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Torque measuring devices – Calibration and classification using continual torque application – Method

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 28, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI and came into effect on 30 September 2009. It was prepared by Subcommittee ISE/NFE/4/1, *Uniaxial testing of metals*, under the authority of Technical Committee ISE/NFE/4, *Mechanical testing of metals*. A list of organizations represented on these committees can be obtained on request to their secretary.

Information about this document

This British Standard describes a method of calibration and classification only and should not be used or quoted as a specification.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and competent people.

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 notes 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.

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1 Scope

This British Standard specifies a method for the calibration and classification of torque measuring devices using continuous torque application where the inertial effects are minimal. This includes torque measuring devices used for the calibration of hand torque tools conforming to BS EN ISO 6789, and torque measuring devices conforming to BS 7882.

The information to be given on the certificate of calibration is also specified in this standard.

Annex A provides diagrams of the continuous application of torque, and examples for the calibration of torque measuring devices. Annex B gives an example of determining uncertainty of the calibration results of the torque measuring device. Annex C shows how to calculate mechanical and electronic bandwidth.

2 Normative references

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

BS 7882*, Method for the calibration and classification of torque measuring devices*

BS EN ISO 6789*, Assembly tools for screws and nuts – Hand torque tools – Requirements and test methods*

JCGM 200, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)* (third edition available at: http://www.bipm.org/utils/common/documents/jcgm/JCGM_200_2008.pdf)

3 Terms, definitions, abbreviations and symbols

For the purposes of this British Standard, the terms and definitions given in JCGM 200 and the following apply.

3.1 acceleration period

time interval during which the rate of change of applied torque starts from zero and then attains a constant value

3.2 bandwidth of the reference standard

B_{RS}

response of the reference standard to a step input (expressed in hertz)

NOTE See Annex C.

3.3 bandwidth of the torque measuring device

B_{TMD}

response of the torque measuring device to a step input (expressed in hertz)

NOTE See Annex C.

3.4 calibration torque

T

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

3.5 constant rate period

time interval between the acceleration and deceleration periods at which the rate of change of applied torque is constant

3.6 continuous application of torque

sequence consisting of three time periods: acceleration period, constant rate period and deceleration period

NOTE Refer to Figure A.1.

3.7 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.

3.8 data skew

change in applied torque during the period between nominally synchronized readings from the reference standard and the torque measuring device

NOTE This period can be due to the readings being taken at different times or propagation delays. It can be determined, at various stable torque values throughout the torque calibration range, by applying a sharp mechanical stimulus to the system and measuring the difference in response times of the outputs from the reference standard and the torque measuring device.

3.9 deceleration period

time interval during which the rate of change of applied torque decreases from a constant value to zero

3.10 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.

3.11 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

3.12 lower limit of calibration

T_{min}

lower value of torque at which a torque measuring device of a given class can be calibrated

3.13 maximum calibration torque

T_{max}

upper calibration torque value applied to the torque measuring device

3.14 rate of applied torque

R_T

change of torque with time

3.15 recording rate

R_r

rate at which the visual or digital output is recorded for subsequent analysis

NOTE 1 The data may be manually recorded or recorded by an optical recognition system, i.e. video, for subsequent analysis.

NOTE 2 The recording rate is sometimes known as the refresh rate.

3.16 reference standard

RS

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.

3.17 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.

3.18 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.

3.19 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

3.20 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

3.21 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.

3.22 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.

3.23 residual deflection

d_0

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

3.24 resolution

r

smallest discernible measurement interval on the torque measuring device indicator

3.25 sampling rate

rate at which the analogue to digital converter samples a waveform

NOTE The analogue waveform may be sampled at a much higher rate than the rate at which data is available.

3.26 torque

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

3.27 torque measuring device

TMD

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

4 Preparation for calibration

4.1 Reference standard

4.1.1 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.

The uncertainty of the calibration torque shall take into account factors such as bandwidth of the system and its own calibration traceability.

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%.

4.1.2 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.

4.1.3 Bandwidth

The bandwidth of the reference standard shall be determined.

Two bandwidth contributions shall be taken into consideration:

a) mechanical: this is controlled by the natural frequency of the sensing element, i.e. transducer (see **C.1**);

b) electronic: this is a function of the instrumentation used (see **C.2**).

The bandwidth of the reference standard shall be taken as the lower of these two values.

4.2 Condition and identification of a torque measuring device

4.2.1 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.

4.2.2 All parts of the torque measuring device shall be identified in accordance with **4.2.1**, 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).

4.2.3 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 and performance characteristics are equal to or better than the original indicator.

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 should have a valid calibration certificate, traceable to national standards, in terms of the same units and covering the range over which it will be 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, shall 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;
   - ±0.05% 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 electrically identical to the original ones to ensure that the calibration remains valid.

4.2.4 The bandwidth of the torque measuring device, B_{TMD}, shall be determined.

Two bandwidth contributions shall be taken into consideration:

a) mechanical: this is controlled by the natural frequency of the sensing element, i.e. transducer (see **C.1**);

b) electronic: this is a function of the instrumentation used (see **C.2**).

