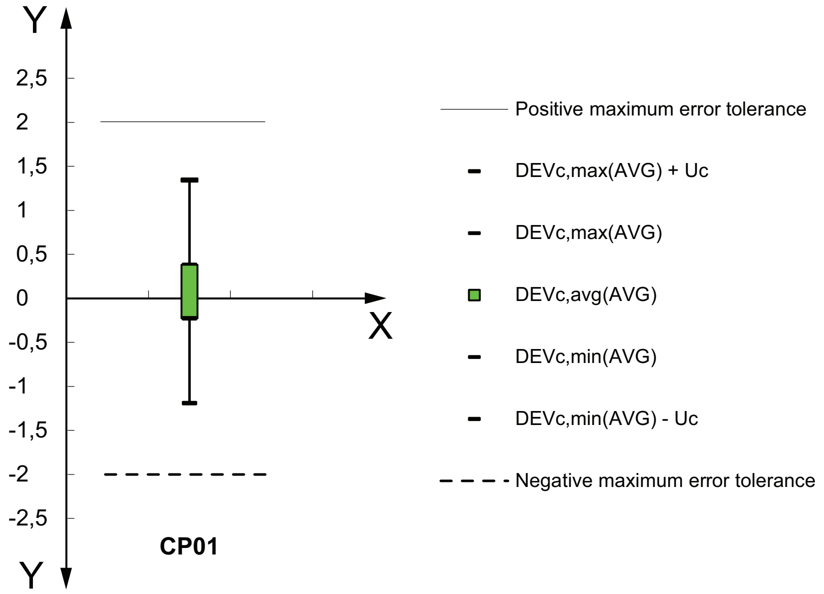
Y deviation from reference (mm)

Figure B.3 — Temperature test

Table B.4 — Combined deviation and expanded uncertainty

Dimensions in millimetres

Calculations at CP1	Value
$\Delta\overline{D}_{AD}$	0,09
$\Delta\overline{D}_{BG,Add}$	0,21
$\Delta\overline{D}_{T05,Add}$	-0,32
$\Delta\overline{D}_{T45,Add}$	0,08
$\Delta\overline{D}_{C,max}$	+0,38
$\Delta\overline{D}_{C,min}$	-0,23
$u_{REF,AD}$	0,10
$u_{REF,BG}$	0,10
$u_{REF,T}$	0,10
u_{DR} (DR = 0,1mm)	0,03
u_{AD}	0,33
$u_{BG,Add}$	0,27
$u_{T,Add}$	0,14
u_c	0,48
U (95 % level of confidence, k = 2)	0,96
$\Delta\overline{D}_{c,max} + U$	1,34
$\Delta\overline{D}_{c,min} - U$	-1,19
Positive maximum error tolerance	+2,00
Negative maximum error tolerance	-2,00



Key

X check point

Y deviation (mm)

Figure B.4 — Combined deviation range ± expanded uncertainty

Table B.5 — Test result at check point CP01

Deviation range of average values:	$\Delta\overline{D}_{C,min} \ldots \Delta\overline{D}_{C,max}$ = - 0,23 mm … + 0,38 mm
Expanded uncertainty of single measurements: (level of confidence 95 %, $k = 2,0$)	U = 0,96 mm
Result:	**within specification**

B.2 Example 2

Typical error tolerance: ±1,0 mm on 100 % target reflectivity, low background illumination, 25 °C, from 10 m additional 0,10 mm/m

Maximum error tolerance: ±1,5 mm on 100 % target reflectivity, high background illumination, –10 °C 50 °C from 10 m additional 0,15 mm/m

Range of device under test: 0,10 m to 50 m

Range of reference system: 0,00 m to 20 m

Check points: CP01 = 0,40 m, CP02 = 0,60 m, CP03 = 1,00 m, CP04 = 1,40 m, CP05 = 2,00 m,

CP06 = 4,00 m, CP07 = 6,00 m, CP08 = 10,00 m, CP09 = 14,00 m, CP10 = 20,00 m.

