The Calibration of Torque Measuring Devices to British Standard BS 7882:2008.

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Abstract – The history of the standard is outlined, with comment on the relevance for calibration laboratories and end users of torque devices.

Application of the standard is demonstrated with a reference to an unsupported beam and masses and example certificates of calibration are included.

Preloading requirements are explained, followed by three series of torque application, with rotation of the device between the second and third series; or five series of torque application, with rotation of the device between the second, third, forth and fifth series. The classification of the device from the calibration data is then demonstrated.

The calculation of uncertainties associated with the calibration is explained and includes assessment of the likely causes of uncertainty; their potential magnitude; and the type of distribution associated with each element. The combination of each uncertainty into the final expanded uncertainty is then demonstrated by the use of example uncertainty budgets.

Introduction

BS 7882:2008 [1] "Method for the calibration and classification of Torque Measuring Devices" describes the method of calibration, calculation of the results, calculation of uncertainties, and the classification of torque measuring devices in a static mode. Its predecessor BS 7882:1997 was the first standard of this type to be published and evolved from the need for accredited calibration laboratories to determine the results of torque measurements in a similar manner. Prior to 1997 UKAS accredited laboratories worked to approved 'in-house methods'. Current best practice has been incorporated into this revision which provides a practical solution for the calibration of torque measuring devices including the technical requirements needed for high accuracy classes without making the calibration too time consuming to perform and hence commercially unacceptable.

This standard is important for calibration laboratories, manufacturers and end users alike because it provides an agreed method of calibrating and evaluating torque measuring devices.

There is a German standard DIN 51309:2005 [2] which was first published in 1998; an EA (European co-operation for Accreditation) reference publication [3] which is a non mandatory

document based on DIN 51309 and a Chinese calibration standard JJG 995:2005 [4]. Other countries are also known to be developing their own standards and currently there is a British standard BS 7996 [5] being written for continuous calibration of torque measuring devices.
A static calibration performed to the DIN standard is more involved than one to BS 7882:2008 and is therefore more expensive.

There is currently no European or International standard.

BS 7882:2008 uses a classification system to differentiate between devices of different accuracy and allows for the classification of devices into one of 7 classes. The classification is determined from the results of the calibration.

The torque measuring device is defined as all parts of a system e.g. electrical, mechanical, hydraulic, or optical torque transducer with associated indicator and cables.

The applied reference torque may be generated by a supported or unsupported length calibrated beam and calibrated masses or alternatively a reference torque measuring device may be used.

The standard allows for calibrations to be performed on analogue or digital devices in torque units (N·m, lbf·ft., lbf·ins) or voltage output (V, mV/V); in incremental and decrement modes and the use of a replacement indicator is allowed providing certain criteria are complied with.

General requirements

The minimum range of measurement over which a classification may be awarded is from 20% to 100% of maximum torque. A secondary classification over an extended range may also be given and if calibration is required below 20% then torque steps of 10%, 5%, and 2% of maximum torque may be used providing they are greater than the calculated lower limit of the calibration range.

The lower limit of calibration (T_{min}) is determined from the resolution (r) of the device and is calculated as follows. The resolution is expressed in the SI unit of torque (N·m).

$(T_{min}) = a \times r$

a has the following values:

- 4000 for a class 0.05 torque measuring device.
- 2000 for a class 0.1 torque measuring device
- 1000 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.

For a digital device the resolution (r) is considered to be one increment of count. If the reading fluctuates (with no torque applied to the instrument) more than this the resolution is determined as one half of the range of fluctuation.

For an analogue device the resolution (r) is determined from the ratio between the width of the pointer and the centre to centre distance of the scale interval. The ratios should be 1/2, 1/5, or 1/10.

Assuming a 100 N·m. device has a resolution of 100.00, one digit of count is 0.01.

The primary classification range is 20 N·m to 100 N·m

(T_{min}) = 0.01 x 2000 = 20 N·m

This shows that there is sufficient resolution to award a class 0.1 classification. Should a secondary classification range of 2 N·m to 100 N·m also be required.

(T_{min}) = 0.01 x 200 = 2 N·m

Therefore the secondary classification is limited to Class 1.0 at best.

If in the above example the resolution is reduced to 100.0 the best primary classification that can be awarded is Class 1.0 and a secondary classification down to 2 N·m is not possible, the lowest classifiable step is 5.0 N·m. which could be awarded a classification of Class 5.0.

Additionally in order to award a particular classification the uncertainty of measurement of the applied torque must be five times better than the overall class reported. Ref: Table 1.

Table 1. Uncertainty of calibration torques

Class of torque measuring device to be calibrated	Maximum permissible uncertainty of calibration torque applied [1)] %
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

[1)] Using a coverage factor of k = 2 to give a confidence level of approximately 95%.

Temperature considerations

The calibration is performed at an ambient temperature within the range 18°C to 28°C and the temperature shall not vary by more than ± 1°C throughout a measurement series.

All torque measuring devices and associated components of the torque measurement system, and all parts of the calibrating equipment shall be allowed to stabilise at the above temperature prior to calibration.

Electrical torque measuring devices and associated components shall be switched on and allowed to warm-up for the period stated by the manufacture. In absence of any recommendation the system shall be energised for at least 15 minutes.

Preload and Calibration procedure

The torque measuring device is set up in an appropriate mounting so that it can, were possible be rotated about its axis between each series of torques. Where it is not possible to rotate the device, it must be physically disconnected and removed from the Calibration Beam and then reconnected. In setting up the device there should be no misalignment of the calibrating beam or reference torque device which could exert a bias within the set up.

