BRITISH STANDARD

Method for calibration and classification of torque measuring devices

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British Standards

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Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 25 and a back cover.

Foreword

This British Standard is published by BSI and came into effect on 31 January 2008. It was prepared by Technical Committee ISE/NFE/4, *Torque measurement and testing*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

BS 7882:2008 supersedes BS 7882:1997, which is withdrawn.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is "shall".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

1 Scope

This British Standard specifies requirements for the calibration and classification of torque measuring devices, including those used for the calibration of hand torque tools to BS EN ISO 6789.

It describes the method of calibration, calculation of calibration results and the classification of the torque measuring device in a static mode. The information to be given on the certificate of calibration is also listed.

2 Terms, definitions, abbreviations and symbols

For the purposes of this British Standard, the following terms, definitions, abbreviations and symbols apply.

NOTE Where applicable, this British Standard has been prepared using PD 6461-1.

2.1 calibration torque
torque with traceability derived from national standards of mass, length and time, and of specified uncertainty of measurement, which can be applied to the torque measuring device

2.2 deflection
d
algebraic difference between the indicator reading prior to the application of a torque and the indicator reading for each applied torque in a given measurement series

NOTE The deflection may be derived from either digital data output or visual data output.

2.3 data acquisition system
electronic module that has the ability to transfer, store, amplify and filter signals from a torque measuring device

NOTE Where analogue signals are acquired by the torque measuring device, and these are converted into a digital data stream using an analogue to digital converter, the stream of data may be digitally filtered, re-sampled and stored, or logged ready for analysis.

2.4 loading direction
direction of applied torque, either clockwise or anti-clockwise about the axis of rotation, when viewed from the end of the torque measuring device to which the calibration torque is applied

2.5 lower limit of calibration
T_{min}
lower value of torque at which a torque measuring device of a given class can be calibrated

2.6 reference standard
equipment used to generate or to measure the reference torque applied to the torque measuring device that is being calibrated

NOTE Torques may be generated by a power source monitored by the reference standard.

2.7 relative error of indication

E_i

mean deflection for a given value of increasing torque minus the corresponding value of applied torque

NOTE 1 For the purposes of this standard, relative error of indication is expressed as a percentage of applied torque.

NOTE 2 Relative error of indication is only used where the deflection is in units of torque.

2.8 relative error of interpolation

E_{it}

difference between the value of the mean deflection for a given value of increasing torque and the corresponding calculated value of deflection for the given torque, obtained from a mathematically fitted curve

NOTE For the purposes of this standard, relative error of interpolation is expressed as a percentage of the computed deflection for the given increasing torque.

2.9 relative repeatability

R_1

closeness of the agreement between the results of two successive measurements from the same applied torque, carried out under the same conditions of measurement

2.10 relative reproducibility

R_2

closeness of agreement between the results of successive measurements from the same applied torque, carried out under changed conditions of measurement

2.11 relative residual deflection

R_0

maximum residual deflection obtained from all the series of torques

NOTE For the purposes of this standard, relative residual deflection is expressed as a percentage of the mean deflection for the maximum torque applied.

2.12 relative reversibility

R_3

difference between the deflection obtained from the last given torque series applied in an increasing mode and the deflection obtained from the same given torque applied in a decreasing mode

NOTE For the purposes of this standard, relative reversibility is expressed as a percentage of the deflection of the last series for the given torque, applied in an increasing mode.

2.13 residual deflection

d_0

algebraic difference between the indicator readings before and after the application of a single series of torques

2.14 resolution

r

smallest discernable measurement interval on the torque measuring device indicator

2.15 torque

product of tangential force and length applied about a known centre of rotation

2.16 torque measuring device

system comprising an electrical, mechanical, hydraulic or optical torque measuring device, with associated instrumentation, including the automated logging of data when part of the device

NOTE The instrumentation can be an electronic instrument, a mechanical device, i.e. a scale and pointer system, or a Bourdon tube instrument.

3 Preparation for calibration

3.1 Reference standard

3.1.1 Uncertainty of calibration torques

Values for the maximum permissible uncertainty of the calibration torques applied for the determination of different classifications of the torque measuring device shall not exceed the values given in Table 1. Where a reference standard is used to determine a calibration torque, it shall conform to Table 1.

Table 1 **Uncertainty of calibration torques**

Class of torque measuring device to be calibrated	Maximum permissible uncertainty of calibration torque applied[A)] %
0.05	±0.01
0.1	±0.02
0.2	±0.04
0.5	±0.10
1.0	±0.20
2.0	±0.40
5.0	±1.00

A) Using a coverage factor of $k = 2$ to give a confidence level of approximately 95%.

3.1.2 Traceability of measurements

All definitive measurements, such as mass, length, time and temperature, shall be traceable to national standards; evidence of this shall be provided by a certificate of calibration.

3.2 Condition and identification of a torque measuring device

3.2.1 Calibration shall not be commenced unless the torque measuring device is considered to be in good working order and is identified with a serial number. The maximum working torque shall first have been established.

NOTE Good working order includes the drive components being of a sufficiently good fit to exert a minimum bias on the system.

3.2.2 All parts of the torque measuring device shall be identified in accordance with **3.2.1**, including the following, where applicable:

a) signal cables;

b) switch boxes;

c) interfaces;

d) data acquisition systems;

e) computers; and

f) software (where information is available).

