European
co-operation for
Accreditation

Publication Reference **EA-10**/14

EA Guidelines on the Calibration of Static Torque Measuring Devices

PURPOSE

This document has been produced by EA to improve harmonisation in determining the calibration results and uncertainties in torque measurements. It provides information on the calibration procedures for torque measuring devices and gives guidance to calibration laboratories to establish a procedure for the expression of the overall uncertainty of calibration results for torque measuring devices.

Authorship
The publication has been written by EA Committee 2 (Technical Activities), based on a draft of the Task Force « Torque Measurements » of the EA Expert Group « Mechanical Measurements ».

Official language
The text may be translated into other languages as required. The English language version remains the definitive version.

Guidance Publications
This document represents a consensus of EA member opinion and preferred practice on how the relevant clauses of the accreditation standards might be applied in the context of the subject matter of this document. The approaches taken are not mandatory and are for the guidance of accreditation bodies and their client laboratories. Nevertheless, the document has been produced as a means of promoting a consistent approach to laboratory accreditation amongst EA member bodies, particularly those participating in the EA Multilateral Agreement.

Further information
For further information about this publication, contact your national member of EA. Please check our website for up-to-date information http://european-accreditation.org

CONTENTS

1 SCOPE

1.01 This guide is generally applicable to torque measuring devices where the torque is obtained by the measurement of the elastic deformation of a body or of a measurand proportional to it.

1.02 The scope of the calibration provided, should be made clear to the customer and recorded on the certificate when calibrating torque systems, i.e. whether all or some of the following are included: clockwise and/or anti-clockwise, incremental and decremental torque.

1.03 The uncertainty of measurement is determined in section 5[1], this should include the parameters of the selected scope.

1.04 This guide applies to the static calibration of torque measuring systems using supported beams or the comparison method with reference transducer and includes an example for calculation of the uncertainty of measurement. A diagram showing an example of the calibration steps and series is given in Annex D.

1.05 The torque measuring device is defined as the complete instrument comprising all parts, from the torque transducer to the indicating device.

2 SYMBOLS

For the purpose of this guide, the symbols given in Table 1 shall apply.

Table 1: Symbols, units and designations

Symbol	Designation	Unit
M_{nom}	nominal torque (maximum design torque of the device)	N·m
M_A	minimum torque value of the measuring range	N·m
M_E	maximum torque value of the measuring range	N·m
M_k	applied calibration torque	N·m
I_0	indication of torque measuring device of the zero signal prior to load application in mounting position	mV/V [2]
I_f	indication of torque measuring device after load removal in mounting position	mV/V [2]
I	indication of torque measuring device at torque step with increasing torque	mV/V [2]

(continued)

[1] The calculation of measurement uncertainty described in this guidance publication is to be considered as preliminary. It follows EA-4/02 in principle and will after a trial period by the national accreditation bodies, in particular by participation in the EA interlaboratory comparison T2, be revised and fully harmonised with EA-4/02 by the relevant EA Expert Group.

Table 1: (continued)

Symbol	Designation	Unit
I'	indication of torque measuring device at torque step with decreasing torque	mV/V [2]
S	sensitivity	(mV/V)/N·m [2]
X	indicated value at torque step with increasing torque	mV/V [2]
X_a	indicated value calculated from the interpolation equation	mV/V [2]
$\overline{X_\mathrm{E}}$	mean value of the torque measuring device at maximum of the measuring range	mV/V [2]
$\overline{X}$	mean value of the torque measuring device of increasing steps in different mounting positions	mV/V [2]
b'	repeatability	mV/V [2]
b	reproducibility	mV/V [2]
f_a	deviation of indication of the torque measuring device from the fitting curve	mV/V [2]
f_q	deviation of indication of the torque measuring device with defined scale	N·m
f_0	residual value at zero signal of the torque measuring device	mV/V [2]
h	reversibility of the torque measuring device	mV/V [2]
r	resolution of the indicating device	N·m
$u_{b'}$	uncertainty contribution of repeatability	N·m
$w_{b'}$	relative uncertainty contribution of repeatability	%
u_b	uncertainty contribution of reproducibility	N·m
w_b	relative uncertainty contribution of reproducibility	%
u_{fa}	uncertainty contribution of interpolation	N·m
w_{fa}	relative uncertainty contribution of interpolation	%
u_r	uncertainty contribution of resolution	N·m
w_r	relative uncertainty contribution of resolution	%
u_tcm	uncertainty contribution of the torque calibration machine	N·m
w_tcm	relative uncertainty contribution of the torque calibration machine	%
$u(\overline{X})$	standard uncertainty of measurement	mV/V [2]

