INTERNATIONAL STANDARD

ISO 6789-2

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Assembly tools for screws and nuts — Hand torque tools —

Part 2: Requirements for calibration and determination of measurement uncertainty

Outils de manoeuvre pour vis et écrous — Outils dynamométriques à commande manuelle —

Partie 2: Exigences d'étalonnage et détermination de l'incertitude de mesure

Reference number
ISO 6789-2:2017(E)

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 29, *Small tools*, Subcommittee SC 10, *Assembly tools for screws and nuts, pliers and nippers*.

This first edition of ISO 6789-2, together with ISO 6789-1, cancels and replaces ISO 6789:2003 which has been technically revised with changes as follows.

a) ISO 6789:2003 has been divided into two parts. ISO 6789:2003 has become ISO 6789-1 which specifies the requirements for design and manufacture including the content of a declaration of conformance. This document specifies the requirements for traceable certificates of calibration. It includes a method for calculation of uncertainties and provides a method for calibration of the torque measurement device used for calibrating hand torque tools.

b) This document includes detailed methods for calculation of the uncertainty budget which shall be performed for each individual tool.

c) This document includes example calculations that are provided for different types of torque tool.

d) Annex C provides requirements for calibrating the torque measurement device where the calibration laboratory does not utilize a national standard giving such requirements.

A list of all parts in the ISO 6789 series can be found on the ISO website.

Introduction

The revision of ISO 6789:2003 has been designed to achieve the following improvements.

ISO 6789 has been split to provide two levels of documentation. It recognizes the different needs of different users of the standard.

ISO 6789-1 continues to provide designers and manufacturers with relevant minimum requirements for the development, production and documentation of hand torque tools.

This document provides detailed methods for calculation of uncertainties and requirements for calibrations. This will allow users of calibration services to more easily compare the calibrations from different laboratories. Additionally, minimum requirements for the calibration of torque measurement devices are described in Annex C.

The purpose of this document is to define the requirements for a calibration in which the sources of uncertainty are evaluated and used to define the range of values within which the readings probably fall. Additional uncertainties may exist in the use of the torque tool. The evaluation of uncertainties for each individual tool is time-consuming and where there are sufficient data to estimate the Type B uncertainty components by statistical means, it is acceptable to use these values for a given model of torque tool, providing that the uncertainty components are subject to periodic review.

Assembly tools for screws and nuts — Hand torque tools —

Part 2: Requirements for calibration and determination of measurement uncertainty

1 Scope

This document specifies the method for the calibration of hand torque tools and describes the method of calculation of measurement uncertainties for the calibration.

This document specifies the minimum requirements for the calibration of the torque measurement device where the relative measurement uncertainty interval, W'_{md}, is not already provided by a traceable calibration certificate.

ISO 6789 is applicable for the step by step (static) and continuous (quasi-static) calibration of torque measurement devices, the torque of which is defined by measuring of the elastic form change of a deformable body or a measured variable which is in proportion to the torque.

This document applies to hand torque tools which are classified as indicating torque tools (Type I) and setting torque tools (Type II).

NOTE Hand torque tools covered by this document are the ones identified in ISO 1703:2005 by reference numbers 6 1 00 11 0, 6 1 00 11 1 and 6 1 00 12 0, 6 1 00 12 1 and 6 1 00 14 0, 6 1 00 15 0. ISO 1703 is currently under revision. In the next edition, torque tools will be moved to an own clause, and with this change the reference numbers will also change and additional reference numbers will be added.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 6789-1:2017, *Assembly tools for screws and nut — Hand torque tools — Part 1: Requirements and methods for design conformance testing and quality conformance testing: minimum requirements for declaration of conformance*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in ISO 6789-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
Type A evaluation (of uncertainty)
method of evaluation of uncertainty by the statistical analysis of series of observations

Note 1 to entry: These data are taken directly from the measurements obtained during calibration of each torque tool and cannot be prepared in advance.

[SOURCE: ISO/IEC Guide 98-3:2008, 2.3.2, modified — Note 1 to entry has been added.]

3.1.2
Type B evaluation (of uncertainty)
method of evaluation of uncertainty by means other than the statistical analysis of series of observations

[SOURCE: ISO/IEC Guide 98-3:2008, 2.3.3]

3.1.3
calibration system
combination of a measurement device and the loading system for application of torque that acts as the measurement standard for the hand torque tool

Note 1 to entry: A calibration system can also be used as a torque measurement system as defined in ISO 6789-1.

3.1.4
measurement device
working measurement standard provided either mechanically or by an electronic torque transducer and display

Note 1 to entry: A measurement device can also be referred to as a torque measurement device as defined in ISO 6789-1.

3.1.5
reference measurement standard
measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location

[SOURCE: ISO Guide 99:2007, 5.6]

3.1.6
measurement error
measured quantity value minus a reference quantity value

[SOURCE: ISO/IEC Guide 99:2007, 2.16, modified — Notes 1 and 2 to entry have been omitted.]

3.2 Symbols, designations and units

The designations used in this document are indicated in Table 1.

Table 1 — Symbols, designations and units

Symbol	Designation	Unit
a_s	Calculated relative measurement error of the torque tool for the calibration torque	%
$\overline{a}_s$	Mean value of the relative measurement error at each calibration torque	%
b_e	Stated measurement error of the measurement device	N·m
$b_{ref,e}$	Measurement error of the reference at the calibration torque	N·m
b_{ep}	Stated relative measurement error of the measurement device	%
NOTE While N·m is the unit commonly used, the output signal can be detected in various units, e.g. voltage.		

Table 1 *(continued)*

Symbol	Designation	Unit
$b_{ref,ep}$	Relative measurement error of the reference at the calibration torque	%
b_{int}	Variation due to geometric effects of the interface between the output drive of the torque tool and the calibration system	N·m
b_l	Variation due to the variation of the force loading point	N·m
b_{od}	Variation due to geometric effects of the output drive of the torque tool	N·m
b_{re}	Variation due to the repeatability of the torque tool	N·m
$b_{md,re}$	Variation due to the repeatability of the measurement device in the same mounting position	N·m
b_{rep}	Variation due to the reproducibility of the torque tool (Type I and Type II Classes A, D and G only)	N·m
$b_{md,rep}$	Variation due to the reproducibility of the measurement device in different mounting positions	N·m
b_z	Measurement hysteresis error of the zero signal after loading	N·m
I	Indicated value of measurement device without zero-value compensation	N·m
I_0	Indicated value of the zero signal 30 s after preload and prior to load in mounting position	N·m
I_z	Indicated value of the zero signal 30 s after unloading	N·m
k	Coverage factor k = 2 applied to the relative measurement uncertainty to achieve a confidence level of approximately 95 %	—
r	Resolution of the display (Type I and Type II Classes A, D and G only)	N·m
r_{md}	Resolution of the measurement device display	N·m
T_A	Minimum limit of measuring range of the measurement device	N·m
T_E	Maximum limit of measuring range of the measurement device	N·m
T_{min}	Minimum limit value of the measurement range of the torque tool declared by the manufacturer	N·m
w	Relative standard measurement uncertainty of the torque tool at the calibration torque	%
w_{int}	Component of w due to geometric effects of the interface between the output drive of the torque tool and the calibration system	%
w_l	Component of w due to the length variation of the force loading point	%
w_{md}	Relative standard measurement uncertainty of the measurement device at the calibration torque	%
$w_{md,c}$	Combined relative standard measurement uncertainty of the measurement device	%
$w_{md,t}$	Relative standard measurement uncertainty of the measurement device transducer	%
$w_{md,d}$	Relative standard measurement uncertainty of the measurement device display	%
w_{od}	Component of w due to geometric effects of the output drive of the torque tool	%
w_r	Relative standard measurement uncertainty due to resolution of the display of the torque tool (Type I and Type II Classes A, D and G only)	%
$w_{md,r}$	Relative standard measurement uncertainty due to resolution of the measurement device display	%
w_{re}	Component of w due to repeatability of the torque tool	%
$w_{md,re}$	Component of w_{md} due to repeatability of the measurement device	%
w_{rep}	Component of w due to reproducibility of the torque tool (Type I and Type II Classes A, D and G only)	%
$w_{md,rep}$	Component of w_{md} due to reproducibility of the measurement device	%
$w_{md,z}$	Component of w_{md} due to the measurement hysteresis error of the zero signal of the measurement device	%
NOTE While N·m is the unit commonly used, the output signal can be detected in various units, e.g. voltage.		

Table 1 *(continued)*

Symbol	Designation	Unit
W	Relative expanded measurement uncertainty of the torque tool at the calibration torque	%
W'	Relative measurement uncertainty interval of the torque tool at the calibration torque	%
W_{md}	Relative expanded measurement uncertainty of the measurement device at the calibration torque	%
W'_{md}	Relative measurement uncertainty interval of the measurement device at the calibration torque	%
W_{ref}	Relative expanded measurement uncertainty of the reference measurement standard	%
W'_{ref}	Relative measurement uncertainty interval of the reference measurement standard	%
X	Indicated value of measurement device with zero-value compensation	N·m
X_a	Target indicated, set or nominal value depending on the type and class of the torque tool	N·m
X_{min}	Minimum value of X observed during different mounting positions	N·m
X_{max}	Maximum value of X observed during different mounting positions	N·m
X_r	Reference value determined by the measurement device	N·m
$\overline{X}_r$	Mean reference value determined by the measurement device	N·m
X_{ref}	Reference value determined by the reference device	N·m
NOTE While N·m is the unit commonly used, the output signal can be detected in various units, e.g. voltage.		