3.2.3 Where an electrical indicator used with a torque measuring device is replaced with another, the following requirements shall be met to ensure that the calibration is not invalidated.

a) The original indicator shall have a valid calibration certificate, traceable to national standards, that gives the results of a calibration made in terms of the units to be measured. The indicator shall have been calibrated over a range equal to or greater than the range over which it is used with the torque measuring device.

b) The replacement indicator shall have a resolution equal to or better than the indicator it is replacing and shall have a valid calibration certificate, traceable to national standards, that gives the results of a calibration made in terms of the units to be measured. The indicator shall have been calibrated over a range equal to or greater than the range over which it is used with the torque measuring device.

c) The date of calibration on the certificate for the original indicator shall not precede that of the certificate for the replacement indicator by more than 12 months.

d) The certificates for the two indicators show that the readings of the torque measuring device, as measured by the two indicators, agree with the values given below, over the range of the classification of the torque measuring device:

   — ±0.025% of indicated reading for a class 0.05 device;
   — ±0.050% of indicated reading for a class 0.1 device;
   — ±0.10% of indicated reading for a class 0.2 device;
   — ±0.25% of indicated reading for a class 0.5 device;
   — ±0.50% of indicated reading for a class 1.0 device;
   — ±1.00% of indicated reading for a class 2.0 device;
   — ±2.50% of indicated reading for a class 5.0 device.

e) If it is necessary to replace cables, the replacement cables shall be of the same specification as the originals to ensure that the calibration remains valid.

3.3 Resolution of the indicator

NOTE An indicator can be a direct reading display or the output of a data acquisition system.

3.3.1 Analogue scale

When the output of the torque measuring device is measured by an indicator with an analogue scale, i.e. a dial gauge or Bourdon tube instrument, the resolution r shall be determined from the ratios between the width of the pointer and the centre-to-centre distance between two adjacent scale graduation marks (scale interval).

NOTE The ratios should be 1/2, 1/5 or 1/10.

A spacing of at least 1.25 mm shall be used for the estimation of a tenth of the division on the scale.

When using an optical recognition system, i.e. video, the video frame rate shall be at least 10 times the display update being recorded.

A vernier scale of dimensions appropriate to the analogue scale may be used to allow direct fractional reading of the instrument scale division.

3.3.2 Digital scale

The resolution shall be considered to be one increment of the last active number of the numerical indicator.

3.3.3 Variation of readings

If the readings fluctuate by more than the value previously calculated for the resolution (with no torque applied to the instrument), the resolution shall be deemed to be equal to half the range of fluctuation.

3.3.4 Units

The resolution r shall be converted to units of torque.

3.4 Lower limit of calibration T_{min}

To ensure that the classification is consistent with the resolution of the torque indicator, a lower limit of calibration shall be determined. The calibration shall not be performed below this lower limit, given by the equation:

$$T_{min} = a \cdot r$$

where:

r is the resolution determined in accordance with **3.3**

a has the following values:

- — 4 000 for a class 0.05 torque measuring device;
- — 2 000 for a class 0.1 torque measuring device;
- — 1 000 for a class 0.2 torque measuring device;
- — 400 for a class 0.5 torque measuring device;
- — 200 for a class 1.0 torque measuring device;
- — 100 for a class 2.0 torque measuring device;
- — 40 for a class 5.0 torque measuring device.

3.5 Number of calibration orientations (see Annex A)

For classes 0.05 and 0.1, the torque measuring device shall be calibrated in either three different mounting positions, each rotated 120° about the measurement axis, or in four different mounting positions, each rotated 90° about the measurement axis. For all other classes, the torque measuring device shall be calibrated at a minimum of two different mounting positions at least 90° apart. Where the design or specification of the torque measuring device does not allow it to be rotated, a physical disconnection and reconnection of the reference standard shall be deemed acceptable.

3.6 Preliminary procedure

3.6.1 Alignment

3.6.1.1 Place the torque measuring device in an appropriate mounting and position it so that it can, where possible, be rotated about its principal measuring axis between series.

NOTE Any bending applied to the torque measuring device during the calibration should be kept to a minimum. Where it is felt that the bending applied could have a significant effect on the torque measuring device's deflection, this should be considered as part of the uncertainty budget.

3.6.1.2 Ensure that there is a minimal misalignment between the reference standard and the torque measuring device.

3.6.2 Temperature considerations

3.6.2.1 Where the torque measuring device is electrical, connect the torque measuring device, indicator, switchboxes, interfaces, etc., using the associated electrical cables. Switch on and allow to warm-up for the period stated in the manufacturer's handbook. In the absence of any recommendation energize the system for at least 15 min.

3.6.2.2 Position a thermometer close to the calibration beam or reference torque measuring device and the torque measuring device to be calibrated. Allow the torque measuring device and all relevant parts of the calibration equipment to attain a stable temperature. Record the temperature at the beginning and end of each measurement series.

3.6.2.3 Calibrate the torque measuring device at a temperature in the range of 18 °C to 28 °C. The temperature shall not vary by more than ±1 °C throughout a measurement series.

3.6.3 Indicator set-up

3.6.3.1 Carry out checks and settings of the indicator in accordance with the manufacturer's handbook. Select the unit of measurement, e.g. N·m, divisions.

3.6.3.2 Where a voltage measuring device is to be used as the indicator, carry out checks and settings in accordance with the manufacturer's handbook. Select the appropriate measuring range, e.g. V, mV or µV.

3.6.4 Preloading procedure

Before any calibration or recalibration, preload the torque measuring device and associated connecting components in the appropriate loading direction (i.e. clockwise or anti-clockwise direction) a minimum of three times in succession to the maximum applied torque of the device. Maintain each preload for a period of between 1 min and 1.5 min. The interval between successive application and removal of preloads shall be as uniform as possible.

Where the torque measuring device is to be calibrated in both clockwise and anti-clockwise loading directions, preload the torque measuring device for a minimum of three times before the commencement of calibration.

4 Calibration procedure

4.1 Selection of calibration torques

4.1.1 Select a series of at least five approximately equally spaced, increasing values of torque from 20% to 100% of maximum applied torque.

4.1.2 If the calibration is required to be made below 20% then torque steps of 10%, 5% and 2% of maximum applied torque may additionally be used, provided that they are greater than the calculated lower limit of the calibration range.

4.1.3 Where the use of a torque measuring device requires that both increasing and decreasing values of torques are measured, select a single series of decreasing values in accordance with **4.1.1** for application at the end of the last series of increasing torques.

4.1.4 An increasing torque shall always be applied in a direction from a lower value of torque. A decreasing torque shall always be applied in a direction from a higher value of torque.