(continued)

Table 1: (continued)

Symbol	Designation	Unit
$w(\overline{X})$	relative standard uncertainty of measurement	%
u_c	combined standard uncertainty of measurement allowing for systematic errors	N·m
w_c	combined relative standard uncertainty of measurement allowing for systematic errors	%
U	expanded uncertainty of measurement	mV/V [2]
W	expanded relative uncertainty of measurement	%

3 CHARACTERISTICS OF THE TORQUE MEASURING DEVICES

3.1 Description and identification of the torque measuring device

The torque measuring device comprises or consists of the complete set of measuring instruments and other equipment assembled to carry out torque measurements. All components of the torque measuring device (including cables for electrical connection) shall be individually and uniquely identified (for example by the manufacturer's name, the type, four or six conductor circuit or similar, and the serial number). For the torque transducer, the maximum working torque and the measuring end of the transducer should be indicated.

3.2 Application of the torque

The torque transducer and any associated mechanical coupling should be designed and assembled such that both clockwise and anti-clockwise torque can be applied without the significant influence of non-torsional forces, such as bending moments.

4 CALIBRATION OF THE TORQUE MEASURING DEVICE

4.1 General

4.1.1 Indicators

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

[2] The output indication will be in units depending on the design (e.g. N·m, mV/V, V, Hz, mm or others) or in arbitrary units (digits)

4.1.2 Overloading test

It is recommended that prior to the first calibration, the torque transducer, including its mechanical couplings, is subjected to two overload tests in the course of which the nominal torque is exceeded by 8% to 12% of the nominal torque and this value is maintained for 1 to 1,5 minutes.

This should exclude unexpected failure of the torque transducer during application of the calibration load, for example by fracture, resulting in consequential damage to the calibration facility.

4.2 Resolution of the indicating device

4.2.1 Analogue scale

The thickness of the graduation marks on the scale should be uniform, and the width of the pointer should be approximately equal to the width of a graduation mark: the resolution r of the indicator shall be obtained from the ratio of the width of the pointer to the centre-to-centre distance between adjacent scale marks (scale spacing) - recommended ratios are 1/2, 1/5 or 1/10 : spacings not smaller than 1,25 mm are required to estimate a tenth of the scale division.

4.2.2 Digital scale

The resolution *r* is considered to be one increment of the least significant active digit of the numerical indicating device, provided that the indication does not fluctuate by more than one increment when the instrument is unloaded.

4.2.3 Fluctuation of readings

If the reading (with the instrument unloaded) fluctuates by more than the value previously determined for the resolution, the resolution should be deemed to be equal to half the range of fluctuation.

4.2.4 Resolution

The resolution *r* shall be converted to units of torque using the sensitivity factor *S* at M_E , the maximum torque value of the measuring range.

4.2.5 Minimum value of the measuring range

Taking into consideration the resolution *r* with which the indicator can be read, the minimum torque M_A (minimum value of the measuring range) applied to a torque measuring device should be not less than 0,02 M_E (2% of the maximum torque value of the measuring range); see also table C.1.

4.3 Preparation of the calibration

4.3.1 Indicating device

The indicating device should be adjusted according to the manufacturer's instructions and in accordance with the customer's specifications. Prior to the calibration, it is recommended that the indicating device is subject to a check to ensure it functions correctly and will not invalidate the calibration. All adjustments and, where appropriate, corresponding setting values should be recorded before and after the calibration.

4.3.2 Temperature stabilisation

Prior to calibrating the torque measuring device, it should be stored with the supply power applied in the calibration environment for sufficient time for its temperature to stabilise.

4.3.3 Transducer zero signal

Prior to the installation of the transducer into the calibration equipment, the zero signal of the mechanically unloaded torque transducer should be measured in a specified (vertical) position and recorded.

4.3.4 Mounting of transducer

Failure to apply the calibration torque at the shaft end position stated by the manufacturer, or specified by the customer, may lead to erroneous measurements. The mounting position should be identified.

4.4 Calibration procedure

The calibration can be carried out for clockwise and/or anti-clockwise torque. For the purpose of this guideline, the calibration of torque transducers should be carried out as a static procedure by measuring discrete approximately equally spaced torque values (typical of calibration facilities with lever-mass systems).