4 Requirements for calibration

4.1 Calibration during use

If the user utilizes procedures for the control of test devices, torque tools shall be included in these procedures. The interval between calibrations shall be chosen on the basis of the factors of operation such as required maximum permissible measurement error, frequency of use, typical load during operation as well as ambient conditions during operation and storage conditions. The interval shall be adapted according to the procedures specified for the control of test devices and by evaluating the results gained during successive calibrations.

If the user does not utilize a control procedure, a period of 12 months, or 5 000 cycles, whichever occurs first, may be taken as default values for the interval between calibrations. The interval starts with the first use of the torque tool.

Shorter interval between calibrations may be used if required by the user, their customer or by legislation.

The torque tool shall be calibrated when it has been subjected to an overload greater than the values given in ISO 6789-1:2017, 5.1.6, after repair, or after any improper handling which might influence the torque tool performance and the fulfilment of the quality conformance requirements.

4.2 Calibration method

The method for the calibration of the torque tools shall be in accordance with the measurement method of ISO 6789-1:2017, Clause 6. Additionally, the requirement for the torque measurement device defined in ISO 6789-1:2017, 6.1 is replaced by 4.3.

4.3 Calibration system

The calibration system shall be chosen to be suitable for the measurement of the specified range of the torque tool.

At each target value, the relative uncertainty interval, W'_{md}, of the measurement device shall not exceed 1/4 of the expected maximum relative uncertainty interval of the torque tool, W'.

The measurement device shall have a valid calibration certificate issued by a laboratory meeting the requirements of ISO/IEC 17025. Alternatively, the measurement device shall be calibrated by a laboratory maintaining the national measurement standard.

If the user does not utilize a control procedure, a period of 24 months shall be the maximum interval between calibrations.

The measurement device shall be re-calibrated if it was exposed to an overload larger than 20 % of T_E, after a repair has been carried out or after an improper use which can influence the measurement uncertainty.

5 Measurement error

5.1 Calculation of the relative measurement error

The calibration values shall be measured and recorded according to the requirements in ISO 6789-1:2017, 6.5.

The evaluation of the relative measurement error is calculated using Formula (1):

$$a_s = \frac{(X_a - X_r) \times 100}{X_r} \tag{1}$$

The mean value of the relative measurement error at each calibration torque is calculated using Formula (2):

$$\overline{a_s} = \frac{1}{n} \sum_{j=1}^{n} a_{s,j} \tag{2}$$

where

$j = 1, 2, \ldots, n$ is the number of individual measurements at each calibration torque.

5.2 Exemplary calculations of the relative measurement error

5.2.1 Example 1

Calculation of the relative measurement error of indicating and setting torque tools (except Type II, Class B, C, E and F):

— indicated value of dial, mechanical scale or display (Type I, Classes A, B, C, D and E), or

— set value of mechanical scale or display (Type II, Classes A, D and G):

$X_a = 100$ N·m

— Reference values (determined by the calibration device):

$X_{r1} = 104{,}0$ N·m

$X_{r2} = 96{,}5$ N·m

$X_{r3} = 102{,}6$ N·m

X_{r4} = 99,0 N·m

X_{r5} = 101,0 N·m

— Calculated relative measurement errors of the torque tools in %:

$$a_{s1} = \frac{(100{,}0 - 104{,}0) \times 100}{104{,}0} = -3{,}85$$

$$a_{s2} = \frac{(100{,}0 - 96{,}5) \times 100}{96{,}5} = +3{,}63$$

$$a_{s3} = \frac{(100{,}0 - 102{,}6) \times 100}{102{,}6} = -2{,}53$$

$$a_{s4} = \frac{(100{,}0 - 99{,}0) \times 100}{99{,}0} = +1{,}01$$

$$a_{s5} = \frac{(100{,}0 - 101{,}0) \times 100}{101{,}0} = -0{,}99$$

5.2.2 Example 2

Calculation of the measurement error of setting torque tools, adjustable, non-graduated (Type II, Class B, C, E and Class F):

— nominal value set (Type II, Class B and E), or

— lowest specified torque value or pre-set value (Type II, Class C and F):

X_a = 100 N·m

— Reference values (determined by the calibration device):

X_{r1} = 104,0 N·m

X_{r2} = 103,0 N·m

X_{r3} = 102,8 N·m

X_{r4} = 102,0 N·m

X_{r5} = 101,0 N·m

X_{r6} = 101,2 N·m

X_{r7} = 101,7 N·m

X_{r8} = 101,9 N·m

X_{r9} = 102,2 N·m

X_{r10} = 102,5 N·m

— Calculated relative measurement errors of the torque tools in %:

$$a_{s1} = \frac{(100{,}0 - 104{,}0) \times 100}{104{,}0} = -3{,}85$$

$$a_{s2} = \frac{(100{,}0 - 103{,}0) \times 100}{103{,}0} = -2{,}91$$

$$a_{s3} = \frac{(100{,}0 - 102{,}8) \times 100}{102{,}8} = -2{,}72$$

$$a_{s4} = \frac{(100{,}0 - 102{,}0) \times 100}{102{,}0} = -1{,}96$$

$$a_{s5} = \frac{(100{,}0 - 101{,}0) \times 100}{101{,}0} = -0{,}99$$

$$a_{s6} = \frac{(100{,}0 - 101{,}2) \times 100}{101{,}2} = -1{,}19$$

$$a_{s7} = \frac{(100{,}0 - 101{,}7) \times 100}{101{,}7} = -1{,}67$$

$$a_{s8} = \frac{(100{,}0 - 101{,}9) \times 100}{101{,}9} = -1{,}86$$

$$a_{s9} = \frac{(100{,}0 - 102{,}2) \times 100}{102{,}2} = -2{,}15$$

$$a_{s10} = \frac{(100{,}0 - 102{,}5) \times 100}{102{,}5} = -2{,}44$$

6 Sources of uncertainty

6.1 General

The elements of uncertainty associated with the calibration of a torque tool shall be derived from at least one of the two following methodologies.

— The uncertainties shall be established using the procedures as set out in 6.2. Where a laboratory or manufacturer has sufficient data as defined in 6.2, this value may be determined statistically for a sufficient number of specimen (at least 10) of a model of tool, and its determination does not need to be repeated each time for future calibrations of this model. The validity of this value shall be reviewed systematically.

— The uncertainties shall be taken from manufacturers or other third-party data. Care shall be taken to ensure that any such data can be sufficiently validated and reproduced in the laboratory.

EXAMPLE Examples of calculations are provided for Type I wrenches in Annex A and Type II wrenches in Annex B.

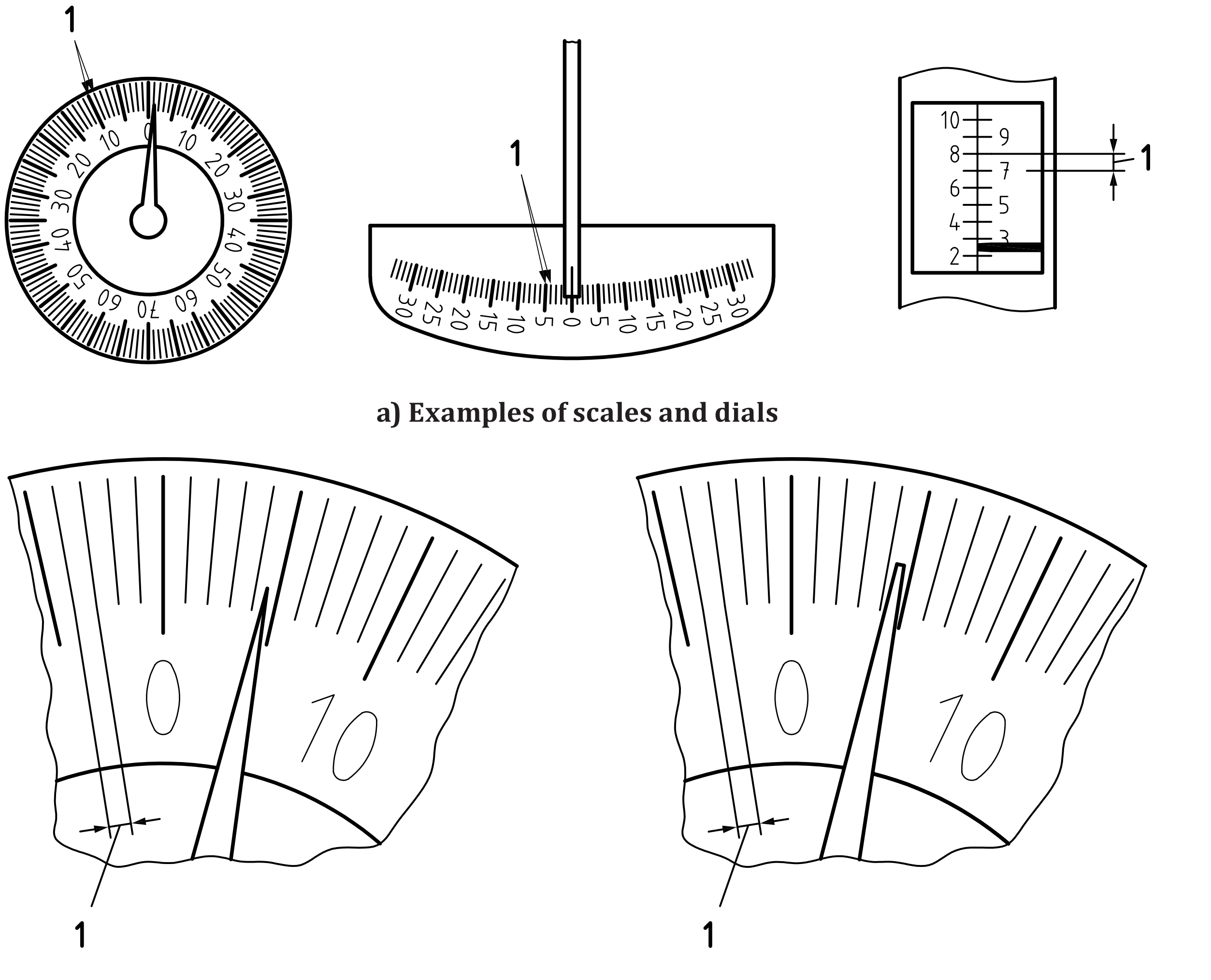
6.2 Evaluation of Type B uncertainties due to the torque tool

6.2.1 Scale, dial or display resolution, *r*

6.2.1.1 Determination of the resolution, *r*, with analogue scales or dials

The torque value shall be read from the position of the active or moving cursor or pointer on a scale or dial. Slave pointers (memory indicators) shall not be used when taking the readings.