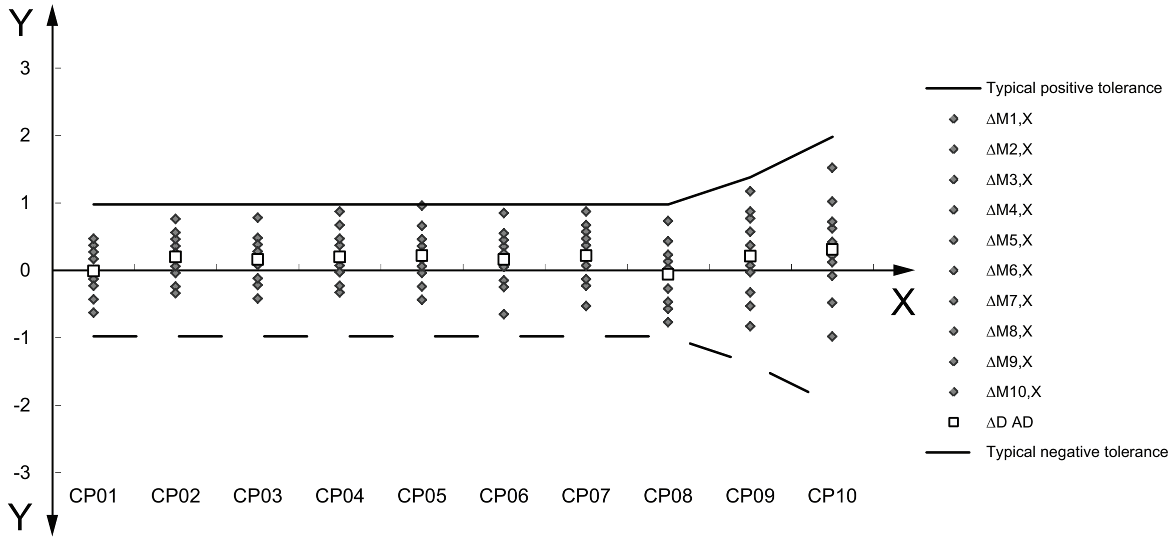
Table B.6 — Absolute distance test

Dimensions in millimetres

CP	01	02	03	04	05	06	07	08	09	10
D_{REF}	400,03	600,04	1000,02	1400,03	2000,04	3999,95	6000,03	10000,07	14000,03	20000,08
M 1	400,2	600,4	1000,5	1400,4	2000,2	4000,3	6000,4	10000,1	14000,4	20000,0
M 2	400,4	600,8	1000,1	1400,1	2000,4	4000,1	6000,1	10000,8	14001,2	20001,1
M 3	399,9	600,0	1000,3	1400,7	1999,6	4000,8	6000,7	10000,5	14000,6	20000,5
M 4	399,6	599,8	999,8	1400,0	2000,5	4000,2	5999,5	9999,3	13999,2	20001,6
M 5	400,2	600,5	1000,4	1400,5	2000,0	3999,8	6000,6	10000,2	14000,1	20000,3
M 6	400,5	600,1	1000,8	1399,7	2000,7	4000,4	5999,8	10000,0	14000,0	20000,7
M 7	399,9	600,6	999,9	1400,2	2000,3	3999,3	6000,9	10000,3	14000,8	19999,1
M 8	399,4	600,2	999,6	1399,8	2001,0	4000,5	5999,9	9999,5	13999,5	20000,8
M 9	399,8	599,7	1000,1	1400,0	2000,1	4000,0	6000,5	9999,8	14000,9	20000,2
M10	400,3	600,3	1000,3	1400,9	1999,8	3999,7	6000,1	9999,6	13999,7	19999,6
Δ M 1	0,17	0,36	0,48	0,37	0,16	0,35	0,37	0,03	0,37	-0,08
Δ M 2	0,37	0,76	0,08	0,07	0,36	0,15	0,07	0,73	1,17	1,02
Δ M 3	-0,13	-0,04	0,28	0,67	-0,44	0,85	0,67	0,43	0,57	0,42
Δ M 4	-0,43	-0,24	-0,22	-0,03	0,46	0,25	-0,53	-0,77	-0,83	1,52
Δ M 5	0,17	0,46	0,38	0,47	-0,04	-0,15	0,57	0,13	0,07	0,22
Δ M 6	0,47	0,06	0,78	-0,33	0,66	0,45	-0,23	-0,07	-0,03	0,62
Δ M 7	-0,13	0,56	-0,12	0,17	0,26	-0,65	0,87	0,23	0,77	-0,98
Δ M 8	-0,63	0,16	-0,42	-0,23	0,96	0,55	-0,13	-0,57	-0,53	0,72
Δ M 9	-0,23	-0,34	0,08	-0,03	0,06	0,05	0,47	-0,27	0,87	0,12
Δ M10	0,27	0,26	0,28	0,87	-0,24	-0,25	0,07	-0,47	-0,33	-0,48