The bandwidth of the torque measuring device shall be taken as the lower of these two values.

4.3 Resolution of the indicator

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

4.3.1 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) multiplied by the value of torque which one scale interval represents.

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 5 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.

4.3.2 Digital scale

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

4.3.3 Variation of readings

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

4.3.4 Units

The resolution, r, shall be converted to units of torque.

4.3.5 Data skew/resolution

If the resolution is smaller than the data skew, the resolution shall be increased to the value of the data skew.

NOTE If this results in too large a value for the resolution, this can be reduced by reducing the applied torque rate.

4.4 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:

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

where:

r is the resolution determined in accordance with **4.3**;

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.

4.5 Rate of applied torque

The values of the rate of applied torque shall conform to the following criteria.

$$R_T \leqslant R_{r(TMD)} . r \qquad (1)$$

$$R_T \leqslant R_{r(RS)} . r \qquad (2)$$

$$R_T \leqslant \frac{B_{TMD} . T_{max}}{10} \qquad (3)$$

$$R_T \leqslant \frac{B_{RS} . T_{max}}{10} \qquad (4)$$

where:

R_T	is the rate of applied torque;
$R_{r(TMD)}$	is the recording rate of the torque measuring device;
r	is the resolution;
$R_{r(RS)}$	is the recording rate of the reference standard;
B_{TMD}	is the bandwidth of the torque measuring device;
B_{RS}	is the bandwidth of the reference standard;
T_{max}	is the maximum calibration torque.

4.6 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 manufacturer's 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.

4.7 Preliminary procedure

4.7.1 Alignment

4.7.1.1 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.

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

4.7.2 Temperature considerations

4.7.2.1 Where the torque measuring device is electrical, connect the torque measuring device, 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.

4.7.2.2 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.

4.7.2.3 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.

4.7.3 Instrumentation set-up

Carry out checks and settings of the instrumentation in accordance with the manufacturer's handbook, where available. Select the unit of measurement, e.g. N·m, divisions, V, mV or μV.

4.7.4 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 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 calibration in each loading direction.

5 Calibration procedure

5.1 Selection of calibration torques

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

5.1.2 If the calibration is required to be made below 20%, torque data samples at approximately 10%, 5%, and 2% of maximum calibration torque may additionally be used, provided that they are greater than the calculated lower limit of the calibration range.

5.1.3 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 **5.1.1** for application at the end of the last series of increasing torques.

5.1.4 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.

5.2 Application of calibration torques

5.2.1 Calibrate in one of the following:

a) clockwise or anti-clockwise direction (see **5.2.2** to **5.2.10**); or

b) in both clockwise and anti-clockwise directions (see **5.2.11**).

5.2.2 After the preloading procedure (see **4.7.4**), 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. Record the output of the torque measuring device at the selected calibration torques.

5.2.3 The constant rate period shall be reached before the first torque data sample is taken.

5.2.4 Ensure that the maximum torque applied to the torque measuring device does not exceed 112% of the maximum calibration torque.

5.2.5 Within the constant rate period, it is permissible to increase the rate of application of torque between data samples provided the rate is lower than the maximum calculated value when readings are being taken and it can be shown that this increase of rate does not affect the measured values.

NOTE Two suggested methods of demonstrating this are: a) to ensure a time delay of the greater of $10/B_{TMD}$ *and* $10/B_{RS}$ *after the constant rate has to be achieved and before the reading is taken, and b) to ensure that the output from the torque measuring device is increasing at the same rate as the applied torque.*

5.2.6 Record the output of the torque measuring device with zero torque applied before and after each application of a series of torques. The torque measuring device output may be tared to zero at the beginning of each measurement series.

5.2.7 Disturb and remount the torque measuring device in accordance with **4.6**. After reconnection, load the torque measuring device once to maximum torque then apply and record the output of the torque measuring device during a further series of increasing torques.

5.2.8 Repeat **5.2.7** until torques have been applied at all required orientations.

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

5.2.10 The interval between successive application and removal of torques shall be as uniform as possible. For the determination of relative residual deflection, record the residual deflection reading not less than 30 s after the torque is completely removed.

5.2.11 Where the torque measuring device is required to be calibrated for both clockwise and anti-clockwise torques, follow the procedure given in **5.2.2** to **5.2.10**.

6 Calculation of results

6.1 Determination of deflection, *d*

Algebraically subtract the torque measuring device output for the initial zero torque from the torque measuring device output for each applied torque and the final zero torque in the measurement series.

NOTE The torque measuring device output can be units of N·m, divisions, V, mV or μV.

6.2 Determination of relative repeatability, R_1

6.2.1 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.

6.2.2 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 (5) and (6).

$$R_1 = \frac{\left(d_1 - d_2\right)}{\bar{d}_{R1}} \times 100 \qquad (5)$$

where:

R_1 is the relative repeatability

$$\bar{d}_{R1} = \frac{d_1 + d_2}{2} \qquad (6)$$

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).