NOTE Where a reference torque measuring device has been calibrated with both increasing and decreasing values of torques, it may be used to determine torques in both of these modes.

4.2 Application of calibration torques

4.2.1 Calibrate in one of the following:

a) clockwise or anti-clockwise direction (see **4.2.2**); or

b) in both clockwise and anti-clockwise directions (see **4.2.8**).

4.2.2 After the preloading procedure (see **3.6.4**), apply two series of increasing torques in a clockwise or anti-clockwise direction, as required, to the torque measuring device without change of the mounting position. The indicator reading may be tared to zero at the beginning of each measurement series.

4.2.3 Record the readings of the indicator with zero torque applied to the torque measuring device before and after each application of a series of torques.

4.2.4 The interval between successive application and removal of torques shall be as uniform as possible. Record the reading of the indicator no less than 30 s after each application or removal of a torque. For the determination of relative residual deflection, record the residual deflection reading no less than 30 s after the torque is completely removed.

4.2.5 Disturb and remount the torque measuring device in accordance with **3.5**. After reconnection, preload the torque measuring device once to maximum applied torque then apply a further series of increasing torques.

4.2.6 Repeat **4.2.5** until torques have been applied at all required orientations.

4.2.7 Where relative reversibility is required, a single series of decreasing values shall be applied at the end of the last series of increasing torques.

4.2.8 Where the torque measuring device is required to be calibrated for both clockwise and anti-clockwise torques, repeat the procedure given in **4.2.2** to **4.2.7** for the opposite direction.

5 Calculation of results

5.1 Determination of deflection (*d*)

Algebraically subtract the indicator reading for the initial zero torque from the indicated reading for each applied torque and the final zero torque in the measurement series.

NOTE The unit of indicator reading is in units of torque, e.g. N·m, or, where a voltage measuring device is used, in units of volts, e.g. V, mV or µV.

5.2 Determination of relative repeatability (R_1)

5.2.1 For each value of increasing torque applied in a clockwise or anti-clockwise direction, calculate the repeatability of the deflection for the first and second series of applied torque.

5.2.2 Express the repeatability as a percentage of the mean deflection $\bar{d}_{R1}$ for the first and second applications of the given torque, using equations (1) and (2).

(1) $$\bar{d}_{R1} = \frac{d_1 + d_2}{2}$$

where:

$\bar{d}_{R1}$ is the mean deflection for a given torque;

d_1 and d_2 are the deflections for a given increasing torque (series 1 and 2).

(2) $$R_1 = \frac{(d_1 - d_2)}{\bar{d}_{R1}} \times 100$$

where:

R_1 is the relative repeatability.

5.3 Determination of relative reproducibility (R_2)

5.3.1 For each value of increasing torque applied in a clockwise or anti-clockwise direction, calculate the reproducibility of the deflection for the series of applied torque.

5.3.2 The reproducibility shall be expressed as a percentage of the mean deflection $\bar{d}_{R2}$ for the applications of the given torque, using equations (3), (4) or (5), as applicable, and (6).

a) for two orientations:

(3) $$\bar{d}_{R2} = \frac{d_1 + d_3}{2}$$

b) for three orientations:

(4) $$\bar{d}_{R2} = \frac{d_1 + d_3 + d_4}{3}$$

c) for four orientations:

(5) $$\bar{d}_{R2} = \frac{d_1 + d_3 + d_4 + d_5}{4}$$

where:

$\bar{d}_{\mathrm{R2}}$ is the mean deflection calculated from the first series at each orientation;

d_1, d_3, d_4 and d_5 are the deflections for a given increasing torque from the first series at each orientation

(6) $$R_2 = \left[\frac{(d_{\mathrm{max}} - d_{\mathrm{min}})}{\bar{d}_{\mathrm{R2}}}\right] \times 100$$

where:

R_2 is the relative reproducibility;

d_{max} is the maximum deflection for a given increasing torque from all series;

d_{min} is the minimum deflection for a given increasing torque from all series.

5.4 Determination of relative error of interpolation (E_{it})

5.4.1 The error of interpolation shall only be determined where the deflection is expressed in units other than those of torque (e.g. in units of V, mV).

5.4.2 Compute a "best fit" first, second or third order polynomial equation relating the mean deflection to the increasing calibration torques. Equal weighting shall be given to all points. Compute the polynomial series such that the sum of the squares of the residuals, i.e. the departure of the actual calibration readings from the computed values given by the equation, is a minimum.

5.4.3 At each increasing calibration torque, calculate the residual as a percentage of the computed deflection for the given torque, using equation (7).

(7) $$E_{it} = \left[\frac{(\bar{d}_{R2} - d_{comp})}{d_{comp}} \right] \times 100$$

where:

E_{it} is the relative error of interpolation;

d_{comp} is the computed deflection for the given increasing torque.

5.5 Determination of relative residual deflection (R_0)

Determine the maximum residual deflection obtained from the applied series of torques and express this as a percentage of the mean deflection at maximum applied torque using equation (8).

(8) $$R_0 = \frac{d_{0max}}{\bar{d}_{R2\,max}} \times 100$$

where:

R_0 is the relative residual deflection;

d_{0max} is the maximum residual deflection;

$\bar{d}_{R2\,max}$ is the mean deflection at maximum applied torque.

5.6 Determination of relative reversibility (R_3)

Express the relative reversibility as a percentage of the deflection for the given torque from the last applied series of torques, using equation (9).

(9) $$R_3 = \frac{(d_{dec} - d_{inc})}{d_{inc}} \times 100$$

where:

R_3 is the relative reversibility;

d_{inc} is the deflection for the application of the last series of a given increasing torque;

d_{dec} is the deflection for the application of the corresponding decreasing torque.

5.7 Determination of relative error of indication (E_i)

5.7.1 The relative error of indication shall only be determined where the deflection is expressed in units of torque.

5.7.2 Calculate for each value of increasing torque applied in a clockwise or anti-clockwise direction the error of indication for the given torque. Calculate the mean deflection ($\bar{d}_{R2}$) for the applications of the given torque and express the relative error of indication as a percentage of the true value of torque (T_a), e.g. the accepted value of the applied calibration torque, using equation (10).