(Unsupported Calibration Beams have advantages in this respect; they are primarily self aligning and are usually coupled directly to the device under calibration which maximises the transfer of torque. They do not exert side loads and cause a possible loss of torque that may be present when using a Bearing Supported Beam and unsuitable couplings. However they do induce bending effects [6] into the device and this should be considered as part of the uncertainty budget. A torque transducers susceptibility to bending can be calculated as given in the NPL good practice guide No. 107 "Guide to the calibration and testing of torque transducers "[7].
Unsupported Calibration Beams are flexible and easy to use and in many instances replicate the way the torque measuring device is subsequently used. This makes them well suited for calibration of devices from 0.05 N·m – 1500 N·m, their use being inappropriate only if the device under calibration exhibits a high susceptibility to bending effects.)

For Classes 0.05 and 0.1, it is mandatory to calibrate the torque measuring device in four different mounting positions (for transducers with square drives) each rotated 90º about the measurement axis (See figure 1). For all other classes the device is calibrated at a minimum of two different mounting position at least 90º apart (See figure 2). Where it is not possible to rotate the device, it can be physically disconnected and removed from the Calibration Beam and then reconnected.

Before any calibration or recalibration the torque measuring device is preloaded three times in succession to the maximum applied torque of the device. Each preload and any subsequent preload are maintained for 1 to 1.5 minutes.

The torque measuring device is then calibrated with a series of at least five approximately equal steps from 20% to 100% of maximum torque, (if calibration is required below 20% then steps of 10%, 5% and 2% may also be used providing they are greater than the lower limit of the calibration range).

Two series of increasing torques are applied to the device and readings taken; the device is then disturbed, generally by being disconnected from the calibration fixture and rotated through 90°. The device is then preloaded once to full scale. The third series of increasing torques is then applied and readings taken. This process is repeated until torques have been applied in all required orientations.

If reversibility is required, a single series of decreasing torques are applied at the end of the last increasing series.

Readings are taken no less than 30 seconds after each application or removal of a torque.

Should calibration be required for both clockwise and anti-clockwise torques, the series of torques are repeated in the opposite direction.

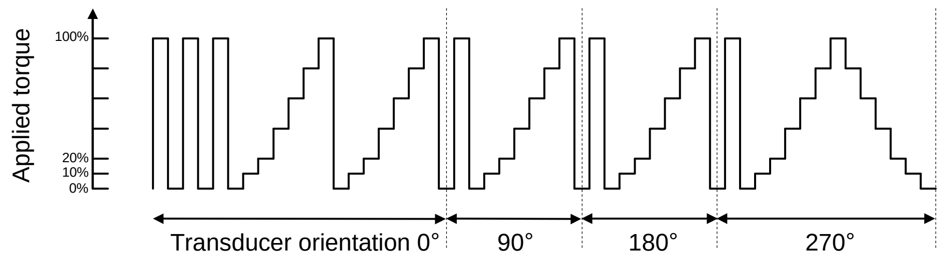


Figure 1: Example of preloading and calibration sequences for a torque transducer with square drives, six increasing and decreasing torques, classes **0.05** to **5.0**.

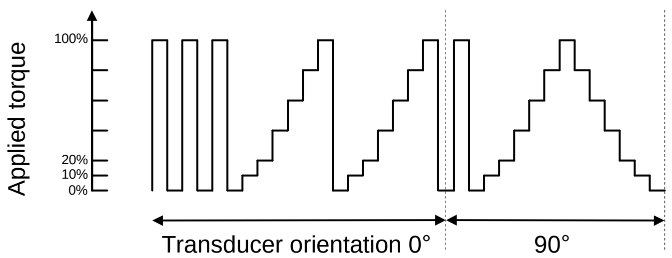


Figure 2: Example of preloading and calibration sequences for a torque transducer, six increasing and decreasing torques, classes **0.2** to **5.0**.

Calculation of results

The calibration data is then analysed to establish the following parameters which are appropriate to the calibration.

Repeatability; reproducibility; error of Indication; residual deflection; error of Interpolation and reversibility.

The parameters are each compared with a table to establish the devices classification. Class 0.05 is the highest performance, and class 5 is the lowest defined by the standard. The overall class reported will be that of the lowest performing parameter. For example reproducibility may be a class 1 when all other parameters meet class 0.5. The device will be classified as a class 1.

Summary of a transducer calibration and classification to BS 7882:2008

Assuming a transducer is to be calibrated in a clockwise direction with increasing torques only, a brief summary of the calibration procedure to BS 7882:2008 would be as follows.

a. Preload, three applications of torque at 100% of full scale.

b. Apply 2 series of increasing torque in at least five approximately equally spaced intervals. (Normally between 20% to 100% of maximum torque)..

c. Disturb the transducer and alter its mounting position (turn through 90° if possible).

d. Preload to maximum torque

e. Apply a 3rd series of increasing torques.

f. Repeat c, d and e above until calibration at all orientations is complete.

From the results the parameters in Table 2 are calculated and a classification for the device is established.

Classification shall be deemed to have been met if all of the appropriate parameters for that class have been complied with over a given measurement range.

Classification ceases to apply at the first calibration torque where the limit for a parameter is exceeded. A secondary classification over an extended range may also be awarded.

An example might be as follows:

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	Maximum permissible values of the torque measuring device (%)					
	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

The parameters are defined as follows:

Relative repeatability (R_1)

The closeness of the agreement between the results of successive measurements from the same applied torque, carried out under the same conditions of measurement. Repeatability (the difference between series 1and 2) is expressed as a percentage of the mean deflection for the first and second series of applied torque.

Relative reproducibility (R_2)

The closeness of the agreement between the results of successive measurements from the same applied torque, carried out under changed conditions of measurement. Reproducibility (the maximum difference between series 1, 2 and 3, or series 1, 2, 3, 4 and 5) is expressed as a percentage of the mean indicated deflection for the given torque.