Table B.6 *(continued)*

CP	01	02	03	04	05	06	07	08	09	10
$\overline{D}_{AD}$	400,02	600,24	1000,18	1400,23	2000,26	4000,11	6000,25	10000,01	14000,24	20000,39
$\Delta\overline{D}_{AD}$	-0,01	0,20	0,16	0,20	0,22	0,16	0,22	-0,06	0,21	0,31
u_{AD}	0,36	0,35	0,36	0,39	0,42	0,43	0,44	0,47	0,65	0,72



Key

X check point

Y deviation from reference (mm)

Figure B.5 — Check points CP01 to CP10 measured at typical conditions

Background illumination test (CP02)

Target: 0,25 m x 0,25 m with 100 % reflectivity

Illumination: low (<3 klx)

and high (>30 klx)

Temperature: 25 °C

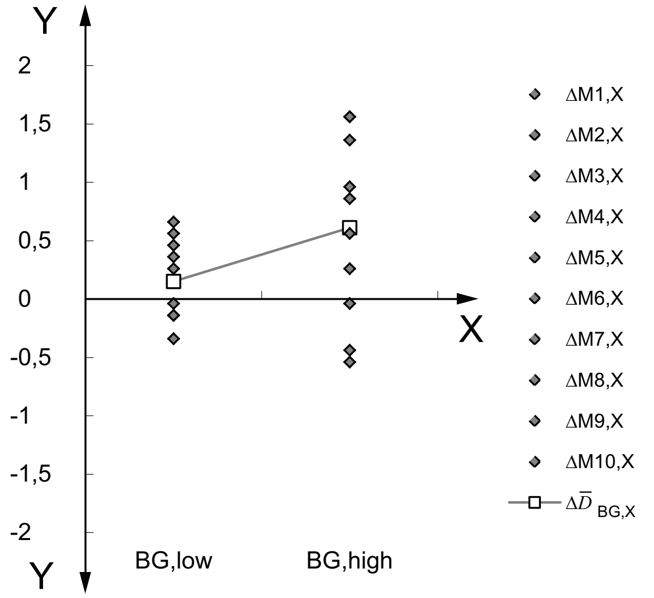
Table B.7 — Background test at CP02

Dimensions in millimetres

Condition	BG low	BG high
D_{REF}	600,04	600,04
M 01	600,6	601,4
M 02	600,5	601,6
M 03	599,9	600,0
M 04	600,0	600,6
M 05	600,7	599,5
M 06	600,3	600,9
M 07	599,9	601,6
M 08	599,7	599,6

Table B.7 *(continued)*

Condition	BG low	BG high
M 09	600,4	601,0
M 10	599,9	600,3
Δ M 1	0,56	1,36
Δ M 2	0,46	1,56
Δ M 3	-0,14	-0,04
Δ M 4	-0,04	0,56
Δ M 5	0,66	-0,54
Δ M 6	0,26	0,86
Δ M 7	-0,14	1,56
Δ M 8	-0,34	-0,44
Δ M 9	0,36	0,96
Δ M10	-0,14	-0,26
$\overline{D}_{\text{BG,X}}$	600,19	600,65
$\Delta\overline{D}_{\text{BG,X}}$	0,15	0,61
$\Delta\overline{D}_{\text{BG,Add}}$	- -	0,46
$u_{\text{BG,X}}$	0,35	0,78
$u_{\text{BG,Add}}$	- -	0,70



Key

X measurement condition

Y deviation from reference (mm)

Figure B.6 — Background illumination test

Temperature Test (CP02)

Target: 0,25 m x 0,25 m with 100 % reflectivity

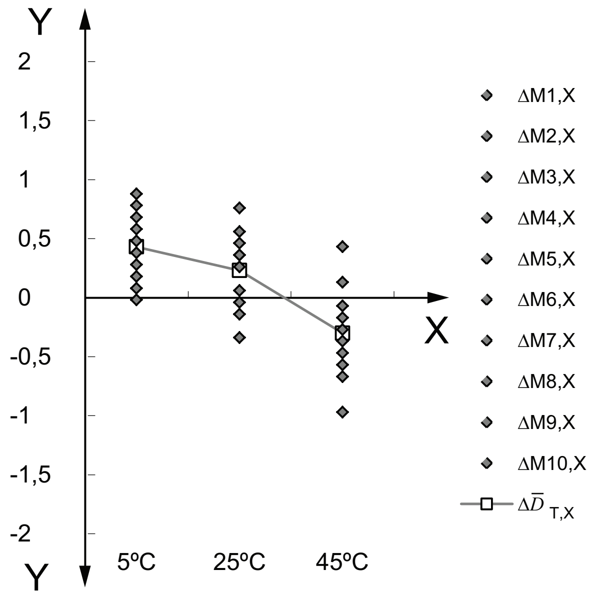
Illumination: low (<3 klx)