(10) $$E_i = \frac{\bar{d}_{R2} - T_a}{T_a} \times 100$$

where:

E_i is the relative error of indication;

$\bar{d}_{R2}$ is the mean deflection calculated from the first series at each orientation;

T_a is a given increasing calibration torque.

6 Classification of torque measuring devices

6.1 Procedures for classification

6.1.1 General

6.1.1.1 Where the deflection is expressed in units of torque, and increasing torques have been applied, the classification and range of that classification shall be determined for the following parameters:

a) repeatability;

b) reproducibility;

c) residual deflection; and

d) error of indication.

Where decreasing torques have also been applied, the classification and its range for the relative reversibility shall also be determined in addition to these parameters.

6.1.1.2 Where the deflection is expressed in units other than those of torque, and increasing torques have been applied, the classification and range of that classification shall be determined for the following parameters;

a) repeatability,

b) reproducibility,

c) residual deflection; and

d) error of interpolation.

Where decreasing torques have also been applied, the classification and its range for the relative reversibility shall also be determined in addition to these parameters.

6.1.1.3 Uncertainties of measurement are not used to determine the classification.

6.1.2 Determination of a classification and its range

6.1.2.1 To permit an analysis of the results of the calibration, a target classification shall be selected consistent with the intended use of the torque measuring device.

6.1.2.2 At each calibration torque from the maximum applied torque to be calibrated downwards, the values of error calculated for each parameter being classified shall not exceed the value given for the selected classifications in the appropriate column of Table 2. The classification shall cease to apply at the first calibration torque where the limit for the selected classification is exceeded. The minimum range of measurement for a selected classification shall be 20% to 100% of maximum applied torque.

6.1.2.3 If conformity with **6.1.2.2** in respect of all of the parameters for which the classification is being sought is achieved, the selected classification shall be deemed to have been met. If the range of one or more of the parameters does not meet the requirements of **6.1.2.2**, then the analysis shall be repeated to determine conformance to a lower classification.

*NOTE 1 Where calibration torques have been applied below 20% of maximum applied torque and all of the results meet the requirements of **6.1.2.2** then the range of classification of the selected classification can be extended.*

*NOTE 2 A second classification of lower class and of an extended range can be awarded, provided that all of the requirements of **6.1.2.2** are met in respect of the lower class. For example:*

— class 1.0: from 100 N·m down to 20 N·m;

— class 2.0: from 100 N·m down to 5 N·m.

Table 2 **Criteria for classification of torque measuring devices**

Class	**Permissible values** %					
	Relative repeatability R_1	**Relative reproducibility** R_2	**Relative error of interpolation** E_{it}	**Relative residual deflection** R_0	**Relative reversibility** R_3	**Relative error of indication** E_i
0.05	±0.025	±0.05	±0.025	±0.01	±0.062	±0.025
0.1	±0.05	±0.10	±0.05	±0.02	±0.125	±0.05
0.2	±0.10	±0.20	±0.10	±0.04	±0.250	±0.10
0.5	±0.25	±0.50	±0.25	±0.10	±0.625	±0.25
1.0	±0.50	±1.00	±0.50	±0.20	±1.250	±0.50
2.0	±1.00	±2.00	±1.00	±0.40	±2.500	±1.00
5.0	±2.50	±5.00	±2.50	±1.00	±6.250	±2.50

7 Calibration certificate

7.1 General

When the torque measuring device has satisfied the requirements of Clause **3** to Clause **6**, a certificate shall be issued stating at least the following.

a) The date of the issue of this certificate, which shall also be identified by a unique reference.

b) The date of calibration.

c) The serial numbers of the torque measuring device and, where appropriate, any mechanical fittings and electrical cables.

d) A brief description of the calibration method and the type of calibration equipment used, including the uncertainty of measurement of the applied calibration torque.

e) A reference to this standard as a basis of test, i.e. BS 7882:2008.

f) The range and loading mode of torques over which the torque measuring device conforms to Clause **3** to Clause **6**, for a given classification.

g) Where the unit of deflection is expressed in units of torque it shall be stated that the device conforms to the parameters of repeatability, reproducibility, relative residual deflection and error of indicator reading. Where reversibility has been determined and classified, this shall also be stated.

h) Where the unit of deflection is expressed in units of other than those of torque it shall be stated that the device conforms to the parameters of repeatability, reproducibility, relative residual deflection and error of interpolation. The degree of the equation determined and the coefficients obtained shall also be stated. Where reversibility has been determined and classified, this shall also be stated.

i) The uncertainty of measurement for the calibration values given (see Annex B).

j) The average temperature and its range of variation or the maximum and minimum temperature recorded of the torque measuring device during the calibration.

k) A table of the applied torques and corresponding deflections.

Where the calibration laboratory supplies the indicating devices, the uncertainty of measurement of the conditioning devices (including the display, energizing device and cables) can also be included in the calibration certificate.

7.2 Frequency of calibration

The torque measuring device shall be recalibrated at least every 12 months and whenever it suffers any damage or has been subject to any repair.

Annex A (informative) Orientation diagrams

The following diagrams show examples for the calibration of torque measuring devices.