6.3 Determination of relative reproducibility, R_2

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

6.3.2 The reproducibility shall be expressed as a percentage of the mean deflection $\bar{d}_{R2}$ for the applications of the given torque, using equations (7) and (8), (9) or (10), as applicable.

$$R_2 = \frac{(d_{\max} - d_{\min})}{\bar{d}_{R2}} \times 100 \qquad (7)$$

where:

R_2 is the relative reproducibility;

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

$d_{\max}$ 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.

a) for two orientations:

$$\bar{d}_{R2} = \frac{d_1 + d_3}{2} \tag{8}$$

b) for three orientations:

$$\bar{d}_{R2} = \frac{d_1 + d_3 + d_4}{3} \tag{9}$$

c) for four orientations:

$$\bar{d}_{R2} = \frac{d_1 + d_3 + d_4 + d_5}{4} \tag{10}$$

where:

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

6.4 Determination of relative error of interpolation, E_{it}

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).

Compute a "best fit" first or second order polynomial equation relating the mean deflection to the increasing calibration torques. 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.

NOTE If sufficient data are collected, a third order polynomial equation may be computed.

At each increasing calibration torque, calculate the residual as a percentage of the computed deflection for the given torque, using equation (11).

$$E_{\text{it}} = \left[\frac{(\bar{d}_{\text{R2}} - d_{\text{comp}})}{d_{\text{comp}}} \right] \times 100 \tag{11}$$

where:

E_{it} is the relative error of interpolation;

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

6.5 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 calibration torque using equation (12).

$$R_0 = \frac{d_{0\text{max}}}{\bar{d}_{R2\text{max}}} \times 100 \tag{12}$$

where:

R_0 is the relative residual deflection;

$d_{0\text{max}}$ is the maximum residual deflection;

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

6.6 Determination of relative reversibility, R_3

Express the relative reversibility as a percentage of the incremental deflection for the given torque from the last applied series of torques, using equation (13).

$$R_3 = \frac{(d_{\text{dec}} - d_{\text{inc}})}{d_{\text{inc}}} \times 100 \tag{13}$$

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.

6.7 Determination of relative error of indication, E_i

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

6.7.2 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 applied torque (T_a), i.e. the accepted value of the applied calibration torque, using equation (14).

$$E_i = \frac{\bar{d}_{R2} - T_a}{T_a} \times 100 \tag{14}$$

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 the increasing calibration torque.

7 Classification of torque measuring devices

7.1 The range of classification of a torque measuring device shall at least cover the range 20% to 100% of $T_{\max}$ (see Table 2).

NOTE 1 Where calibration torques have been applied below 20% of maximum torque and all of the results meet the requirements of Table 2 then the range of classification can be extended downwards.

NOTE 2 A second classification of lower class and of an extended range can be awarded, provided that all of the requirements of Table 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.*

7.2 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.

7.3 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.

7.4 Uncertainties of measurement shall not be used to determine the classification.

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 error of zero** 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

8 Calibration certificate

8.1 General

When the torque measuring device has been calibrated and classified, and has satisfied the requirements of Clause **4** to Clause **7**, 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 7996:2009;

f) the classification or classifications for the range and loading direction of torques over which the torque measuring device conforms to Table 2; where reversibility has been determined and classified, this shall also be stated;

g) a table of the applied torques and corresponding deflections;

h) the uncertainty of measurement for the calibration values given (see Annex B);

i) where the deflection is expressed in units other than those of torque, the degree of the equation determined and the coefficients obtained;

j) the rate of applied torque during data sampling and the duration of the constant rate period;

k) the average temperature and its range of variation or the maximum and minimum temperature recorded of the torque measuring device during the calibration;

l) where the calibration laboratory supplies the indicating devices, the uncertainty of measurement of the conditioning devices (including the display, energizing device and cables).