Temperature: 5 °C, 25 °C, 45 °C

Table B.8 — Temperature test at CP02

Dimensions in millimetres

Condition	5 °C	25 °C	45 °C
D_{REF}	600,02	600,04	600,07
M 01	600,5	600,4	600,2
M 02	600,8	600,8	599,9
M 03	600,3	600,0	599,5
M 04	600,1	600,1	600.5
M 05	600,7	600,5	599,7
M 06	600,0	600,3	600,0
M 07	600,6	599,9	599,4
M 08	600,9	600,4	599,8
M 09	600,4	600,6	599,6
M 10	600,2	599,7	599,1
Δ M 1	0,48	0,36	0,13
Δ M 2	0,78	0,76	-0,17
Δ M 3	0,28	-0,04	-0,57
Δ M 4	0,08	0,06	0,43
Δ M 5	0,68	0,46	-0,37
Δ M 6	-0,02	0,26	-0,07
Δ M 7	0,58	-0,14	-0,67
Δ M 8	0,88	0,36	-0,27
Δ M 9	0,38	0,56	-0,47
Δ M10	-0,18	-0,34	-0,97
$\overline{D}_{T,X}$	600,45	600,27	599,77
$\Delta\overline{D}_{T,X}$	0,43	0,23	-0,30
$\Delta\overline{D}_{T,Add}$	0,20	0,00	-0,53
$u_{T,X}$	0,30	0,34	0,41
$u_{T,Add}$	- -	- -	0,22



Key

X measurement condition

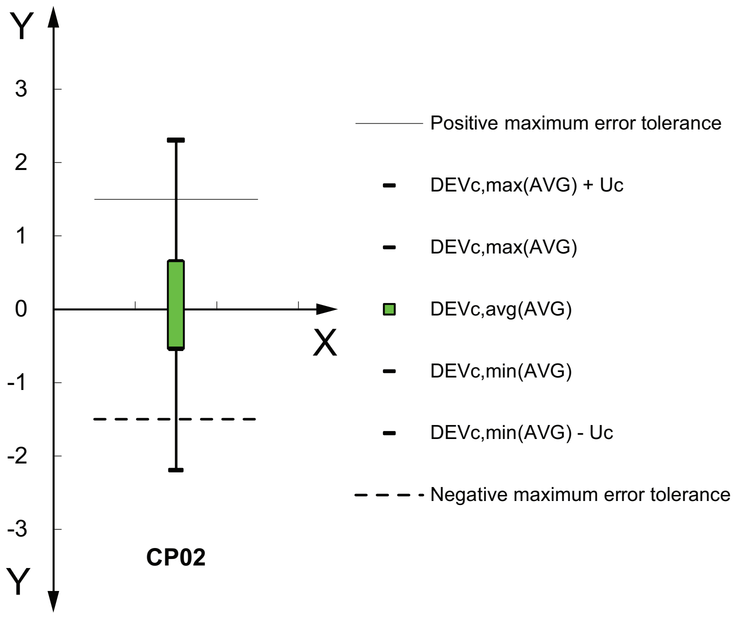
Y deviation from reference (mm)

Figure B.7 — Temperature test

Table B.9 — Combined deviation and expanded uncertainty

Dimensions in millimetres

Calculations at CP02	Value
$\Delta\overline{D}$ AD	-0,01
$\Delta\overline{D}$ BG,Add	0,46
$\Delta\overline{D}$ T05,Add	0,20
$\Delta\overline{D}$ T45,Add	-0,53
$\Delta\overline{D}$ C,max	0,65
$\Delta\overline{D}$ C,min	-0,54
$u_{REF,AD}$	0,05
$u_{REF,BG}$	0,10
$u_{REF,T}$	0,10
u_{DR} (DR = 0,1mm)	0,03
u_{AD}	0,35
$u_{BG,Add}$	0,70
$u_{T,Add}$	0,22
u_{C}	0,83
U (95 % level of confidence, k = 2)	1,66
$\Delta\overline{D}$ c,max + U	2,31
$\Delta\overline{D}$ c,min - U	-2,20
Positive maximum error tolerance	1,50
Negative maximum error tolerance	-1,50