Figure A.1 **Example of preloading and calibration sequences for a torque measuring device with round shaft drives, six increasing and decreasing torques, classes 0.05 to 5.0**

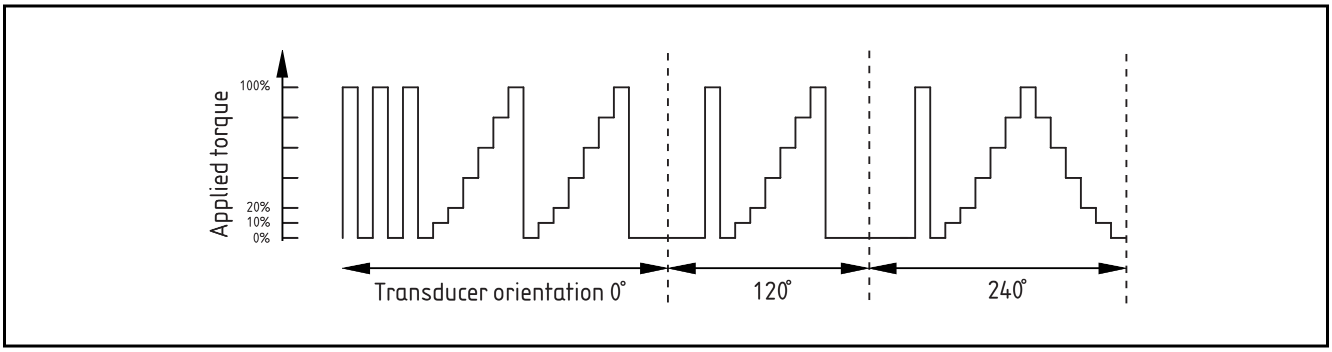


Figure A.2 **Example of preloading and calibration sequences for a torque measuring device with round shaft drives, six increasing torques only, classes 0.05 to 5.0**

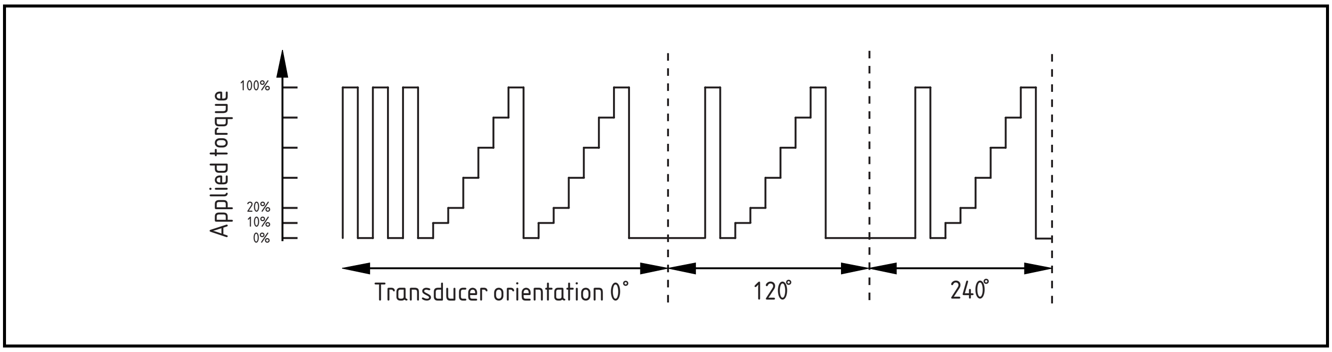


Figure A.3 **Example of preloading and calibration sequences for a torque measuring device with square drives, six increasing and decreasing torques, classes 0.05 to 5.0**

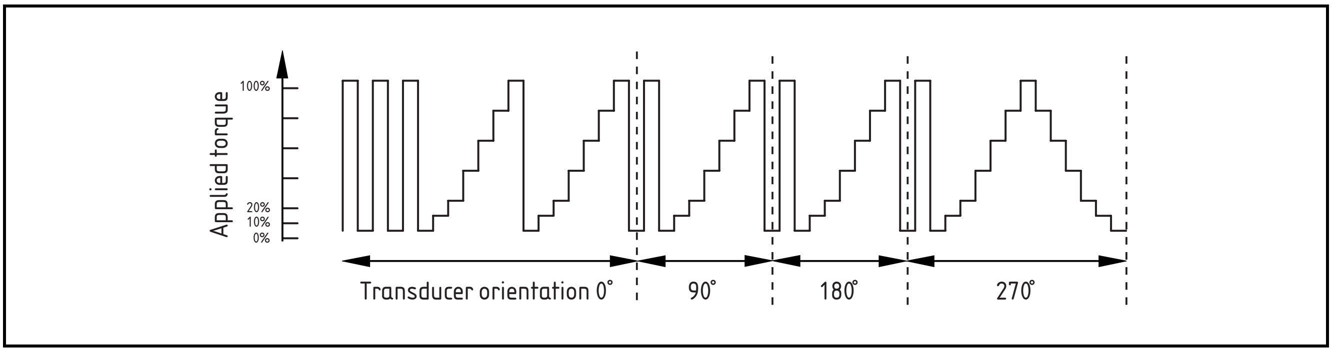


Figure A.4 **Example of preloading and calibration sequences for a torque measuring device with square drives, six increasing torques only, classes 0.05 to 5.0**

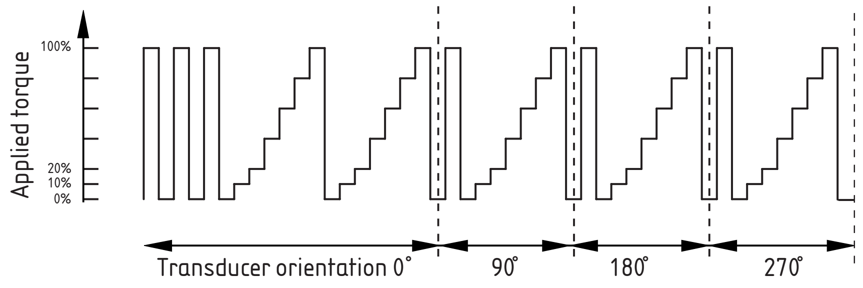


Figure A.5 **Example of preloading and calibration sequences for a torque measuring device, six increasing and decreasing torques, classes 0.2 to 5.0.**