Relative error of interpolation (E_{it})

The difference of the value of the mean deflection (in mV/V; Volts) for a given value of increasing torque and the corresponding calculated value of deflection for the given torque, obtained from a mathematically fitted curve. Expressed as a percentage of the computed deflection for the given torque.

Relative residual deflection (R_0)

The maximum residual deflection obtained from all the series of torques. Expressed as a percentage of the mean indicated deflection for the maximum torque applied.

Relative reversibility (R_3)

The difference between the deflection obtained from the last given torque series applied in an increasing mode and the deflection obtained for the same given torque applied in a decreasing mode. Reversibility is expressed as a percentage of the deflection of the last series for the given torque, applied in an increasing mode.

Relative error of Indication (E_i)

Where the unit of display of the indicator is in units of torque, the error of indication is the mean indicated deflection for a given increasing torque minus the corresponding value of applied torque. The error is expressed as a percentage of applied torque.

Calibration certificate

When the torque measuring device has been calibrated and classified a certificate of calibration is issued, example certificates for a transducer calibrated in torque units and voltage ratio are given.

Frequency of calibration

BS 7882:2008 requires that “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.”

Benefits of a calibration to BS 7882:2008

1. A classification system is used to differentiate devices of different accuracy, the classification is determined from the results of the calibration. This provides for:

    a. Ease of use, once a device is classified the end user does not have to correct for reported errors, these are allowed for within the classification i.e. class 1 equates to an accuracy of ± 0.5% of reading over the classification range (20% - 100% of full scale).

    b. A way of comparing different manufacturer’s products without having to interpret ambiguous accuracy claims i.e. “Accuracy 1%”.

2. The classification allows for the devices ability to reproduce its results under different conditions of use, so providing the end user with more confidence about the measurement he is making.

3. Although it is always preferable to calibrate as a system the standard allows for devices to be calibrated independently of the indicator they are finally used with, providing that the indicators used have a valid Certificate of Calibration.

(Norbar is currently the only torque equipment manufacturer to offer UKAS accredited Certificates of Calibration for the display instrument, this provides full traceability of each element of the system. This means that any Norbar transducer can be used with any appropriate Display Instrument without affecting the validity of the transducer calibration, the only requirement being that the Display Instruments used are themselves in Calibration).

Note. If a replacement indicator is used the uncertainty for the transducer has to be recalculated allowing for the replacement indicator.

Summary of DIN 51309:2005

DIN 51309 uses the same classification system. Its scope is primarily intended to cover the calibration of torque measurement devices which have cylindrical shaft drives at each end of the device but it also recognises the use of square drives.

Similar to BS7882:2008 all classes require three preloads to 100% of full scale at the start of the calibration and one preload at the beginning of each subsequent series of torques.

It is mandatory that all classes of device have to be calibrated with a series of increasing and decreasing torques.

Classes 0.05 and 0.1 are restricted to transducers with cylindrical shaft drives and the standard requires 3½ series of measurements 120° apart.

Classes 0.2 and 0.5 requires 3½ series of measurements 120° apart or 4½ series of measurements with a 90° turn between each measurement series allowing the calibration of devices with square drives.

Classes 1, 2 and 5 require two series of readings with the devices being turned through 90° or 120°. However, this is inferior to BS 7882:2008, because less measurement points are taken and it does not allow all the parameters to be calculated.

Two types of calibration are allowed for within the standard and both are required to be reported on the calibration certificate; case 1 where the mean deflection value is calculated from the increasing torques only, reversibility is not included in the classification or the uncertainty calculation; and case 2 where the mean deflection value is calculated from the deflection of the increasing and decreasing series of torques, reversibility is included in the classification, and reversibility and error of indication are included in the uncertainty calculation.

The standard gives a comprehensive recommendation on the calculation of uncertainty but makes specific reference that it's only applicable where the torque is applied by a bearing supported beam or reference device.

Comparison between BS 7882:2008 and DIN 51309:2005

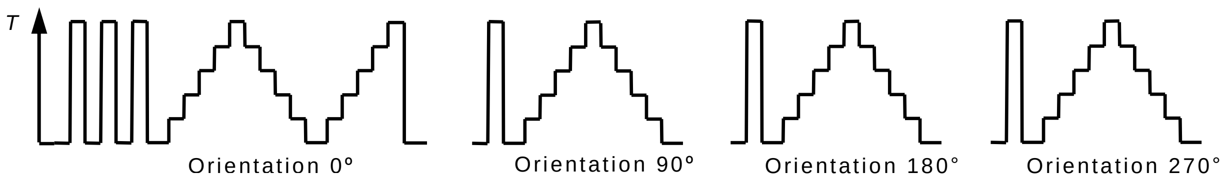
DIN 51309:2005 uses a classification system the same as BS 7882:2008. The main difference is that there is much more work involved in a calibration to DIN 51309, as all classes (0.05 – 5) of devices have to be calibrated with up to 4½ (for transducers with square drives) series of increasing and decreasing torques, irrespective of the intended use of the device, this can increases the calibration time by up to a factor of 3. The time taken to perform a calibration to BS 7882:2008 for a typical 100.00 N·m transducer is already 45 to 60 minutes therefore the increase is significant. Many users do not require a decreasing torque calibration and BS 7882:2008 allows the customer to specify if decreasing torques are required. Where they are required a single series of decreasing torques applied at the end of the last series of increasing torques enables the hysteresis of the device to be established; there is only a minimal difference between reversibility values calculated from a single series and those calculated from all four series. For classes 0.2 to 5.0 BS 7882:2008 requires only 3 series of measurements to be taken, for classes 0.2 and 0.5 the DIN standard requires 4½ series of increasing and decreasing measurements.