8.2 Frequency of calibration

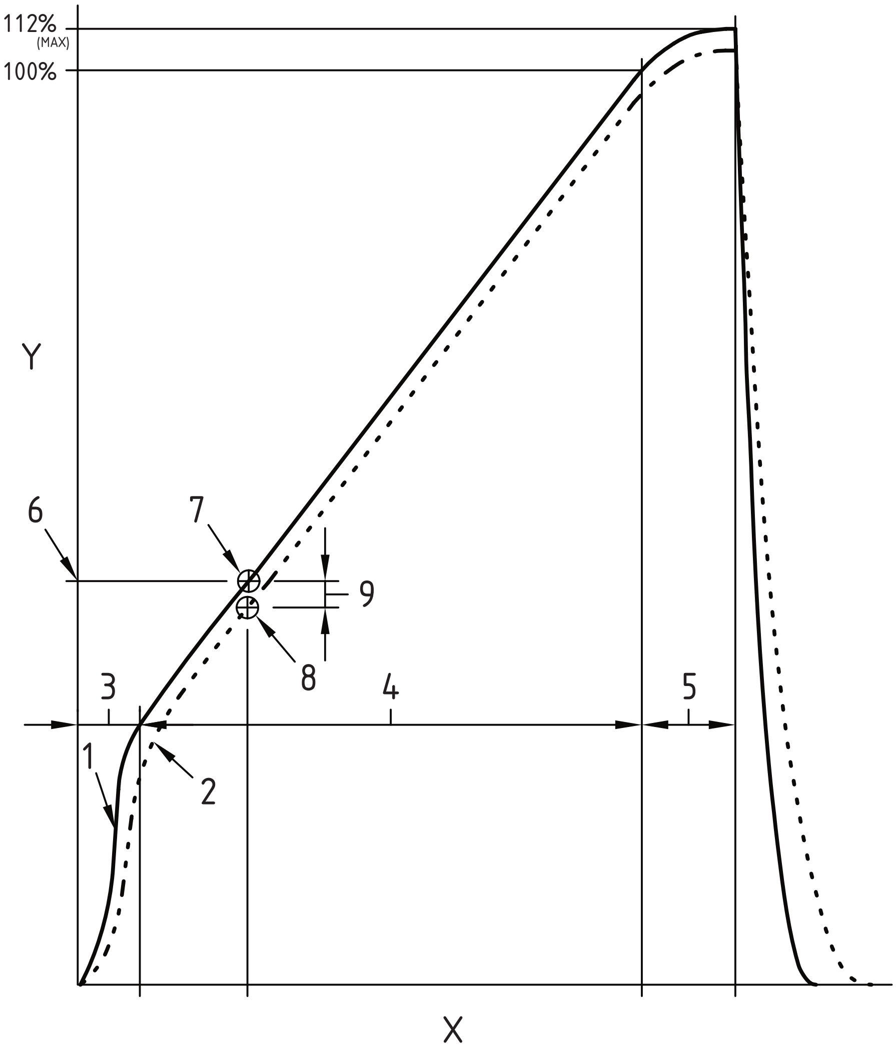
The torque measuring device shall be recalibrated at least once every 12 months and whenever it suffers any damage or has been subject to any repair.

Annex A (informative) Orientation diagrams

A.1 Continuous application of torque

Figure A.1 illustrates the continuous application of torque.

Figure A.1 **Continuous application of torque**



Key

X	Time
Y	Torque
1	Calibration torque applied, *T*
2	Displayed output (visual digital output)
3	Acceleration period
4	Constant rate period, R_T
5	Deceleration period
6	T_{min}
7	First valid data sample, d_{RS}
8	First valid data sample, d_{TMD}
9	Data skew due to propagation delay

A.2 Orientation diagrams

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

Figure A.2 **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**

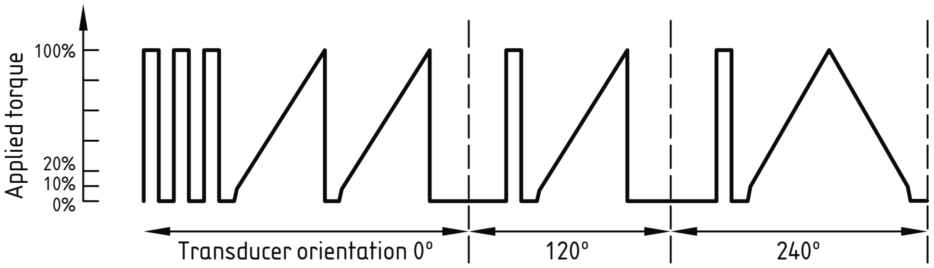


Figure A.3 **Example of preloading and calibration sequences for a torque measuring device with round shaft drives, six increasing torques only, classes 0.05 to 5.0**

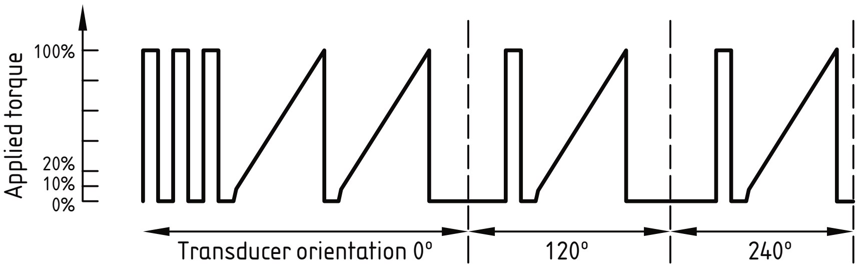


Figure A.4 **Example of preloading and calibration sequences for a torque measuring device with square drives, six increasing and decreasing torques, classes 0.05 to 5.0**

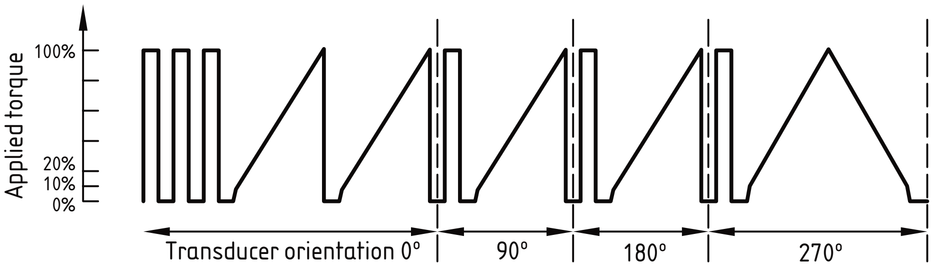


Figure A.5 **Example of preloading and calibration sequences for a torque measuring device with square drives, six increasing torques only, classes 0.05 to 5.0**