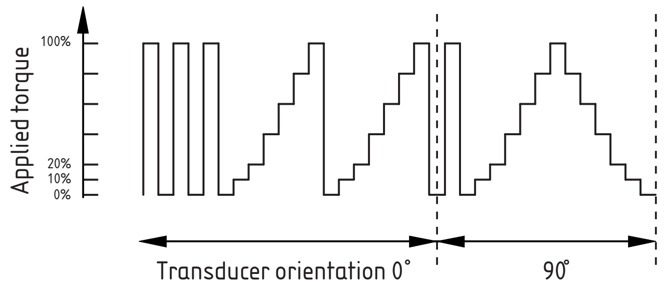
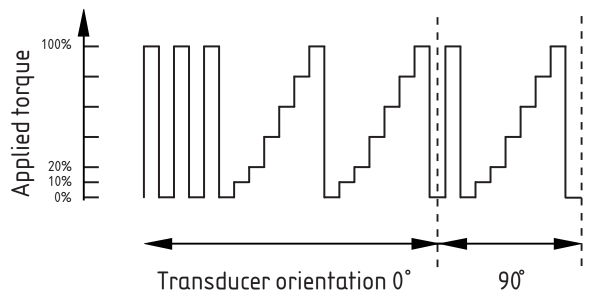


Figure A.6 **Example of preloading and calibration sequences for a torque measuring device, six increasing torques only, classes 0.2 to 5.0**



Annex B (informative) Method example of determining uncertainty of the calibration results of the torque measuring device

B.1 Uncertainty of the calibration results

B.1.1 General

For torque measuring devices where the deflection is in torque units, the calibration uncertainty is that of the torque value given by the error of indication when the deflection of the device is a specific torque value. For devices where the deflection is in other units, the calibration uncertainty is that of the torque value calculated from the interpolation equation, at any measured deflection.

At each calibration torque T, a combined standard uncertainty u_c is calculated from the readings obtained during the calibration. These uncertainties are then multiplied by the coverage factor $k = 2$ to give an expanded uncertainty value U.

(B.1) $$u_c = \sqrt{\sum_{i=1}^{n} u_i^2} \text{ and } U = k \cdot u_c$$

where all units are expressed as relative values and:

u_1 is the standard uncertainty associated with the calibration torque;

u_2 is the standard uncertainty associated with the reproducibility of the device;

u_3 is the standard uncertainty associated with the repeatability of the device;

u_4 is the standard uncertainty associated with the resolution of indicator;

u_5 is the standard uncertainty associated with the residual deflection of the device;

u_6 is the standard uncertainty associated with the temperature of the device;

u_7 is the standard uncertainty associated with the error of interpolation when units other than those of torque are used (see **5.4**);

u_8 is the standard uncertainty associated with the reversibility of the device;

n is the number of uncertainty contributions u_i.

B.1.2 Calculation of calibration torque uncertainty, u_1

u_1 is the standard uncertainty associated with the torques generated by the calibration machine. This value should be obtained from the calibration certificate of the calibration machine.

B.1.3 Calculation of reproducibility uncertainty, u_2

u_2 is the standard deviation associated with the population of incremental deflections obtained during the calibration.

$$u_2 = \frac{0.5R_2}{\sqrt{2}} \quad \text{(B.2)}$$

where R_2 is the relative reproducibility defined in **5.3**.

B.1.4 Calculation of repeatability uncertainty, u_3

u_3 is the uncertainty contribution due to the repeatability of the measured deflection. It can be assumed that, at each calibration torque T:

$$u_3 = \frac{0.5R_1}{\sqrt{3}} \quad \text{(B.3)}$$

where R_1 is the relative repeatability defined in **5.2**.

B.1.5 Calculation of resolution uncertainty, u_4

Each deflection value is calculated from two readings (the reading with an applied torque minus the reading at zero torque). Because of this, the resolution of the indicator needs to be included twice as a single triangular distribution with a standard uncertainty of $r/\sqrt{6}$, where r is the resolution expressed as a relative value. Where it is possible to tare the initial reading of each series to zero, a single rectangular distribution with a standard uncertainty of $r/\sqrt{12}$ can be used.

$$u_4 = \frac{r}{\sqrt{6}} \quad \text{(B.4)}$$

B.1.6 Calculation of residual deflection uncertainty, u_5

u_5 is the uncertainty component due to the variation in the relative residual deflection R_0.

$$u_5 = \frac{0.5R_0}{\sqrt{3}} \quad \text{(B.5)}$$

B.1.7 Calculation of temperature uncertainty, u_6

u_6 is the contribution due to the variation of temperature throughout the calibration, together with the uncertainty in the measurement of the calibration temperature. The sensitivity of the device to temperature needs to be determined:

$$u_6 = \frac{K\Delta t}{2\sqrt{3}} \quad \text{(B.6)}$$

where:

K is the device's relative temperature coefficient expressed as a percentage of maximum applied torque per degree Celsius, derived either by tests or from the manufacturer's specifications;

NOTE The temperature coefficient to be used is that of sensitivity, not of zero.

Δt is the calibration temperature range, allowing for the uncertainty in the measurement of the temperature.

B.1.8 Calculation of error of interpolation uncertainty, u_7

u_7 is the uncertainty contribution due to the relative error of interpolation.

(B.7) $$u_7 = \frac{0.5E_{it}}{\sqrt{6}}$$

B.1.9 Calculation of reversibility uncertainty, u_8

u_8 is the uncertainty component due to the relative reversibility R_3.

(B.8) $$u_8 = \frac{0.5R_3}{\sqrt{3}}$$

B.1.10 Calculation of combined standard uncertainty, u_c

For each calibration torque, calculate the combined standard uncertainty u_c by combining the individual standard uncertainties in quadrature.

B.1.11 Calculation of expanded uncertainty, U

(B.9) $$u_c = \sqrt{\sum_{i=1}^{n} u_i^2} \text{ and } U = k \cdot u_c$$

where $k = 2$.

B.2 Overall accuracy of the device, O_a

The overall accuracy O_a of the device can be obtained by combining the classification accuracy with the expanded uncertainty in quadrature.

(B.10) $$O_a = \sqrt{\left(\frac{E_i}{\sqrt{3}}\right)^2 + \left(\frac{U}{2}\right)^2}$$

The overall accuracy of the device is then multiplied by the coverage factor $k = 2$ to give an expanded uncertainty value U_{Oa}.

Classification accuracy is obtained from the error of indication E_i column in Table 2.