Only for the lower classes of accuracy (classes 1 – 5) will DIN 51309 allow two series of measurements, as the calibration engineer does not know what class the transducer may attain until the results have been taken, this is a potential problem. As less measurement points are taken it does not allow all the parameters to be calculated accurately. Repeatability is not established, only a reproducibility characteristic. Also as there are fewer measurement points it is not possible to fit a 2nd order equation to them only a linear fit is allowed.

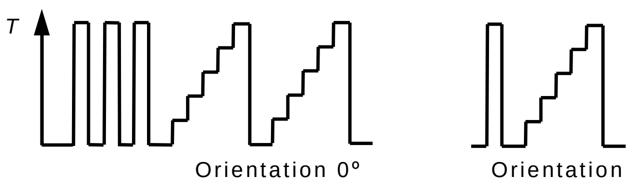
BS 7882:2008 is a practical solution for the calibration of all types of torque measuring devices and recognises for the higher classifications of 0.05 and 0.1 the need to calibrate the device symmetrically in four or three orientations, it also allows the use of unsupported calibration beams. With series 1 and 2 being performed in the same orientation repeatability can be calculated and with the third series turned through 90° reproducibility can be calculated, reversibility is established from a single series of decreasing torques – so obtaining valuable information with a minimum amount of work.

Uncertainties are covered in annex B of BS 7882:2008, they are treated in a comprehensive easy to understand way and work examples in both torque units and mV/V are given. The uncertainty calculation does not included the error of indication (as required by DIN 51309 case 2) for a calibration in torque units which can lead to large values being reported, this error is left to the end users discretion as to how they choose to account for it.

There are differences between the mean deflection values of a calibration performed to BS 7882:2008 and DIN 51309:2005 case 2 where the value is calculated from the increasing and decreasing torques.



Calibration series to DIN 51309



Calibration series to BS 7882:2008

Example Certificate of Calibration for a
Static Torque Measuring Device

1000 N·m max. capacity

Calibrated in torque units (N·m)

CERTIFICATE OF CALIBRATION

ISSUED BY NORBAR TORQUE TOOLS CALIBRATION LABORATORY No. 0256

DATE OF ISSUE : 17 July 2008 **CERTIFICATE NUMBER : 137335**

0256

Norbar Torque Tools

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APPROVED SIGNATORY
R. COCHRANE
M. HERBERT

CUSTOMER	: NORBAR TORQUE TOOLS LTD, CALIBRATION LABORATORY, BEAUMONT ROAD, BANBURY, OXON, OX16 1XJ.
DESCRIPTION OF DEVICE	: STATIC TRANSDUCER
MANUFACTURER	: Norbar Torque Tools Ltd.
DEVICE MODEL NUMBER	: 50597.LOG
MAXIMUM CAPACITY	: 1000.0 N·m
VOLTAGE OUTPUT	: 1.9844 mV/V at maximum capacity
DEVICE SERIAL NUMBER	: 47639
DATE OF CALIBRATION	: 10 JUL 2008
BASIS OF CALIBRATION	: BS 7882:2008
DISPLAY INSTRUMENT	: Norbar Torque Tool Tester Serial No. 47698 supplied by Norbar for the calibration only.
CABLE	: Connection cable Serial No. 48526 supplied by Norbar for the calibration only.

Classification

The torque measuring device satisfies the requirements of BS 7882:2008 for the following classification ranges:

Clockwise Torques (as left)

Class	0.1	from 1000.0 N·m	to 200.0 N·m
Class	0.2	from 1000.0 N·m	to 100.0 N·m

Calibration Method

The above torque measuring device has been statically calibrated by the application of known torques, which were generated by the application of masses, calibrated to produce forces, at the known radius of an unsupported length calibrated beam.

The torque measuring system was switched on and allowed to warm up for at least 15 minutes before commencing the calibration. The electrical output from the torque measuring device was measured and displayed in N·m, by the instrumentation (Serial Number : 47698) which is supported by a UKAS accredited certificate of calibration.

The torque measuring device was mounted in a suitable fixture which permitted the length beam drive to be engaged into the device and the device to be rotated in a clockwise direction about its principal measuring axis between the series of applied torques.

The torque measuring device was preloaded three times to its rated capacity and then five series of increasing torques, in a clockwise direction when viewed from the drive end, were applied to the torque measuring device and the indicated readings recorded. After the last series of increasing torques a single series of decreasing torques was applied and the indicated readings recorded. Between the second and third, third and fourth, and fourth and fifth series, the torque measuring device was disconnected from the calibrating beam and rotated through 90 degrees, then preloaded once to maximum torque before applying the next series of torques. The readings of zero torque before and after each application of the series of torques were recorded. The indicator output was tared to zero at the beginning of each series.

The calculations as described in clauses 5.1, 5.2, 5.3, 5.5, 5.6 and 5.7 of BS 7882:2008 were then made for the results.

NOTES

The calibration was performed at an ambient temperature within the range 20° Celsius ± 2° Celsius and did not fluctuate by more than ±1° Celsius during a measurement series.

The uncertainty of the applied torque is <= ± 0.02% k=2. The estimated uncertainty of the device under the conditions of calibration is inclusive of this value.

The indicated readings obtained in the loading series and the calculated parameters are given overleaf. The reported mean deflection values are rounded. The lower limit of calibration as required by clause 3.4 of BS 7882:2008 may cause the device to be classified outside the range of the calculated parameters.

A deflection of 1.9844mV/V is produced by the torque measuring device at its rated capacity. The indicated readings are inclusive of any voltage loading effects caused by the device and the connection cable. Connection cables Part No. 60217.200 may be interchanged with other cables of the same part number. The use of connection cables of other lengths or types than the one specified may affect the validity of the calibration.