4.4.1 Preloading

After installation into the calibration equipment, the torque transducer should be preloaded three times in the direction to be calibrated, applying the maximum torque value M_E of the measuring range of the device, and additionally once after each change of the mounting position. The duration of the application of preload should be approximately 30 seconds. After each preload has been removed for approximately 30 seconds, the indicator reading should be recorded.

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

4.4.2 Mounting position

The torque transducer should preferably be calibrated in three different mounting positions with the transducer or its mechanical coupling part rotated each time through 120° about the measurement axis. Four relative mounting positions can be used for a square drive (see Annex D).

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

4.4.3 Range of calibration

The recommended number of calibration steps should be a minimum of 5 approximately equally spaced from 20% to 100 % of M_E.

For the calculation of a fitting curve, a minimum of 5 steps must be taken.

When calibration points below 20% of M_E are required, calibration steps of 10%, 5%, 2% of M_E should be used.

4.4.4 Loading conditions

The time interval between two successive calibration steps should, if possible, be similar. Recording the measured value may take place only after the indication has stabilised. Indication drift due to creep requires that the time sequence be maintained.

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

4.4.5 Indicated value

The indicated value is defined as the difference between an indication in loaded condition and an indication in unloaded condition. The indication at the beginning of each measurement series should be zeroed, or taken into account by computation during the evaluation following the measurement.

> NOTE: Recording of non-zeroed values provides additional information about the zero signal behaviour.

For torque measuring devices with defined scale (indication in the unit of torque), the indication should be zeroed at the beginning of each measurement series.

4.4.6 Evaluation of the torque measuring device: Calibration result (Annex E - Worked example of calibration sequence and interpolation of data)

4.4.6.1 Determination of the sensitivity S

The sensitivity S shall be calculated according to the following equation:

$$S = \frac{\overline{X}_E}{M_E} \qquad (1)$$

4.4.6.2 Determination of mean value $\overline{X}$

The mean value $\overline{X}$ for each torque step shall be calculated according to equation (2) as the mean value of the measurement results obtained in the increasing series in changed mounting positions:

$$\overline{X} = \frac{1}{n}\sum_{j=1}^{n}\left(I_j - I_{j,0}\right) \tag{2}$$

Where:

j index of selected series
n number of increasing series in different mounting positions

NOTE: The values measured in the 0° position in the second series at increasing torque are not included in the calculation of $\overline{X}$.

4.4.6.3 Determination of repeatability *b'*

The repeatability in unchanged mounting position (*b'*) shall be calculated for each torque step according to the following equation:

$$b' = \left|X_1 - X_2\right| \tag{3}$$

Where:

X_1 and X_2 are the values measured in unchanged position.

4.4.6.4 Determination of reproducibility *b*

The reproducibility in changed mounting position *b* shall be calculated for each torque step according to the following equation:

$$b = \sqrt{\frac{\sum_{j=1}^{n}\left(X_j - \overline{X}\right)^2}{n-1}} \tag{4}$$

Where:

n number of increasing series in different mounting positions

NOTE: For the 0° position, the second series at increasing torque is not included in the calculation of *b*.

4.4.6.5 Determination of residual value f_0 at zero torque

The zero value shall be recorded prior to and after each measurement series. The zero value shall be read approximately 30 seconds after complete unloading. The residual value of the zero signal shall be calculated according to equation (5):

$$f_0 = \max\left|I_f - I_0\right| \tag{5}$$

4.4.6.6 Determination of reversibility h

The reversibility shall be determined according to equation (6) as the mean of the absolute values of the differences between the values indicated for the series of increasing and decreasing torque series for each torque step:

$$h = \frac{1}{k}\sum_{j=1}^{k}\left|I_j - I'_j\right| \tag{6}$$

Where:

k number of torque series

NOTE: In this section a series is defined as increasing and decreasing torque.

4.4.6.7 Determination of the deviation of indication from the fitting curve f_a

The deviation from the fitting curve shall be determined for each torque step for the indication as a function of the torque using an equation of the 1st, 2nd or 3rd degree without absolute term. The equation used shall be stated in the calibration certificate.

The equation shall be calculated as the least squares fit.

The deviation from the fitting curve shall be calculated from the following equation (7).

$$f_a = \left(\overline{X} - X_a\right) \tag{7}$$

NOTE: An alternate method consists to calculate the fitting curve and the associated standard uncertainty (u_{fa}) using the orthogonal polynomial method (Forsythe's algorithm). If this approach is adopted, it should be stated in the certificate.