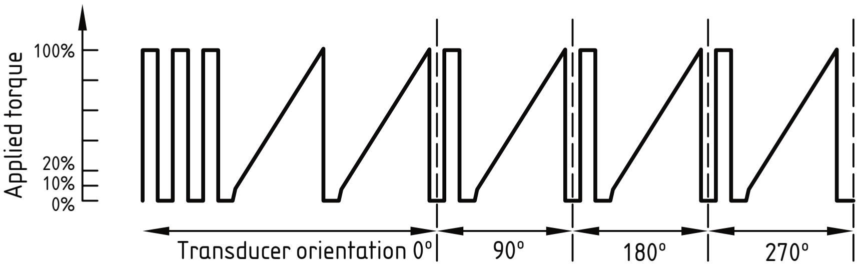


Figure A.6 **Example of preloading and calibration sequences for a torque measuring device, six increasing and decreasing torques, classes 0.2 to 5.0**

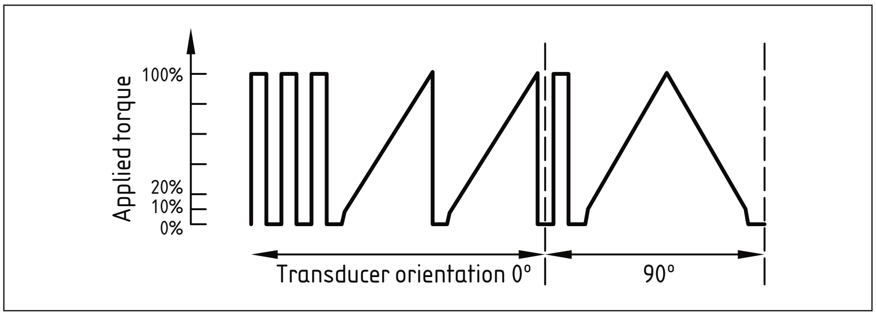
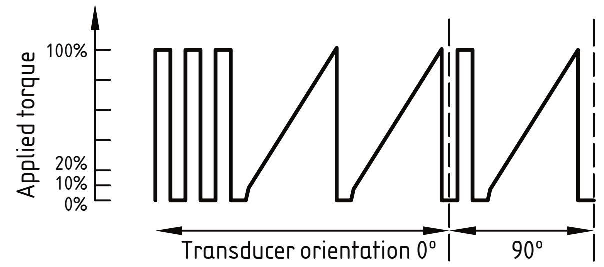


Figure A.7 **Example of preloading and calibration sequences for a torque measuring device, six increasing torques only, classes 0.2 to 5.0**



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, 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.

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

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 **6.4**);

u_8 is the standard uncertainty associated with the reversibility of the device where the reversibility has been determined;

u_9 is the standard uncertainty associated with the error of indication when the device displays in units of torque (see **6.7**);

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 (see Table 1). 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.

$$u_2 = \left| \frac{100}{\bar{d}} \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} \left(d_i - \bar{d}\right)^2} \right| \tag{B.2}$$

where:

$\bar{d}$ is the mean of all the incremental deflections;

n is the number of incremental runs.

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:

$$u_3 = \left| \frac{0.5R_1}{\sqrt{3}} \right| \tag{B.3}$$

where R_1 is the relative repeatability defined in **6.2**.

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 in percentage terms. 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.

$$u_4 = \left| \frac{r}{\sqrt{6}} \right| \tag{B.4}$$

Where the resolution has been increased by more than a factor of 1.4 to equal the data skew (see **4.3.5**), a standard uncertainty of $r/\sqrt{12}$ can be used.

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.

$$u_5 = \left| \frac{0.5R_0}{\sqrt{3}} \right| \tag{B.5}$$

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:

$$u_6 = \left| \frac{K\Delta t}{2\sqrt{3}} \right| \tag{B.6}$$

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.

$$u_7 = |E_{it}| \tag{B.7}$$

B.1.9 Calculation of reversibility uncertainty, u_8

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

a) For units of torque:

$$u_8 = \left|100\left(\frac{d_{\text{dec}} - T}{T}\right)\right| \tag{B.8}$$

where:

d_{dec} is decremental deflection;

T is applied torque.

NOTE Only the greater of u_8 and u_9 needs to be in the uncertainty calculation.

b) For units other than torque:

$$u_8 = \left|100\left(\frac{d_{\text{dec}} - d_{\text{comp}}}{d_{\text{comp}}}\right)\right| \tag{B.9}$$

where:

d_{comp} is the deflection computed from the interpolation equation.

NOTE Only the greater of u_7 and u_8 needs to be in the uncertainty calculation.

If the device is subsequently used to measure only incremental torques, this uncertainty component can be excluded.

B.1.10 Calculation of error of indication uncertainty, u_9

u_9 is the uncertainty contribution due to the error of indication

$$u_9 = |E_i| \tag{B.10}$$

B.1.11 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.1.12 Calculation of expanded uncertainty, *U*

$$u_c = \sqrt{\sum_{i=1}^{n} u_i^2} \text{ and } U = k \cdot u_c \qquad \text{(B.11)}$$

where $k = 2$.