Key

X check point

Y deviation (mm)

Figure B.8 — Combined deviation range ± expanded uncertainty

Table B.10 — Test result at check point CP02

Deviation range of average values:	$\Delta\overline{D}_{\mathrm{C,min}} \ldots \Delta\overline{D}_{\mathrm{C,max}} = -0{,}54$ mm … $+0{,}65$ mm
Expanded uncertainty of single measurements: (level of confidence 95 %, $k = 2{,}0$)	$U = 1{,}66$ mm
Result:	**out of specification**

Annex C
(informative)

Examples of determination of compliance with range specifications

C.1 Example 3

Specification of range on natural targets: 50 m

Specification of maximum error tolerance: ± 3 mm, from 30 m additional 0,1 mm/m (±5 mm at 50 m)

Air temperature = 22 °C, air pressure = 955 hPa, relative air humidity = 45 %

Background illumination of approximately 30 klx

Table C.1 — Range test measurements

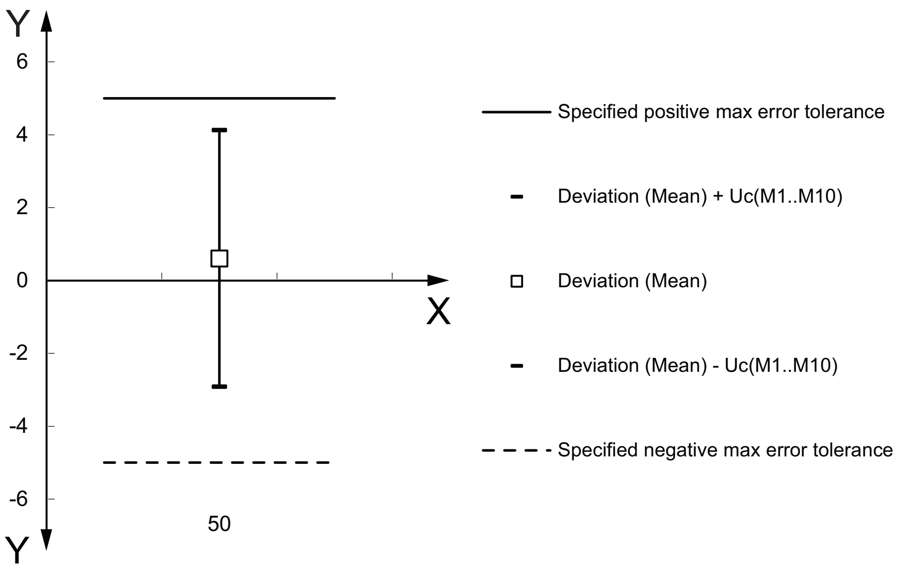
Dimensions in metres

Measurement	Value
$\overline{D}$ Ref	50,0015
M 01	50,005
M 02	50,001
M 03	50,000
M 04	50,002
M 05	50,003
M 06	50,004
M 07	50,001
M 08	50,002
M 09	50,003
M 10	50,000

Table C.2 — Range test calculations

Dimensions in metres

Calculation	Value
$\overline{D}$ RT/m	50,0021
$\Delta\overline{D}$ RT/mm	0,6
u_{REF}/mm	0,50
u_{DR} (DR = 1,0mm)	0,29
u_{RT}/mm	1,66
$u_{C,RT}$/mm	1,76
U_{RT} (95 % level of confidence, $k = 2,0$)	3,52
$\Delta\overline{D}$ RT + U_{RT}	4,12
$\Delta\overline{D}$ RT - U_{RT}	-2,92
Positive maximum error tolerance at 50m	5,00
Negative maximum error tolerance at 50m	-5,00



Key

X range (m)

Y deviation from reference (mm)

Figure C.1 —Average deviation and expanded uncertainty at range test

Table C.3 — Test results

Deviation of average value at range test:	$\Delta\overline{D}_{RT} = +0,6$ mm
Expanded uncertainty of single measurements: (level of confidence 95 %, $k = 2,0$)	$U_{RT} = 3,5$ mm
Result:	**within specification**