Where the pointer tip width is less than 1/5 of the scale or dial increment, the resolution is 1/5 of the scale or dial increment value. Where the pointer tip width is equal to or greater than 1/5 but less than 1/2 of the scale or dial increment, the resolution is 1/2 of the scale or dial increment value. Where the pointer tip width is greater than 1/2 of the scale or dial increment, the resolution is the scale or dial increment value.



a) Examples of scales and dials

b) Scale or dial where pointer tip width is less than or equal to 1/5 increment width

c) Scale or dial where pointer tip width is larger than 1/5 but less than or equal to 1/2 increment width

Key

1 main scale or dial increment (in these examples 1 N·m)

Figure 1 — Examples of different pointer widths of scales and dials

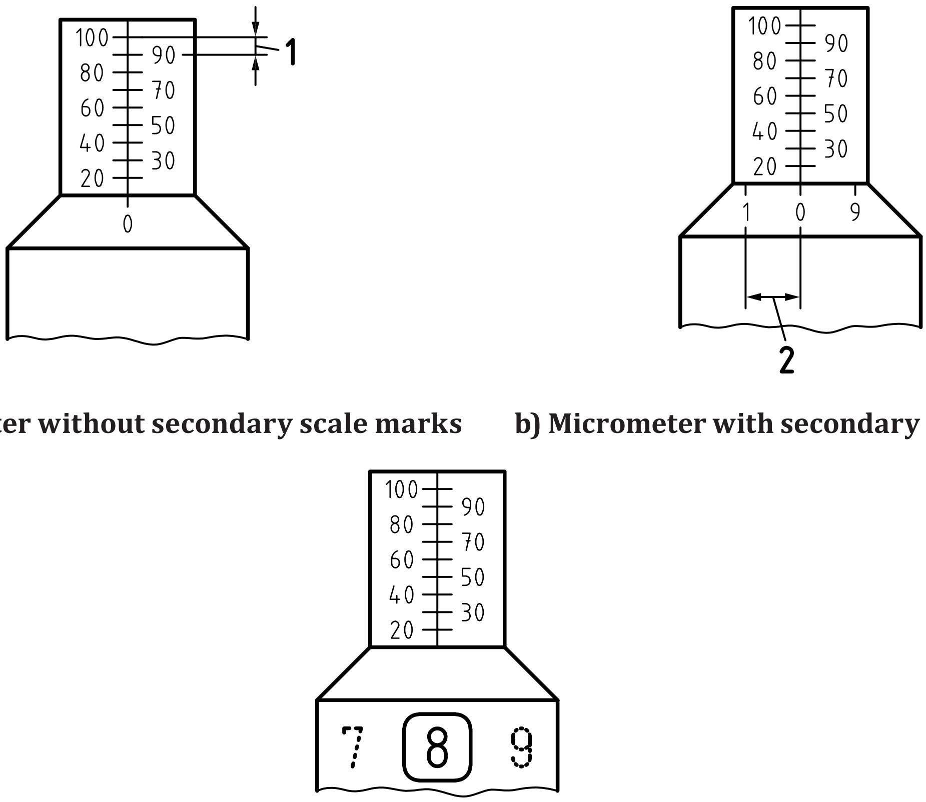
The resolution in Figure 1 b) is determined as: $r = \frac{1}{5} \times 1\ \text{N} \cdot \text{m} = 0{,}2\ \text{N} \cdot \text{m}$

The resolution in Figure 1 c) is determined as: $r = \frac{1}{2} \times 1\ \text{N} \cdot \text{m} = 0{,}5\ \text{N} \cdot \text{m}$

6.2.1.2 Determination of the resolution, *r*, with micrometer scales

Where the torque tool utilizes a “micrometer” scale, a second set of scale marks appropriate to the main scale may be used to allow direct fractional reading of the torque value.

Where there is no secondary scale, its resolution is 1/2 of the main scale increment value. Where there is a secondary scale, the resolution is 1/2 of the secondary scale increment value.



a) Micrometer without secondary scale marks

b) Micrometer with secondary scale marks

c) Partially covered secondary scale

Key

1 main scale increment (in these examples 10 N·m)

2 secondary scale increment (in these examples 1 N·m)

Figure 2 — Examples of micrometer scales

The resolution in Figure 2 a) is determined as: $r = \frac{1}{2} \times 10\ \text{N} \cdot \text{m} = 5\,\text{N} \cdot \text{m}$

The resolution in Figure 2 b) is determined as: $r = \frac{1}{2} \times 1\ \text{N} \cdot \text{m} = 0{,}5\,\text{N} \cdot \text{m}$

The resolution in Figure 2 c) is determined as: $r = \frac{1}{2} \times 1\ \text{N} \cdot \text{m} = 0{,}5\,\text{N} \cdot \text{m}$

6.2.1.3 Determination of the resolution, r, with digital scales or dials

For torque tools with a digital scale, dial or display the resolution, r, shall be determined as follows.

The value of r shall be a single increment of the last active digit, provided the display does not fluctuate by more than one digit when the device is at the lowest calibrated torque value. Where the values fluctuate by more than one digit when the device is at the lowest calibrated torque value, the value of r shall be a single increment of the last active digit plus one half of the fluctuation range; see Table 2.

Table 2 — Examples of resolution

Case		Resolution N·m		
		Example 1	**Example 2**	**Example 3**
1	Increment size	0,001	0,02	0,05
	Amount of fluctuation at lowest calibrated value	0,000	0,00	0,00
	Resolution	0,001	0,02	0,05
2	Increment size	0,001	0,02	0,05
	Amount of fluctuation at lowest calibrated value	0,002	0,06	0,10
	Resolution	0,002	0,05	0,10

6.2.2 Variation due to the reproducibility of the torque tool, b_{rep}

Reproducibility is affected by the ability to identify exactly the value at which loading should be stopped for indicating torque tools Type I and the ability of the mechanism to return in exactly the same place each time after adjustment of the tool in the case of setting torque tools Type II. For both Type I and Type II tools, it includes parallax errors.

For torque tools of all types, the following method is described for the determination of reproducibility, b_{rep}. The tool shall be subjected to the loading sequence defined in ISO 6789-1:2017, 6.5, at the lowest specified torque value only and the values recorded. The sequence shall be performed four times and the torque tool shall be removed from the calibration system between each sequence. Where more than one operator performs such calibrations, the sequences will be distributed between operators.

The variation due to the reproducibility of the torque tool is calculated using Formula (3):

$$b_{rep} = \max(\overline{X}_{r,i}) - \min(\overline{X}_{r,i}) \quad (3)$$

The mean value of the measurement series i is calculated using Formula (4):

$$\overline{X}_{r,i} = \frac{1}{n}\sum_{j=1}^{n} X_{i,j} \quad (4)$$

where

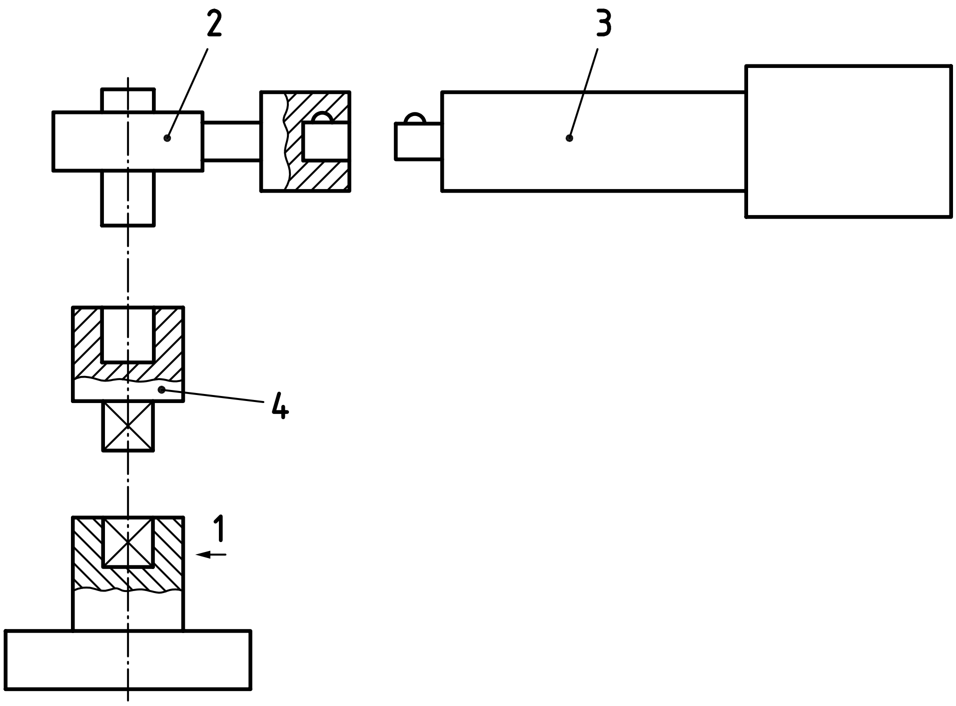
$i = 1, ..., 4$ is the number of the series;

$j = 1, 2, ..., n$ is the number of individual measurements for series i with $n = 5$.