Plot a graph of *U* against torque and determine the coefficients of a best fit, least squares line through all of the data points. The equation of this line will give the expanded uncertainty of the calibration results across the range of calibrated torque values.

B.2 Worked example of calculation of uncertainty of the calibration results of the torque measuring device calibrated in torque units (increasing torques only)

B.2.1 Obtain raw data.

B.2.2 Calculate parameters: mean deflection, relative repeatability, relative error of indication and relative residual deflection.

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

Applied torque N·m	Raw data			Mean deflection
	0°		90°	
	1	2	3	
0	0.00	0.00	0.00	—
10	10.05	10.06	10.07	**10.06**
20	20.06	20.07	20.08	**20.07**
40	40.05	40.06	40.09	**40.07**
60	60.03	60.04	60.09	**60.06**
80	80.01	80.02	80.08	**80.05**
100	100.00	100.01	100.07	**100.04**
0	0.00	0.00	0.01	

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

Applied torque N·m	Relative repeatability, R_1 %	Relative error of indication, E_i %	Relative residual deflection, R_0 %
0			
10	–0.099	0.600	
20	0.050	0.350	
40	0.025	0.175	
60	0.017	0.100	
80	0.012	0.056	
100	0.010	0.035	
0			0.010

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

Applied torque N·m	u_1 %	u_2 %	u_3 %	u_4 %	u_5 %	u_6 %	u_9 %	u_c %	U (k = 2) %
10	0.010	0.099	0.029	0.029		0.017	0.600	0.610	1.220
20	0.010	0.050	0.014	0.014		0.017	0.350	0.355	0.709
40	0.010	0.052	0.007	0.007		0.017	0.175	0.184	0.368
60	0.010	0.054	0.005	0.005		0.017	0.100	0.115	0.231
80	0.010	0.047	0.004	0.004		0.017	0.056	0.076	0.153
100	0.010	0.038	0.003	0.003		0.017	0.035	0.056	0.111
0					0.003				

Figure B.2 **Worked example in torque units: Expanded uncertainty as a function of applied torque**

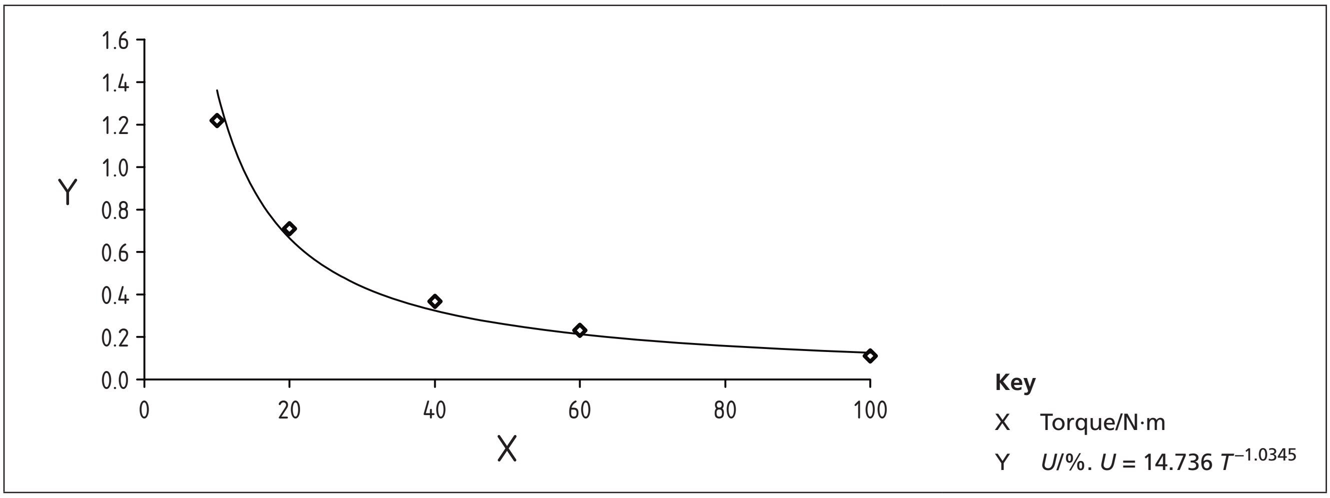
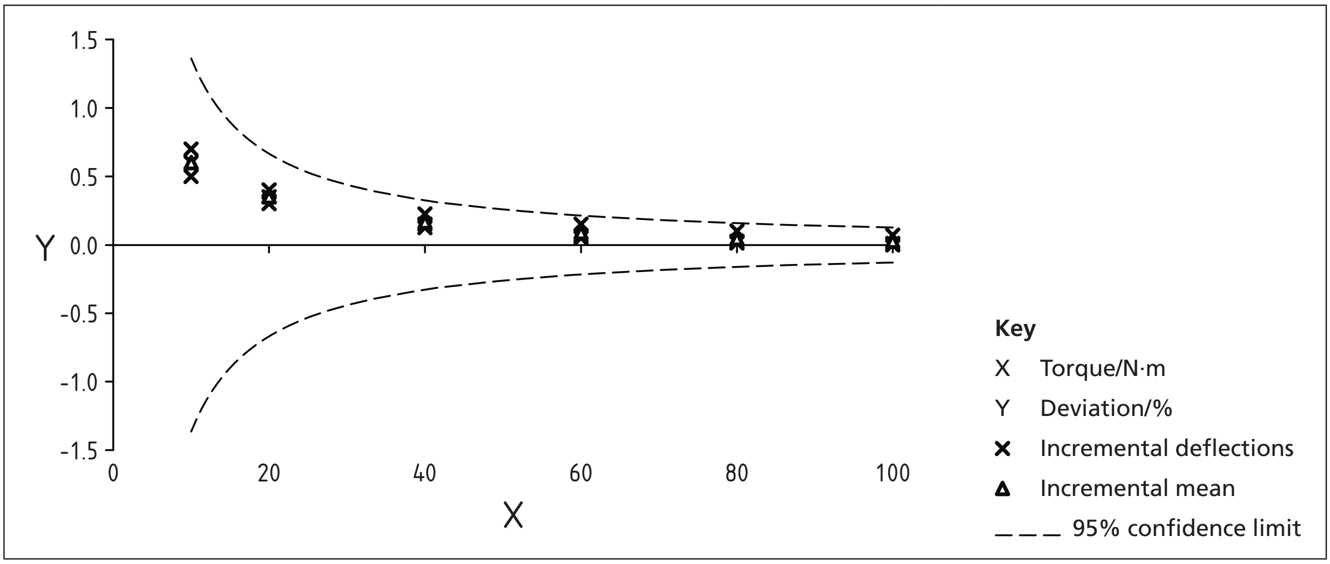