C.2 Example 4

Specification of range on natural targets: 70 m

Specification of maximum tolerance: ± 2 mm, from 20 m additional 0,05 mm/m

Air temperature = 25 °C, air pressure = 970 hPa, relative air humidity = 50 %

Background illumination of approximately 30 klx

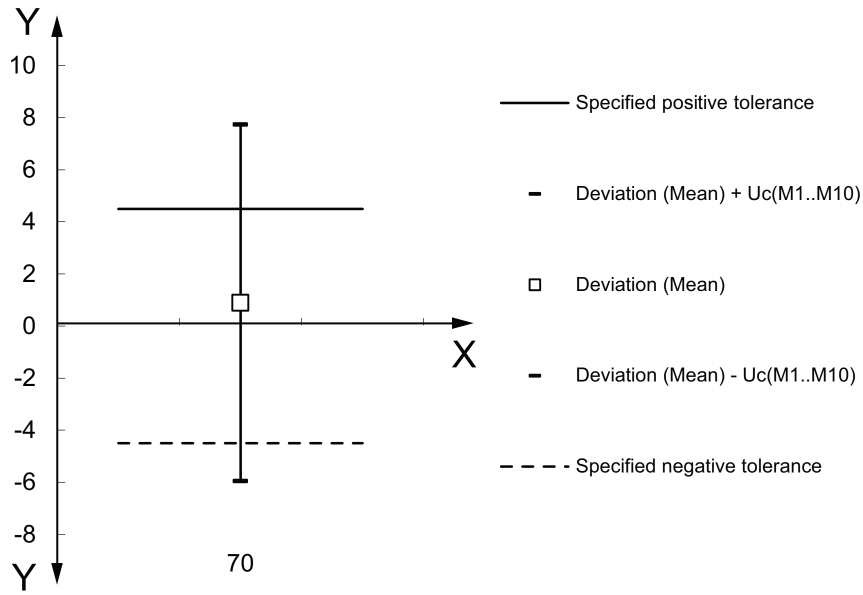
Table C.4 — Range test measurements

Dimensions in millimetres

Measurement	Value
(Ref)	69,9950
M 01	69,999
M 02	69,994
M 03	69,997
M 04	70,000
M 05	69,995
M 06	69,990
M 07	n.m.
M 08	69,999
M 09	69,993
M 10	69,996

Table C.5 — Range test calculations

Calculation	Value
$\overline{D}$ RT/m	69,9959
$\Delta\overline{D}$ RT/mm	0,89
u_{REF}/mm	1,00
u_{DR} (DR = 1,0mm)	0,29
u_{RT}/mm	3,26
$u_{C,RT}$/mm	3,42
U_{RT} (95 % level of confidence, k = 2,0)	6,84
$\Delta\overline{D}$ RT + URT	7,73
$\Delta\overline{D}$ RT - URT	-5,95
Positive maximum error tolerance at 70m	4,50
Negative maximum error tolerance at 70m	-4,50



Key

X range (m)

Y deviation from reference (mm)

Figure C.2 — Deviation of mean value and expanded uncertainty at range test

Table C.6 — Test results

Deviation of average value at range test:	$\Delta\overline{D}_{RT} = +0{,}9$ mm
Expanded uncertainty of single measurements: (level of confidence 95 %, $k = 2{,}0$)	$U_{RT} = 6{,}8$ mm
Result:	**out of specification**

Annex D
(informative)