6.2.3 Variation due to the interface between the torque tool and the calibration system

6.2.3.1 General

The variation due to the interface is evaluated as two separate influences in 6.2.3.2 and 6.2.3.3 (see also Figure 3).



Key

1 calibration system

2 interchangeable head; see 6.2.3.2

3 torque tool

4 Adapter; see 6.2.3.3

Figure 3 — Schematic interfaces between the torque tool and the calibration system

6.2.3.2 Variation due to geometric effects of the output drive of the torque tool, b_{od}

Ratchets, hexagon and square drive outputs of the torque tool in particular have an influence since they can potentially run out of true and if not used in the same orientation each time, they can cause variation of reading. Interchangeable drive ends can also cause variation.

Interchangeable drive ends of the torque tool including the centre distance shall be identified and documented.

The following method is described for the determination of the output drive variation, b_{od}. This value may be determined statistically for a sufficient number of specimen (at least 10) of a model of tool and its determination does not need to be repeated each time for future calibrations of this model. Where the output drive is not capable of rotation, this variation shall be set to zero.

The tool shall be positioned on the calibration system according to ISO 6789-1:2017, 6.5, and subjected to five preloadings at the lower limit value of the measurement range, T_{min}.

The torque tool is removed from the calibration system and the output drive is rotated by 60° (hexagonal drive output) or 90° (square drive output). Ten measurements are recorded for each of at least four positions distributed evenly over 360°, at the lower limit value of the measurement range, T_{min}, without changing the load application point.

The variation due to the influence of the output drive is calculated using Formula (5):

$$b_{od} = \max(\bar{X}_{r,i}) - \min(\bar{X}_{r,i}) \quad (5)$$

The mean value of the measurement series is calculated using Formula (4) with $n = 10$.

6.2.3.3 Variation due to geometric effects of the interface between the output drive of the torque tool and the calibration system, b_{int}

Hexagon and square drive interfaces between the output drive of the torque tool and the calibration system have an influence since they can potentially run out of true and if not used in the same orientation each time, they can cause variation of reading.

The interface between the output drive of the torque tool and the calibration system shall be identified and documented.

The following method is described for the determination of the variation b_{int} due to the drive interface. This value may be determined statistically for a sufficient number of specimens (at least 10) of a model of tool and its determination does not need to be repeated each time for future calibrations of this model.

The tool shall be positioned on the calibration system according to ISO 6789-1:2017, 6.5, and subjected to five preloadings at the lower limit value of the measurement range, T_{min}.

The torque tool is removed from the calibration system and the drive interface is rotated by 60° (hexagonal drive output) or 90° (square drive output). Ten measurements are recorded for each of at least four positions distributed evenly over 360°, at the lower limit value of the measurement range, T_{min}, without changing the load application point.

The variation due to the influence of the drive interface is calculated using Formula (6):

$$b_{int} = \max(\bar{X}_{r,i}) - \min(\bar{X}_{r,i}) \quad (6)$$

The mean value of the measurement series is calculated using Formula (4) with $n = 10$.

6.2.4 Variation due to the variation of the force loading point, b_l

Most torque wrenches have some variation in torque observed depending on the exact force loading point on the handle. This does apply to both indicating and setting wrenches, but not to torque screwdrivers of either type. For torque screwdrivers, the value of b_l shall be set to zero.

Where the loading point is not marked on the torque tool and no manufacturer information is available, the dimension from the axis of rotation to the loading point used shall be documented.

The following method is described for the determination of the force loading point variation, b_l. This value may be determined statistically for a sufficient number of specimens (at least 10) of a model of tool and its determination does not need to be repeated each time for future calibrations of this model.

The tool shall be positioned on the calibration system according to ISO 6789-1:2017, 6.5, and subjected to five preloadings at the lower limit value of the measurement range, T_{min}.

Ten measurements are then recorded for each of two positions with changed force loading point, at the lower limit value of the measurement range, T_{min}. The two force loading points shall be 10 mm on either side of the centre of the hand hold position or the marked loading point.

The mean value of the 10 values at the longest lever length are subtracted from the mean value of the measurements of the shortest lever length and this value is defined as the force loading point variation, b_l; see Formula (7):

$$b_l = \overline{X_{short}} - \overline{X_{long}} \tag{7}$$

6.3 Evaluation of Type A uncertainty due to the torque tool

6.3.1 General

Only one Type A uncertainty is considered in this document. When calibrated in accordance with 4.2, a variation of readings will be observed at each calibration torque. This applies both to Type I and Type II tools.

6.3.2 Variation due to the repeatability of the torque tool, b_{re}

This variation is defined as b_{re} evaluated using Formula (8):

$$b_{re} = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(X_{r,j} - \bar{X}_r)^2} \tag{8}$$

The mean value of the measurement series is calculated using Formula (9):

$$\bar{X}_r = \frac{1}{n}\sum_{j=1}^{n} X_{r,j} \tag{9}$$

where

$j = 1, 2, 3, \ldots, n$ is the number of individual measurements with n depending on the type and class of torque tool.

7 Determination of the calibration result

7.1 Determination of the relative standard measurement uncertainty, w

The relative standard measurement uncertainty, w, assigned to the torque tool at each calibration point is given for uncorrelated input quantities by Formulae (10) and (11).

For indicating torque tools:

$$w = \sqrt{\left(\frac{W_{md}}{2}\right)^2 + 2w_r^2 + w_{rep}^2 + w_{od}^2 + w_{int}^2 + w_l^2 + w_{re}^2} \tag{10}$$

Because readings are taken twice (at the scale's zero point or minimum, respectively, and at the calibration value), the measurement uncertainty of the resolution, r, appears in the result twice. These two random fractions are added up geometrically.

For setting torque tools:

$$w = \sqrt{\left(\frac{W_{md}}{2}\right)^2 + w_r^2 + w_{rep}^2 + w_{od}^2 + w_{int}^2 + w_l^2 + w_{re}^2} \tag{11}$$

The formulae for calculating elements of the uncertainty are shown in Table 3. Each resulting element of w shall first be rounded to three decimal places before being combined in Formula (10) or Formula (11).

Table 3 — Distribution functions for calculating the relative standard measurement uncertainties for characteristic values calculated from the variations determined experimentally

Clause reference	Characteristic value	Distribution function	Relative standard measurement uncertainty, *w* in %
6.2.1	Uncertainty due to the variation in the scale, dial or display resolution, w_r	Type B Rectangular distribution	$w_r = \frac{r \times 0{,}5}{\sqrt{3}} \times \frac{100}{\overline{X}_r}$
6.2.2	Uncertainty due to reproducibility of torque tools, w_{rep}	Type B Rectangular distribution	$w_{rep} = \frac{b_{rep} \times 0{,}5}{\sqrt{3}} \times \frac{100}{\overline{X}_r}$
6.2.3.2	Uncertainty due to geometric effects of the output drive of the torque tool, w_{od}	Type B Rectangular distribution	$w_{od} = \frac{b_{od} \times 0{,}5}{\sqrt{3}} \times \frac{100}{\overline{X}_r}$
6.2.3.3	Uncertainty due to geometric effects of the interface between the output drive of the torque tool and the calibration system, w_{int}	Type B Rectangular distribution	$w_{int} = \frac{b_{int} \times 0{,}5}{\sqrt{3}} \times \frac{100}{\overline{X}_r}$
6.2.4	Uncertainty due to the variation of the force loading point, w_l	Type B Rectangular distribution	$w_l = \frac{b_l \times 0{,}5}{\sqrt{3}} \times \frac{100}{\overline{X}_r}$
6.3	Uncertainty due to the repeatability, w_{re}	Type A Normal distribution	$w_{re} = \frac{b_{re}}{\sqrt{n}} \times \frac{100}{\overline{X}_r}$
NOTE The value of $\overline{X}_r$ for each calculation in this table is the value established by Formula (9).			

7.2 Determination of the relative expanded measurement uncertainty, *W*

The relative expanded measurement uncertainty, *W*, of the calibration result for the torque tool is calculated from the standard measurement uncertainty by multiplication by the coverage factor, *k*. The default value of $k = 2$. A check shall be made in order to ensure a confidence interval of approximately 95 %. The value for *w* shall first be rounded to three decimal places.

$$W = k \times w \tag{12}$$

NOTE Further information on the value of *k* can be determined from ISO/IEC Guide 98-3:2008, Annexes C and G.

7.3 Determination of the relative measurement uncertainty interval, *W'*

The relative uncertainty interval, *W'*, of a calibration including all systematic and random components shall be calculated using Formula (13):

$$W' = \left|\overline{a}_s\right| + W + \left|b_{ep}\right| \tag{13}$$

where

$\overline{a}_s$ is the mean value of relative measurement error at each calibration torque [see Formula (2)].

$$b_{ep} = \frac{b_{e,max}}{\bar{X}_r} 100 \text{ in } \% \quad (14)$$

8 Calibration certificate

Calibration certificates in accordance with this document shall comply with ISO/IEC 17025 and contain at least the following additional information:

a) statement that it is a certificate of calibration in accordance with this document;

b) identification (type and serial number) of the torque tool;

c) where an interchangeable element has been used with the tool, the effective length or dimension of that interchangeable element shall be recorded;

d) specified torque range or fixed torque value of the torque tool;

e) identification (type and serial number) of the measurement device where the calibration has not been performed by a laboratory meeting the requirements of ISO/IEC 17025;

f) direction(s) of operation;

g) all values recorded during calibration (see ISO 6789-1:2017, 6.5);

h) for all tools except setting tools Type II Class B, C, E and F, the mean value, $\bar{X}_r$, at each calibration point;

i) for setting tools Type II Class B, C, E and F, the nominal torque and mean value, $\bar{X}_r$;

j) relative expanded uncertainty of the torque tool, *W*, for the mean value at each calibration point;

k) relative measurement uncertainty interval, *W′*, at each calibration point.