Clause 7.2 of BS 7882:2008 requires that " 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 ".

When used with the display instrument detailed on page one or an equivalent unit, a classification of between 1.0 and 0.05, with an uncertainty of less than 0.7% will meet the requirement of clause 6.1 of BS EN ISO 6789:2003.

Where the display instrument is required to be replaced by an equivalent unit, the requirements of clause 3.2.3 of BS 7882:2008 shall be fully met to ensure that the calibration is not invalidated.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0256

CERTIFICATE NUMBER:
137335

Calibration Results

CLOCKWISE READINGS FOR THE DEVICE (as left : 10 JUL 2008)

Applied Torque N·m	0° Indicated Reading N·m Preload	0° Indicated Reading N·m Preload	0° Indicated Reading N·m Preload	0° Indicated Reading N·m Series 1	0° Indicated Reading N·m Series 2
0.0	0.0	1.3	1.3	0.0	0.0
100.0				100.0	100.0
200.0				200.0	199.9
400.0				400.0	399.9
600.0				600.0	599.9
800.0				800.0	800.0
1000.0	1001.2	1001.3	1001.3	1000.0	999.9
0.0	1.3	1.3	1.4	0.0	0.0

Applied Torque N·m	90° Indicated Reading N·m Preload	90° Indicated Reading N·m Series 3	180° Indicated Reading N·m Preload	180° Indicated Reading N·m Series 4
0.0	0.0	0.0	0.0	0.0
100.0		100.0		100.0
200.0		200.0		200.0
400.0		400.0		400.1
600.0		600.0		600.1
800.0		800.0		800.2
1000.0	1000.0	1000.0	1000.3	1000.3
0.0	0.0	0.0	0.0	0.0

Applied Torque N·m	270° Indicated Reading N·m Preload	270° Indicated Reading N·m Series 5	270° Indicated Reading N·m Down	Mean Indicated Deflection N·m
0.0	0.0	0.0	0.0	
100.0		100.1	100.2	100.0
200.0		200.1	200.3	200.0
400.0		400.1	400.5	400.1
600.0		600.2	600.5	600.1
800.0		800.3	800.5	800.1
1000.0	1000.4	1000.3	1000.3	1000.2
0.0	0.1			

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UKAS ACCREDITED CALIBRATION LABORATORY No. 0256

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Calibration Results

CALCULATED PARAMETERS FOR THE DEVICE (as left)

Applied Torque N·m	Relative Repeatability %	Relative Reproducibility %	Relative Reversibility %	Relative Residual Deflection %	Relative Error of Indication %
100.0	0.000	0.100	0.100		0.025
200.0	0.050	0.100	0.100		0.013
400.0	0.025	0.050	0.100		0.013
600.0	0.017	0.050	0.050		0.013
800.0	0.000	0.037	0.025		0.016
1000.0	0.010	0.040		0.000	0.015

MAXIMUM PERMISSIBLE ERROR FOR THE DEVICE

Class	Relative Repeatability %	Relative Reproducibility %	Relative Reversibility %	Relative Residual Deflection %	Relative Error of Indication %
0.10	0.05	0.10	0.125	±0.020	±0.05
0.20	0.10	0.20	0.250	±0.040	±0.10

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Expression of Uncertainties (as left)

The estimated expanded uncertainty of the torque measuring device under the conditions of calibration,

for increasing torques:

at 100.00 N·m	is ±0.17%	k = 2.0
at 200.00 N·m	is ±0.15%	k = 2.0
at 400.00 N·m	is ±0.14%	k = 2.0
at 600.00 N·m	is ±0.14%	k = 2.0
at 800.00 N·m	is ±0.13%	k = 2.0
at 1000.00 N·m	is ±0.13%	k = 2.0

for increasing and decreasing torques:

at 100.00 N·m	is ±0.18%	k = 2.0
at 200.00 N·m	is ±0.17%	k = 2.0
at 400.00 N·m	is ±0.15%	k = 2.0
at 600.00 N·m	is ±0.14%	k = 2.0
at 800.00 N·m	is ±0.14%	k = 2.0
at 1000.00 N·m	is ±0.13%	k = 2.0

Observations

The "as left" results are those taken after the device was adjusted in order to optimise its performance.

This device has been linearized using a 2nd degree polynomial equation; the coefficients are reported on certificate No. 137162.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

Example Certificate of Calibration for a
Static Torque Measuring Device

1000 N·m max. capacity

Calibrated in voltage ratio (mV/V)

CERTIFICATE OF CALIBRATION

ISSUED BY NORBAR TORQUE TOOLS CALIBRATION LABORATORY No. 0256

DATE OF ISSUE : 30 July 2008 **CERTIFICATE NUMBER : 135243**

0256

Norbar Torque Tools

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APPROVED SIGNATORY
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CUSTOMER	: NORBAR TORQUE TOOLS, CALIBRATION LABORATORY, BEAUMONT ROAD, BANBURY, OXON, OX16 1XJ.
DESCRIPTION OF DEVICE	: STATIC TRANSDUCER
MANUFACTURER	: Norbar Torque Tools Ltd.
DEVICE MODEL NUMBER	: 50597.IND
MAXIMUM CAPACITY	: 1000.0 N·m
VOLTAGE OUTPUT	: 1.9841 mV/V at maximum capacity
DEVICE SERIAL NUMBER	: 47639
DATE OF CALIBRATION	: 09 JUL 2008
BASIS OF CALIBRATION	: BS 7882:2008
CABLE	: Connection cable Serial No. 48526 supplied by Norbar for the calibration only.
VOLTAGE RATIO METER	: Thermo Nobel FTS3 Serial No. 11-1734 supplied by Norbar for the calibration only.