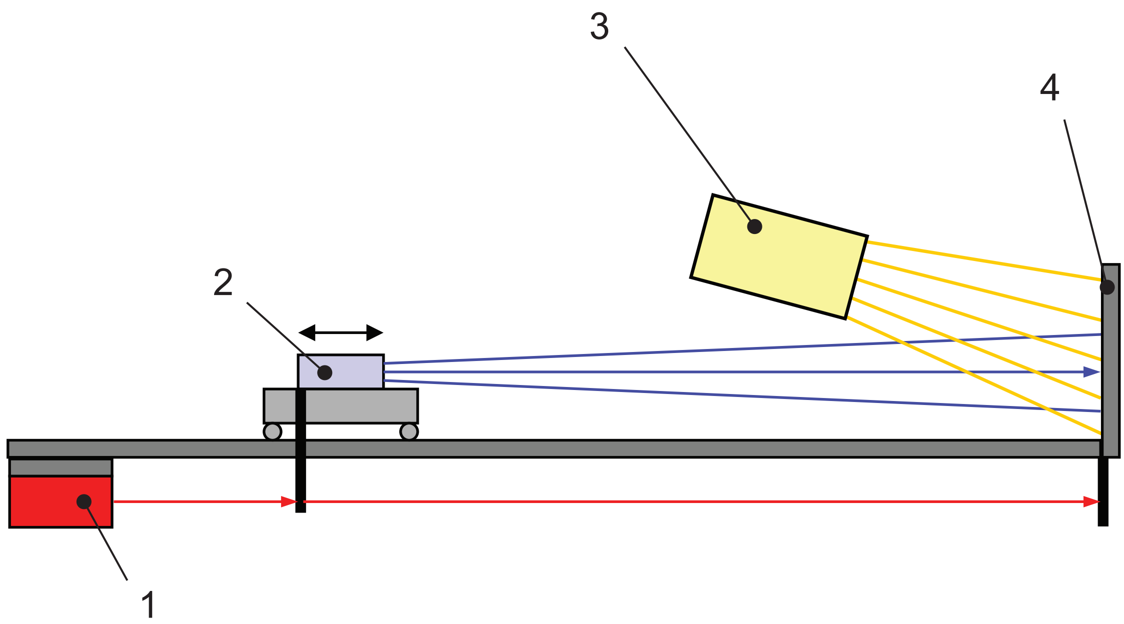
Background illumination simulation

D.1 General

There are different ways to simulate background illumination or the impact of background illumination on the performance of handheld laser distance meters.

D.2 Direct background illumination with front illumination

The setup for direct background illumination simulation is shown in Figure D.1. A fixed target is illuminated by a lamp with a light spectrum and a density similar to daylight. In this case the device under test is moved from one checkpoint to the next. The reference system (REF) should be able to determine the distance between the fixed target and the movable device under test.



Key

1 REF

2 DUT

3 lamp

4 target

Figure D.1 — Setup for front side background illumination simulation

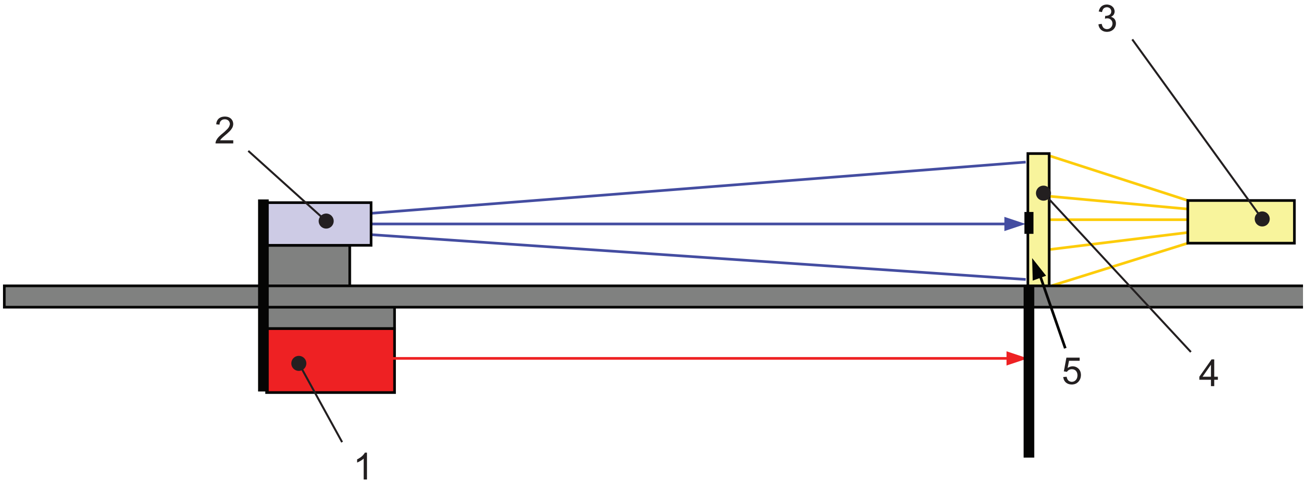
Advantage: The simulation of daylight influences is very realistic.

Disadvantages: A very powerful lamp or a combination of various lamps is required.

The device under test with all the connections for automatic testing has to be moveable. At close distances to the target, the powerful lamp heats the device under test significantly.

D.3 Direct background illumination with backside illumination

Another setup for an direct background illumination simulation is shown in Figure D.2. This is a very cost efficient solution as the requirements for the lamp are not stringent. The target plate is very small (slightly larger than the laser spot) and mounted on (or into) a translucent milky glass plate. This glass plate is illuminated from the backside by a simple halogen lamp of about 500 W. The required background illumination of approximately 30 klx is achievable by varying the power supply voltage for the lamp and/or the distance of the lamp to the glass plate.