B.3 Worked examples of calculation of uncertainty of the calibration results of the torque measuring device calibrated in torque units (increasing torques only)

B.3.1 Obtain raw data.

B.3.2 Calculate parameters: mean indicated output, relative repeatability, relative reproducibility, relative error of indication and relative residual deflection.

B.3.3 Classify device using Table 2.

B.3.4 Calculate uncertainties.

B.3.4.1 Obtain applied torque uncertainty, u_1.

B.3.4.2 Calculate reproducibility, u_2.

B.3.4.3 Calculate repeatability, u_3.

B.3.4.4 Calculate resolution, u_4.

B.3.4.5 Calculate residual zero deflection, u_5.

B.3.4.6 Calculate temperature, u_6.

B.3.4.7 Calculate the combined uncertainty, u_c.

B.3.4.8 Calculate the expanded uncertainty, U.

Figure B.1 **Worked example in torque units: 100 N·m torque measuring device clockwise torque, increasing series only**

Applied torque N·m	**Raw data**			**Mean indicated deflection**
	0°		90°	
	1	2	3	
0	0.00	0.00	0.00	
10	9.96	9.96	10.04	**10.00**
20	19.93	19.94	20.07	**20.00**
40	39.92	39.93	40.11	**40.02**
60	59.93	59.94	60.14	**60.04**
80	79.96	79.97	80.17	**80.07**
100	100.00	100.01	100.21	**100.11**
0	0.00	0.01	0.01	

Applied torque N·m	**Relative repeatability R_1** %	**Relative reproducibility R_2** %	**Relative error of indication E_i** %	**Relative residual deflection R_0** %
0				
10	0.000	0.800	0.000	
20	−0.050	0.700	0.000	
40	−0.025	0.475	0.038	
60	−0.017	0.350	0.058	
80	−0.013	0.262	0.081	
100	−0.010	0.210	0.105	
0				0.010

Applied torque N·m	**Classification**				
	Relative repeatability R_1	**Relative reproducibility R_2**	**Error of indication E_i**	**Relative residual deflection R_0**	**Lower limit of calibration**
10	0.05	1.0	0.05		0.2
20	0.1	1.0	0.05		0.1
40	0.05	0.5	0.1		0.05
60	0.05	0.5	0.2		0.05
80	0.05	0.5	0.2		0.05
100	0.05	0.5	0.5	0.05	0.05

Figure B.2 Uncertainties calculated in accordance with B.3

Applied torque N·m	Uncertainty contribution													
	Applied torque u_1		**Reproducibility u_2**		**Repeatability u_3**		**Resolution u_4**		**Residual deflection u_5**		**Temperature u_6**		**Combined uncertainty**	**Expanded uncertainty** $k = 2$
	Taken from the calibration certificate of the calibration machine.		$u_2 = \frac{0.5R_2}{\sqrt{2}}$		$u_3 = \frac{0.5R_1}{\sqrt{3}}$		$u_4 = \frac{r}{\sqrt{6}}$		$u_5 = \frac{0.5R_0}{\sqrt{3}}$		$u_6 = \frac{K\Delta t}{2\sqrt{3}}$		$u_c = \sqrt{\sum_{i=1}^{n} u_i^2}$	$U = k \cdot u_c$
	Value %	**Uncertainty** %	**Value** %	**Uncertainty** %	**Value** %	**Uncertainty** %	**Value** %	**Uncertainty** %	**Value** %	**Uncertainty** %	**Value** %	**Uncertainty** %	%	%
0														
10	0.020	0.010	0.800	0.283	0.000	0.000	0.100	0.029			0.015	0.017	0.285	0.570
20	0.020	0.010	0.700	0.247	–0.050	–0.014	0.050	0.014			0.015	0.017	0.249	0.498
40	0.020	0.010	0.475	0.168	–0.025	–0.007	0.025	0.007			0.015	0.017	0.169	0.339
60	0.020	0.010	0.350	0.124	–0.017	–0.005	0.017	0.005			0.015	0.017	0.125	0.251
80	0.020	0.010	0.262	0.093	–0.013	–0.004	0.013	0.004			0.015	0.017	0.095	0.190
100	0.020	0.010	0.210	0.074	–0.010	–0.003	0.010	0.003	0.010	0.003	0.015	0.017	0.077	0.154

B.4 Worked examples of calculation of uncertainty of the calibration results of the torque measuring device calibrated in units other than torque (increasing and decreasing torques)

B.4.1 Obtain raw data.

B.4.2 Calculate parameters: mean indicated output, relative repeatability, relative reproducibility, relative error of interpolation, relative residual deflection and relative error of reversibility.

B.4.3 Classify device using Table 2.

B.4.4 Calculate uncertainties.

B.4.4.1 Obtain applied torque uncertainty, u_1.

B.4.4.2 Calculate reproducibility, u_2.

B.4.4.3 Calculate repeatability, u_3.

B.4.4.4 Calculate resolution, u_4.

B.4.4.5 Calculate residual zero deflection, u_5.

B.4.4.6 Calculate temperature, u_6.

B.4.4.7 Calculate error of interpolation, u_7.

B.4.4.8 Calculate error of reversibility, u_8.

B.4.4.9 Calculate the combined uncertainty, u_c.

B.4.4.10 Calculate the expanded uncertainty, U.