Figure B.3 **Worked examples in torque units: Deviation as a function of applied torque**



B.3 Worked examples of calculation of uncertainty of the calibration results of the torque measuring device displaying deflection in units other than torque (increasing and decreasing torques)

B.3.1 Obtain raw data.

B.3.2 Calculate parameters: mean deflection, relative repeatability, relative error of interpolation, relative residual deflection and relative error of reversibility.

Figure B.4A **Worked example in mV/V: 2 kN·m torque measuring device clockwise torque, increasing and decreasing series**

Applied torque N·m	**Raw data** 0° 1	0° 2	120° 3	240° 4	**Mean deflection**
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 measured deflection d (mV/V), the applied torque T (N·m) is calculated from:

$T = a_1 d + a_2 d^2 + a_3 d^3$

$a_1 = 1.489\ 59 \times 10^3$

$a_2 = -3.004 \times 10^{-1}$

$a_3 = 9.65 \times 10^{-2}$

For an applied torque T (N·m), the expected deflection d (mV/V) is calculated from:

$d = b_1 T + b_2 T^2 + b_3 T^3$

$b_1 = 6.713\ 254 \times 10^{-4}$

$b_2 = 9.089 \times 10^{-11}$

$b_3 = -1.96 \times 10^{-14}$

Figure B.4B **Worked example in mV/V: 2 kN·m torque measuring device clockwise torque, increasing and decreasing series**

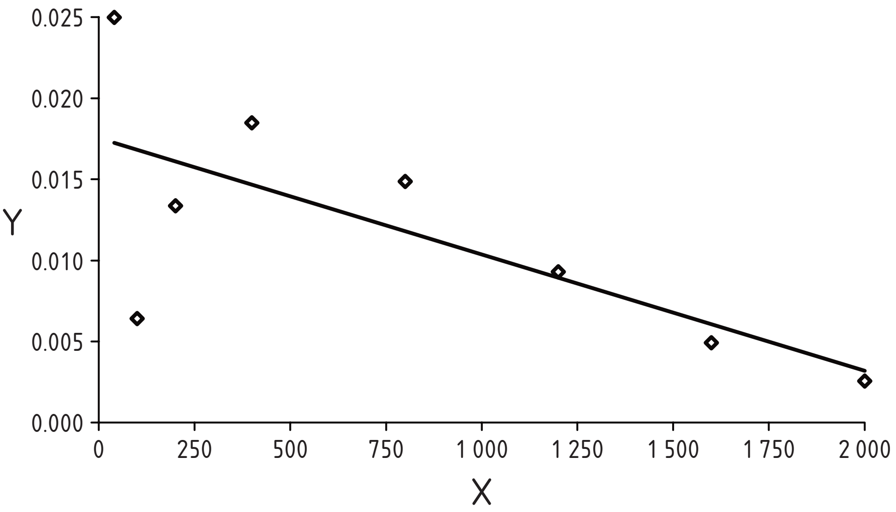
Applied torque N·m	Relative repeatability, R_1 %	Relative error of interpolation, E_{it} %	Relative residual deflection, R_0 %
40	0.003 7	–0.001 9	
100	0.003 0	–0.001 6	
200	0.003 0	0.002 8	
400	0.000 4	0.002 2	
800	–0.000 2	–0.000 5	
1 200	–0.000 4	–0.001 1	
1 600	–0.000 2	–0.000 5	
2 000	–0.000 1	0.000 7	
0			–0.000 8