Key

1 REF
2 DUT
3 lamp
4 target
5 translucent glass plate

Figure D.2 — Setup for backside background illumination simulation

Advantage**s:** The setup is very cost efficient.

The setup is compact.

Disadvantages: Safety issues exist due to the high thermal heating of the glass plate.

In practice, it only works well for a small distance range.

Annex E
(informative)

Target plates

Table E.1 — Target plate examples

Target plate (diffuse reflectance)[a]	**Size** mm	**Reflectance at** 635 nm	**Depth of penetration** mm	**Comments**
Spectralon reflectance target (Labsphere)	254 × 254	0,99	> 2,0	With calibration certificate (NIST). As reference for relative measurement of reflectance.
White Balanced Card (Edmund Optics)	295 × 205	0,90	< 0,2	
Target Plate 723385 (white) (Leica Geosystems)	297 × 210	0,95	< 1,0	
Glass plate with Duraflect Reflectance Coating (Labsphere)	adjustable	094 .. 096	< 1,0	For outdoor use in case of testing range specifications.

[a] The items in this column are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

Annex F
(informative)

Typical characteristics of natural targets

On natural targets laser light is reflected mostly in a diffuse way. A complete matte material scatters the laser light evenly in all directions, reflecting the radiation independently of the incident angle. Therefore a laser distance meter is able to receive a small portion of the laser light which was sent out, even when the laser beam hits the target under a small angle in reference to the target surface. Targets with a sleek surface reflect the laser light in a less diffuse and more directional way. Therefore the amount of the reflected laser light that comes back to the laser distance meter depends significantly on the incident angle of the laser beam in reference to the target surface.

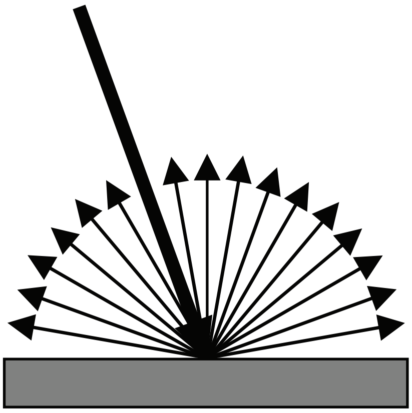


Figure F.1 — Ideal diffuse reflection (Lambertian surface)

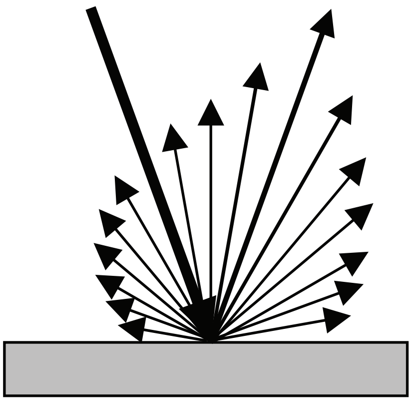


Figure F.2 — Diffuse reflection with directional component

A matte white and plane surface has by definition a diffuse reflectance of 1,0 (100 %). This is the reason why a sleek and plane surface might have a reflectance of > 1,0, depending on the incident angle of the laser beam, e.g. measuring on a polished plane metal surface in a perfect perpendicular position will reflect the laser beam nearly completely into the receiver optics. In comparison with the received portion of laser light reflected on a complete matte and white target, the portion of reflected laser light in this case will be many times higher.

Table F.1 — Reflectance and laser penetration of typical target materials

Target	Reflectance at 635 nm	Average depth of penetration mm	Comments
White painted wall	0,9 … 1,0	< 0,5	
Concrete, dry	0,3 … 0,4	1 …20	Air bubbles lead to deviations
Concrete, wet	0,2 …0,3	1 …20	Air bubbles lead to deviations
Granite stone	0,3 … 0,4	< 1	
White marble	0,6 … 0,8	> 5	Danger of inaccurate measurements
Red brick	0,2 … 0,4	< 1	
Oak wood	0,6 … 0,8	< 2	
Balsa wood	0,7 … 0,8	> 2	Danger of inaccurate measurements
Styrofoam	0,3 … 0,4	> 5	Danger of inaccurate measurements
Polystyrol 495F lightgrey	0,5	< 0,5	
Polystyrol 495F red	0,6	> 2	Danger of inaccurate measurements
Polystyrol 495F black	0,4	< 0,3	
Black velvet	0,05 … 0,1	1…2	
Aluminium matt	1,0 … 1,5	< 0,3	Danger of multi-path measurements
Aluminium polished	2,0 … 10	< 0,1	Danger of multi-path measurements

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