4.4.6.8 Determination of the deviation of indication f_q

The deviation of indication shall be determined only for such torque measuring devices where the measured value is directly indicated in the unit of torque and the indicated value is not fitted. It shall be determined from the mean value of the increasing series in changed mounting positions, equation (8):

$$f_q = \left(\overline{X} - M_k\right) \tag{8}$$

5 DETERMINATION OF THE STANDARD UNCERTAINTY OF MEASUREMENT FOR INCREASING TORQUE

5.01 The following statements are intended to serve as an example for the calculation of the uncertainty of measurement of a uniform calibration, described in this guide. According to the application of the measuring instrument to be calibrated, it may be useful to deviate from this example or to add further uncertainty components. In such cases, the calculation must be documented.

5.02 The calibration of the torque measuring device is carried out by comparison, using a torque calibration machine with known torque steps, or calibration equipment with a torque reference transducer.

5.03 The calibration result is the output signal of the torque measuring device and is obtained from the approximate model (9):

$$\overline{X} = (S + \delta S_{b'} + \delta S_b + \delta S_{fa}) M_{\mathrm{k}} + \delta X_r \tag{9}$$

where:

M_{k} - torque generated by the torque calibration machine with an associated uncertainty $u(M_{\mathrm{k}}) = u_{\mathrm{tcm}}$

$\delta S_{b'}$ - repeatability with an associated uncertainty $u(\delta S_{b'}) = \dfrac{S}{M_{\mathrm{k}}} u_{b'}$

δS_b - reproducibility with an associated uncertainty $u(\delta S_b) = \dfrac{S}{M_{\mathrm{k}}} u_b$

δS_{fa} - deviation resulting from the fitting curve with an associated uncertainty $u(\delta S_{fa}) = \dfrac{S}{M_{\mathrm{k}}} u_{fa}$

δX_r - observed influence due to instrument resolution with an associated uncertainty $u(\delta X_r) = S \cdot u_r \sqrt{2}$ (two readings for one value indicated)

5.04 The standard uncertainty $u(\overline{X})$ expressed in units of indication and the relative standard uncertainty $w(\overline{X})$ are obtained by the law of propagation of uncertainty in the approximation of non-correlated variables:

$$u(\overline{X}) = \sqrt{\sum_{i=1}^{5} \left(\frac{\partial \overline{X}}{\partial x_i} \right)^2 u^2(x_i)} \tag{10}$$

$$w(\overline{X}) = \frac{u(\overline{X})}{\overline{X}} \cdot 100 \tag{10a}$$

with

$$u^2(\overline{X}) = S^2 \left(u_{\mathrm{tcm}}^2 + u_{b'}^2 + u_b^2 + 2u_r^2 + u_{fa}^2 \right) \tag{11}$$

$$w^2(\overline{X}) = \left(w_{\mathrm{tcm}}^2 + w_{b'}^2 + w_b^2 + 2w_r^2 + w_{fa}^2 \right) \tag{11a}$$

5.05 The example furnishes information on the uncertainty of measurement at the time of calibration. It does not allow for the uncertainty of components' long-term stability, or the influence of angular velocity and/or the effects of mechanical couplings used in practice, for example.

Table 2: Uncertainty budget - increasing torque only

Quantity	evaluation of standard uncertainty	standard uncertainty in N·m	relative standard uncertainty in %
Repeatability in unchanged mounting position *b'*	type A	$u_{b'} = \frac{b'}{S\sqrt{2}}$	$w_{b'} = \frac{b'}{\sqrt{2}} \cdot \frac{100}{\overline{X}}$
Reproducibility in different mounting positions *b*	type A	$u_b = \frac{b}{S\sqrt{n}}$	$w_b = \frac{b}{\sqrt{n}} \cdot \frac{100}{\overline{X}}$
Deviation resulting from fitting curve f_a	type B with triangular distribution	$u_{fa} = \frac{\lvert f_a \rvert}{S\sqrt{6}}$	$w_{fa} = \frac{\lvert f_a \rvert}{\sqrt{6}} \cdot \frac{100}{X_a}$
Resolution *r*	type B with rectangular distribution	$u_r = \frac{r}{\sqrt{12}}$	$w_r = \frac{r}{\sqrt{12}} \cdot \frac{100}{M_k}$
Reference torque	type B	u_{tcm}	w_{tcm}

NOTE: For u_{fa}, see also note chapter 4.4.6.