Figure B.3 **Worked example in mV/V: 2 kN·m torque measuring device clockwise torque, increasing and decreasing series**

Applied torque N·m	**Raw data**				**Mean indicated deflection**
	0°		120°	240°	
	1	2	3	4	
0	0.000 000	0.000 000	0.000 000	0.000 000	**0.000 000**
40	0.026 852	0.026 851	0.026 853	0.026 853	**0.026 853**
100	0.067 132	0.067 130	0.067 132	0.067 133	**0.067 132**
200	0.134 272	0.134 268	0.134 274	0.134 271	**0.134 272**
400	0.268 547	0.268 546	0.268 552	0.268 549	**0.268 549**
800	0.537 103	0.537 104	0.537 107	0.537 107	**0.537 106**
1 200	0.805 676	0.805 679	0.805 678	0.805 681	**0.805 678**
1 600	1.074 266	1.074 268	1.074 267	1.074 270	**1.074 268**
2 000	1.342 867	1.342 868	1.342 865	1.342 870	**1.342 867**
1 600				1.074 297	
1 200				0.805 724	
800				0.537 148	
400				0.268 568	
200				0.134 277	
100				0.067 132	
40				0.026 850	
0	–0.000 008	–0.000 011	–0.000 005	–0.000 003	**–0.000 005**

Coefficients

For a deflection d (mV/V) the applied torque T (N·m) is calculated thus:

$T = a_1\, d + a_2\, d^2 + a_3\, d^3$
a_1 = 1489.5325E+3
a_2 = –0.1265E–1
a_3 = –7.E–3

For a given applied torque T (N·m) the expected deflection d (mV/V) is calculated thus:

$d = b_1\, T + b_2\, T^2 + b_3\, T^3$
b_1 = 6.713516E–4
b_2 = 3.827E–11
b_3 = 1.44E–15

Figure B.3 **Worked example in mV/V: 2 kN·m torque measuring device clockwise torque, increasing and decreasing series** *(continued)*

Applied torque N·m	**Relative repeatability R_1** %	**Relative reproducibility R_2** %	**Relative error of interpolation E_{it}** %	**Relative residual deflection R_0** %	**Relative reversibility R_3** %
0					
40	0.003 7	0.074	–0.005 4		–0.001 1
100	0.003 0	0.045	–0.004 8		–0.000 1
200	0.003 0	0.045	–0.000 4		0.000 4
400	0.000 4	0.022	–0.000 9		0.007
800	–0.000 2	0.007	–0.000 2		0.008
1 200	–0.000 4	0.006	–0.000 1		0.005
1 600	–0.000 2	0.004	–0.000 1		0.003
2 000	–0.000 1	0.004	–0.000 0		
0				–0.000 4	

Applied torque N·m	**Classification**					
	Relative repeatability R_1	**Relative reproducibility R_2**	**Relative error of interpolation E_{it}**	**Relative residual deflection R_0**	**Relative reversibility R_3**	**Lower limit of calibration**
40	0.05	0.05	0.05		0.05	0.05
100	0.05	0.05	0.05		0.05	0.05
200	0.05	0.05	0.05		0.05	0.05
400	0.05	0.05	0.05		0.05	0.05
800	0.05	0.05	0.05		0.05	0.05
1 200	0.05	0.05	0.05		0.05	0.05
1 600	0.05	0.05	0.05		0.05	0.05
2 000	0.05	0.05	0.05	0.05	0.05	0.05

Figure B.4 Uncertainties calculated in accordance with B.4

Applied torque N·m	Uncertainty contribution													
	Applied torque u_1		**Reproducibility u_2**		**Repeatability u_3**		**Resolution u_4**		**Residual deflection u_5**		**Temperature u_6**		**Interpolation u_7**	
	Taken from the calibration certificate of the calibration machine.		$u_2 = \frac{0.5R_2}{\sqrt{2}}$		$u_3 = \frac{0.5R_1}{\sqrt{3}}$		$u_4 = \frac{r}{\sqrt{6}}$		$u_5 = \frac{0.5R_0}{\sqrt{3}}$		$u_6 = \frac{K\Delta t}{2\sqrt{3}}$		$u_7 = \frac{0.5E_{it}}{\sqrt{6}}$	
	Value %	**Uncertainty** %	**Value** %	**Uncertainty** %	**Value** %	**Uncertainty** %	**Value** %	**Uncertainty** %	**Value** %	**Uncertainty** %	**Value** %	**Uncertainty** %	**Value** %	**Uncertainty** %
0														
40	0.002	0.001	0.007 4	0.002 6	0.003 72	0.001 08	0.003 7	0.001 5			0.003	0.000 2	0.005 43	0.001 11
100	0.002	0.001	0.004 5	0.001 6	0.002 98	0.000 86	0.001 5	0.000 6			0.003	0.000 2	0.004 78	0.000 98
200	0.002	0.001	0.004 5	0.001 6	0.002 98	0.000 86	0.000 7	0.000 3			0.003	0.000 2	0.000 35	0.000 07
400	0.002	0.001	0.002 2	0.000 8	0.000 37	0.000 11	0.000 4	0.000 2			0.003	0.000 2	0.000 92	0.000 19
800	0.002	0.001	0.000 7	0.000 3	0.000 19	0.000 05	0.000 2	0.000 1			0.003	0.000 2	0.000 16	0.000 03
1 200	0.002	0.001	0.000 6	0.000 2	0.000 37	0.000 11	0.000 1	0.000 1			0.003	0.000 2	0.000 15	0.000 03
1 600	0.002	0.001	0.000 4	0.000 1	0.000 19	0.000 05	0.000 1	0.000 0			0.003	0.000 2	0.000 12	0.000 02
2 000	0.002	0.001	0.000 4	0.000 1	0.000 07	0.000 05	0.000 1	0.000 0	−0.000 4	−0.000 1	0.003	0.000 2	0.000 03	0.000 01

Applied torque N·m	Reversibility		Combined uncertainty	Expanded uncertainty $k = 2$
	$u_8 = \frac{0.5R_3}{\sqrt{3}}$		$u_c = \sqrt{\sum_{i=1}^{n} u_i^2}$	$U = k \cdot u_c$
	Value %	**Uncertainty** %	%	%
0				
40	0.011 2	0.003 2	0.004 8	0.009 6
100	0.001 5	0.000 4	0.002 4	0.004 8
200	0.004 5	0.001 3	0.002 5	0.004 9
400	0.007 1	0.002 0	0.002 4	0.004 9
800	0.007 6	0.002 2	0.002 4	0.004 9
1 200	0.005 3	0.001 5	0.001 9	0.003 7
1 600	0.002 5	0.000 7	0.001 3	0.002 5
2 000	0.000 0	0.000 0	0.001 0	0.002 1

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