Figure B.4C **Worked example in mV/V: 2 kN·m torque measuring device clockwise torque, increasing and decreasing series**

Applied torque N·m	u_1 %	u_2 %	u_3 %	u_4 %	u_5 %	u_6 %	u_7 %	u_8 %	u_c %	U (k = 2) %
40	0.001 0	0.003 6	0.001 1	0.001 5	0.000 2	0.000 2	(see note)	0.011 8	0.012 5	0.025 0
100	0.001 0	0.001 9	0.000 9	0.000 6	0.000 2	0.000 2		0.002 1	0.003 2	0.006 4
200	0.001 0	0.001 9	0.000 9	0.000 3	0.000 2	0.000 2		0.006 3	0.006 7	0.013 4
400	0.001 0	0.001 0	0.000 1	0.000 2	0.000 2	0.000 2		0.009 1	0.009 2	0.018 5
800	0.001 0	0.000 4	0.000 1	0.000 1	0.000 2	0.000 2		0.007 3	0.007 4	0.014 9
1 200	0.001 0	0.000 3	0.000 1	0.000 1	0.000 2	0.000 2		0.004 5	0.004 6	0.009 3
1 600	0.001 0	0.000 2	0.000 1	0.000 0	0.000 2	0.000 2		0.002 2	0.002 5	0.004 9
2 000	0.001 0	0.000 2	0.000 0	0.000 0	0.000 2	0.000 2	0.000 7	(see note)	0.001 3	0.002 5

NOTE Only the larger of u_7 and u_8 is included in the combined uncertainty.

Figure B.5 **Worked example in mV/V: Expanded uncertainty as a function of applied torque**

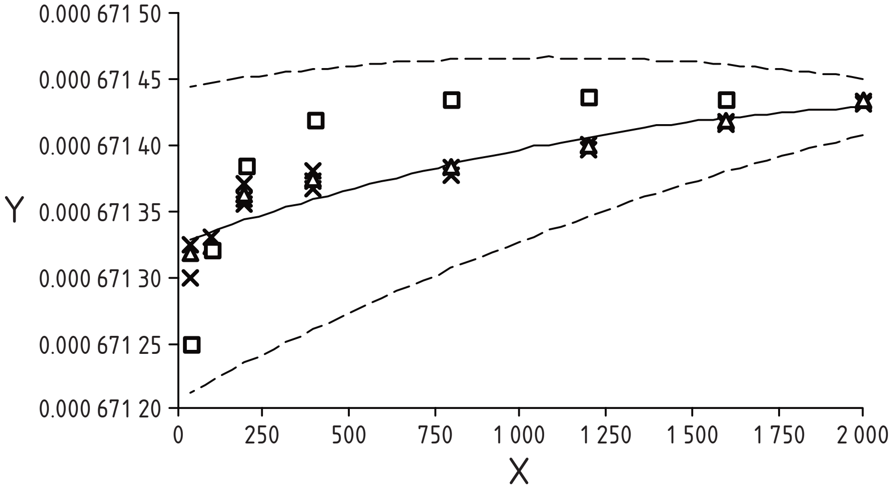


Key

X Torque/N·m

Y $U = 0.017\ 55 - 7.181 \times 10^{-6}\ T$

Figure B.6 **Worked example in mV/V: Deviation as a function of applied torque**



Key

X	Torque/N·m
Y	Calibration factor/mV/V/N·m
✕	Incremental deflections
△	Incremental mean
———	Interpolation curve
□	Decremental deflection
– – –	95% confidence limit

Annex C (informative) Bandwidth

C.1 Mechanical bandwidth, B_{mech}

To calculate the mechanical bandwidth, use the following:

$$B_{\mathrm{mech}} = f_{\mathrm{n}}/4 \qquad \text{(C.1)}$$

where f_{n} is natural frequency, which is obtained:

a) from manufacturer's information

b) by calculation from the following:

$$f_{\mathrm{n}} = \frac{1}{2\pi}\sqrt{\frac{K_{\mathrm{t}}}{J}} \qquad \text{(C.2)}$$

where:

K_{t} is torsional stiffness (N·m/rad);

J is moment of inertia, including couplings where applicable (kg·m^2);

c) where f_{n} is not known and cannot be calculated, a value of 400 Hz may be assumed.

NOTE For devices with f_n of less than 400 Hz this assumption can result in significant differences between static and continuous calibration results.

C.2 Electronic bandwidth, B_{elec}

Where manufacturer's information is not available, the actual bandwidth of the instrumentation can be estimated by making a measurement of its response to a step change in the input signal. The bandwidth (in hertz) is then calculated from the following:

$$B_{\mathrm{elec}} = \frac{0.35}{t_{10-90}} \qquad \text{(C.3)}$$

where:

t_{10-90} is the time between 10% to 90% values of the step change.

The step change is created by placing a shunt relay across the transducer output signal and recording the sudden change in transducer signal on a storage oscilloscope. It is essential to capture the response at a sufficiently high sampling rate to ensure that an accurate measurement of the rise time can be made.

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