5.1 Calibration of devices with undefined scale

The expanded uncertainty of measurement U for each calibration step is calculated from the uncertainty of measurement, equation (10), according to equation (12). The expanded relative uncertainty of measurement W for each calibration step is calculated from the uncertainty of measurement, equation (11a), according to equation (12a). The coverage factor k=2 applies in both cases.

$$U = k \cdot u(\overline{X}) \qquad (12)$$

$$W = k \cdot w(\overline{X}) \qquad (12a)$$

5.2 Calibration of devices with a non-adjustable defined scale or where a straight line fit only, can be applied.

5.21 An exceptional case is where the indicator of the torque measuring device is non-adjustable, or has the capability only of fitting a straight line to the data. The values determined for f_q or f_a are treated as systematic errors whose moduli represent a non-dominant part of the uncertainty. In these cases the expanded uncertainty statement at the desired coverage probability of 95% (cf. Ref. No. 3) can only be obtained by equations (16) and (16a), a procedure described in F.2.4.5 of the *Guide to the Expression of Uncertainty in Measurement* (cf. Ref. No. 4).

5.22 The standard uncertainty $u(\overline{X})$ expressed in units of indication and the relative standard uncertainty $w(\overline{X})$ of the random variables is calculated for each calibration step:

$$u(\overline{X}) = S\sqrt{u_{\mathrm{tcm}}^2 + u_{b'}^2 + u_b^2 + 2u_r^2} \qquad (13)$$

$$w(\overline{X}) = \sqrt{w_{\mathrm{tcm}}^2 + w_{b'}^2 + w_b^2 + 2w_r^2} \qquad (13a)$$

The appropriate formulae for the straight line fit are:

$$u_c(\overline{X}) = \sqrt{\left(\frac{f_a}{S}\right)^2 + u^2(\overline{X})} \qquad (14)$$

$$w_c(\overline{X}) = \sqrt{\left(\frac{f_a}{\overline{X}}\right)^2 + w^2(\overline{X})} \qquad (14a)$$

f_a - is the deviation from the straight line fit

The appropriate formulae for the defined scale are:

$$u_c(\overline{X}) = \sqrt{\left(\frac{f_q}{S}\right)^2 + u^2(\overline{X})} \qquad (15)$$

$$w_c(\overline{X}) = \sqrt{\left(\frac{f_q}{\overline{X}}\right)^2 + w^2(\overline{X})} \qquad (15a)$$

5.23 The expanded uncertainty of measurement U or the expanded relative uncertainty of measurement W for each calibration step is calculated from the combined uncertainty of measurement, using equation (16 or 16a), with coverage factor k=2:

$$U = k \cdot u_{\mathrm{c}}(\overline{X}) \qquad (16)$$

$$W = k \cdot w_{\mathrm{c}}(\overline{X}) \qquad (16a)$$

6 CALIBRATION CERTIFICATE

6.1 Information to be included on the certificate in addition to that specified in EA-4/01

Where the calibration of a torque measuring device has satisfied the requirements of this guide, the calibration laboratory should draw up a certificate stating the following information, in addition to that shown in guide EA-4/01 (cf. Ref. No. 2).

a) Identify all the elements of the torque measuring device and its components, including mechanical coupling components to the calibration equipment;

b) The method used, identifying whether clockwise and/or anti-clockwise torque, incremental and/or decremental, together with reference to this guide;

c) The resolution of the torque measuring device;

d) The temperature at which the calibration was performed;

e) A statement on the expanded uncertainty of measurement and the equation of the fitting curve where applicable;

f) Where required, a statement regarding the conformity of the calibration results to a particular classification at the criteria used, for example, see Table C.1.

6.2 Re-calibration after damage

The torque measuring device shall be recalibrated when it has been subjected to an overload higher than that applied in the overloading test (cf. § 4.1.2), after repair or after inexpert handling, which may have an effect on the uncertainty of measurement.

7 LIST OF REFERENCES

Dated references; modifications or revisions to these publications made at a later date are part of this guide only if they have been incorporated.

1 *International Vocabulary of Basic and General Terms in Metrology*, second edition, 1993, International Organisation for Standardisation (Geneva, Switzerland).

2 EA-4/01: *Requirements Concerning Certificates Issued by Accredited Calibration Laboratories*, edition 1, November 1995.

3 EA-4/02: *Expression of the Uncertainty of Measurement in Calibration,* edition 1, April 1997

4 *Guide to the Expression of Uncertainty in Measurement*, first edition, 1993, corrected and reprinted 1995, International Organisation for Standardisation (Geneva, Switzerland).