Annex A
(informative)

Calculation example for an indicating torque tool (Type I)

A.1 Indicating torque tool, Type I, Class C

Torque wrench: Rigid housing and electronic measurement with a fixed ratchet square drive.

Measuring range: 10 N·m – 50 N·m

Last active digit: 0,01 N·m

Expected measurement error, a_s: ±1 %

Expected relative uncertainty interval, W': ±2 %

Calibrated in a clockwise direction only. Interfaced to calibration device with an adapter.

A.2 Relative measurement error, a_s

Table A.1 gives the values observed X_r at each value of X_a according to ISO 6789-1:2017, 6.5. Shown additionally are a_s using Formula (1), $\overline{a_s}$ using Formula (2) and $\overline{X_r}$ using Formula (9).

Table A.1

Target value X_a	Reference value X_r N·m	Measurement error $X_a - X_r$ N·m	Relative measurement error a_s %
X_a = 10 N·m at 20 % T_{max}	10,037	−0,037	−0,369
	10,066	−0,066	−0,656
	10,072	−0,072	−0,715
	10,086	−0,086	−0,853
	10,068	−0,068	−0,675
	$\overline{X_r}$ = 10,066	—	$\overline{a_s}$ = −0,654
X_a = 30 N·m at 60 % T_{max}	30,096	−0,096	−0,319
	30,127	−0,127	−0,422
	30,140	−0,140	−0,464
	30,097	−0,097	−0,322
	30,128	−0,128	−0,425
	$\overline{X_r}$ = 30,118	—	$\overline{a_s}$ = −0,390

Table A.1 *(continued)*

Target value X_a	Reference value X_r N·m	Measurement error $X_a - X_r$ N·m	Relative measurement error a_s %
X_a = 50 N·m at 100 % T_{max}	50,118	−0,118	−0,235
	50,150	−0,150	−0,299
	50,179	−0,179	−0,357
	50,180	−0,180	−0,359
	50,176	−0,176	−0,351
	$\overline{X}_r$ = 50,161	—	$\overline{a_s}$ = −0,320

A.3 Sources of uncertainty

A.3.1 Resolution (see 6.2.1.3)

A.3.1.1 Resolution, r

Last active digit: 0,01 N·m with no fluctuation of the last digit.

r = 0,01 N·m

A.3.1.2 Relative standard measurement uncertainty, w_r

Using the formula for w_r taken from Table 3, the values are presented in Table A.2.

Table A.2

X_a N·m	r N·m	$\overline{X}_r$ N·m	w_r %
10	0,01	10,066	0,029
30	0,01	30,118	0,010
50	0,01	50,161	0,006

A.3.2 Reproducibility (see 6.2.2)

A.3.2.1 Variation due to the reproducibility, b_{rep}

Table A.3 gives the values observed according to 6.2.2.

Table A.3

Target value X_a	**Reference value** X_r N·m			
	Sequence I	**Sequence II**	**Sequence III**	**Sequence IV**
X_a = 10 N·m at 20 % T_{max}	9,985	10,093	9,986	9,966
	10,004	10,068	9,996	9,965
	9,981	10,062	9,987	9,989
	10,007	10,094	10,022	9,980
	9,988	10,085	10,013	9,968
	$\bar{X}_r = 9{,}993$	$\bar{X}_r = 10{,}080$	$\bar{X}_r = 10{,}001$	$\bar{X}_r = 9{,}974$

The following calculations use Formula (3):

$$b_{rep,10} = 10{,}080 \text{ N} \cdot \text{m} - 9{,}974 \text{ N} \cdot \text{m} = 0{,}106 \text{ N} \cdot \text{m}$$

$$b_{rep,30} = 0{,}106 \text{ N} \cdot \text{m}$$

$$b_{rep,50} = 0{,}106 \text{ N} \cdot \text{m}$$

A.3.2.2 Relative standard measurement uncertainty, w_{rep}

Using the formula taken from Table 3, the values are presented in Table A.4.

Table A.4

X_a N·m	b_{rep} N·m	$\bar{X}_r$ N·m	w_{rep} %
10	0,106	10,066	0,304
30	0,106	30,118	0,102
50	0,106	50,161	0,061

A.3.3 Geometric effects of the output drive of the torque tool (see 6.2.3.2)

A.3.3.1 Variation due to geometric effects of the output drive of the torque tool, b_{od}

Table A.5 gives the values observed when rotating the output drive according to 6.2.3.2.

Table A.5

Target value T_{min} N·m	Reference value X_r N·m			
	Position 1 (0°)	**Position 2 (90°)**	**Position 3 (180°)**	**Position 4 (270°)**
10	9,881	9,992	9,839	9,974
	9,920	9,972	9,844	9,990
	9,930	9,980	9,846	9,965
	9,880	9,989	9,844	9,975
	9,862	9,992	9,850	9,940
	9,901	9,985	9,817	9,964
	9,905	9,860	9,822	9,954
	9,900	9,988	9,833	9,865
	9,901	9,990	9,830	9,966
	9,874	9,991	9,830	9,945
	$\overline{X}_r = 9{,}895$	$\overline{X}_r = 9{,}974$	$\overline{X}_r = 9{,}836$	$\overline{X}_r = 9{,}954$

The following calculation uses Formula (5):

$$b_{od} = 9{,}974\ \text{N}\cdot\text{m} - 9{,}836\ \text{N}\cdot\text{m} = 0{,}138\ \text{N}\cdot\text{m}$$

A.3.3.2 Relative standard measurement uncertainty, w_{od}

Using the formula taken from Table 3, the values are presented in Table A.6.

Table A.6

X_a N·m	b_{od} N·m	$\overline{X}_r$ N·m	w_{od} %
10	0,138	10,066	0,396
30	0,138	30,118	0,132
50	0,138	50,161	0,079

A.3.4 Variation due to the interface between the torque tool and the calibration system (see 6.2.3.3)

A.3.4.1 Variation due to geometric effects of the interface between the output drive of the torque tool and the calibration system, b_{int}

Table A.7 gives the values observed when rotating the interface adapter according to 6.2.3.3.

Table A.7

Target value T_{min} N·m	Reference value X_r N·m			
	Position 1 (0°)	**Position 2 (90°)**	**Position 3 (180°)**	**Position 4 (270°)**
10	10,007	9,980	10,012	10,020
	10,002	9,983	10,009	10,019
	10,009	9,988	10,014	10,017
	10,004	9,985	10,010	10,019
	10,003	9,985	10,008	10,017
	10,008	9,983	10,011	10,020
	10,007	9,990	10,014	10,021
	10,001	9,991	10,007	10,019
	10,002	9,989	10,009	10,018
	10,005	9,993	10,010	10,020
	$\overline{X}_r = 10{,}005$	$\overline{X}_r = 9{,}987$	$\overline{X}_r = 10{,}010$	$\overline{X}_r = 10{,}019$

The following calculation uses Formula (6):

$$b_{int} = 10{,}019 \text{ N} \cdot \text{m} - 9{,}987 \text{ N} \cdot \text{m} = 0{,}032 \text{ N} \cdot \text{m}$$

A.3.4.2 Relative standard measurement uncertainty, w_{int}

Using the formula taken from Table 3, the values are presented in Table A.8.

Table A.8

X_a N·m	b_{int} N·m	$\overline{X}_r$ N·m	w_{int} %
10	0,032	10,066	0,092
30	0,032	30,118	0,031
50	0,032	50,161	0,018

A.3.5 Variation of the torque loading point (see 6.2.4)

A.3.5.1 Variation due to the length variation of the torque loading point, b_l

Table A.9 gives the values taken according to 6.2.4.

Table A.9

Target value T_{min} N·m	Reference value X_r N·m	
	Position 1 (–10 mm)	Position 2 (+10 mm)
10	9,999	9,918
	9,998	9,908
	10,012	9,911
	10,006	9,917
	10,019	9,915
	9,986	9,922
	10,000	9,904
	10,006	9,924
	10,016	9,909
	10,011	9,931
	$\overline{X}_r$ = 10,005	$\overline{X}_r$ = 9,916

The following calculation uses Formula (7):

$$b_l = 10{,}005 \text{ N} \cdot \text{m} - 9{,}916 \text{ N} \cdot \text{m} = 0{,}089 \text{ N} \cdot \text{m}$$

A.3.5.2 Relative standard measurement uncertainty, w_l

Using the formula taken from Table 3, the values are presented in Table A.10.

Table A.10

X_a N·m	b_l N·m	$\overline{X}_r$ N·m	w_l %
10	0,089	10,066	0,255
30	0,089	30,118	0,085
50	0,089	50,161	0,051

A.3.6 Repeatability of the torque tool (see 6.3)

A.3.6.1 Variation due to the repeatability, b_{re}

Table A.11 gives the values observed and the variation calculated according to Formula (8).

Table A.11

Target value X_a	Reference value X_r N·m	Deviation $(X_r - \bar{X}_r)$ N·m	Variation due to the repeatability b_{re} N·m
X_a = 10 N·m at 20 % T_{max}	10,037	−0,029	0,018
	10,066	0,000	
	10,072	0,006	
	10,086	0,020	
	10,068	0,002	
	$\bar{X}_r$ = 10,066	—	
X_a = 30 N·m at 60 % T_{max}	30,096	−0,022	0,020
	30,127	0,009	
	30,140	0,022	
	30,097	−0,021	
	30,128	0,010	
	$\bar{X}_r$ = 30,118	—	
X_a = 50 N·m at 100 % T_{max}	50,118	−0,043	0,027
	50,150	−0,011	
	50,179	0,018	
	50,180	0,019	
	50,176	0,015	
	$\bar{X}_r$ = 50,161	—	

A.3.6.2 Relative standard measurement uncertainty, w_{re}

Using the formula taken from Table 3, the values are presented in Table A.12.