Classification

The torque measuring device satisfies the requirements of BS 7882:2008 for the following classification ranges:

Clockwise Torques (as found)

Class 0.2 from 1000.0 N·m to 100.0 N·m

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0256

CERTIFICATE NUMBER: 135243

Calibration Method

The above torque measuring device has been statically calibrated by the application of known torques, which were generated by the application of masses, calibrated to produce forces, at the known radius of an unsupported length calibrated beam.

The torque measuring system was switched on and allowed to warm up for at least 15 minutes before commencing the calibration. The torque measuring device was energised by a nominal voltage of 10V. Its output was measured by the voltage ratio meter and displayed as a ratio of the energisation and output voltages. The voltage ratio meter (serial no. 11-1734), is supported by a UKAS certificate of calibration.

The torque measuring device was mounted in a suitable fixture which permitted the length beam drive to be engaged into the device and the device to be rotated in a clockwise direction about its principal measuring axis between the series of applied torques.

The torque measuring device was preloaded three times to its rated capacity and then three series of increasing torques, in a clockwise direction when viewed from the drive end, were applied to the torque measuring device and the voltage readings recorded. Between the second and third series, the torque measuring device was disconnected from the calibrating beam and rotated through 90 degrees, then preloaded once to maximum torque before applying the third series. The readings of zero torque before and after each application of the series of torques were recorded.

The calculations as described in clauses 5.1, 5.2, 5.3, 5.4 and 5.5 of BS 7882:2008 were then made for the results.

NOTES

The calibration was performed at an ambient temperature within the range 20° Celsius ± 2° Celsius and did not fluctuate by more than ±1° Celsius during a measurement series.

The uncertainty of the applied torque is <= ± 0.02% k=2. The estimated uncertainty of the device under the conditions of calibration is inclusive of this value.

The indicated readings (mV/V) of the device are inclusive of any voltage loading effects caused by the device and the connection cable. Connection cables Part No. 60217.200 may be interchanged with other cables of the same part number. The use of connection cables of other lengths or types than the one specified may affect the validity of the calibration.

The indicated readings obtained in the loading series and the calculated parameters are given overleaf. The reported mean deflection values are rounded. The lower limit of calibration as required by clause 3.4 of BS 7882:2008 may cause the device to be classified outside the range of the calculated parameters.

The coefficients of a second degree polynomial equation relating the mean indicated deflection as a function of the applied calibration torques were calculated by the method of least squares. The coefficients of a second degree equation relating a given applied torque to the estimate of the mean indicated deflection were also calculated. The differences between the mean value of indicated deflection with rotation for each torque and the computed value by the equation were used to determine the relative interpolation error. The coefficients are given overleaf. The expected non-linearity errors of the device relative to the computed indicated deflection are also given.

Clause 7.2 of BS 7882:2008 requires that " 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 ".

When used with the voltage ratio meter detailed on page one or an equivalent unit, a classification of between 1.0 and 0.05, with an uncertainty of less than 0.7% will meet the requirements of clause 6.1 of BS EN ISO 6789:2003.

Where the voltage ratio meter is required to be replaced by an equivalent unit, the requirements of clause 3.2.3 of BS 7882:2008 shall be fully met to ensure that the calibration is not invalidated.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0256

CERTIFICATE NUMBER:
135243

Calibration Results

CLOCKWISE READINGS FOR THE DEVICE (as found : 09 JUL 2008)

Applied Torque N·m	0° Indicated Reading mV/V Preload	0° Indicated Reading mV/V Preload	0° Indicated Reading mV/V Preload	0° Indicated Reading mV/V Series 1	0° Indicated Reading mV/V Series 2
0.0	0.0064	0.0087	0.0088	0.0000	0.0000
100.0				0.1983	0.1983
200.0				0.3966	0.3966
400.0				0.7933	0.7933
600.0				1.1901	1.1902
800.0				1.5871	1.5871
1000.0	1.9928	1.9928	1.9928	1.9840	1.9840
0.0	0.0087	0.0088	0.0088	0.0000	0.0000

Applied Torque N·m	90° Indicated Reading mV/V Preload	90° Indicated Reading mV/V Series 3	Mean Indicated Deflection mV/V
0.0	0.0087	0.0000	
100.0		0.1983	0.1983
200.0		0.3966	0.3966
400.0		0.7933	0.7933
600.0		1.1902	1.1902
800.0		1.5872	1.5872
1000.0	1.9929	1.9841	1.9841
0.0	0.0088	0.0000	

CALCULATED PARAMETERS FOR THE DEVICE (as found)

Applied Torque N·m	Relative Repeatability %	Relative Reproducibility %	Relative Residual Deflection %	Relative Error of Interpolation %
100.0	0.000	0.000		0.002
200.0	0.000	0.000		-0.005
400.0	0.000	0.000		-0.005
600.0	-0.008	0.008		0.000
800.0	0.000	0.006		0.005
1000.0	0.000	0.005	0.000	-0.002

MAXIMUM PERMISSIBLE ERROR FOR THE DEVICE

Class	Relative Repeatability %	Relative Reproducibility %	Relative Residual Deflection %	Relative Error of Interpolation %
0.20	0.10	0.20	±0.040	±0.10

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CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0256

Coefficients (as found)

For a measured deflection 'D' (in mV/V) the applied torque 'T' (in N·m) is calculated from:

$$T = bD + cD^2$$

For a clockwise torque: b = 5.0432694E+002, c = -1.6021630E-001.

For a given applied torque 'T' (in N·m) the expected indicated deflection 'D' (in mV/V) is calculated from:

$$D = bT + cT^2$$

For a clockwise torque: b = 1.9828401E-003, c = 1.2512136E-009.