APPENDIX A

Recommendation for use of calibrated torque measuring devices

The calibration is valid only for applications in which the torque measuring device is used in accordance with the conditions in 4.1 to 4.3. Precautions should be taken to prevent the device from being subjected to torque greater than the nominal torque; from being loaded with extraneous forces due to unsuitable coupling components.

The calibration, and hence the classification of a torque measuring device whose indication was evaluated as allowing no interpolation, shall be exclusively valid for the discrete values selected. If such an instrument is used at intermediate values, it should be borne in mind that the uncertainty of measurement may be greater than that corresponding to its classification and that the assignment to the class will be invalid.

If a torque measuring device is used at a temperature deviating from the calibration temperature as defined in sections 4.3.2 and 4.4.5, the resulting additional uncertainty of measurement shall be calculated from the data provided by the manufacturer.

APPENDIX B

Example of dimensions of torque transducers including couplings for their adaptation to torque calibration facilities

In view of the great variety of designs of torque measuring devices and of the types of torsionally rigid couplings recommended for them, the table below offers the calibration laboratories the possibility of substantially reducing the large number of adapters. The proposal allows a design with cylindrical shaft ends, with hubs and as a shaft/hub combination (in each case without feather key and keyway) with shaft frictional clamped couples.

Table B.1

Nominal torque M_{nom} N·m	Shaft diameter D_s mm	Shaft length L_s mm	Hub diameter d_h mm	Hub length L_h mm
≤20	15_{h7}	≥40	19^{H7}	≥25
>20 to 100	20_{h7}	≥45	25^{H7}	≥30
>100 to 500	30_{h7}	≥60	38^{H7}	≥40
>500 to 2000	50_{h7}	≥80	65^{H7}	≥60
>2000 to 5000	70_{h7}	≥110	90^{H7}	≥85
>5000 to 20000	110_{h7}	≥115	155^{H7}	≥100

If the design with a hub is selected, depending on the material used, the minimum wall thickness shall be according to the table B.2 below (D_h - outside hub diameter)

Table B.2

Material	Steel	Grey cast iron	Aluminium
D_h/d_h	1,5	2,0	2,5

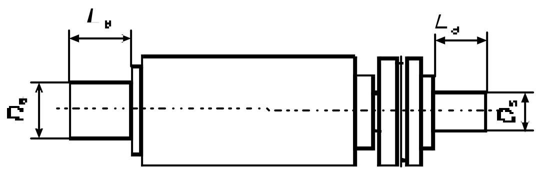

Fig. B.1

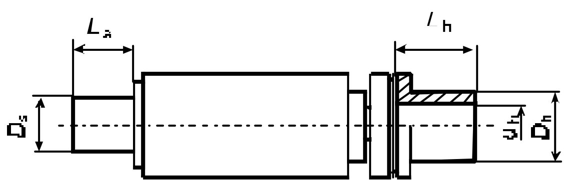

Fig. B.2

APPENDIX C

Classification of the torque measuring device

C.1 Principle of classification

The range for which the torque measuring device is classified shall be determined by considering each calibration torque one after the other, starting with the maximum torque and decreasing from this to the minimum torque. The classification range ceases at the last torque for which the classification requirements in C.2 are satisfied.

C.2 Classification criteria

C.2.1 For the classification, the minimum value of the measuring range M_A shall be

- 20 % of M_E, alternatively
- 40 % of M_E for the classes 0,05 and 0,1.

C.2.2 For the instruments classified for interpolation, the following criteria shall be taken into consideration:

- relative repeatability in unchanged mounting position,
- relative reproducibility in different mounting positions,
- relative deviation of indication or of fitting curve,
- relative residual value at zero torque,
- relative reversibility when increasing and decreasing torque is applied,
- resolution of the indicating device by at the minimum value of the measuring range M_A.

C.2.3 Table C.1 states the values of these different parameters for the torque measuring device class and the respective expanded relatively uncertainty required for calibration torque.