Table A.12

X_a N·m	b_{re} N·m	$\bar{X}_r$ N·m	w_{re} %
10	0,018	10,066	0,080
30	0,020	30,118	0,030
50	0,027	50,161	0,024

A.3.7 Relative measurement uncertainty interval of the measurement device, W'_{md}

The value of W'_{md} has been taken from the current calibration certificate of the measurement device.

Relative measurement uncertainty interval, W'_{md} = ± 0,25 %

Relative expanded measurement uncertainty, W_{md} = ± 0,15 %

Maximum relative value of the measurement error, b_{ep} = 0,10 %

The value of W'_{md} is less than 1/4 of the expected value of W' and this fulfils the requirements according to 4.3.

A.4 Calculation

A.4.1 Determination of the relative standard measurement uncertainty, *w*

The data presented in Table A.13 are rounded to three decimal places and combined using Formula (10) to produce the results for *w* rounded to three decimal places and presented in Table A.14.

Table A.13

X_a N·m	W_{md} %	w_r %	w_{rep} %	w_{od} %	w_{int} %	w_l %	w_{re} %
10	0,15	0,029	0,304	0,396	0,092	0,255	0,080
30	0,15	0,010	0,102	0,132	0,031	0,085	0,030
50	0,15	0,006	0,061	0,079	0,018	0,051	0,024

A.4.2 Determination of the relative expanded measurement uncertainty, *W*

The results for *W* using Formula (12) with $k = 2$ are rounded to three decimal places and presented in Table A.14.

Table A.14

X_a N·m	w %	W %
10	0,580	1,160
30	0,207	0,413
50	0,138	0,277

A.4.3 Determination of the relative measurement uncertainty interval, *W′*

The results for W' using Formula (13) are presented in Table A.15.

Table A.15

Calibration value X_a N·m	Mean value of the measurement error $\lvert \overline{a_s} \rvert$ %	Relative expanded measurement uncertainty W %	Maximum value of the calibration device measurement error $\lvert b_{ep} \rvert$ %	Relative measurement uncertainty interval W' %
10	0,654	1,660	0,10	1,914
30	0,390	0,413	0,10	0,903
50	0,320	0,277	0,10	0,697

A.5 Conclusion of this calculation example

In this example, the expected values of a_s and W' are achieved:

— Maximum a_s: −0,853 % is smaller than the expected measurement error, a_s: ±1 %

— Maximum W': 1,914 % is smaller than the expected relative uncertainty interval, W': ±2 %

Annex B
(informative)

Calculation example for a setting torque tool (Type II)

B.1 Setting torque tool, Type II, Class A

Torque wrench: Adjustable, graduated with micrometer scale and fixed ratchet with square drive.

Measuring range:	60 N·m – 300 N·m
Main scale: Value between adjacent scale marks:	10 N·m
Secondary scale: Value between adjacent scale marks:	2,0 N·m
Expected measurement error, a_s:	±3 %
Expected relative uncertainty interval, W':	±5 %

Calibrated in clockwise direction only. Interfaced to calibration device with an adapter.

B.2 Relative measurement error, a_s

Table B.1 gives the values observed X_r at each value of X_a according to ISO 6789-1:2017, 6.5.

Shown additionally are a_s using Formula (1), $\overline{a_s}$ using Formula (2) and $\overline{X_r}$ using Formula (9).

Table B.1

Target values X_a	Reference value X_r N·m	Measurement error $X_a - X_r$ N·m	Relative measurement error a_s %
X_a = 60 N·m at 20 % T_{max}	59,210	0,790	1,334
	59,170	0,830	1,403
	59,070	0,930	1,574
	59,020	0,980	1,660
	59,200	0,800	1,351
	$\overline{X_r}$ = 59,134	—	$\overline{a_s}$ = 1,465
X_a = 180 N·m at 60 % T_{max}	179,050	0,950	0,531
	178,590	1,410	0,790
	178,800	1,200	0,671
	177,830	2,170	1,220
	178,390	1,610	0,903
	$\overline{X_r}$ = 178,532	—	$\overline{a_s}$ = 0,823

Table B.1 *(continued)*

Target values X_a	Reference value X_r N·m	Measurement error $X_a - X_r$ N·m	Relative measurement error a_s %
X_a = 300 N·m at 100 % T_{max}	301,640	−1,640	−0,544
	301,500	−1,500	−0,498
	301,130	−1,130	−0,375
	300,860	−0,860	−0,286
	300,040	−0,040	−0,013
	$\overline{X}_r$ = 301,034	—	$\overline{a}_s$ = −0,343

B.3 Sources of uncertainty

B.3.1 Resolution (see 6.2.1.2)

B.3.1.1 Resolution, r

Secondary scale: Value between adjacent scale marks: 2,0 N·m

r = 1,0 N·m because the resolution is 1/2 of the secondary scale increment value.

B.3.1.2 Relative standard measurement uncertainty, w_r

Using the formula for w_r taken from Table 3, the values are presented in Table B.2.

Table B.2

X_a N·m	r N·m	$\overline{X}_r$ N·m	w_r %
60	1,0	59,134	0,488
180	1,0	178,532	0,162
300	1,0	301,034	0,096

B.3.2 Reproducibility (see 6.2.2)

B.3.2.1 Variation due to the reproducibility, b_{rep}

Table B.3 gives the values observed according to 6.2.2

Table B.3

Target values X_a	Reference value X_r N·m			
	Sequence I	Sequence II	Sequence III	Sequence IV
X_a = 60 N·m at 20 % T_{max}	59,230	60,350	58,630	60,030
	59,120	59,950	58,640	60,150
	58,100	60,120	58,010	60,150
	58,930	60,090	58,140	60,110
	58,210	59,930	58,620	60,160
	$\overline{X}_r$ = 58,718	$\overline{X}_r$ = 60,088	$\overline{X}_r$ = 58,408	$\overline{X}_r$ = 60,120

The following calculations use Formula (3):

$$b_{rep,60} = 60{,}120\ \text{N}\cdot\text{m} - 58{,}408\ \text{N}\cdot\text{m} = 1{,}712\ \text{N}\cdot\text{m}$$

$$b_{rep,180} = 1{,}712\ \text{N}\cdot\text{m}$$

$$b_{rep,300} = 1{,}712\ \text{N}\cdot\text{m}$$

B.3.2.2 Relative standard measurement uncertainty, w_{rep}

Using the formula taken from Table 3, the values are presented in Table B.4.

Table B.4

X_a N·m	b_{rep} N·m	$\overline{X}_r$ N·m	w_{rep} %
60	1,712	59,134	0,836
180	1,712	178,532	0,277
300	1,712	301,034	0,164

B.3.3 Geometric effects of the output drive of the torque tool (see 6.2.3.2)

B.3.3.1 Variation due to geometric effects of the output drive of the torque tool, b_{od}

Table B.5 gives the values observed when rotating the output drive according to 6.2.3.2.

Table B.5

Target value T_{min} N·m	Reference value X_r N·m			
	Position 1 (0°)	**Position 2 (90°)**	**Position 3 (180°)**	**Position 4 (270°)**
60	62,480	60,890	63,000	61,970
	59,360	58,920	59,620	59,200
	59,550	59,780	59,400	61,070
	59,330	58,850	60,580	60,000
	59,260	59,430	59,460	59,340
	59,210	59,180	60,340	59,220
	59,790	58,970	60,240	60,590
	60,640	58,980	60,020	58,880
	59,430	58,880	59,180	60,520
	59,560	58,740	59,980	59,420
	$\overline{X}_r$ = 59,861	$\overline{X}_r$ = 59,262	$\overline{X}_r$ = 60,182	$\overline{X}_r$ = 60,021

The following calculation uses Formula (5):

$$b_{od} = 60{,}182 \text{ N} \cdot \text{m} - 59{,}262 \text{ N} \cdot \text{m} = 0{,}920 \text{ N} \cdot \text{m}$$

B.3.3.2 Relative standard measurement uncertainty, w_{od}

Using the formula taken from Table 3, the values are presented in Table B.6.

Table B.6

X_a N·m	b_{od} N·m	$\overline{X}_r$ N·m	w_{od} %
60	0,920	59,134	0,449
180	0,920	178,532	0,149
300	0,920	301,034	0,088

B.3.4 Variation of interface between the tool and the calibration system (see 6.2.3.3)

B.3.4.1 Variation due to geometric effects of the interface between the output drive of the torque tool and the calibration system, b_{int}

Table B.7 gives the values observed when rotating the interface adapter according to 6.2.3.3.

Table B.7

Target value T_{min} N·m	**Reference value** X_r N·m			
	Position 1 (0°)	**Position 2 (90°)**	**Position 3 (180°)**	**Position 4 (270°)**
60	61,010	61,010	58,660	58,660
	58,710	58,710	59,010	59,010
	58,700	58,700	58,650	58,650
	58,650	58,650	59,080	59,080
	59,060	59,060	59,090	59,090
	58,840	58,840	58,530	58,530
	58,990	58,990	59,080	59,080
	58,600	58,600	58,960	58,960
	59,300	59,300	59,750	59,750
	59,120	59,120	59,090	59,090
	$\overline{X}_r = 59{,}098$	$\overline{X}_r = 59{,}098$	$\overline{X}_r = 58{,}990$	$\overline{X}_r = 58{,}990$

The following calculation uses Formula (6):

$$b_{int} = 59{,}098\ \text{N}\cdot\text{m} - 58{,}990\ \text{N}\cdot\text{m} = 0{,}108\ \text{N}\cdot\text{m}$$

B.3.4.2 Relative standard measurement uncertainty, w_{int}

Using the formula taken from Table 3, the values are presented in Table B.8.