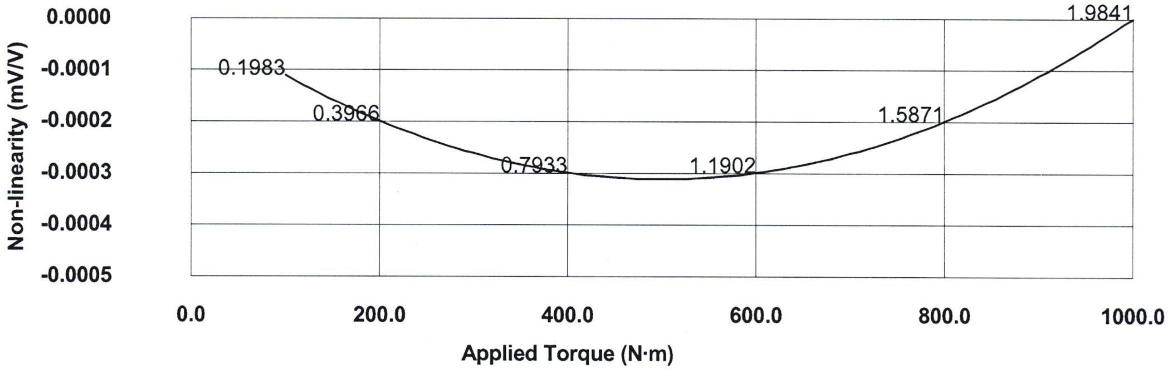
Deflection 'D' calculated from the above equation:

N·m	0.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
0.0	0.0000	0.0198	0.0397	0.0595	0.0793	0.0991	0.1190	0.1388	0.1586	0.1785
100.0	0.1983	0.2181	0.2380	0.2578	0.2776	0.2975	0.3173	0.3371	0.3570	0.3768
200.0	0.3966	0.4165	0.4363	0.4561	0.4760	0.4958	0.5156	0.5355	0.5553	0.5751
300.0	0.5950	0.6148	0.6346	0.6545	0.6743	0.6941	0.7140	0.7338	0.7537	0.7735
400.0	0.7933	0.8132	0.8330	0.8529	0.8727	0.8925	0.9124	0.9322	0.9521	0.9719
500.0	0.9917	1.0116	1.0314	1.0513	1.0711	1.0909	1.1108	1.1306	1.1505	1.1703
600.0	1.1902	1.2100	1.2298	1.2497	1.2695	1.2894	1.3092	1.3291	1.3489	1.3688
700.0	1.3886	1.4084	1.4283	1.4481	1.4680	1.4878	1.5077	1.5275	1.5474	1.5672
800.0	1.5871	1.6069	1.6268	1.6466	1.6665	1.6863	1.7062	1.7260	1.7459	1.7657
900.0	1.7856	1.8054	1.8253	1.8451	1.8650	1.8848	1.9047	1.9245	1.9444	1.9642
1000.0	1.9841									mV/V

Using the above deflection values 'D', the non-linearity errors of the device are:

N·m	100.0	200.0	400.0	600.0	800.0	1000.0
Non-linearity (% of reading)	-0.0568	-0.0504	-0.0378	-0.0252	-0.0126	0.0000

Non-linearity v. Applied Torque



The maximum non-linearity error of the device occurs at 500.0 N·m and expressed as a percentage of full-scale deflection is -0.0158%.

Expression of Uncertainties (as found)

The estimated expanded uncertainty of the torque measuring device under the conditions of calibration,

for increasing torques:

at 100.00 N·m	is ± 0.14%	k = 2.0
at 200.00 N·m	is ± 0.14%	k = 2.0
at 400.00 N·m	is ± 0.13%	k = 2.0
at 600.00 N·m	is ± 0.13%	k = 2.0
at 800.00 N·m	is ± 0.13%	k = 2.0
at 1000.00 N·m	is ± 0.13%	k = 2.0

Observations

The "as found" results are for the device as found by the laboratory on receipt, i.e. no adjustments were made to the device.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

Calculation of uncertainties [8] [9] [10]

It is a requirement for all accredited Calibration Laboratories that results reported in a Calibration Certificate are accompanied by a statement describing the uncertainty associated with those results. Without such an indication results cannot be compared either amongst themselves or with reference values.

BS 7882:2008 annex B gives a " Method example of determining uncertainty of the calibration results of the toque measuring device."

Norbar UKAS accredited Certificates of Calibration report the expanded uncertainty associated with each calibration point given in the certificate. The expanded uncertainties are derived from the calibration results and associated type B (systematic) uncertainty contributions in accordance with the requirements of BS 7882:2008.

Some possible sources of uncertainty in transducer calibration are:

Uncertainty due to the application of torque (see table 1).
Uncertainty due to repeatability.
Uncertainty due to reproducibility.
Uncertainty due to the error of resolution.
Uncertainty due to temperature variations[7].
Uncertainty due to the error of interpolation.
Uncertainty due to the axis of the applied torque not being horizontal.
Uncertainty due to the transducers susceptibility to bending effects [6][7].
Uncertainty due to the slack in the couple between beam and transducer.

The above list includes sources of uncertainty which are not referenced in BS 7882:2008 but are specific to unsupported calibration beams. Depending on individual circumstances uncertainty contribution may come from other sources that those listed, and some of the above may not be relevant in all situations, for example the transducers susceptibility to bending effects, would only be a valid contribution if an unsupported calibration beam was used in the transducers calibration, (however there still maybe some validity in including it in the uncertainty budget depending on the transducers subsequent use. i.e. if it was used for torque wrench calibrations). It is the responsibility of the Laboratory concerned to identify those sources of uncertainty that are present during the calibration and to formulate their uncertainty budgets accordingly.