Table C.1 Classification criteria for torque measuring devices

class	Maximum permissible error of the torque measuring device in %					min. value of torque	Calibration torque M_k
	relative repeat-ability $\frac{b'}{\overline{\overline{X}}}$	relative reprodu-cibility $\frac{b}{\overline{\overline{X}}}$	Relative residual value at zero torque $\frac{f_0}{\overline{\overline{X}}_E}$	relative reversibility $\frac{h}{\overline{\overline{X}}}$	relative dev. of indication or of fitting curve $\frac{f_q}{\overline{\overline{X}}}$, $\frac{f_a}{\overline{\overline{X}}}$	M_A	expanded rel. uncertainty of measurement in % $W_{tcm} = k \cdot w_{tcm}$
0,05	0,025	0,050	0,0125	0,063	±0,025	≥4000 r	0,010
0,1	0,05	0,10	0,025	0,125	±0,05	≥2000 r	0,020
0,2	0,10	0,20	0,050	0,250	±0,10	≥1000 r	0,040
0,5	0,25	0,50	0,125	0,63	±0,25	≥400 r	0,10
1	0,5	1,0	0,25	1,25	±0,5	≥200 r	0,20
2	1,0	2,0	0,50	2,50	±1,0	≥100 r	0,40
5	2,5	5	1,25	6,25	±2,5	≥40 r	1,0

APPENDIX D

Examples of calibration sequences

The following sketch shows examples for the calibration of torque measuring devices.

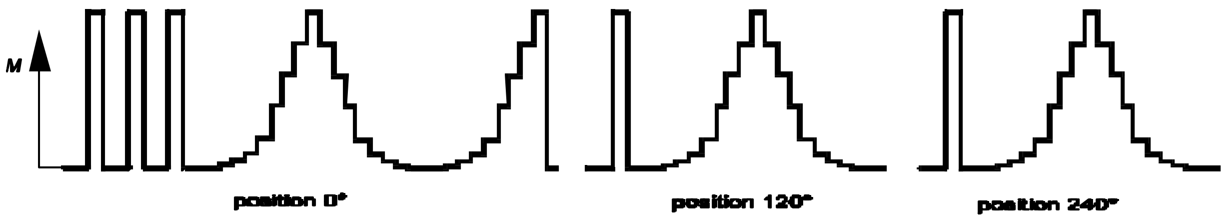

Fig. D.1: Example of preloadings and sequences for torque measuring devices with a minimum 8 steps and U<0,1%

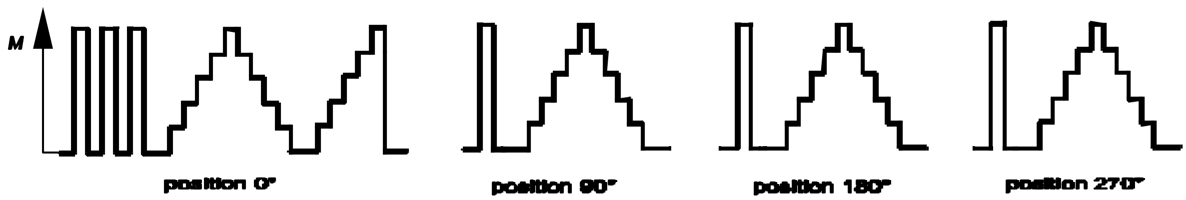

Fig. D.2: Example of preloadings and sequences for torque measuring devices with square drive, a minimum 5 steps and 0,1% =< U <1%

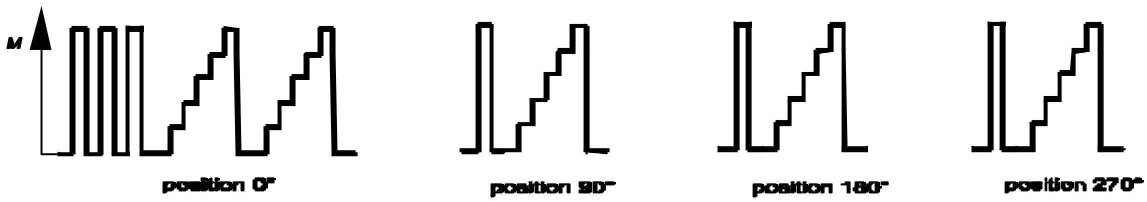

Fig. D.3: Example of preloadings and sequences for torque measuring devices with square drive, a minimum 5 steps, only increasing series and 0,1% =< U <1%

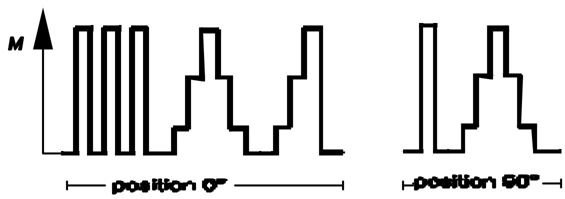

Fig. D.4: Example of preloadings and sequences for torque measuring devices with square drive, a minimum 3 steps and U>=1%

APPENDIX E

Worked example of calibration sequence and interpolation of data.