Table B.8

X_a N·m	b_{int} N·m	$\overline{X}_r$ N·m	w_{int} %
60	0,108	59,134	0,053
180	0,108	178,532	0,017
300	0,108	301,034	0,010

B.3.5 Variation of the torque loading point (see 6.2.4)

B.3.5.1 Variation due to the length variation of the torque loading point, b_l

Table B.9 gives the values taken according to 6.2.4.

Table B.9

Target value T_{min} N·m	**Reference value** X_r N·m	
	Position 1 (−10 mm)	**Position 2 (+10 mm)**
60	61,010	58,660
	58,710	59,010
	58,700	58,650
	58,650	59,080
	59,060	59,090
	58,840	58,530
	58,990	59,080
	58,600	58,960
	59,300	59,750
	59,120	59,090
	$\overline{X}_r = 59{,}098$	$\overline{X}_r = 58{,}990$

The following calculation uses Formula (7):

$$b_l = 59{,}098\ \text{N}\cdot\text{m} - 58{,}990\ \text{N}\cdot\text{m} = 0{,}108\ \text{N}\cdot\text{m}$$

B.3.5.2 Relative standard measurement uncertainty, w_l

Using the formula taken from Table 3, the values are presented in Table B.10.

Table B.10

X_a N·m	b_l N·m	$\overline{X}_r$ N·m	w_l %
60	0,108	59,134	0,053
180	0,108	178,532	0,017
300	0,108	301,034	0,010

B.3.6 Repeatability of the torque tool (see 6.3)

B.3.6.1 Variation due to the repeatability, b_{re}

Table B.11 gives the values observed and the variation calculated according to Formula (8).

Table B.11

Target values X_a	Reference value X_r N·m	Deviation $\left(X_r - \overline{X}_r\right)$ N·m	Variation due to the repeatability b_{re} N·m
X_a = 60 N·m at 20 % T_{max}	59,210	0,076	0,084
	59,170	0,036	
	59,070	−0,064	
	59,020	−0,114	
	59,200	0,066	
	$\overline{X}_r$ = 59,134	—	
X_a = 180 N·m at 60 % T_{max}	179,050	0,518	0,463
	178,590	0,058	
	178,800	0,268	
	177,830	−0,702	
	178,390	−0,142	
	$\overline{X}_r$ = 178,532	—	
X_a = 300 N·m at 100 % T_{max}	301,640	0,606	0,635
	301,500	0,466	
	301,130	0,096	
	300,860	−0,174	
	300,040	−0,994	
	$\overline{X}_r$ = 301,034	—	

B.3.6.2 Relative standard measurement uncertainty, w_{re}

Using the formula taken from Table 3, the values are presented in Table B.12.

Table B.12

X_a N·m	b_{re} N·m	$\overline{X}_r$ N·m	w_{re} %
60	0,084	59,134	0,064
180	0,463	178,532	0,116
300	0,635	301,034	0,094

B.3.7 Relative measurement uncertainty interval of the calibration device, W'_{md}

The value of W'_{md} has been taken from the current calibration certificate of the calibration device. Formula C.11 can be used to assist if required.

Relative measurement uncertainty interval, W'_{md} = ±1,00 %

Relative expanded measurement uncertainty, W_{md} = ±0,30 %

Maximum relative value of the measurement error, b_{ep} = 0,70 %

The value of W'_{md} is less than 1/4 of the expected value of W' and this fulfils the requirements according to 4.3.

B.4 Calculation

B.4.1 Determination of the relative standard measurement uncertainty, *w*

The data presented in Table B.13 are rounded to three decimal places and combined using Formula (11) to produce the results for w rounded to three decimal places and presented in Table B.14.

Table B.13

X_a N·m	W_{md} %	w_r %	w_{rep} %	w_{int} %	w_{od}	w_l %	w_{re} %
60	0,3	0,488	0,836	0,053	0,449	0,053	0,064
180	0,3	0,162	0,277	0,017	0,149	0,017	0,116
300	0,3	0,096	0,164	0,010	0,088	0,010	0,094

B.4.2 Determination of the relative expanded measurement uncertainty, *W*

The results for W using Formula (12) with $k = 2$ are rounded to three decimal places and presented in Table B.14.

Table B.14

X_a N·m	w %	W %
60	1,082	2,164
180	0,402	0,804
300	0,275	0,549

B.4.3 Determination of the relative measurement uncertainty interval, *W′*

The results using Formula (13) are presented in Table B.15.

Table B.15

Calibration value X_a N·m	Mean value of the measurement error $\lvert \overline{a_s} \rvert$ %	Relative expanded measurement uncertainty W %	Maximum value of the calibration device measurement error $\lvert b_{ep} \rvert$ %	Relative measurement uncertainty interval W' %
60	1,465	2,164	0,70	4,329
180	0,823	0,804	0,70	2,327
300	0,343	0,549	0,70	1,592

B.5 Conclusion of this calculation example

In this example, the expected values of a_s and W' are achieved:

— Maximum a_s: 1,660 % is smaller than the expected measurement error, a_s: ±3 %

— Maximum W': 4,329 % is smaller than the expected relative uncertainty interval, W': ±5 %

Annex C
(normative)

Minimum requirements for the calibration of the torque measurement device and the estimation of its measurement uncertainty

C.1 General

Where the torque measurement device calibrated by a laboratory meeting the requirements of ISO/IEC 17025, the maximum relative measurement uncertainty interval W'_{md} may be stated on the calibration certificate of that calibration device calibrate.

Where this information is not available, Annex C provides the minimum requirements for the calibration of the torque measurement device and the estimation of its measurement uncertainty interval, W'_{md}.

C.2 Symbols

For the application of this annex, the symbols, units and terms stated in Table 1 are applicable.

C.3 General guidelines for the reference measurement standard

Step by step or progressive calibration is achieved by the incremental loading of the measurement device to be calibrated. An example of a progressive loading method is using a length beam and a series of masses that generate a force under gravity.

In continuous calibration, the torque measurement device is subjected to a continuously changing load. An example of a continuous loading method is using a length beam and hydraulic cylinders delivering a measurably increasing force.

Transfer torque wrenches can also be used to measure the torque provided by the measurement device being calibrated. The torque can be increased in a progressive or continuous manner.

The reference measurement standard should be designed and assembled such that both clockwise and anti-clockwise torque can be applied without the significant influence of non-torsional forces, such as bending moments.

The torque measurement axis can be either horizontal or vertical. The preferred orientation reflects the orientation of the measurement device when in use.

Where a reference measurement standard is achieved by means of a transfer torque wrench, it shall be possible to vary the lever arm length over the range of the lever arm lengths of commercially available torque tools having the measurement range to be calibrated.

C.4 Calibration of the measurement device

C.4.1 General requirements

The measurement uncertainty interval, W'_{ref}, of the reference measurement standard shall not exceed 2/5 of the claimed measurement uncertainty interval, W'_{md}, of the torque measurement device to be calibrated at each calibration value.

C.4.2 Combined relative uncertainty of calibration of the measurement device, $w_{md,c}$

Where the torque measurement device consists of a transducer and an electrical indicator or display with separate accuracies, the combined uncertainty can be determined by combining the separate uncertainties using the square root of the sum of the squares.

This value is defined as the combined relative measurement device uncertainty, $w_{md,c}$; see Formula (C.1):

$$w_{md,c} = \sqrt{w_{md,t}^2 + w_{md,d}^2} \tag{C.1}$$

C.4.3 Calibration device indicators

Where an electrical indicator is replaced with another, both indicators shall have a valid calibration certificate traceable to national standards. The replacement indicator shall have been calibrated over at least the same range of indication as the original indicator. Where the uncertainty of calibration of the replacement indicator differs from the original, the standard measurement uncertainty of the measurement device shall be recalculated.

C.4.4 Resolution of the measurement device, r

C.4.4.1 Analogue scale

The thickness of the graduation marks on the scale should be uniform, and the width of the pointer should be approximately equal to the width of a graduation mark: the resolution, r, of the indicator shall be obtained from the ratio of the width of the pointer to the centre-to-centre distance between adjacent scale marks. Recommended ratios are 1/2, 1/5 or 1/10. Centre-to-centre distances equal to or larger than 1,25 mm are required to estimate a tenth of the scale division.

C.4.4.2 Digital scale

The value of r shall be one increment of the last active digit, provided the display does not vary by more than one increment when the device is at the lowest calibrated torque value, or in cases where the readings fluctuate, one increment of the last active digit plus one half of the fluctuation range.

C.4.4.3 Resolution units

The resolution r shall be converted into and indicated in torque units.

C.4.5 Lowest allowable value for the minimum limit of the measurement range, T_A

The lowest allowable value for T_A shall be determined using Formula (C.2):

$$T_A \geq \frac{r}{W'_{md}} 100 \tag{C.2}$$

The lowest allowable value for T_A shall not be less than 5 % of the maximum torque value of the measurement range.

EXAMPLE For an expected W'_{md} of 0,5 % and a resolution of 0,25 N·m, the requirement will allow $T_A \geq 50$ N·m.

Where the measurement device has a resolution that changes through the range, the value of r shall be the value at T_A.

C.4.6 Preparation of the calibration

C.4.6.1 Measurement device

The measurement device shall be adjusted according to the manufacturer's instructions. Prior to the calibration, it is recommended that the measurement device is subject to a check to ensure that it functions correctly and will allow a safe and valid calibration. All adjustments and, where appropriate, corresponding setting values should be recorded before and after the calibration.

C.4.6.2 Temperature stabilization

Prior to calibrating the torque measurement device, it shall be stored with the supply power applied in the calibration environment for sufficient time for its temperature to stabilize.