Example uncertainty budgets for a 1000 N·m. transducer calibrated in accordance with BS 7882:2008 at 60% of full scale are given. These correspond to the example certificates in torque units and voltage ratio.

The uncertainty contributions for repeatability, reproducibility, residual deflection, reversibility and error of interpolation are taken as the relative half width of the parameter calculated in accordance with BS 7882:2008. A rectangular distribution is assumed for repeatability, residual deflection and reversibility. A 'U' distribution is assumed for reproducibility and a triangular distribution for interpolation.
Multiplier 'k' is assumed to be 2 and vi = 0.

The uncertainty of applied Torque (Tq) is subject to its own uncertainty budget and a normal distribution is assumed.

The other uncertainty contributions and their associated distributions are given in the examples.

EXAMPLE ONLY

CALIBRATION LABORATORY WORKSHEET FOR UNCERTAINTY CALCULATIONS

UNCERTAINTY BUDGET FOR 1000 N·m TRANSDUCER @ 60% OF FULL SCALE SYSTEM CALIBRATION IN N·m

BCP8B

Symbol	Source of uncertainty	value ±	Probability distribution	Divisor	c*i*	u*i* (TRAN) ± % (units)	v*i* or v*eff*
T_Q	TORQUE APPLICATION	0.02	Normal	2	1	.01	
$T_{mV/V.sys}$	VARIATION DUE TO TEMPERATURE CHANGE	2°C	Triangular	√6	0.035% per °C	.029	
H_{axis}	ERROR DUE TO THE AXIS OF APPLIED TORQUE NOT BEING HORIZONTAL	0.015%	Rectangular	√3	1	.009	
D_{RE}	ERROR DUE TO RESOLUTION	.0083%	Rectangular	√3	1	.005	
R_0	ERROR DUE TO RESIDUAL DEFLECTION	0.00%	Rectangular	√3	1	0.000	
R_1	ERROR DUE TO REPEATABILITY	0.008%	Rectangular	√3	1	0.005	
R_2	ERROR DUE TO REPRODUCIBILITY	0.025%	U	√2	1	0.018	
R_3	ERROR DUE TO REVERSIBILITY	0.025%	Rectangular	√3	1	.014	
D_b	ERROR DUE TO BENDING	0.10%	Rectangular	√3	1	.058	
u*c* (TRAN)	Root, Sum, Squ. U*i* (TRAN) Combined uncertainty		normal			0.0699	
U	Expanded uncertainty		normal (k=2)			0.14	

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EXAMPLE ONLY

CALIBRATION LABORATORY WORKSHEET FOR UNCERTAINTY CALCULATIONS

UNCERTAINTY BUDGET FOR 1000 N·m TRANSDUCER @ 60% OF FULL SCALE CALIBRATION IN mV/V

BCP8B

Symbol	Source of uncertainty	value ±	Probability distribution	Divisor	c*i*	u*i* (TRAN) ± % (units)	v*i* or v*eff*
T_Q	TORQUE APPLICATION	0.02	Normal	2	1	.01	
$T_{mV/V.sys}$	VARIATION DUE TO TEMPERATURE CHANGE	2°C	Triangular	√6	0.035% per °C	.029	
H_{axis}	ERROR DUE TO THE AXIS OF APPLIED TORQUE NOT BEING HORIZONTAL	0.015%	Rectangular	√3	1	.009	
UN_{Vratio}	UNCERTAINTY OF VOLTAGE RATIO MEASUREMENT	0.01%	Normal	2	1	.005	
M_{mer}	VOLTAGE RATIO METER UNCORRECTED ERRORS	0.006%	Rectangular	√3	1	.0035	
D_{RE}	ERROR DUE TO RESOLUTION	.008%	Rectangular	√3	1	.005	
R_0	ERROR DUE TO RESIDUAL DEFLECTION	0.00%	Rectangular	√3	1	0.000	
R_1	ERROR DUE TO REPEATABILITY	0.004%	Rectangular	√3	1	0.0024	
R_2	ERROR DUE TO REPRODUCIBILITY	0.004%	U	√2	1	0.003	
E_{it}	ERROR OF INTERPOLATION	0.00019%	Triangular	√6	1	.00008	
D_b	ERROR DUE TO BENDING	0.10%	Rectangular	√3	1	.058	
u*c* (TRAN)	Root, Sum, Squ. U*i* (TRAN) Combined uncertainty		normal			0.066	
U	Expanded uncertainty		normal (k=2)			0.13	

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References

[1] BS7882:2008; Calibration and classification of torque measuring devices

[2] DIN 51309:2005 Calibration of Static Torque Measuring Devices.

[3] EA-10/14 EA Guidelines on the Calibration of Static Torque Measuring Devices June 2000.

[4] JJG 995-2005; Calibration and classification of torque measuring devices

[5] BS7996 Draft; Torque measuring devices — Calibration and classification using continual torque application — Method

[6] Pratt B, Robinson A, 2006 A comparison between supported and unsupported beams for use in static torque calibrations. *Proceedings of the* 18th Imeko World Congress, Rio de Janeiro.

[7] Robinson A, 2008 Guide to the calibration and testing of torque transducers. NPL. National measurement good practice guide No.107.

[8]. ISO TAG 4 Guide to the Expression of Uncertainty in Measurement, BIPM, IEC, IFCC, ISO, IUPAC, OIML. International Organisation for Standardization, Geneva, Switzerland, First Edition, 1993.

[9] The Expression of Uncertainty and Confidence in Measurement. United Kingdom Accreditation Service, 21 – 47 High Street, Feltham, Middlesex, TW13 4UN, UK. M3003, Edition 2, 2007.

[10] Pratt B.C., Sources of uncertainty of torque generation using masses hanging from and unsupported calibration beam. Issue 4, 24 July 2001.