E.1 Calibration results for clockwise calibration of 50 N·m torque transducer with amplifier in mV/V (see example in annex D, fig. D.1)

M_E	unit	temperature in °C	output in	last significant digit in mV/V	W_{tcm} in %
50	N·m	21,8	mV/V	0,000002	0,002

Indication / in unchanged position

steps in %	steps in N·m	1. preload 0°	2. preload 0°	3. preload 0°	0° serie 1	0°/1 down	0° serie2
0	0	-0,015190	-0,015102	-0,015090	-0,015114	-0,015096	-0,015108
4	2				0,046278	0,046326	0,046292
8	4				0,107682	0,107746	0,107696
12	6				0,169090	0,169168	0,169104
20	10				0,291914	0,292014	0,291926
40	20				0,598976	0,599104	0,598992
60	30				0,906066	0,906186	0,906076
80	40				1,213174	1,213252	1,213184
100	50	1,520234	1,520252	1,520264	1,520292	1,520292	1,520304

Indication / in changed position

steps in %	steps in N·m	preload 120°	120°	120° down	preload 240°	240°	240° down
0	0	-0,015174	-0,015162	-0,015134	-0,014826	-0,014798	-0,014772
4	2		0,046242	0,046286		0,046600	0,046644
8	4		0,107648	0,107704		0,108008	0,108068
12	6		0,169054	0,169130		0,169420	0,169494
20	10		0,291874	0,291972		0,292232	0,292338
40	20		0,598938	0,599058		0,599300	0,599426
60	30		0,906024	0,906144		0,906388	0,906504
80	40		1,213130	1,213204		1,213494	1,213572
100	50	1,520192	1,520244	1,520244	1,520558	1,520616	1,520616

E.2 Determination of mean value and uncertainty

M_k in N·m	$\overline{X}$ in mV/V	expanded relative uncertainty W in %, k = 2 (3rd degree fitting curve)	expanded uncertainty U in mV/V, k = 2 (3rd degree fitting curve)
0	0,000000		
2	0,061398	0,023	0,000014
4	0,122804	0,012	0,000015
6	0,184213	0,008	0,000015
10	0,307031	0,004	0,000012
20	0,614096	0,003	0,000020
30	0,921184	0,002	0,000020
40	1,228291	0,002	0,000025
50	1,535409	0,002	0,000032

E.3 Determination of the sensitivity

$$S = \frac{\overline{X}_E}{M_E} \qquad S = 0{,}0307082\ \text{(mV/V)/N·m}$$

E.4 Determination of repeatability *b'*, reproducibility *b*, residual value f_0 at zero torque, reversibility *h*, deviation of indication from the fitting curve f_a, resolution *r*

M_k N·m	$\frac{b'}{\overline{X}}$ %	$\frac{b}{\overline{X}}$ %	$\frac{f_0}{\overline{X}_E}$ %	$\frac{h}{\overline{X}}$ %	$\frac{f_a}{\overline{X}}$ (3rd degree) %	$\frac{r}{M_k}$ %
0			0,0018			
2	0,0130	0,0098		0,0738	-0,0077	0,00326
4	0,0065	0,0059		0,0489	-0,0026	0,00163
6	0,0043	0,0041		0,0413	-0,0003	0,00109
10	0,0020	0,0014		0,0330	0,0006	0,00065
20	0,0016	0,0009		0,0203	0,0003	0,00033
30	0,0004	0,0004		0,0129	0,0000	0,00022
40	0,0003	0,0002		0,0062	-0,0001	0,00016
50	0,0004	0,0003		0,0000	0,0000	0,00013

E.5 Determination of the 3rd degree fitting curve

$$X_a = 3{,}0700937 \cdot 10^{-2} \cdot M + 2{,}1724 \cdot 10^{-7} \cdot M^2 - 1{,}4552 \cdot 10^{-9} \cdot M^3$$

$$M_a = 32{,}572295 \cdot X - 7{,}504 \cdot 10^{-3} \cdot X^2 + 1{,}6374 \cdot 10^{-3} \cdot X^3$$

E.6 Classification of the torque measuring device:

class 0,05 in the range 4 N·m to 50 N·m
class 0,1 in the range 2 N·m to 50 N·m