C.4.6.3 Mounting of the transducer

Failure to apply the calibration torque in the orientation stated by the manufacturer, or specified by the customer, may lead to erroneous measurements. The orientation shall be documented in the certificate.

C.4.7 Calibration procedure

C.4.7.1 Preloading

The torque measurement device shall be preloaded three times in the direction to be calibrated, applying the maximum torque value, T_E, of the measurement range of the measurement device, and additionally once after each change of the mounting position. The duration of the application of preload should be not less than 30 s. The indicator reading shall be taken before each preload and after each preload has been removed for not less than 30 s, the indicator reading shall again be recorded.

NOTE The stability of the zero signal can provide an indication of the performance of the device during its calibration.

C.4.7.2 Mounting position

For torque measurement devices utilizing a square drive, four mounting positions are preferred although dependent on the performance of the measurement device and the customer requirements, two mounting positions may be sufficient.

Torque measurement devices without square drive shall be calibrated in three different mounting positions with the transducer or its mechanical coupling part rotated each time through 120° about the measurement axis.

If the torque measurement device cannot be rotated, it shall be dismounted and remounted from the reference measurement standard to determine reproducibility.

Two incremental calibration series are required at the same mounting position, normally at the start of calibration, for determination of repeatability.

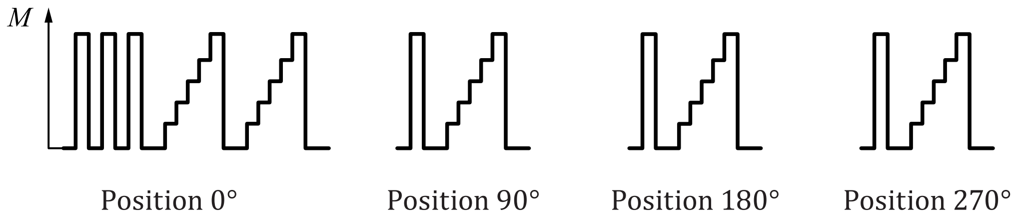


Figure C.1 — Examples of preloading and sequences for torque measurement devices with square drive (minimum of five steps)

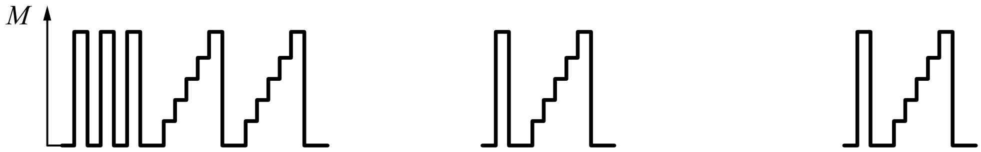


Figure C.2 — Examples of preloading and sequences for torque measurement devices with hexagon drive (minimum of four steps)

C.4.7.3 Range of calibration

The recommended number of calibration steps shall be a minimum of five approximately equally spaced from 20 % to 100 % of T_E.

For the calculation of a fitting curve, a minimum of five steps shall be taken.

When calibration points below 20 % of T_E are required, additional steps may be specified provided that they comply with C.4.5.

The time interval between two successive calibration steps shall, if possible, be similar. Recording the measured value shall take place only after the indication has stabilized and no sooner than 30 s after the application of the calibration step. After the final calibration step of each series, the measurement device reading in unloaded condition, I_Z, shall be recorded.

C.4.7.4 Loading conditions

Calibration shall be carried out at a temperature stable to ±1 K. This temperature shall be in the range between 18 °C and 28 °C (preferably between 20 °C and 22 °C) and recorded.

The humidity shall not exceed 65 % and shall be recorded.

C.5 Measurement error

C.5.1 Indicated value, *X*

The indicated value is defined as the difference between an indication in loaded condition and an indication in unloaded condition.

$$X = I - I_0 \tag{C.3}$$

The indication at the beginning of each measurement series shall be zeroed or taken into account by computation during the evaluation following the measurement.

NOTE Recording of the indication in unloaded condition provides additional information about the measurement device.

C.5.2 Determination of mean value, $\bar{X}_r$

The mean value, $\bar{X}_r$, for each torque level shall be calculated according to Formula (C.4) as the mean value of the measurement results obtained in the increasing series in changed mounting positions:

$$\bar{X}_r = \frac{1}{n}\sum_{j=1}^{n}\left(I_j - I_{j,0}\right) \tag{C.4}$$

where

j is the index of selected series;

n is the number of increasing series in different mounting positions.

NOTE The values measured in the second series of the 0° position are not included in the calculation of $\bar{X}_r$.

C.5.3 Recorded measurement error, b_e

The measurement error is calculated according to Formula (C.5) for each torque level from the mean value of all increasing series.

$$b_e = \bar{X}_r - X_{ref} \tag{C.5}$$

C.6 Sources of uncertainty

C.6.1 Evaluation of Type A uncertainties due to the torque measurement device — Determination of repeatability, b_{re}

The repeatability in unchanged mounting position shall be calculated for each torque level according to Formula (C.6):

$$b_{re} = X_1 - X_2 \tag{C.6}$$

where

X_1 and X_2 are the values measured in unchanged position.

C.6.2 Evaluation of Type B uncertainties due to the torque measurement device

C.6.2.1 Determination of reproducibility, b_{rep}

The reproducibility in changed mounting position shall be calculated for each torque level according to the following formula:

$$b_{rep} = X_{max} - X_{min} \tag{C.7}$$

NOTE The values measured in the second series of the 0° position are not included in the calculation of b_{rep}.

C.6.2.2 Measurement hysteresis error of the zero signal, b_z

To evaluate the uncertainty created by zero drift, the indication in unloaded condition following each loading series defined in C.4.7.3 shall be used.

The deviation of the zero signal, b_z, shall be calculated using Formula (C.8):

$$b_z = \max \left| I_{z,j} - I_0 \right| \tag{C.8}$$

where

$j = 1, 2, ..., n$ is the number of loading cycles.

C.6.3 Thermal sensitivity

During calibration and use, different temperatures, thermal drifts and temperature gradients can influence the measurement results. Where such influences are present, the calculation of uncertainty shall include these factors.

C.7 Determination of the calibration result

C.7.1 Determination of the relative standard measurement uncertainty, w_{md}

The relative standard measurement uncertainty, w_{md}, assigned to the measurement device at each calibration point is given for uncorrelated input quantities by Formula (C.9):

$$w_{md} = \sqrt{\left(\frac{W_{ref}}{2}\right)^2 2 w_r^2 + w_z^2 + w_{re}^2 + w_{rep}^2} \tag{C.9}$$

The formulae for calculating elements of the relative standard uncertainty are shown in Table C.1.

The expanded standard measurement uncertainty, W_{ref}, can be obtained from the certificate of reference measurement standard.

Because readings are taken twice (at the scale's zero point or minimum, respectively, and at the calibration value), the measurement uncertainty of the resolution, r, appears in the result twice. These two random fractions are added up geometrically.

Table C.1 — Distribution functions for calculating the relative standard measurement uncertainties for characteristic values calculated from the variation ranges determined experimentally

Clause reference	Characteristic value	Distribution function	Relative standard measurement uncertainty, w, in %
C.4.4	Uncertainty due to the resolution of the measurement device	Type B Rectangular distribution	$w_r = \frac{r \times 0{,}5}{\sqrt{3}} \times \frac{100}{\overline{X}_r}$
C.6.2.2	Uncertainty due to the zero drift of the measurement device	Type B Rectangular distribution	$w_z = \frac{b_z \times 0{,}5}{\sqrt{3}} \times \frac{100}{\overline{X}_r}$
C.6.2.1	Uncertainty due to the reproducibility of the measurement device	Type B Rectangular distribution	$w_{rep} = \frac{b_{rep} \times 0{,}5}{\sqrt{3}} \times \frac{100}{\overline{X}_r}$
C.6.1	Uncertainty due to the repeatability of the measurement device	Type A Rectangular distribution	$w_{re} = \frac{b_{re} \times 0{,}5}{\sqrt{3}} \times \frac{100}{\overline{X}_r}$

C.7.2 Determination of the relative expanded measurement uncertainty, W_{md}

The relative expanded measurement uncertainty, W_{md}, of the calibration result for the measurement device is calculated from the standard measurement uncertainty multiplied by the coverage factor, k. The default value of k = 2. A check shall be made in order to ensure a confidence interval of approximately 95 %.

$$W_{md} = k \times w_{md} \tag{C.10}$$

NOTE Further information on the value of k can be determined from ISO/IEC Guide 98-3:2008, Annexes C and G.

C.7.3 Determination of the relative measurement uncertainty interval, W'_{md}

The relative measurement uncertainty interval, W'_{md}, of a calibration including all systematic and random components shall be calculated using Formulae (C.11) and (C.12):

$$W'_{md} = \max \left| b_{ep} \right| + \left| b_{ref,ep} \right| + W_{md} \tag{C.11}$$

where

$$b_{ref,ep} = \frac{\max(b_{ref,e})}{\bar{X}_{ref}} \text{ in } \% \tag{C.12}$$

The measurement error, $b_{ref,e}$, can be obtained from the certificate of the reference measurement standard.

C.8 Calibration certificate

Calibration certificates in accordance with Annex C shall comply with ISO/IEC 17025 and contain at least the following additional information:

a) identification of certificate stating that it is a certificate in accordance with Annex C;

b) identity of all elements of the calibration device and the adaptors;

c) information on the lever arm lengths, if using a transfer standard;

d) position of the measurement axis during the calibration (horizontal and/or vertical);

e) calibration result according to Annex C, including the evaluated mean values together with the measurement uncertainty values according to C.5.4.

The calibration certificate may include in addition:

— a table of the measurement values and of the calculated characteristic values;

— graphic representation of the characteristic curve.

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